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Research Article

A Heterogeneous IoV Architecture for Data Forwarding in Vehicle to Infrastructure Communication

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The Internet of vehicles (IoV) is a newly emerged wave that converges Internet of things (IoT) into vehicular networks to benefit from ubiquitous Internet connectivity. Despite various research efforts, vehicular networks are still striving to achieve higher data rate, seamless connectivity, scalability, security, and improved quality of service, which are the key enablers for IoV. It becomes even more critical to investigate novel design architectures to accomplish efficient and reliable data forwarding when it comes to handling the emergency communication infrastructure in the presence of natural epidemics. The article proposes a heterogeneous network architecture incorporating multiple wireless interfaces (e.g., wireless access in vehicular environment (WAVE), long-range wireless fidelity (WiFi), and fourth generation/long-term evolution (4G/LTE)) installed on the on-board units, exploiting the radio over fiber approach to establish a context-aware network connectivity. This heterogeneous network architecture attempts to meet the requirements of pervasive connectivity for vehicular ad hoc networks (VANETs) to make them scalable and adaptable for IoV supporting a range of emergency services. The architecture employs the Best Interface Selection (BIS) algorithm to always ensure reliable communication through the best available wireless interface to support seamless connectivity required for efficient data forwarding in vehicle to infrastructure (V2I) communication successfully avoiding the single point of failure. Moreover, the simulation results clearly argue about the suitability of the proposed architecture in IoV environment coping with different types of applications against individual wireless technologies.

1. Introduction

Internet of Things (IoT) is paving a way forward for VANETs towards an evolution of Internet of vehicles (IoV) [1]. IoV paradigm not only benefits from pervasive vehicular connectivity for a bunch of services but also incorporates vehicular intelligence. To accomplish smart tasks, it also integrates vehicle to human (V2H) and vehicle to sensor (V2S) interactions in addition to conventional vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication modes. IoV is capable to process comprehensive information collected through the vehicles, roads, and surroundings to effectively supervise the drivers based on the integrated information. Thanks to the merger of industrial and Intelligent Transportation System (ITS) applications for IoV, it has successfully extended its support for several intelligent services (e.g., online vehicle status checking, intelligent root navigation and rescue, and avoiding illegal cyberspace operations).

ITS [2] is expected to be extensively deployed for the IoV paradigm to support a wide variety of applications ranging from low data rate traffic control services to high data rate and delay-critical multimedia services [3]. The ITS employs the coordination of sensors, on-board unit (OBU), and trusted platform module (TPM) to share vital information of the vehicles with the road side unit (RSU). In the recent years, the number of vehicle users has immensely been increased which has turned the VANET [4] to be even more challenging. Moreover, the 24×7 demand for high speed internet access on-board and provision of multimedia services are inevitable for service providers to enable a robust, reliable, and secure data communication infrastructure [5].

Vehicular users demand ubiquitous communication with affordability while moving around in the urban, suburban, or even rural areas in countryside areas. Hence, moving vehicles are being designed keeping in view these demands, and a lot of work is being done in developing a range of ITS applications including road safety, traffic control, and numerous entertainment applications. The condition monitoring/warning systems, analytic systems, partner systems, location-based services, and different real-time applications are some of the examples that are expected to be installed on the modern vehicles being a part of IoV environment as shown in Figure 1.

In fact, VANETs still undergo some critical issues that cannot be tolerated towards the future IoV deployments. On the contrary, several quality of service (QoS) parameters are still compromised while data forwarding for multimedia (throughput intensive) applications that are anticipated to be an integral part of IoV to improve the driving experience through most updated multimedia contents [6]. The challenges of data forwarding in conventional VANETs environment vary as compared to the heterogeneous forwarding in IoV mainly due to the pervasive connectivity in V2V and V2I modes and frequent switching among the different operating modes. Moreover, the IoV infrastructures for persistent data forwarding in different scenarios (such as urban or highway) are still in their infancy and paving their way forward gradually. The IoV communication infrastructure is expected to improve the disaster and emergency situations in ITS through different applications (e.g., safety critical applications). Moreover, the IoV is expected to provide nonstop network connectivity and adaptiveness against network disconnections and long delays in emergency situations, even when the 4G/LTE [7] interface is connected. However, data forwarding based applications in the VANET infrastructure are limited in terms of modes of connectivity, switching, and bandwidth availability through the IEEE 802.11p WAVE [8] standard. The heterogeneous IoV framework applications require higher bandwidth and continuous network connectivity, but the challenge is unavailability of such networks, and increased user demand creates network resources hunt (such as safety, emergency videos, emergency audio and text messages dissemination, and reception) in such situations [9].

The IoV paradigm is a group of heterogeneous networks with increased number of different users in V2I and V2V under the centralized software-defined network (SDN) controller [10] using the desired applications in various environments. The problem of providing on-time and robust network interface-based connectivity is very crucial. The resilient multi-interfaced architecture for the Emergency Management Systems (EMS) [11] is a requirement of the modern era.

To circumvent these issues, a heterogeneous VANET architecture is proposed hereby keeping in view the requirements of IoV to make them more scalable and adaptable. The proposed architecture can exhibit several features to the network providers after successful deployment. First, it would be economical using inexpensive access units. Second, the heterogeneous architecture provides flexibility to the IoV paradigm by not only supporting current technology interfaces installed on Global ID (GID) but also being capable to implicitly support most of the future technologies (Section 3). Third, thanks to the presence of multiple interfaces available, it enables IoV nodes to avoid single point of failure. Forth, it can offer higher data rate support with reduced collisions by exploiting optical fiber at the backhaul. Fifth, the architecture is simple but robust to provide ease of management offering (i) fewer control stations, (ii) a centralized control for all the processing, and (iii) separating planes for client, connection, and cloud layers. Last, but not the least, it may reduce the extent carbon emission is polluting the environment due to Information and Communication Technology (ICT) infrastructures with fewer wireless links, hence, a step forward towards achieving "Green Networks" [12].

The rest of the paper is organized as follows. Section 2 provides the related work with discussion on major standards available in the state of the art for IoV. The proposed system model comprising the architecture, protocol design, and BIS algorithm for interface selection is described in Section 3. The simulation environment, results, and the discussion are presented in Section 4. Finally, the conclusions are given in Section 5.

2. Related Works

The industry and research community have proposed different wireless access technologies in the context of vehicular communications. They can broadly be seen into intravehicular, intervehicular, and vehicle to infrastructure communication in the context of an IoV environment. Although a rich variety of technologies is available in the literature for all the abovementioned categories, however, the point of focus for our domain would be the last category. Several access technologies have already been proposed and evaluated in the context of VANET (such as wireless local area network (WLAN) [13], Worldwide Interoperability for Microwave Access (WiMAX) [14], and cellular technologies such as 4G/LTE [7]). A quick overview of the state of the art of these access technologies for V2I communication is presented throughout this section.

The WLAN is foremost and widely accepted option available in the market. The most popular family in this category is IEEE 802.11. Several target groups have been working towards different variations of 802.11 family (e.g., 802.11 a/b/g/ah/n/p) All of them bear different characteristics and challenges associated with them that make them suitable for different environments. Overall, the standard supports short radio coverage with relatively higher data rate. A data rate of 600 Mbps is claimed to be supported by 802.11n which is based on 802.11a/b/g [6]. However, they

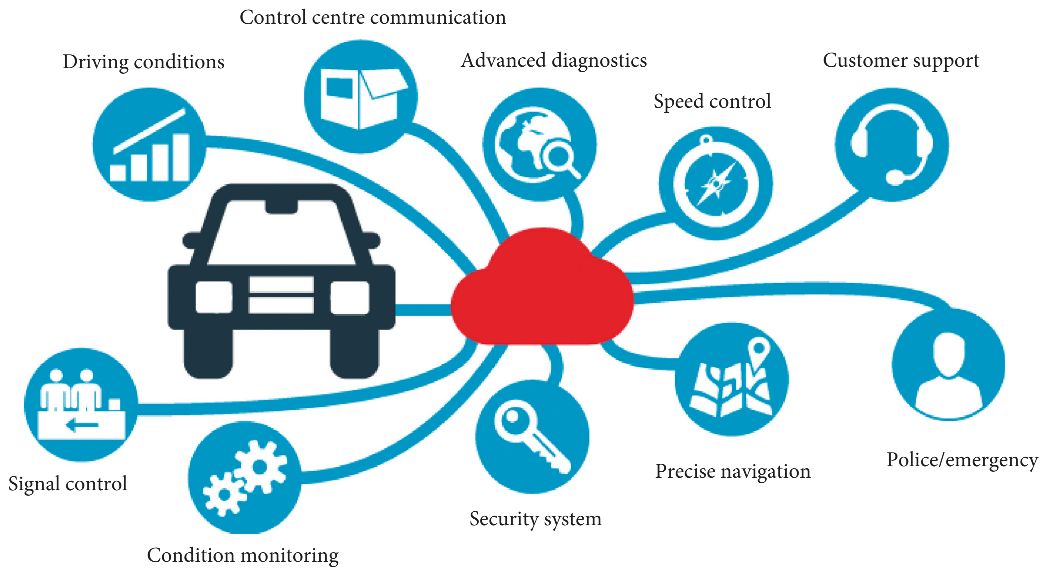

Figure 1: An ITS vehicle being a part of Internet of vehicles.

were not physically achievable in mobile environment. All these variations were not feasible for VANET environment with very high mobility and frequently changing topologies. Hence, a new variation of WAVE for 802.11p [8] was introduced for specific support in vehicular networks. WAVE is capable to support a range of applications and services belonging to ITS with a special focus on safety critical applications [15]. Several research efforts have been put in place to physically evaluate the performance of 802.11p with its predecessors [13, 16] on a highway environment. A recent addition to the same family is 802.11ah (that is, long-range WiFi) [17] which is also expected to be a decent option in vehicular environment. Long-range WiFi can provide a better radio coverage up to over 1 km as compared to other siblings which can improve the connection duration to provide sustainability with least number of handovers [18].

WiMAX [14] is another wide area network (WAN) access technology, belonging to WLANs, that has been considered for VANETs due to its large geographical coverage and capability to theoretically support a higher data rate up to 72 Mbps. The IEEE 802.16e was emerged as the mobile WiMAX standard that could support communication up to 160 km/h speed of moving vehicles with different QoS parameters, even for nonline of sight communication. A scheduling algorithm is employed in WiMAX as a channel access method where a mobile terminal needs to compete once initially, which could be more robust in collision scenarios [19]. The only problem with the WiMAX was nonconformance of a specific standard for high mobility environment; hence, the technology could not take off in VANETs as expected.

With the evolution of cellular infrastructures, 4G/LTE [7] has been a hot choice in vehicular environment. It can also support reasonable data rate with the smoother handover management mechanism as compared to WiMAX and WLAN. Several works throw light on various issues of 4G/LTE when employing into a very high mobility environment. The authors in [20] first presented an analytical framework to compare the performance of 4G/LTE with the WAVE in terms of beacon probability before the deadline expiry. Similarly, authors in [21] identified the potential use cases for operator-controlled device-to-device (D2D) [22] communication in VANET. Another article [23] discussed the suitability of LTE service with high bandwidth and long radio coverage in an urban environment. Satellite communication can be another access technology to be used in VANET [24]. Due to the huge costs involved, this access technology has not been employed widely except for some safety critical applications. However, it can still be considered a backup option in the absence/failure of other available technologies in case of an emergency.

In the recently conducted research discussed above, most of the roadside infrastructures use a single communication technology (single interface) to communicate with peer infrastructures and other entities of the network that inherits the limitations of that communication technology. Till date, no literature is available that proposes a system with multi-interface (heterogeneous) communication technology in VANETs. In this paper, the authors have proposed a heterogeneous VANET architecture to be used in IoV networks to enhance the overall performance and efficiency of data forwarding (data communication) in vehicular networks.

3. Proposed System Model

This section presents the generic system model for proposed heterogeneous solution leveraging multiple access technologies to enable ubiquitous communication in IoV targeting V2I communication. Three different access technologies have been considered in this work such as WAVE [8], long-range WiFi [17], and 4G/LTE [7]. The IEEE802.11p (WAVE) and IEEE802.11ah (long-range WiFi) are the members of WLAN family while 4G/LTE belonging to wireless cellular technologies. There are several reasons to choose these three as access technologies among a bulk of options available in the market. First, they have already got equal acceptance by the academia and the industry. Second, the standards are already on the mature stage. Third, they have been individually deployed and tested and conform to the characteristics of vehicular environments. The system architecture, protocol stack, and BIS algorithm are presented in the rest of this section.

3.1. A Holistic View of Heterogeneous IoV Architecture. The multi-interfaced IoV system exploiting the radio over fiber (RoF) [15] paradigm is proposed where moving vehicles are equipped with the vehicular GID terminal with more than one wireless interfaces installed. These interfaces are capable to communicate with small radio access units (RAUs) installed along the roadside to relay the communication onto control station (CS) in the V2I mode. The optical fiber is employed to connect RAUs with the CS and for the onward backhaul connectivity with the network backbone as shown in Figure 2.

The architecture follows a three-layered approach in order to simplify the functionality of various components. The client layer at the bottom covers intravehicular and intervehicular communications (e.g., communication among various sensor nodes within a vehicle). It is also responsible for enabling IoV addressing and maintaining a trustworthy identity in the cyberspace. The connection layer deals with the interconnectivity of different network components within a network and integration of other available networks within vehicular environment. Similarly, the cloud layer is finally responsible for enabling all the IoV services and applications. It also offers many cloud-based services like mass storage, virtualization, and real-time interactions among different network entities. We now highlight the functionality of various components of this architecture.

3.1.1. Radio Access Unit. RAU is a radio antenna with very simple functionality that is capable to listen on a range of frequency bands irrespective of the underlying technology being used at the transmitter side. RAU moves all the other functionalities of a RSU onto CS. It only receives the signal and subsequently performs electrical to optical (E/O) conversion before relaying the packet onto fiber link. Similarly, it receives the reply back from the fiber link, the optoelectrical converter does its job, and the response is relayed back to the respective vehicle. Exploiting this kind of antenna structure brings several advantages, such as easier network planning and management due to very simple antenna structure and functionality, low interchannel interference, longer battery life, and very low capital expenditure (CAPEX) [25].

3.1.2. Control Station. The CS is another fundamental component that is responsible for controlling the rest of the operations of heterogeneous IoV architecture. The control functions of the system, such as frequency allocation, modulation/demodulation, and processing, are performed at the central site, simplifying the design of the RAU. Centralized architecture allows a dynamic configuration of radio resource and capacity allocation. The optical fiber is transparent to modulation, radio frequency, and bit rate; hence, multiple services on a single multimode fiber can be supported at the same time using RoF managed by the CS. The CS is further connected to cloud such as Public Switched Telephone Network (PSTN) or the Internet. Multimode optical fiber can dramatically play its role to achieve higher throughputs at the CS. In the context of VANETs, we argue that an RoF-based V2I architecture can provide reliable, secure, and cost-effective infrastructure if the fiber has already been deployed in an area. The proposed system is fully capable of exploiting the advantages of integrated wired (i.e., fiber) and wireless solutions for the throughput intensive infotainment applications as well as pervasive internet connectivity.

3.1.3. GID Terminal. The moving vehicles are equipped with GID terminals and are connected with RAUs using a radio link, and the front-end transmission takes place using the same radio link but irrespective of the fact which wireless interface at the vehicle side is currently active. Multi-interfaced GIDs are capable of providing continuous radio connectivity with different kind of wireless access options (such as WAVE, long-range WiFi, and 4G/LTE). Although different wireless interfaces possess different properties in terms of available bandwidth, data rates, communication range, and billing cost, however, the users demand continuous connectivity to fully utilize the set of communication services being always connected to the internet.

3.2. Protocol Design of Heterogeneous IoV Architecture. The protocol stack for the proposed multi-interfaced IoV architecture depicting the role of various communication layers is shown in Figure 3. There may be different kinds of throughput requirements for the apps running within different vehicles. All the radio signals irrespective of the technology are received by a nearby RAU and are further converted to optical signals through the electrooptical (E/O) conversion unit. Similarly, optoelectrical (O/E) conversion unit is present on the CS side which converts optical signals back into electrical ones for onward processing of the user request by the CS.

Let λ be the wavelength to represent a certain type of communication on the fiber link, and then different wavelength values ranging from $\lambda_1, \lambda_2, \lambda_3 \ldots \lambda_n$ may be multiplexed to travel through multimode fiber to support multiple communications simultaneously. For example, the well-known IEEE 802.11p signal may be assigned as λ_1, IEEE 802.11ah is λ_2 and, similarly, the communication on the 4G/LTE interface can be assigned as λ_3. The optical fiber link is capable to carry these different lambdas employing multimode fiber. However, the data rates offered by multimode fiber may vary from 10 Gbps to 1 Gbps up to a distance of 550 m and 1000 m, respectively [26]. Different communication layers depicted in Figure 3 have certain type of roles.

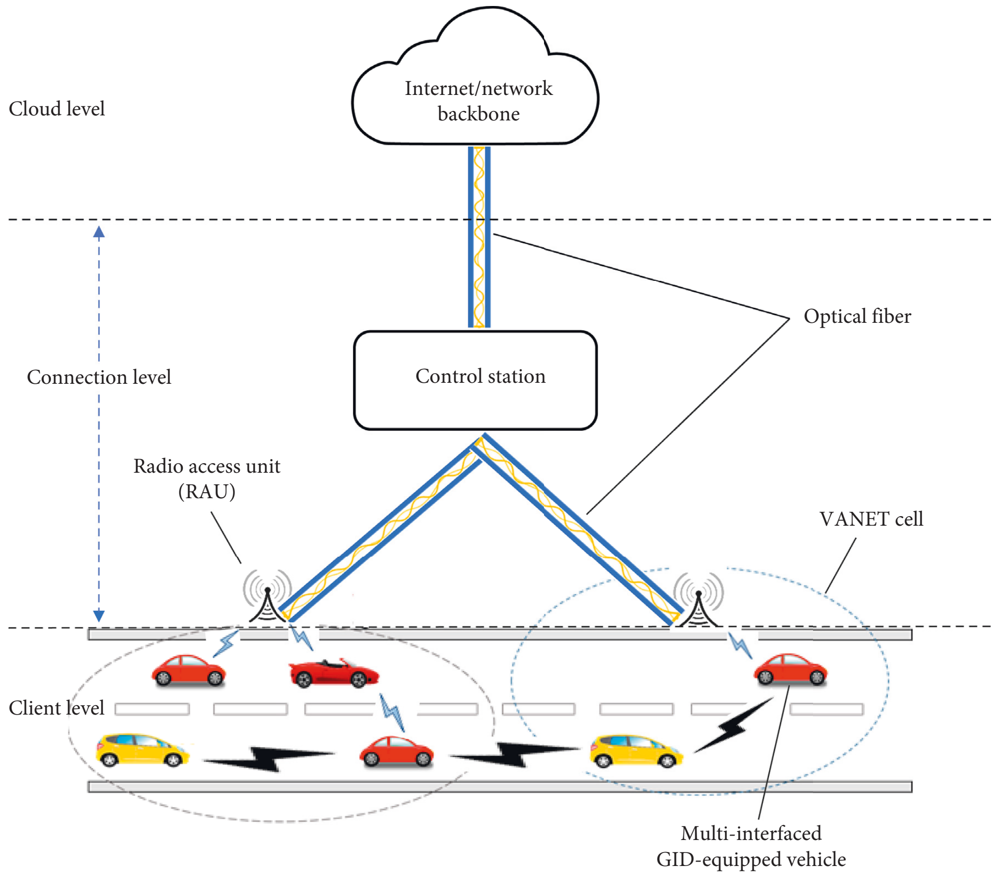

Figure 2: A generalized view of proposed heterogeneous VANETs architecture.

After the physical layer on the fiber channel (FC-0), the FC-1 layer performs the duty of data encoding and decoding. Similarly, framing is the responsibility of FC-2. Many other types of services related to different communication tasks are carried out at fiber channel 3 while layer 4 of the protocol stack performs protocol mapping. For vehicles using WAVE, long-range WiFi, or 4G/LTE interfaces at a particular instance, the data packets forwarding follows through all the layers of 802.11p, 802.11ah, and International Mobile Telecommunications (IMT) Advanced standard stacks, respectively. The summary of notations used throughout the paper is shown in Table 1.

3.3. Best Interface Selection (BIS) Algorithm. The idea of employing BIS interface permits the vehicular users to switch between the interfaces belonging to different technologies as per the best suitability of application requirements as shown in Table 2. In fact, the interface selection criterion for connectivity may depend on several QoS parameters such as throughput, delay, or other user preference like cost-effectiveness. Therefore, the presence of multiple wireless interfaces ensures services through always best-connected user interface at all the times.

The multiple interfaces (WAVE, long-range WiFi, and 4G/LTE) also serve as a back-up to each other in case one interface is a bottleneck for any reason for a certain type of services. There may be a variety of different applications running by vehicular users. The algorithm randomly selects the interface of an access network from the available options and checks if QoS requirements (in terms of bandwidth and/or delay) are successfully met by the chosen interface or it needs to switch over to some new interface. Cost may be another user-defined preference. If the QoS parameters are satisfied, the interface with lowest cost would be opted. The algorithm also serves the purpose to manage load sharing between different interfaces. For example, if an interface undergoing congestion can start causing longer delays, if it does not meet the maximum delay requirement, and the algorithm run will result in changing to some other interface.

4. Results and Discussion

4.1. Simulation Environment. In this section, the simulation environment is discussed in detail highlighting several application parameters. Each vehicle is equipped with multiple wireless interfaces that is (long-range WiFi [17], 4G/LTE [7], and WAVE [8]) installed on GID for establishing connectivity in the given simulation scenario. The performance of the proposed heterogeneous architecture is evaluated in comparison with existing wireless standards on the basis of different performance metrics such as throughput, delay, and server load. The general parameters for the simulation environment can be seen in Table 3.

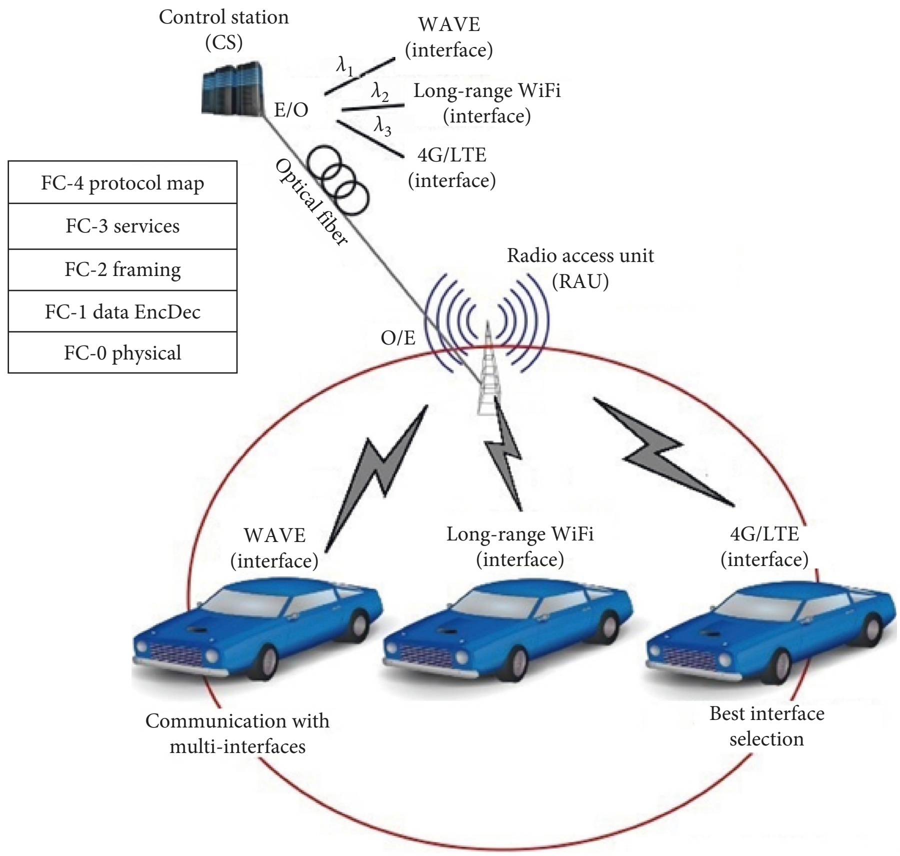

Figure 3: Protocol stack for multi-interfaced VANET.

In the first phase, all the available wireless interfaces are evaluated individually in a given scenario against a set of requirements imposed by various applications. Then, the proposed heterogeneous architecture is evaluated in the same scenario against the same set of requirements to identify the variation among different performance indicators. The detailed performance analysis based on the chosen indicators is presented in the following section.

4.2. Comparison of the Proposed Heterogeneous Architecture with Individual Wireless Interfaces

4.2.1. Analysis of Throughput Parameter with respect to Simulation Time. The simulation results in Figure 4 illustrated the throughput parameter using different communication technologies in a scenario compliant with the simulation parameters in Table 3. The graph shows that the heterogeneous architecture with dynamic and adaptive network selection outperformed WAVE and long-range WiFi standards and shows a high peak of 1100 packets/second at the beginning of the simulation time and then gradually goes on declining with time. Although proposed heterogeneous architecture selects the best network interface depending on the availability at that time with respect to several parameters (e.g., radio propagation and coverage, signal strength, sufficient bandwidth, higher data rate, and lower latency) but, heavy user applications such as, Voice over Internet Protocol (VoIP) and video conferencing, are continuously entertained, and thus the throughout tends to go down below to 30 packets/seconds in all the cases. Nevertheless, the proposed architecture remains in the leading role as compared to other counterparts throughout the simulation time.

4.2.2. Analysis of Delay Parameter with respect to Simulation Time. The graph in Figure 5 depicted the end-to-end delay offered by different communication standards. The figure clearly shows that the delay gradually increases above the simulation time of 15 seconds for all communication standards. Especially, the 4G/LTE standard shows higher delay peak of 1800 ms at 300 s simulation time than 1400.18 ms for the long-range WiFi standard at the same simulation time. However, heterogeneous architecture shows least delay of 451.80 ms at 300 s of simulation time. The reason for such a long delay shown in the case of the 4G/LTE standard might be the higher number of requests by data intensive applications such as VoIP of global system for mobile (GSM) quality and video conferencing, and hence, the network gets loaded causing congestion on the link. In case of the heterogeneous architecture, initially, the rapid switching of communication technologies based on number of requests from various applications with varying distances between the source and the destination causes similar latency as compared to other cases, but it soon

Table 1: A summary of notations used throughout the paper.

Symbol	Definition
d_{proc}	The processing delay is the time that a node spends processing a packet
d_{queue}	The queuing delay is the time required to put an entire packet into the communication media multiplied by an average length of the queue
D_{a}	Delay requirement of the application
d_{ltetotal}	Total delay of the LTE interface
$d_{\text{wavetotal}}$	Total delay of the WAVE interface
$D_{(m\times t)}$	Delay availability matrix for single hop communication
$d_{k,n}\ \varepsilon\ D_{(m\times t)}$	The delay of network interface k at time n
B	Bandwidth of the network interface
B_{wifi}	Bandwidth of the WiFi interface
$B_{(\text{m}\times\text{t})}$	Network availability matrix for single hop communication
c	Unit cost
$c_k\ \varepsilon\ C_{(\text{m})}$	Unit cost of any network interface k
$S_{(m\times t)}$	Network scheduling according to interface m in time slot t
N_n	Network utilization of the interface
N_{inclte}	Network utilization of the LTE interface
N_{incwave}	Network utilization of the WAVE interface
M	The number of network interfaces
$d_{\text{total},k}$	Total delay of the selected network interface k
T	The number of time slot periods
d_{trans}	The transmission delay is the time required to put an entire packet into the communication media
d_{prop}	The propagation delay is the time required for a packet to reach from vehicle to the RAU divided by propagation speed of the media or speed of light
d_{total}	Total delay
$d_{\text{wifitotal}}$	Total delay of the WiFi interface
$d_{\text{wifitotal}}$	Total delay of the WiFi interface
$d_{\text{wavetotal}}$	Total delay of the WAVE interface
$d_{k,n}\ \varepsilon\ D_{(m\times t)}$	The delay of network interface k at time n
B_{lte}	Bandwidth of the LTE interface
B_{wave}	Bandwidth of the WAVE interface
$b_{k,n}\ \varepsilon\ B_{(m\times t)}$	The bandwidth of that network interface k can provide at time n
$C_{(\text{m})}$	Vector of unit cost of all the available network interfaces
$C_{(\text{e})}$	Cost of all network interfaces e
$s_{k,n}\ \varepsilon\ S_{(m\times t)}$	Network k selected at time n
N_{a}	Network utilization by the application
N_{incwifi}	Network utilization of the WiFi interface
N_{inc}	Sum of bandwidth x delay product of all network interfaces
k	Current selected network interface
c_k	Unit cost of selected network interface k
b_{a}	Bandwidth requirement of the application

stabilizes itself after 60 s on the average value of 445.5 ms throughout the simulation time.

4.2.3. Analysis of the Server Load Parameter with respect to Simulation Time. As the number of requests per second on the server increases by the clients running Hypertext Transfer Protocol (HTTP), E-mail, File Transfer Protocol (FTP), VoIP of GSM quality, and video conferencing applications, Figure 6 shows a gradual decrease due to frequent switching between different technologies in the presence of a hard requirements imposed by a plethora of running applications. The heterogeneous architecture exhibits a higher server load starting from 27.6 requests per second that remains higher throughout the simulation as compared to long-range WiFi and other available interfaces. As the proposed heterogeneous architecture is an adaptive multi-interfaced architecture that selects best available interfaces, it is capable enough to serve a higher number of requests as compared to other counterparts.

4.2.4. Impact of Mobility Speed on the Throughput Parameter. As shown in Figure 7, by varying the mobility speed, the throughput parameter demonstrates relatively irregular trend in the graph. However, the proposed heterogeneous architecture offers a reasonable throughput of 101.55 packets/second at mobility speed of 55 kmph. Furthermore, it can also be seen from the figure that the throughput tends to decrease as mobility speed varies from 60 till 80 kmph. On the contrary, the WAVE standard demonstrates a significantly lower throughput of 58.41 packets/second at the same level of mobility. The main factor behind faded throughput is the increase in mobility speed of source and destination vehicles during communication. The heterogeneous architecture is able to cope well with increasing mobility speed as compared to other options due to dynamic interface selection based on application demand. Then, it goes on decreasing between 65 and 70 kmph due to frequent disconnections.

4.2.5. Impact of Mobility Speed on the Throughput Parameter. In Figure 8, the impact of mobility on delay is quite significant for all wireless options especially for 4G/LTE and long-range WiFi, that is, 1811.38 and 1402.18 ms at the speed of 80 kmph, respectively. The reason behind high delay is mainly due to sparseness of source and destination nodes as mobility speed goes on increasing. The demand for running user's applications (such as VoIP and video conference) causes congestion hindering the traffic flow and reduces bandwidth for delay intensive applications. However, heterogeneous architecture tackles the delay by dynamic switching to different available wireless interfaces as per mobility requirement and exhibits moderate delays.

4.2.6. Impact of Server Load with respect to Mobility Speed. The graph depicted the effect of varying mobility on server load for different wireless technologies. As shown in Figure 9, the server load can have huge impact on mobility speed from 55 kmph to 62 kmph. The proposed heterogeneous architecture serves the maximum number of client requests right from the start of the simulation time but goes down rapidly until the mobility speed of 62 kmph. Then, it starts stabilizing from approximately 9 request/s to less than 5 request/s as compared with other

Table 2: Best interface selection algorithm for IoV.

Procedure: $m(B, C, D, N)$ //selecting interface for an application requirement app
$B \longleftarrow$ set bandwidth requirement
$C \longleftarrow$ set cost requirement
$D \longleftarrow$ set delay requirement
$N \longleftarrow$ set network utilization requirement
SET $s_{k,n} = 1$ such that $s_{kn}\ \varepsilon\ S_{(m\times t)}$ //Interface $\longleftarrow$ select a random network ID for initialization
SWITCH app's access preferences (B, C, D, Nn)
CASE B:
IF b_{kn} >= ba such that $b_{k,n}\ \varepsilon\ B_{(m\times t)}$ //if the current network interface meets application bandwidth requirements then,
RETURN B
ELSE $B_{(m\times t)} >= b_{\mathrm{a}}$ such that $B_{(m\times t)} = B = B_{\mathrm{lte}} = B_{\mathrm{wave}} = B_{\mathrm{wifi}}$ //compare it with //the bandwidths available to other access networks
RETURN B //network interface with highest bandwidth support
BREAK;
CASE C:
$C_{(\mathrm{m})} = \sum_{c_{\mathrm{k}}\ \varepsilon\ C_{(\mathrm{m})}} C_{(\mathrm{e})}$ //sum of costs of all links "e"
For all $C_{(\mathrm{m})}$, $c_{\mathrm{k}}\ \varepsilon\ C_{(\mathrm{m})}$ do //FOR get the list of networks to iterate and sort in the increasing cost order
RETURN $(\min(\sum c_{\mathrm{k}}))$ //return the network interface with least cost. k, m
BREAK;
CASE D:
IF d_{kn} <= da such that $d_{k,n}\ \varepsilon\ D_{(m\times t)}$ where $\sum d_{\mathrm{total,k}} = d_{\mathrm{proc}} + d_{\mathrm{queu}} + d_{\mathrm{trans}} + d_{\mathrm{prop}}$ //if the current network interface meets the delay requirements then, return void
ELSE $D_{(m\times t)} <= d_{\mathrm{a}}$ *such that* $D_{(m\times t)} = d_{\mathrm{total}} = d_{\mathrm{ltetotal}} = d_{\mathrm{wavetotal}} = d_{\mathrm{wifitotal}}$ //compare it with the delays of other access networks
RETURN $\forall\ d_{\mathrm{total}}\ e\ D$ $\min_{\mathrm{total},\,m}(\sum d_{\mathrm{total}})$ //return the network interface with least delay
BREAK;
CASE default:
For all $c_k = 0$ to n, //where n is the nth cost amount subject to vector of unit cost, that is, $C_{(\mathrm{m})}$, $c_{\mathrm{k}}\ e\ C_{(\mathrm{m})}$ //FOR get the list of network interfaces to iterate and sort in an increasing cost order
IF $N_{\mathrm{n}} >= N_{\mathrm{a}}$ *such that* $b_{k,n}\ e\ B_{(m\times t)}$ and $d_{k,n}\ e\ D_{(m\times t)}$, where $N_{\mathrm{n}} = B * d_{\mathrm{total,n}}$ //if the current network interface meets bandwidth and delay requirements then,
RETURN N_{n}
ELSE $N_{\mathrm{n}} < N_{\mathrm{a}}$ such that $N_{\mathrm{n}} = N_{\mathrm{inclte}} = N_{\mathrm{incwave}} = N_{\mathrm{incwifi}}$ and $N_{\mathrm{inclte}} = B_{\mathrm{lte}} * d_{\mathrm{ltetotal}}$, $N_{\mathrm{incwave}} = B_{\mathrm{wave}} * d_{\mathrm{wavetotal}}$, $N_{\mathrm{incwifi}} = B_{\mathrm{wifi}} * d_{\mathrm{wifitotal}}$ //compare it with the bandwidth and delay for other available access networks, and
RETURN $(\max_{N_{\mathrm{inc}}\ e\ N}(\sum N_{\mathrm{inc}}))$ //the one with highest bandwidth and least delay
BREAK;
$F\ s_{k,n} = 0$ //no network interface is assigned then,
RETURN false;
ELSE RETURN true;

Table 3: Simulation parameters.

Parameters	Values
Simulator	NCTUns 6.0 [27], OPNET Modeler [28]
Wireless technologies	Long-range WiFi, 4G/LTE, WAVE
Standards	IEEE802.11ah, IMT advanced, IEEE 802.11p
Frequency bands	2.4 GHz, 700–2570 MHz, 5.9 GHz
Simulation time	300 sec
Number of vehicles	30
Acceleration	1
Deacceleration	4
Speed of vehicles	55–80 km/hour
Traffic type	TCP/UDP
Traffic application	VoIP, video, FTP, HTTP, E-mail
Scenario	Semi-Rural, Rural

counterparts which do not specifically perform better against increasing mobility speed.

4.3. Benefits of the Proposed Heterogeneous Architecture. This section presents some prevalent features of the proposed multi-interfaced architecture from various aspects of VANET. These features are enlisted as follows.

4.3.1. Cost-Effective Solution. The cost-effectiveness is of utmost significance in the multi-interfaced architecture. The effort was to make the design inexpensive introducing cheaper RAUs following a very simple transmission mechanism. It is pertinent to mention that the costs may be higher in the areas where the fiber needs to be installed from the scratch. The proposed RoF approach

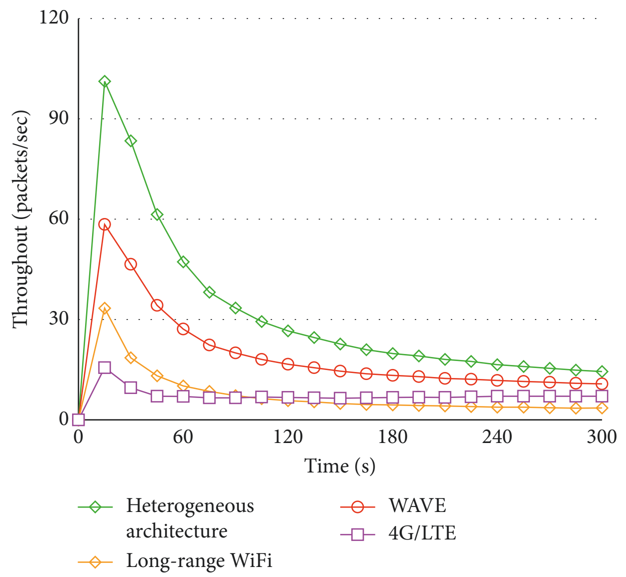

Figure 4: Throughput of RoF-based proposed heterogeneous architecture against other wireless interfaces.

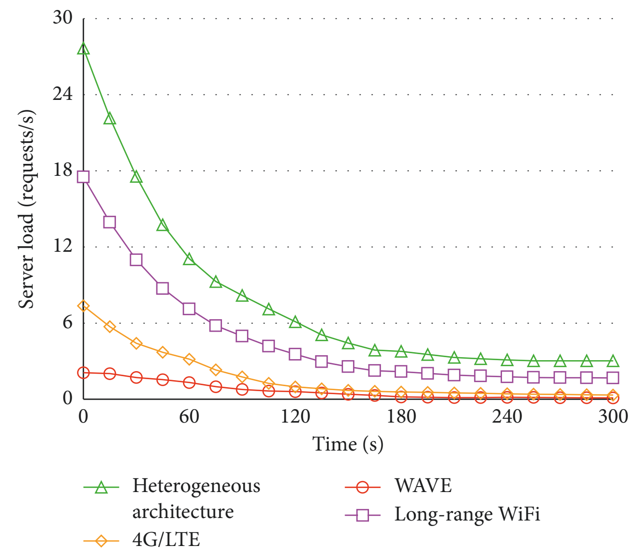

Figure 6: Server load of proposed RoF-based heterogeneous architecture against other wireless interfaces.

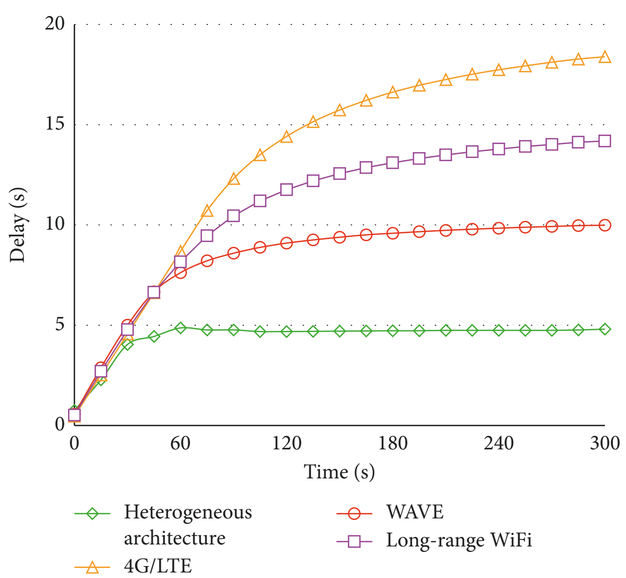

Figure 5: Delay of proposed RoF-based heterogeneous architecture against other wireless interfaces.

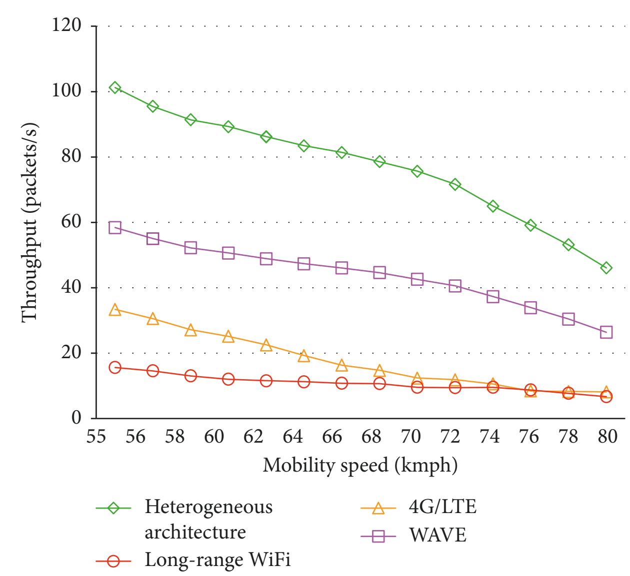

Figure 7: Throughout comparison of proposed RoF-based heterogeneous architecture with other wireless interfaces against different mobility speeds.

is robust than the existing architectures in terms of data rate, bandwidth availability, and quality of service provision. The overall cost factor depends on the existing infrastructure available. For example, if the proposed architecture is to be deployed in an area already covered by fiber services, the only major cost can be the RAU deployment which can be up to tens of USDs.

4.3.2. Congestion Control. Congestion on the network is one of the few troublesome aspects that may gradually lead to slower down the performance of overall network. Accidents, emergencies, or other mishaps usually cause this congestion in VANET as a single point of failure; the entire network appears to be bottleneck and goes down. As the proposed architecture supports many interfaces so if there is some problem with one interface, other nodes can carry on their communication by some other interfaces.

4.3.3. Support for Future Technologies. The proposed architecture demonstrates its compatibility to support many future technologies (such as Fifth Generation (5G) or HaLow) [29] as the RAU design can support a wide range of frequency bands irrespective of the wireless technology

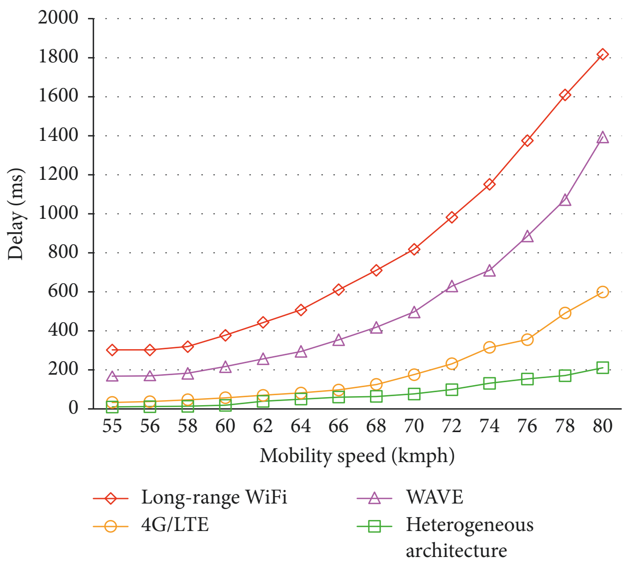

Figure 8: Delay comparison of the proposed RoF-based heterogeneous architecture with other wireless interfaces against different mobility speeds.

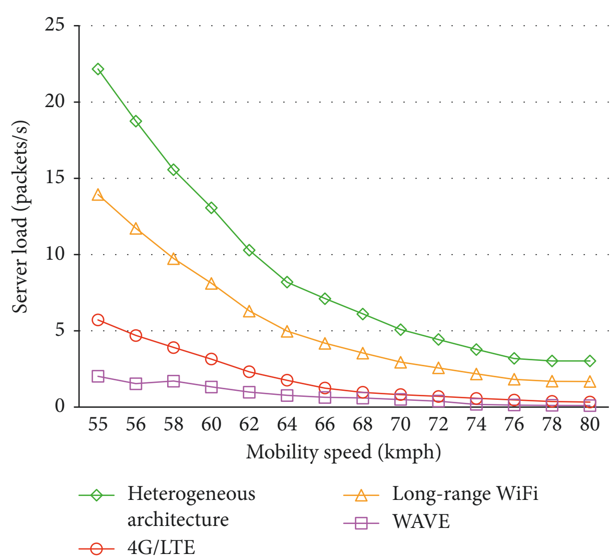

Figure 9: Server load comparison of the proposed RoF-based heterogeneous architecture with other wireless interfaces against different mobility speeds.

standard. Therefore, the deployed RAUs along the roadways can serve to listen on various frequency channels without fearing technology obsoleteness.

4.3.4. Capacity. Utilizing fiber as communication link between several RAUs and CS provides a large number of benefits to network providers because the existing fiber infrastructure spread over most of the areas in advanced countries can be shared for VANET services, and hence, higher throughputs can be achieved. Thanks to the availability of multiple interfaces at a time where each interface can support a bulk of nodes, the proposed architecture is more scalable as well.

4.3.5. Ease of Management. The regions where fiber is already deployed, the proposed architecture can be implemented rapidly with least control infrastructure. A small number of CS are enough to provide the infrastructure management facility due to the idea of fiber connectivity at the backhaul, and CS is the only centralized entity for all kind of processing on the user requests.

4.3.6. Carbon Footprint Savings. As per the statistics, ICT is accounted for 2% of the global carbon footprints, and this trend is going to continue with an annual increase of 10% [30]. Every effort made to minimize this effect would eventually prevent the environment. The proposed architecture employs fiber at the backhaul to connect with the network backbone. Hence, it would contribute in the carbon emission savings towards the phenomenon of Green Networks [3].

5. Conclusion

This paper proposes a novel heterogeneous architecture for Internet of vehicles based on multiple wireless interfaces available for communication. One of the critical requirements of the vehicular communication is the future compatibility for a variety of modern network standards. The proposed heterogeneous architecture outperformed the existing wireless technologies when evaluated individually on the basis of high throughput and low latency in comparison with long-range WiFi, 4G/LTE, and conventional WAVE architectures by varying simulation time and mobility speeds. Moreover, the performance of existing architecture compared to proposed architecture varies as per underlying application demands and network support (i.e. bandwidth intensive applications require high-speed network interface). The proposed architecture ensures the provision of best available connectivity that can fulfill users' demands frequently, thus serving higher number of clients. The proposed RoF-based architecture with multi-interfacing will be a promising solution for future vehicular networks which simultaneously ensures integrity, compatibility, and reliability of the interconnected devices in IoV environment. The work can further be extended towards the classification of vehicles on the basis of application requirements in order to minimize the access control issues as the number of vehicles and application demand increases, thereby reducing congestion on radio access units. Moreover, a more detailed analysis on the capital and operating costs of such approaches has been scheduled as a future work. Furthermore, several other themes can be integrated with the proposed architecture (such as, information centric networks (ICN) [31] and mobile edge computing (MEC) [32] paradigms) to further exploit the advantages of the proposed architecture.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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