Integrating Fog Computing with VANETs: A Consumer Perspective

Hasan Ali Khattak, Saif Ul Islam, Ikram Ud Din, and Mohsen Guizani

Abstract

Emerging vehicular ad hoc network (VANET) applications are requiring a lot more communication and computation capabilities. Today's cloud infrastructures are not specifically designed to cope with the requirements presented by promising VANET applications. In this regard, fog computing focuses on moving computational resources toward the edge of the network to cater for these increasing processing and storage requirements. Thus, vehicular fog extends the fog computing paradigm to traditional vehicular networks that consist of several IoT devices. This overcomes the shortcomings of vehicular clouds by enabling ubiquitous vehicles, efficient communication, location-aware service provision, improved response time, and lower latency. This article presents fog-computing-based VANET architecture along with an infotainment application scenario. In the experiments, the cache size of fog nodes has been used as a parameter to evaluate its impact on different performance metrics in the fog-enabled VANET environment. We conclude the article by presenting various benefits of a fog-enabled VANET while investigating future challenges and their potential solutions.

Introduction

The explosive increase in end-user smart devices has increased the burden on the availability of storage, computing, and overall networking resources. These devices, categorized as the Internet of Things (IoT), are equipped with numerous sensors capable of sensing the environment around them and communicating this information to improve the services provided by a smart city. Nonetheless, due to the existing as well as future demands for extensive and high-quality-oriented service provision, there are many challenges that should be addressed. Since the advent of cloud computing, it has served a vital role for providing effective and reliable services through provision of easy access to computing resources from enterprise level networks to individual users. Although the realization of IoT-based applications, cloud-computing-based solutions are becoming not as optimal and effective. Applications built using these technologies such as healthcare monitoring, home and building control, industrial automation and vehicular networks (especially autonomous vehicles) have emerged and have shown promising results [1]. Most of these application scenarios are delay-sensitive, hence requiring computing and storage resources to be made available in the vicinity of end users [2, 3].

Advancements in the domains of sensor networks and vehicular technologies have made it easier to gather fine-grained data to support even more application scenarios such as vehicle fault detection, pollution detection, vehicle behavior, and traffic forecasting [3]. These benefits are highly desired in vehicular smart city applications such as traffic control, driver safety, improved navigation, and vehicular infotainment systems. Localization is of prime importance for vehicular networks as all this information gathered by intra- and inter-vehicle sensors has its own life span associated with geo-spatial scope. For example, traffic information for a certain area and within a certain time period is of interest to other vehicles in that area at that given time. This gives rise to utilizing decentralized computing paradigms such as vehicular fog networks (VFNs).

Cisco Systems introduced a new term, fog computing [4], a concept derived from content distribution networks (CDNs). Fog computing involves an overlay network that has been introduced in order to address the limitations of the centralized processing architecture and is done by delivering contents based on geographical location of end users through localized surrogate servers. The VFN is one such application scenario where traditional vehicle ad hoc networks (VANETs) can utilize the potential of IoT. Intra-vehicle information gathered periodically by onboard sensors can be used for reporting driving information such as speed, location, and dash cam video feed. Similarly, inter-vehicle information accompanied by information from the environment through different external sensors can be used to report weather conditions, road conditions, and traffic conditions.

Fog nodes, also called edge nodes, can be deployed on roadside units (RSUs) to effectively gather data generated by all these sensors and efficiently organize, store, and process data in a real-time manner. The overall goal of the VFN is enhanced overall VANET throughput, reduced delay, efficient load balancing, maximized availability, and reliable performance by placing computing resources closer to vehicles. The VFN can be thought of as an extension of the existing vehicular cloud infrastructure. The VFN is a prom-

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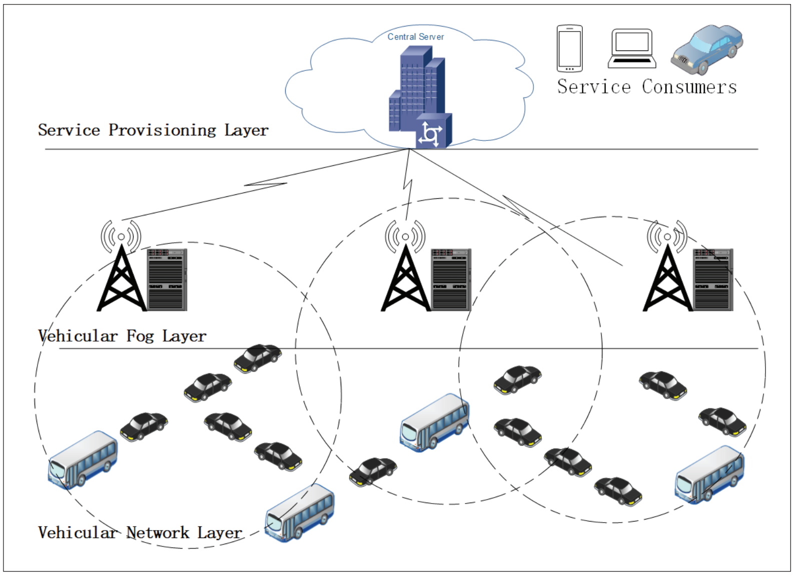

FIGURE 1. Vehicular fog computing architecture [3].

ising and efficient solution to overcoming the limitations of vehicular clouds [5]. Along with its promising capabilities, there are several challenges such as standardizing novel protocol stacks, developing software as well as hardware requirements, provisioning of security and privacy, and above all reliable and full coverage.

This article provides a study of fog computing in VANETs context along with the benefits of the VFN through a vehicular infotainment use case. The remainder of this article is structured as follows. We provide a definition of fog computing along with a generic architecture. We compare fog computing to cloud computing in the vehicular network context. We discuss integration of fog in a VANET scenario along with a generic use case. We present a proof-of-concept implementation of vehicular fog followed by results and detailed discussion. Last, we discuss open issues and challenges for a model vehicular fog, and we then conclude the article.

Vehicular Fog Network Architecture

In the recent past, cloud computing, an extension of distributed systems, has emerged as an effective and efficient computing solution offering a diverse range of computing services to end users and enterprises [6]. The cloud computing model became a de facto standard for leveraging private data centers by offering benefits of file storage, database management, and hybrid computing services. However, the benefits of cloud computing are steadily challenged by latency-sensitive applications such as a VANET [7].

Micro-electro-mechanical system (MEMS) technology brought about a noticeable increase in smart devices, and the emergence of sensors ignited the penetration of IoT devices in human social life. To meet the complex and time-sensitive needs of present and future applications, involving wireless networks, data analysis, or distributed data collection points, the concept of cloud computing needs to be extended to the edge of the networks.

VANETs are self-organized networks that facilitate different kinds of vehicular communications such as intra-vehicle, inter-vehicle, vehicle-to-roadside, vehicle-to-infrastructure, and vehicle-to-anything communication through RSUs. A VFN offers great flexibility, improved mobility, and reduced latency by allowing resources and services to be hosted near end devices [8], as shown in Fig. 1. A VFN can be considered as an overlay network comprising several layers namely, the vehicular network layer, vehicular fog layer, and service provisioning layer.

Vehicular Network Layer

Most vehicles are equipped with an enormous array of sensors onboard, and these onboard units (OBUs) have communication capabilities that enable them to share information with other vehicles. Modern vehicles have OBUs with extended capabilities that enable them to collect data as well as perform preliminary processing on the collected information and communicate the already processed information to the nearby edge node of the VFN.

Vehicular Fog Layer

The vehicular fog layer comprises RSUs that host vehicular fog nodes equipped with communication capabilities, processing power, and storage space. These fog nodes are installed at critical locations like significant junctions and parking lots or at appropriate distances to provide sufficient coverage to a smart city that can take advantage of a VFN. RSUs hosting these fog nodes are equipped with persistent links to a service provider hosted on the cloud as well as short-range communication capabilities to "talk" to vehicles.

Service Provisioning Layer

The service provider exposes different services through the cloud, which has an exponentially huge storage configuration and large computational power. The service provisioning layer not only communicates with the vehicular fog nodes but also coordinates requests received from service consumers to fog nodes through an efficient load balancing and energy optimization policy. The service consumer can be administrative personnel who consume vehicular network information for managing traffic and providing better services. Similarly, other vehicles can request information regarding conditions of road segments or traffic in order to calculate optimum routes. There are several other service consumption scenarios such as weather monitoring, weather forecasting, and vehicular infotainment systems, to name a few.

Fog computing has a multi-layered architecture, and different variations of fog computing are discussed in [9–11]. Figure 2 presents a taxonomy of different protocols used on each layer of the VFN. Since the VFN is still evolving, and an increasing number of characteristics are being affiliated with it, a definite and unified definition of the technology may still take time to surface. Fog computing provides the traditional services of storage, data management, sharing, platforms as a service, information processing, and other extended application services [8, 12]. Moreover, the fog computing paradigm offers heterogeneity with fog devices extended to the access points, routers and end user devices, ensuring more suitability to IoTs, smart environments, pervasive wireless networks, smart watches, green cities, and micro-grids due to their time-sensitive nature [13].

Why Vehicular Fog Networks

Cloud computing offers a wide variety of solutions for diverse VANET applications; therefore, it has become the dominant computing model compared to traditional computing infrastructures. Cloud computing also offers flexibility, cost effectiveness, and on demand services, which has resulted in steady growth in this domain. The potential of cloud computing and the immediate involvement of the transportation industry in clouds brought on rapid growth in this field and extended the cloud computing infrastructure to a much wider scale [14].

Present-day cloud computing is not limited to traditional static networks; rather, it bears the potential to handle applications with high mobility. The success of the cloud has inspired extensive cloud-based transportation services and vehicular applications [14, 15]. But with the extension of the infrastructure, many significant research challenges have also surfaced [8, 14]. The emergence of Internet-connected vehicles and vehicular networks has introduced a major change in the global Internet usage pattern and demands unique features for which the traditional cloud infrastructure may no longer be a suitable solution for VANETs [3]. Some of the salient features and key differences of cloud and fog computing with respect to vehicular networks are presented in Table 1. Fog computing is an enormous step forward from the cloud computing paradigm in many ways, such as providing low latency, and efficient and massive processing by utilizing cloudlets near vehicles.

Fog computing and cloud computing are to be considered as collaborative technologies for enabling variety of services in VANETs. By relocating the vehicular data processing to fog nodes, users have responsive and efficient service experience while cloud is still used for long term storage and processing intensive tasks. In cloud computing, not only data has to be transported to far away resources from the roads which not only introduces bandwidth cost but also introduce latency that is not much feasible in case of VANET applications. Moreover, due to the location awareness feature offered by fog-empowered VANET, timely and relevant content delivery has become potentially proficient and up-to-date. By providing the services in the vehicular proximity, the communication cost and load on the core network has also been tremendously reduced. As a result, processing data locally enables edge nodes to contribute achieving higher through-puts as compared to sending it to cloud infrastructure and reducing burden on the core Internet.

While using VFN architecture, the cloud is only responsible to handle resource intensive jobs and for long term storage purposes. By releasing the cloud from little jobs and short-term storage, the overall performance of cloud is increased that has a great impact on QoS in overall VANET applications. One of the salient feature of VANET is mobility support that is highly neglected in cloud-supported VANET that ultimately limited the vehicular based applications. However, fog computing has made it possible by providing high mobility support thought putting the resources closer to the data generating sources. By enabling this underlined capability, the VANET applications will surely increase exponentially to facilitate the community by integrating intelligence at the edge of transportation system. Consequently, the vehicular data will play a primary role to incorporate smartness in transportation systems. Whereas, this generated data requires timely and quick analytical services that can be enabled by providing computing nodes closer to roads instead of moving data to remotely located data centers.

Fog nodes are supposed to be capable enough to compute the incoming vehicular information and perform data analysis for further decision making. Long term decision making requires larger history of vehicular data that needs more computational resources. For such type of services, cloud will back up the fog nodes by providing longer history and offering high performance computing to perform big data analysis for long term planning and forecasting. Fully distributed architecture of fog-enabled VANET reduces the cost and bandwidth issues. This model also offers service providers to ensure security and privacy for localized data. fog computing can also leverage future Internet technologies such Software Defined Networking [11] approaches to scale whole VANET infrastructure on demand.

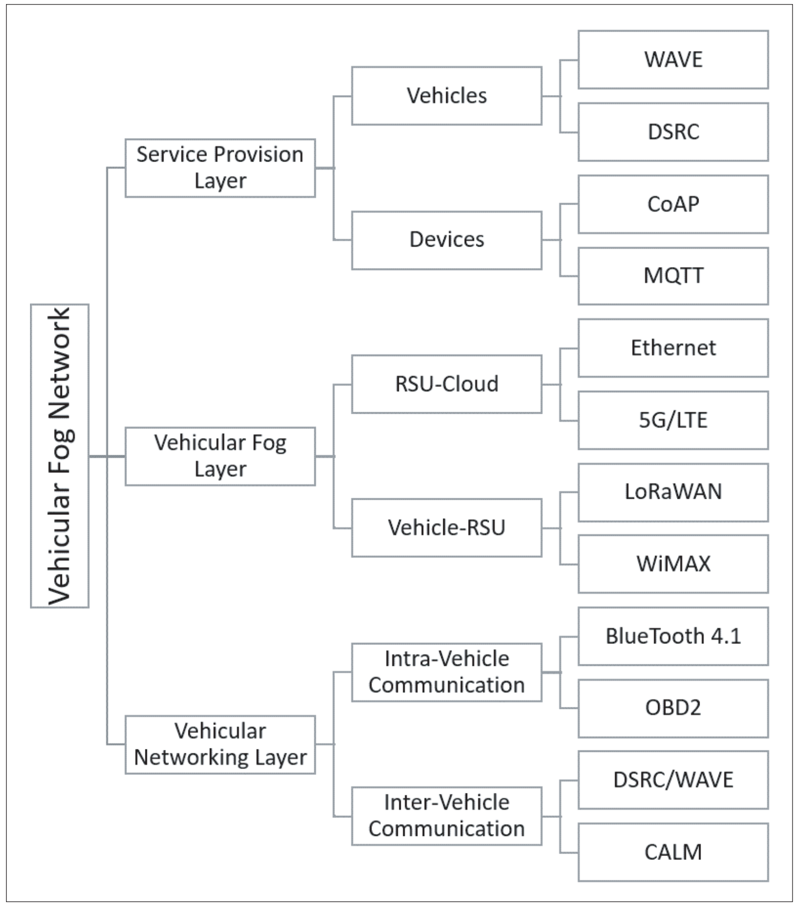

Figure 2. Taxonomy of protocol stack for vehicular fog networking.

Service attributes	Vehicular fog network	Vehicular cloud network
Location of service	Edge of the VANET	Remote from VANET and majorly centralized
Distance between vehicle and resources (computing, storage)	In close proximity of vehicles	May be situated multiple hops away from the road
Vehicle location awareness	Strongly supported	Not supported
Mobility	Fully supported	No suitable mobility support available
Architecture	Fully distributed	Partially centralized
Vehicular data routing and load on core Internet	Localized data communication, less effect on Internet backbone	Lots of data needs to be routed; excessively overloads Internet resources
Security	Less vulnerable to external attacks	Cannot be fully ensured
Time-sensitive and streaming applications	Highly suitable	Slower response times degrades the quality of service (QoS)
Resource specifications	Limited storage and computing capabilities, but can connect to cloud resources	Massive computing and storage capacity; consists of a large number of resources
Scalability	Highly scalable	Limited scalability

TABLE 1. Service attributes of the cloud-supported and VFN paradigm.

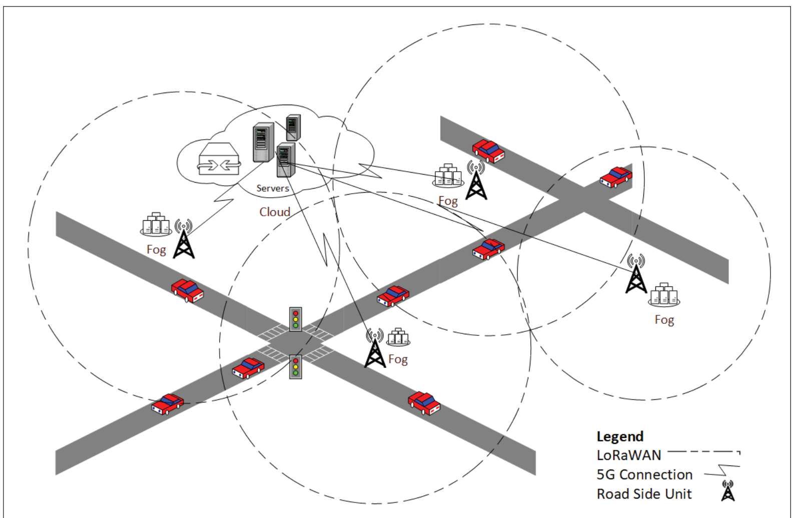

FIGURE 3. Fog-computing-based intelligent traffic lights (ITLs)}

Fog Computing Integration in VANETs

Most of the applications depending on cloud computing are ready to leverage benefits of fog computing. In the case of time-critical applications, processing and storage can be performed on near-edge devices that will not only reduce latency but also improve bandwidth utilization. The near-edge nodes receivie data from vehicles in real time. Depending on the context and nature of job requirements, resources are assigned at near-edge devices or forwarded to the cloud. Similarly, all communications are forwarded to the cloud for analysis and long-term storage; for example, a vehicular network's generated data is stored for predicting traffic patterns and traffic routing. Near-edge resource availability not only conserves overall bandwidth, but also lowers load on the core network, thus decreasing the response time for critical jobs from vehicular networks and giving better control over data flow over the Internet.

Fog computing can also leverage from policies and controls over the security of the data by localizing penetration of sensitive vehicular data. Many VANET scenarios are rich candidates capable of taking advantage of fog computing features such as localization for critical data and globalization for analytical data. Localization of resources helps in information filtering at an early stage so that only relevant information is stored and communicated further toward the core network. This means that edge nodes should support different types of storage; similarly, the cloud should have more powerful processing and storage capabilities.

An interesting use case for vehicular fog computing is intelligent traffic lights (ITLs), as shown in Fig. 3. In ITLs, various kinds of sensors onboard either vehicles or RSUs, continuously monitoring various parameters. Based on the gathered information from various sources, the aggregated data is transmitted to the edge nodes. This data is utilized to coordinate with neighboring vehicles as well as with corresponding RSUs to maintain an efficient and stable traffic flow. Furthermore, RSUs are capable of generating notifications for other vehicles in case any incident occurs. While this data is locally useful, it is also disseminated for long-term analysis to the cloud. Another main goal is efficient storage and processing of ITS for providing better understanding of smart city transportation requirements.

Improved architectures and resource management systems for networking, computation, and storage management would be required for leveraging fog computing. Most vehicular network applications are developed for cloud computing paradigms. However, these vehicular cloud applications need to be upgraded to support these innovative services to fully leverage fog computing's benefits.

Experimental Setup

We performed simulations in OMNet++ to evaluate the impact of varied cache sizes of fog-enabled RSUs on the energy and performance of a VFN. We consider 15 fog nodes serving content requests of VANET users. These RSUs have the

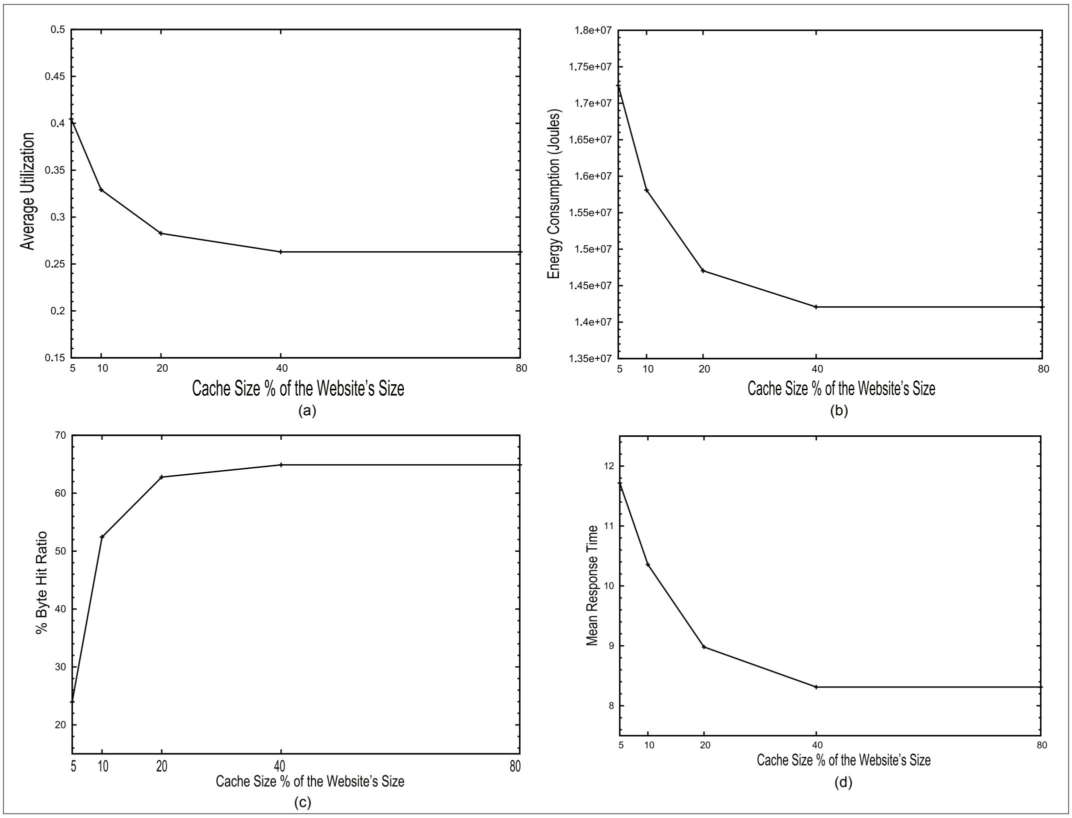

Figure 4. An experimental study on the impact of cache size variations on energy consumption of fog nodes and performance of a fog-enabled VANET environment: a) average utilization of fog nodes vs. cache size; b) energy consumed by fog nodes vs. cache size; c) cache size vs. byte hit ratio; d) cache size vs. mean response time.

The utilization of fog nodes in a VANET environment depends on many factors, for instance, number of incoming content requests, frequency of content requests, capacity of a fog node to simultaneously serve the requests, and its cache size. Among these factors, the cache is considered the most critical aspect, having a direct and significant impact on the utilization of fog resources.

capacity to serve 500 requests simultaneously. The nodes are distributed across the side. These fog-enabled edge nodes are then connected to the cloud data centers via the Internet. The fog nodes have a percentage of overall contents stored in the cloud according to their capacity. A least recently used (LRU) cache replacement policy is used to update the contents in the cache of fog nodes.

The experiments are conducted with varied cache sizes (i.e., 5, 10, 20, 40, and 80 percent) to rigorously evaluate the impact of cache size on different evaluation metrics. In the given context, utilization of RSUs, their energy consumption, mean response time, and byte hit ratio are taken into account as evaluation metrics. The experiments are conducted with 1 million content requests. The overall content size is 1 GB. The load balancing policy is used for the uniform utilization of fog nodes.

Results and Discussion

Average Utilization vs. Cache Size

The utilization of fog nodes in a VANET environment depends on many factors, for instance, number of incoming content requests, frequency of content requests, capacity of fog node to simultaneously serve the requests, and its cache size. Among these factors, the cache is considered the most critical aspect, having a direct and significant impact on the utilization of fog resources. The content provider needs to make the right choice regarding the cache size of fog nodes for efficient resource utilization. The exponential growth in the demand of media contents in a VANET environment forced the content provider to provide scalable and efficient services while using the minimum resources that can only be achieved by making smart decisions from designing scheduling policies to cache size of fog nodes.

The efficient resource utilization can ultimately lead toward providing effective services with minimum resources. Consequently, it can reduce the overall infrastructure cost. It is observed that content provisioning resources along roadsides are not utilized according to their capacity,resulting in waste of resources. In the given perspective, Figure 4a presents the average utilization of fog nodes against the varied cache size. The x-axis shows the different cache sizes used during the experiments, and the y-axis exhibits the average utilization of fog nodes serving the contents. It is clear from the figure that the increase in cache size decreases the utilization of fog nodes. However, a slight change can be observed when the cache size is higher (i.e., 40 and 80 percent of the website size). Higher utilization of fog resources is observed while using the smaller cache size. Less content is mirrored to the local fog nodes, which increases the activity of the node. However, smaller cache size has an advantage of getting smarter in less time.

Energy Consumption vs. Cache Size

One of the important metrics to consider in the fog-enabled VANET environment is energy consumption as it has a direct impact on the environment, services cost, and overall energy resources

Response time is one of the most important metric to measure the user satisfaction. The lowest values of the response time are desired. The higher values can degrade the user experience towards provided services. Moreover, it can also effect the number of clients for a service provider.

around the globe. Information and communication technologies (ICTs) contribute 2–10 percent of the global CO_2 footprint. With the evolution of vehicular technologies and need for processing and content storage, a great increase is observed in large-scale geographically distributed systems (e.g., fog-enabled VANETs). Hence, there is a dire need for energy-aware hardware and software solutions in such ICT environments. There are two types of energy costs at the fog node level: static and dynamic. Static cost is more related to hardware, and dynamic energy cost depends on the utilization of resources. The cache size has a considerable impact on the energy cost.

Figure 4b shows the energy consumed by fog devices in a VANET environment against varied cache size. More energy is consumed when the cache size is smaller, which is due to the fact that when the cache is smaller, the activity in fog nodes is increased, resulting in higher utilization. The utilization has shown a direct impact on the energy utilization of fog nodes. When the utilization increases, it ultimately augments the energy consumption. It can be observed from the graph that when the cache size is 40 percent or greater it exhibits the same behavior due to gaining the maturity level.

Byte Hit Ratio and Mean Response Time vs. Cache Size

Response time is one of the most important metrics to measure user satisfaction. The lowest values of response time are desired. The higher values can degrade the user experience of provided services. Moreover, it can also effect the number of clients for a service provider. Figure 4c shows the mean response time against the cache size. When the number of original contents replicated to the local fog caches is augmented, the response time is also decreased. This means that more contents are brought closer to the user, which reduces the content delivery time from the fog nodes to the VANET users.

Another important metric in the given context is the byte hit ratio, which is basically the hit ratio exhibited in bytes. It is used to measure the bandwidth consumption and network activity. Figure 4c presents the byte hit ratio against the cache size of fog nodes. The x-axis shows the cache size, and the y-axis presents the byte hit ratio. In our experiments, the byte hit ratio is measured in percentage. We have observed that the increase in fog node cache size results in higher local bandwidth consumption. If the cache size is lower, it means that less content is closer to the vehicles, and bandwidth consumption is also decreased. In this case, the network activity is increased in the core network.

Challenges and Open Issues

Integration of fog-enabled RSUs with VANETs needs to address key issues and challenges that keep stakeholders from deploying integrated VFN technologies. Some of the prominent research issues, challenges, and their proposed solutions are outlined in the following subsections.

Scalability and Mobility

While designing protocols for fog-enabled vehicular networks, information about location of nodes and predicted future movement is used. Similarly, all the forwarding protocols need to utlize simple but accurate and reliable link availability prediction techniques to make intelligent decisions. Defining user profiles can help in estimating link availability. Mobility of vehicles leads to network partitions, for which directional antennas normally transmit data over a longer range of distances and can be used to mend such partitions. The core idea behind this technique is to leverage the capability of specific directional antennas to communicate over long distances. Moreover, several methods of closing broken links for ad hoc networks need development for coping with limited inter-connectivity issues.

Load Balancing

In order to be energy- and storage-efficient, an effective buffer management system in fog-enabled vehicular networks can help process rather significant messages, thus reducing overall energy consumption. Better-designed transport protocols can provide improve reliability and effective congestion control.

Scheduling

Scheduling becomes really complex in fog-enabled vehicular networks, because connections in VANETs can be irregular. Efficient buffer management schemes such as distinct queues for different outgoing links can help improve resource management and scheduling. Similarly, nodes with unstable links can be given priority. However, the diverse nature of fog computing and VANET technologies support detailed analysis of trade-offs among various factors. A full-scale deployment of such dynamic behavior is also a very challenging task for the service providers. It must handled while keeping in mind consumer satisfaction. Various mechanisms exist for coping with resource management and heterogeneity exhibited by integrated VFN calls.

Security and Privacy

Privacy and security are of real significance in vehicular fog networking. Data generated by vehicles is privacy-sensitive and hence requires effective privacy provisioning mechanisms for both data on wire as well as at rest. Without effective privacy preservation techniques, data shared by these vehicles causes user privacy abuse. Usually, the standard privacy-preserving data sharing schemes have an effect on data granularity. Therefore, privacy may affect performance. Thus, the trade-off between overall performance of the applications and data granularity needs to be well defined. However, context-aware techniques for privacy preserving could be incorporated to enable the VFN to adapt to changing environments. VFN RSUs can be enabled to locally process the data, thus making sure that the data is protected through industry standard privacy preserving techniques and is not being propagated in the core network without user consent.

Data Quality

Industrial breakthroughs, especially in the domain of miniaturization, have made it possible to benefit from the potentially millions of easily available wireless sensors. In most scenarios these devices are left unattended for gathering certain variables over longer time periods. This characteristic of IoT also puts data quality in question as to whether these sensors are gathering and submitting, which may be affected due to uncertain network and environmental conditions. While perceiving a VFN, the data quality problem becomes more important due to the mobile nature of vehicular nodes. To circumvent data quality problems, it is beneficial to have in-place data quality checks for attaining well-defined consistency. Also, calibration of vehicular sensors needs to be maintained as well as the resulting aggregate data.

Conclusion

We have presented the state of the art in vehicular networks and fog computing. Both IoT and VANETs are potential technology enablers for future smart cities. Several service providers are testing various kinds of applications catering for different problem situations. In this article, we present a model implementation of a vehicular fog network where we have utilized an infotainment system example. Infotainment systems in vehicular networks not only consume infrastructure-generated data, but also disseminate vehicular data to the network.

It is worth mentioning that various service providers are also experimenting with large-scale VFN deployments. Therefore, promising protocols such as Long Range (LoRa), Communications Access for Land Mobiles (CALM) and Wireless Access for Vehicular Environments (WAVE) need to be standardized. Dedicated Short-Range Communications (DSRC) is an 802.11a-based ITS communication protocol for using the 5.9/5.8 GHz band, and Wireless Access in Vehicular Environments (WAVE) is a mode of operation used by these IEEE 802.11-enabled standards to operate in the DSRC band. Through experimental analysis, we have shown promising improvements in the latency and overall network throughput. Moreover, this also elaborates that the cache size has a major impact on promising vehicular network applications.

For future work we intend to deploy a full-scale implementation of vehicular IoT using fog-enabled RSUs as discussed in our previous work [3]. Apart from working toward an efficient VFN implementation, we will explore the vehicle request re-direction policy for improving the quality of service of the overall network.

For future work we intend to deploy a full-scale implementation of vehicular IoT using fog-enabled RSUs as discussed in our previous work. Apart from working toward an efficient VFN implementation, we will explore the vehicle request re-direction policy for improving the quality of service of the overall network.

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Biographies

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