

Received April 4, 2020, accepted April 9, 2020, date of publication April 28, 2020, date of current version May 14, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2990915

Dynamic Priority-Based Efficient Resource Allocation and Computing Framework for Vehicular Multimedia Cloud Computing

MUHAMMAD HAMEED SIDDIQI¹, MADALLAH ALRUWAILI¹, AMJAD ALI²,
SYED FAWAD HAIDER³, FARMAN ALI⁴, AND MUDDESAR IQBAL⁵

¹College of Computer and Information Sciences, Jouf University, Sakaka 42421, Saudi Arabia

²Department of Computer Science, COMSATS University Islamabad, Lahore Campus 54000, Pakistan

³Department of Information Technology, University of Gujrat, Gujrat 50700, Pakistan

⁴Department of Software, Sejong University, Seoul 05006, South Korea

⁵Division of Computer Science and Informatics, London South Bank University, London SE1 0AA, U.K.

Corresponding author: Amjad Ali (amjad.khu@gmail.com)

This work was supported by the Jouf University, Sakaka, Aljouf, Kingdom of Saudi Arabia under Grant 40/359.

ABSTRACT In intelligent transportation system, smart vehicles are equipped with a variety of sensing devices those offer various multimedia applications and services related to smart driving assistance, weather forecasting, traffic congestion information, road safety alarms, and many entertainment and comfort-related applications. These smart vehicles produce a massive amount of multimedia related data that required fast and real-time processing which cannot be fully handled by the standalone onboard computing devices due to their limited computational power and storage capacities. Therefore, handling such multimedia applications and services demanded changes in the underlying networking and computing models. Recently, the integration of vehicles with cloud computing is emerged as a challenging computing paradigm. However, there are certain challenges related to multimedia contents processing, (i.e., resource cost, fast service response time, and quality of experience) that severely affect the performance of vehicular communication. Thus, in this paper, we propose an efficient resource allocation and computation framework for vehicular multimedia cloud computing to overcome the aforementioned challenges. The performance of the proposed scheme is evaluated in terms of quality of experience, service response time, and resource cost by using the Cloudsim simulator.

INDEX TERMS Intelligent transportation system, multimedia cloud computing, vehicular networks, quality of experience, multimedia contents processing, response time, smart vehicle.

I. INTRODUCTION

These days automobile industry in collaboration with the academia is focusing on autonomous or driver-less vehicles all around the globe, in which the fast Internet is a primary need. These smart vehicles can take high resolution images, record videos, and need to process many sensory data for their successful and smooth drive, and to enjoy a range of multimedia applications and services from comfortability to entertainment [3] as shown in Figure 1. Furthermore, such smart vehicles can communicate and share various types of information, such as road map images, road safety, and traffic load

The associate editor coordinating the review of this manuscript and approving it for publication was Honghao Gao.

information for safe driving with each other via a roadside infrastructure. Furthermore, such vehicles can also exchange many other information (e.g., automatic parking, map location, Internet access, cooperative cruise control and driving, security distance and collision warnings, driver assistance, and dissemination of road information [1], [2]). Thus, overall vehicles are producing a huge amount of critical and delay sensitive data which required on-time processing to ensure on time delivery to maintain the quality of experience. However, due to limited storage and computational capabilities such a huge amount of multimedia-related data cannot be processed on the standalone onboard devices. Furthermore, intermittent connectivity, short radio communication, lack of bandwidth, and high mobility can make the task more challenging.



FIGURE 1. Vehicle equipped with real-time and multimedia applications for efficient and smooth driving [4].

cloud computing (CC) is an emerging computing paradigm that offers fast and high speed computation facilities as a service to its users without installing any hardware [5]. Thus, CC is an efficient solution for processing of large amount of data at low cost [6]. The integration of CC with smart vehicles is an effective way to enhance the accessibility to multimedia services which also can inspire various potential applications and research topics [9]. The, conventional CC is not suitable for such delay-sensitive and critical multimedia-related applications and services [7]. Thus, to handle such delay-sensitive and critical multimedia applications and services another type of computing paradigm is introduced known as multimedia cloud computing (MCC) [8]. The MCC focuses on how to provide required quality of service (QoS) to multimedia applications. However, multimedia processing of vehicular data is more critical and challenging as it required fast processing, and on-time response at reduced cost. For example the MCC has to process and disseminate the information regarding bad weather conditions (i.e., fog) or some accident happened on the highway and if such information is not process and dissemination to other coming vehicles on-time then there will be more accidents and loss of more lives.

In this paper, we propose a Dynamic Priority-based Efficient Resource Allocation and COMputing (DP-ERACOM) scheme to process the delay-sensitive and multimedia related computation (i.e., video and image data) for vehicular networks at reduced cost based on multimedia tasks priority. In the proposed DP-ERACOM scheme, we divide each multimedia task into four sub-tasks and allocate resources (i.e., MCC resources) dynamically as shown in Figure 2. The proposed scheme has three main computing and processing units: 1) *load manager*, 2) *computing cluster unit*, and 3) *transmission unit*. In DP-ERACOM, vehicular multimedia processing request are received at *request queue* that forward them to *load manager (LM)* for further processing. The *LM* analyzes the nature of incoming requests and assigns them to the particular *computing cluster (CC)*. The *CC* process the received requests and send them to the next *CC* or to *transmission unit (TU)* based on the type of requests. Finally, the *TU* broadcast/unicast the processed request a single or group of vehicles. The proposed scheme

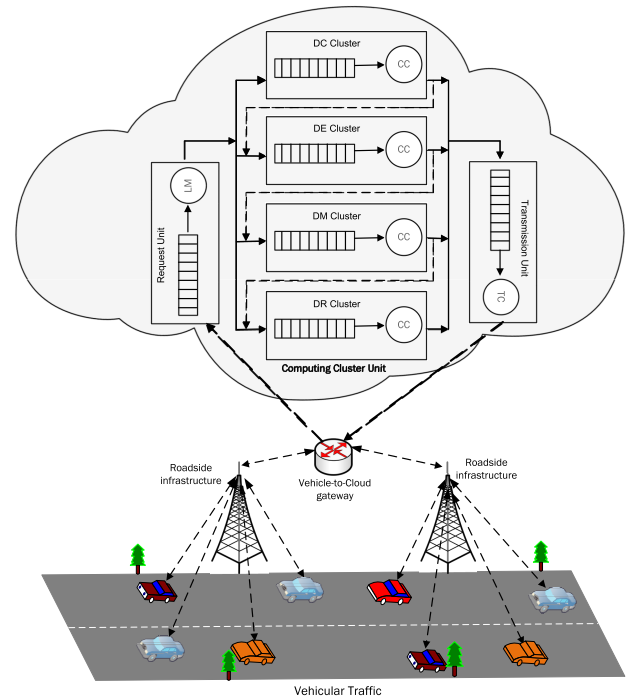


FIGURE 2. Multimedia-oriented cloud computing architecture for vehicular networks.

handles the priority or urgency of any processing request with the help of *job queues (JQ's)*. In DP-ERACOM, each CC and TU contain single job queue to store all multimedia requests. This concept is demonstrated in Figure 2. However, Table 1 enlists the symbols and acronyms used in our paper. Our main contributions of this paper are listed as below:

- We propose a Dynamic Priority-based Efficient Resource Allocation and COMputing (DP-ERACOM) scheme to process the delay-sensitive and multimedia computations based on multimedia tasks priority for vehicular networks at reduced cost.
- The proposed DP-ERACOM scheme comprises on three main computing and processing units: 1) *load manager*, 2) *computing cluster unit*, and 3) *transmission unit*.
- In the DP-ERACOM scheme, we divide each multimedia task into four sub-tasks and allocate them the cloud resources dynamically.
- The performance of the proposed scheme is compared with the static resource allocation and single datacenter-based resource allocation schemes and evaluated in terms of quality of experience, service response time, and resource cost by using the Cloudsim simulator.

The remaining of our paper is organized as follows: Section II presents the state-of-the-art related to multimedia cloud computing and vehicular networks. Section III deals with proposed DP-ERACOM. Section IV describes our performance and comparative analysis. Finally, Section V, concludes the paper and future work.

TABLE 1. Summary of notations.

Notation	Description
α_t	Time to collect job request from vehicles
N	Number of task received in time α_t
R_Q	Request queue
LM	Load manager
χ_{α_t}	Computing resource at time α_t
CC	Computing cluster
DCC	Data conversion cluster
DEC	Data extraction cluster
DMC	Data matching cluster
DRC	Data reconstruction cluster
TU	Transmission unit
P_Q	Priority queue
λ	Arrival rate
ϵ	Predefined threshold for delay

II. RELATED WORK

This section summarizes the state-of-the-art related to the vehicular data processing and resource allocations methodologies especially for delay-sensitive, critical, and QoS demanding multimedia contents.

In order to minimize the average offloading delay, a learning-based offloading scheme for VCC is proposed in [25]. In the proposed scheme, “an adaptive upper confidence bound algorithm” is developed based on the multi armed bandit theory which makes it adaptive for time varying action and load space. In [26], Ashok *et al.* introduced a heuristic scheme for offloading vehicular tasks and their scheduling over the cloud. The authors compared the proposed scheme with the on-board computation scheme and measures the performance in terms of response time. In [27], Limbasiya *et al.* introduced a scheme to verify the correctness of the received information from the VCC to prevent the security attacks, such as modification, man-in-the-middle, plain text, and impersonation. The correctness of the proposed scheme is verified against various schemes. Similarly, ID-based signature technique for information verification in the VCC is developed in [28]. In the proposed scheme, the signature verification is carried out with the help of the pseudonymous revocation and batch verification techniques. Message passing among the vehicles in the critical and emergency situations is getting more attention under heavy traffic scenarios. Therefore, in such critical scenarios, it is highly important to verify the source of information. Thus, to achieve this goal a framework called SmartVeh is introduced in [29]. In the proposed scheme, an encryption technique based on attributes is developed to securely share the message among the vehicles. Furthermore, in the proposed scheme all heavy computations, such as signing certificate, encryption and decryption are outsourced on the cloud or RSUs.

In order to deal with the problem of spectrum scarcity a cognitive radio relay-based communication scheme is introduced in [12]. In the proposed scheme, an optimization is formulated to increase the network lifetime and save the vehicles power. Primary user (PU) transmissions are protected by using energy-based PU detection scheme, in which PU

arrival probability is calculated based on the energy detection technique. In [11], the authors proposed a channel assignment scheme for VANETs, in which vehicles dynamically adopt the contention window (CW) size based on the vehicle’s speed. In order to support the VANETs services, such as the speed-based lane changing, time of arrival (TOD), and collision avoidance some new methods are suggested in [16]. The performance of the proposed algorithms is tested in both the network simulator-2 (NS-2) and simulation of urban mobility (SUMO) simulators. Moreover, an on-board mobile-app is designed for efficient, smart, and remote traffic monitoring. In [17], the authors addressed the message on time delivery problem in VANETs. The authors formulated the problem as bi-objective binary linear programming. Moreover, the proposed solution has two main objectives; 1) extending the network lifetime by using the roadside units (RSUs) as relay nodes and also sensing is essential for them, and 2) ensuring the on-time delivery of sensed information to the sink nodes. A distributed resource management scheme for real-time applications in VANETs is introduced in [18]. The proposed scheme allocates the access time window (ATW) to RSU’s, traffic flows, and access rates dynamically based on the hard reliability collisions constraints. Moreover, the authors proposed a memoryless scheduler for optimizing the network utility. The same authors extended their work in [19] and proposed an adaptive and distributed resource allocator scheme for cognitive radio-enabled VANETs. The main objective of this scheme is to enable the computing and battery limited vehicles to exploit the vehicular-to-infrastructure wireless fidelity (WiFi) connections for traffic offloading from remote and local cloud by using the cognitive radio-enabled wireless channels. The authors formulated the resource allocation problem as “constrained stochastic network utility optimization problem”, in which the serving SRU’s dynamically allocated the ATW along with traffic flows, and access rates.

In [20], the authors proposed a *cooperative and adaptive resource scheduling* scheme for VCC known as CARESS, in which requested service is allocated the demanding resource to maintain a certain threshold of quality of service. The proposed scheme also maintains a cache to help the vehicles during searching of required resources. Furthermore, to facilitate the vehicles in searching and managing the required resources, the same authors extended their work in [21] and introduced a more efficient resource allocation and research protocol called SERVitES. In the proposed scheme, vehicles share information by organizing themselves into clusters without the help of the RSU. A three-tier architecture for the VCC is introduced in [22] which comprises on roadside cloudlet, vehicular cloud, and centralized cloud. The authors formulated an *adaptive particle swarm optimization problem* to allocate the demanded resources to the resource hungry applications and services (i.e., multimedia services) to meet their demanded QoS requirements from the any of the three-tier cloud architecture.

Intelligent transportation system faces serious frequency-handoff challenges when the vehicles speed crossing over

the 300 km/h speed limit. Therefore, in such high-speed scenarios, vehicles cannot perform exchange of information or data computations among each other. Thus, there is a need of designing an efficient cloud-based solution to handle such critical scenarios. So, in order to tackle such a high-speed handoff issues, a novel framework called SVCC-HSR is introduced in [30]. The proposed scheme is comprising on a three-layer cloud-computing architecture, in which some other techniques are also introduced to tackle the other important challenges, such as fast encryption-decryption, authentication, multi-path transmissions, identifier mapping, and packet compression. Vehicular ad hoc networks can greatly improve their storage, computation and sensing abilities by adopting the cloud computing solutions. Thus, a VCC-based model is suggested in [31] to improve the vehicular computational and communication services. The proposed model also addressed other services issues like resource management, security, privacy, and data aggregation. Vigneri *et al.* proposed that the vehicles could be used as mobile caches to meet the increasing demand of Internet contents and reducing the overload on the cellular infrastructure in [32]. In the proposed scheme, users can connect to the nearby vehicle for the related contents temporarily and then the connection is shifted towards the cellular infrastructure after the expiry of the predefined timeline. In [33], the authors focus the underutilization of onboard computational resources and their efficient allocation as per the nature of the applications. Thus, they proposed a scheme for the VCC to efficiently utilizing the onboard computational resources. In the proposed scheme, the vehicular-tasks are divided mainly into three categories for computational purposes and to reduce the response time for more critical tasks they are being computed via a onboard available resources, the less critical and more computational-heavy tasks are offloaded to the VCC and more heavy and least important tasks are being offloaded on the cloud. In [34], the authors proposed that the offline or parked vehicles can be used as a mean of storage for the moving or active vehicles data. However, to reduce the response time for accessing the relevant data or information an efficient and fast scheduler is required. Thus, they proposed a scheduler called TSP-HVC for the VCC.

In [35], authors introduced a novel channel clustering scheme called “NOBEL” for transmitting real time and multimedia contents in MCRNs. The proposed scheme, quantifies the licensed channels based on their available QoS parameters and make them available for SUs to select the licensed channel as per their desired QoS requirements. In [36], the authors proposed a priority-based channel allocation scheme for IoT-based CRNs for transmitting time-critical applications. In the proposed scheme, more channels are reserved for higher-priority SUs to reduce its call-blocking probability and similarity lower number of channels for the low-priority SUs. An efficient real-time and multimedia transmission scheme using RaptorQ is introduced for underlay cellular CRNs in [37]. In the proposed scheme, the packet losses occurred due to interference with PUs are combat using

RaptorQ. Moreover, to assist the successful decode at receiver node different time-sharing ratios are adopted. A soft handoff scheme based on fuzzy logic is introduced to reduce the channel switching rate and for enhanced transmissions for CRN in [38]. In [11], Hussain *et al.* introduced an efficient channel access scheme for VANETs under high mobility and dense traffic conditions. In the proposed scheme, the contention window is adjusted dynamically based on the deadlines measured in terms of time. Conventional path planning based on the shortest path is not recommended for the advanced vehicular systems, such as driverless or autonomous vehicles. Therefore, an efficient path planning is a vital task for the modern systems. The authors in [39], proposed a more efficient and optimal path for the critical and emergency situations based on the road conditions, traffic accidents, and traffic congestions parameters. Many resource models have been investigated previously based on the human interaction and sensors in IoT. In [40], the authors have proposed a new resource model based on information, knowledge, extension of data, and wisdom architecture to construct modeling for both entity and relationship. In order to predict the QoS values in IoT, a neural collaborative filtering-based holistic framework is proposed in [41]. The propose scheme is further based on fuzzy filtering technique to cluster the contextual information.

A vehicular edge computing based collaborative framework called *collaborative vehicular edge computing framework* (CVEC) is introduced in [13]. The proposed framework has flexibility to support various vehicular applications and services both in vertical and horizontal collaborations. In [14], a joint VCC and information-centric-based network architecture is considered for VANETs. In the proposed framework, the information-centric network (ICN) is used to defines the ways for contents dissemination and data routing. Whereas, the VCC helps in defining the ways for network service provisioning by bringing the mobile cloud model to VAVETs. A cloud-architecture for VANETs called *VANETs-Cloud* is introduced in [15]. The proposed architecture is further divided into two sub-models; 1) temporary cloud and permanent cloud. Moreover, the VANETs cloud is based on three layers; 1) client layer, 2) cloud layer, and 3) communication layer. The VANETs cloud provides digital services (i.e., computational infrastructures, software, and platforms) at reduced cost. In our preliminary work [10], we introduced an cloud-architecture for multimedia processing. In this work, each multimedia request is kept in a separate job queue for processing; therefore, the multimedia processing architecture with N different job queues makes system complex and difficult to compute.

III. PROPOSED DP-ERACOM SCHEME

In this section, we discuss the proposed DP-ERACOM scheme for vehicular multimedia cloud computing (VMCC). The DP-ERACOM has three main components: 1) VMCC architecture, 2) resource allocation for VMCC and 3) VMCC queuing model.

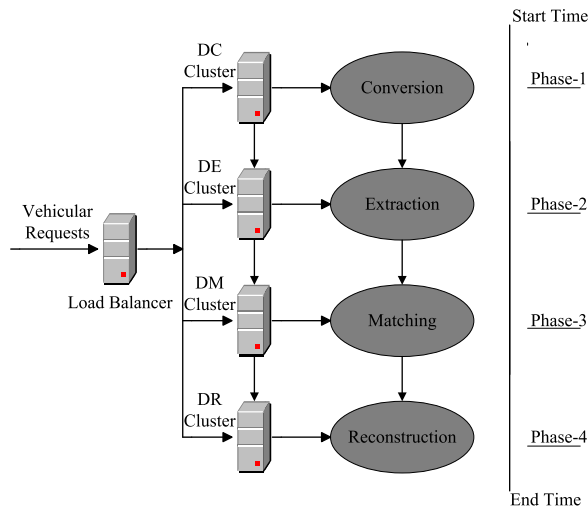


FIGURE 3. Task level parallel processing procedure.

A. VMCC ARCHITECTURE

In this subsection, we discuss the proposed VMCC architecture for processing vehicular multimedia related tasks, such as image or video analysis. We have divided the whole multimedia processing structure into four phases: 1) conversion, 2) extraction, 3) matching, and 4) reconstruction as shown in Figure 3. This categorization is similar to the presented in [8]. However, in the DP-ERACOM all of these four computation phases are performed separately by four dedicated computing clusters rather than a single computing cluster. Thus, in order to minimize the computing cost, computing resources to each computing cluster are assigned dynamically according to the need or load information. Moreover, in the proposed VMCC architecture each dedicated computing cluster (DCC) contains single priority queue for storing jobs to maintain the priority of the vehicular multimedia tasks. Furthermore, to achieve higher computing performance all of these four DCC’s perform execution of vehicular multimedia tasks in cooperative manner as shown in Figure 1.

The VMCC architecture is further divided into four main components: 1) request unit (RU), 2) LM, 3) computing cluster unit (CCU), and 4) TU. Vehicles submit their multimedia computing requests to RU via a vehicle-to-cloud gateway by using any wireless interface, such as WiFi, WiMAX or LTE. The LU module in VMCC is smart and intelligent module, it not only analyses the nature of the media tasks for task scheduling but also estimates the total aggregated load at any time α_t . This load estimation information will be used further for optimal resources allocation to each DCC. The CCU is divided into four sub-computing clusters called: 1) dynamic conversion cluster (DCC), 2) dynamic extraction cluster (DEC), 3) dynamic matching cluster (DMC), and 4) dynamic reconstruction cluster (DRC) as shown in Figure 2 and 3. Each DCC contain a single priority queue, in which LM submits vehicular multimedia tasks for computation according to their predefined priority policy/value.

Algorithm 1 Priority-Based Task Scheduling and Processing Procedure

```

input : Global channel set  $N$ 
output: Sorted Set of available channel  $K$ 
1 Initialize request queue with  $R_Q \leftarrow \text{null}$ 
2 Assign collection time  $C_t$  with initial value  $\alpha_t$ ;
 $C_t \leftarrow \alpha_t$ 
3 Collect requests from vehicles till the expiry of  $\alpha_t$ 
4 LM analyzes the  $R_Q$  to estimate the total workload  $N$ 
5 for  $n_i \leftarrow 1$  to  $N$  do
6    $\lfloor$  /* Sort  $n_i$  based on priority value */
7   LM assigns computing resource  $\chi_{\alpha_t}$  to each
   computing cluster  $CC$  based on the value of total
   workload  $N$ 
8    $DCC \leftarrow \chi_{\alpha_t}$ 
9    $DEC \leftarrow \chi_{\alpha_t}$ 
10   $DMC \leftarrow \chi_{\alpha_t}$ 
11   $DRC \leftarrow \chi_{\alpha_t}$ 
12 for  $I \leftarrow 1$  to  $N$  do
13    $\lfloor$  /* LM sends multimedia task  $I$  into the priority
   queue  $P_Q$  of its appropriate  $CC$  */
14 for  $J \leftarrow 1$  to  $N$  do
15    $\lfloor$  /*  $CC$  processes the multimedia task  $J$  */
16   if  $J$  wants further processing step then
17     Add  $J$  into the  $P_Q$  of next  $CC$ 
18   else
19     Add  $J$  into the  $P_Q^T$  of  $TU$ 
20 for  $K \leftarrow 1$  to  $P_Q^T$  do
21    $\lfloor$  /*  $TU$  transmits processed multimedia task  $K$  to
   its intended vehicle(s) */

```

In this paper, we assume that the priority of each vehicular multimedia task is computed and assigned based on the type and nature of the task. For example the least important and critical tasks are assigned the least priority and similarly the most important and critical tasks are assigned the higher priority. Thus, a media task processed by CCU is placed in the job queue of TU. The TU may apply some conversion before forwarding the processed job to vehicle-to-cloud gateway that further forward to the requested vehicle via a roadside infrastructure.

B. MVCC JOB QUEUES MODEL

This subsection present the description of the job queues used in MVCC architecture and their working. Overall, there are three different types of job queues: 1) request’s queue, in which all vehicles submit their media tasks that need to be processed by the media cloud, 2) computing or job queues, those store the vehicular media tasks for cloud processing, and 3) transmission queue that store and hold processed tasks before forwarding to the destination(s). This concept illustrated in Figure 2.

C. DYNAMIC RESOURCE ALLOCATION FOR THE VMCC

The main objectives of the proposed dynamic resource allocation scheme are; 1) efficient processing, 2) on-time delivery, and 3) minimizing the computing cost. In the proposed dynamic resource allocation scheme cloud has four dedicated media clusters where virtual machines are installed that are responsible for processing of multimedia vehicular tasks. Computing resources to each DCC is allocated dynamically based on the vehicular multimedia requests load that is estimated by the *LM*. For example if vehicular requests are more than the allocated resources then more computing resources are allocated to DCCs, similarly if the estimated load is less than the already allocated computing resources then computing resources are removed. Thus, based on vehicular load estimation the computing resources are periodically updated to minimize the computing cost and to provide better QoE to moving vehicles.

Algorithm 1 (*Priority-based Task Scheduling and Processing Procedure*): From lines 1–4, the initial assignments and analyses were carried out upon the arrival of real-time and multimedia tasks from various vehicular users in the time span, α_t . From lines 5–7, all received multimedia requests are analyzed and sorted in the form of priority non-preemptive based on their priority values. In this paper, the lower value of priority show the higher priority of task for processing. From lines 8–12, each of the four computing clusters are assigned the resources for job processing. The computing resources to each *CC* is assigned based on the analyses of initial workload received in time α_t . Thus, for next time the amount of computing resources will varies based on the received workload. This is done to utilize the computing resources efficiently and meeting the multimedia tasks delay deadlines. From lines 13–15, the *LM* assigns the each multimedia task to its appropriate *CC* and place to the task into its job queue for further processing. From lines 16–22, the *CC* processes the multimedia tasks and place them into the job queue of further computing unit or transmission unit based on the task processing nature. For example, if the task is fully processed then it will be sent to the job queue of transmission unit for transmission to the intended vehicular user(s) or send it into to the job queue of next *CC* if its processing is not completed yet. Finally, from lines 23–25, the processed multimedia tasks are forwarded towards their intended vehicular user(s) simultaneously to avoid any further queuing delay and to meet the delay deadline of multimedia tasks for achieving better quality of experience (QoE).

IV. PERFORMANCE ANALYSIS

In this section, first we present our experimental settings then, discuss the schemes for performance evaluation and evaluation criteria. Finally, we discuss our simulation results.

A. EXPERIMENTAL SETUP

In this subsection, we provide the detail of our experimental setup. We use the CloudSim [23] simulator for performance

analysis of the proposed scheme. Cloudsim is a Java-based library model which is widely used for performing cloud-related simulations [24]. In Cloudsim, the validity of the performed simulations are carried out via a cloud-based content distribution service which sets the corresponding application complexity according to the calculation requests of the service. As discussed previously, we model our scenario into three main components, 1) *LU*, 2) *CCU*, and 3) *TU*. We perform simulation on multimedia tasks (i.e., images) and for this purpose, we modified the characteristics of cloudlet class and modeled it as per our requirement. In our proposed scheme, the arrival of vehicular media-tasks follow the Poisson distribution with t time interval. We carried simulations under different hardware settings (i.e., MIPS, RAM, and number of CPUs) as given in Table 2.

TABLE 2. Simulation settings.

Sr. no.	RAM	MIPS	CPUs
Setting 1	4096	2100	2
Setting 2	4096	4200	1
Setting 3	4096	2100	1

B. PERFORMANCE EVALUATION SCHEME AND CRITERIA

We evaluate and compare the proposed scheme with the baseline single cluster and static resource allocation schemes. All the four phases related to image processing are being performed by a single cluster in the baseline single cluster scheme. However, in the static resource allocation scheme, resources to each DCC are allocated at startup with no periodic updation of computing resources. We conducted comparisons based on the following parameters:

1) QUALITY OF EXPERIENCE

The QoE is measured in terms of end-to-end or SRT time, that is a time measured from vehicle media request initiate phase till vehicle receives its required response. In our paper the QoE is directly proportional to the value of SRT. For example if a particular vehicle receive its required response in-time then it experience better QoE. However, if a particular vehicle do not receive the required response in-time then its experience low QoE. The overall QoE of the proposed system is measured as follows:

$$T^{tot} = T^{sch} + T^{com} + T^{tra} \quad (1)$$

For scheduling all priority-classes, the mean service response time given in [10] as follows:

$$T^{sch} = \frac{1}{\mu - \frac{\lambda}{\mu}} \quad (2)$$

where the scheduling rate is denoted as μ for processing according to the assigned or allocated priority-classes. Multimedia requests arrival is modeled by using a Poisson distribution with the λ arrival rate. In this paper, we assume high-speed wired communications links among each *CC*.

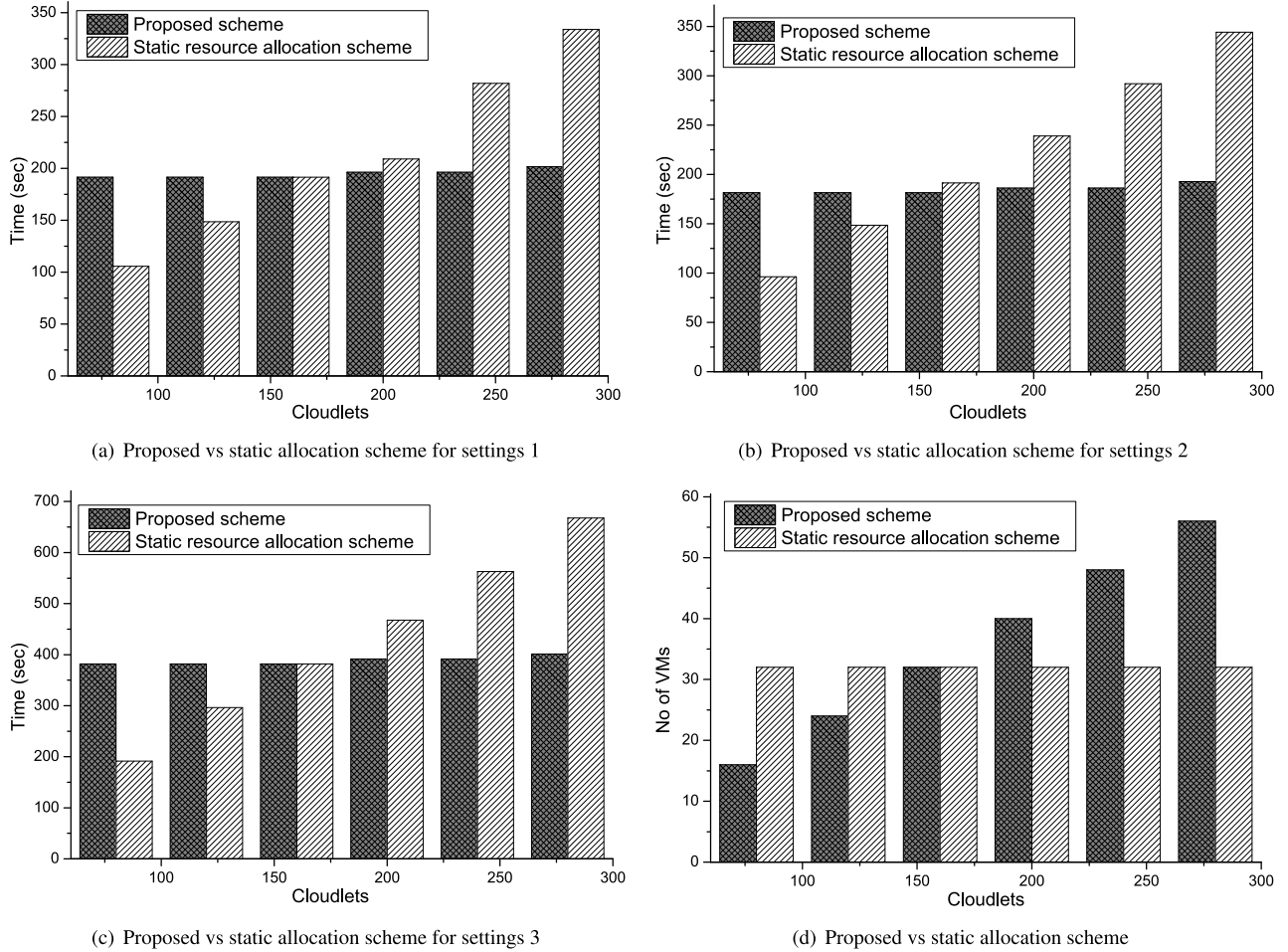


FIGURE 4. Proposed vs static allocation scheme under different simulation settings.

Therefore, the delay of moving one sub-tasks from one CC to another CC is negligible. Thus, the mean service time (MST) for multimedia tasks for all four computing sub-phases is given as follows:

$$T^{com} = \sum_{k=1}^4 T^{com_k} \tag{3}$$

Finally, the MST for computing of all types of priority is given as below:

$$T^{com} = \sum_{j=1}^N \frac{\lambda_j T_j^{com}}{\lambda} \tag{4}$$

where N is total multimedia tasks received in time \mathfrak{N}_t for processing. Finally, the SRT for transmitting all multimedia results towards their intended vehicular user(s) is given in [10] as below:

$$T^{tra} = \sum_{j=1}^N \frac{\lambda_j T_j^{tra}}{\lambda} \tag{5}$$

Thus, substituting the values of T^{sch} from Eq. (2), T^{com} from Eq. (4), and T^{tra} from Eq. (5) in Eq. (1), we get

$$T^{tot} = \frac{\frac{1}{\mu}}{1 - \frac{\lambda}{\mu}} + \sum_{i=1}^N \frac{\lambda_i T_i^{com}}{\lambda} + \sum_{i=1}^N \frac{\lambda_i T_i^{tra}}{\lambda} \tag{6}$$

If the end-to-end latency T^{tot} of any multimedia request is below then its given threshold (i.e., the upper bound of service time, ϵ). Then, the end user(s) experience the satisfactory QoE. This QoE constraint is defined as follows:

$$T^{tot} < \epsilon \tag{7}$$

If the above given condition is not met, then more resources are needed to improve the QoE at end user.

2) COMPUTING COST

For any cloud service provide, providing the desired QoE at reduced coast is always a challenging task. In this paper, the computing cost is directly proportional to the number of computing resources, such as the no. of virtual machines allocated for computation of any particular media task. Hence, the more no. of idle resources the more will be computing cost.

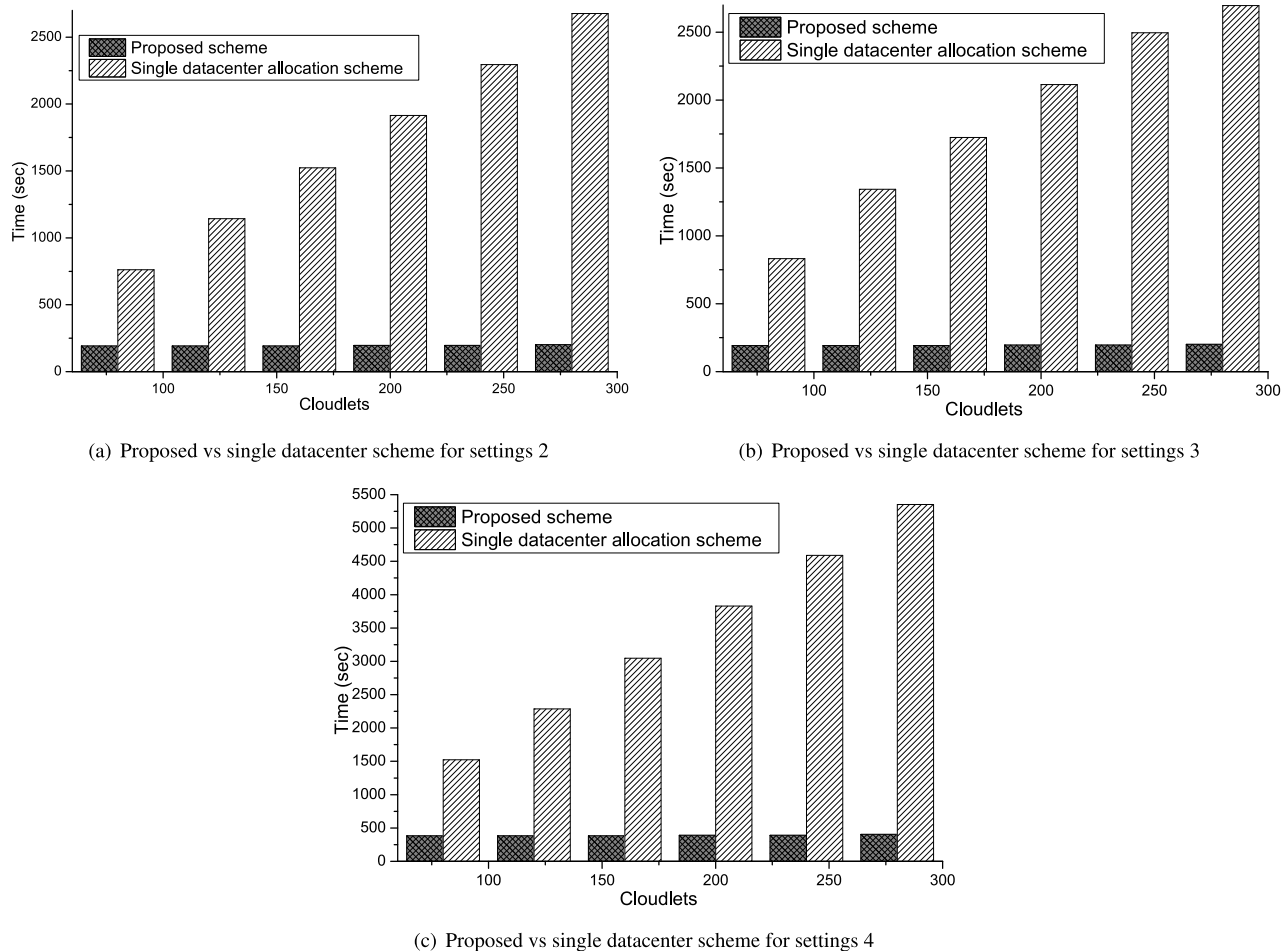


FIGURE 5. Proposed vs single datacenter allocation scheme under different simulation settings.

C. SIMULATION RESULTS

In this section, we present the simulation results of the proposed scheme compared with the static allocation, and baseline single cluster allocation schemes.

Figure 4(a)-4(d) present the performance evaluation results of the proposed scheme with static resource allocation scheme under various simulation settings (i.e., setting 1 - setting 3) as given in Table 2. Figure 4(a) presents SRT under configurations setting 1 of virtual machines in the media server in which VM has processing speed 2100 MIPS, 2 CPUs, and 4 GBs of RAM. It is clear from the figure that the proposed scheme perform better than the static resource allocation scheme in terms of SRT. In static resource allocation scheme, the resources are assigned once at the beginning of simulation. Under the fewer no. of cloudlets the static scheme performs better. However, as the no. of cloudlets increases the SRT also increase which consequently reduce the QoE at receiver vehicle. As in the proposed scheme the resources are dynamically updated according to the load information. Therefore, the proposed scheme performs better even under more no. of tasks and it provides batter and guaranteed QoE at the receiving vehicle. Similarly, the figures 4(b)- 4(c) show

that the proposed scheme perform batter under other simulation settings. Figure 4(d) represents simulation result of the proposed scheme with static resource allocation scheme in terms of number of amount computing resources (i.e., number of Virtual Machines (VMs)) required for computation. Figure shows that with the increase in number of cloudlets the number of VMs also increase. This is because of maintaining a guaranteed QoE to vehicles and providing on-time responses.

Figure 5(a) - 5(c) present the simulation results for the SRT of the proposed scheme with baseline single cluster or data-center based resource allocation scheme under various configuration settings given in Table 2. It is clear from the Figure 5(a) - 5(c) that the proposed scheme outperform the single cluster-based computing scheme. The proposed scheme provides the minimum computation time and consequently, supports the guaranteed QoE for vehicles. However, it can be clearly seen that the SRT increase as the cloudlets increase in single cluster-based computing scheme. This happens as only the single cluster is responsible for performing all four image related tasks. Whereas, in the proposed scheme, a image processing task in divided into

four sub-tasks those are further assigned to the four dedicated computing clusters, accordingly. Thus, the proposed scheme performs better than the baseline single cluster computing scheme in terms of the SRT.

V. CONCLUSION

In intelligent transportation systems, vehicles are equipped with multiple sensors, cameras, and other smart devices that produces a huge amount of multimedia-related contents for processing which cannot be performed by the on-board standalone computing devices due to their limited storage, battery powers, and computation capacities. Therefore, integration of vehicles with multimedia cloud computing (MCC) is highly required as it provide a powerful computing tool that offers the fast and efficient computation of vehicles multimedia applications and services. In this paper, we proposed an dynamic priority-based efficient resource allocation and computing architecture for vehicles to address the challenges of fast response time, guaranteed quality of experience, and minimum computing cost. In our proposed scheme, multimedia tasks are divided into four sub-tasks and assigned to appropriate dedicated computing cluster for processing. Priority non-preemptive queue is used to ensure the on-time response delivery to different vehicular multimedia tasks with different priorities. Moreover, in our proposed scheme, computing resource are dynamically updated based on load information. The performance of the proposed scheme is evaluated using Cloudsim simulator with static resource allocation scheme and baseline single cluster-based computing scheme in terms of the QoE, resource cost, and response time. The simulation results show that the proposed scheme outperforms the baseline single cluster-based computing and static resource allocation scheme.

REFERENCES

- [1] T. Mekki, I. Jabri, A. Rachedi, and M. ben Jemaa, "Vehicular cloud networks: Challenges, architectures, and future directions," *Veh. Commun.*, vol. 9, pp. 268–280, Jul. 2017.
- [2] S. Midya, A. Roy, K. Majumder, and S. Phadikar, "Multi-objective optimization technique for resource allocation and task scheduling in vehicular cloud architecture: A hybrid adaptive nature inspired approach," *J. Netw. Comput. Appl.*, vol. 103, pp. 58–84, Feb. 2018.
- [3] M. Gerla, E.-K. Lee, G. Pau, and U. Lee, "Internet of vehicles: From intelligent grid to autonomous cars and vehicular clouds," in *Proc. IEEE World Forum Internet Things (WF-IoT)*, Seoul, South Korea, Mar. 2014, pp. 241–246.
- [4] Accessed: Mar. 23, 2020. [Online]. Available: <https://www.gsa.europa.eu/newsroom/news/central-role-robust-gnss-autonomous-driving>
- [5] J.-L. Chen, S.-L. Wuy, Y. T. Larosa, P.-J. Yang, and Y.-F. Li, "IMS cloud computing architecture for high-quality multimedia applications," in *Proc. 7th Int. Wireless Commun. Mobile Comput. Conf.*, Istanbul, Turkey, Jul. 2011, pp. 1463–1468.
- [6] Y. Wu, C. Wu, B. Li, X. Qiu, and F. C. M. Lau, "CloudMedia: When cloud on demand meets video on demand," in *Proc. 31st Int. Conf. Distrib. Comput. Syst.*, Minneapolis, MN, USA, Jun. 2011, pp. 268–277.
- [7] X. Nan, Y. He, and L. Guan, "Optimal resource allocation for multimedia cloud based on queuing model," in *Proc. IEEE 13th Int. Workshop Multimedia Signal Process.*, Hangzhou, China, Oct. 2011, pp. 1–6.
- [8] W. Zhu, C. Luo, J. Wang, and S. Li, "Multimedia cloud computing," *IEEE Signal Process. Mag.*, vol. 28, no. 3, pp. 59–69, May 2011.
- [9] M.-K. Jiau, S.-C. Huang, J.-N. Hwang, and A. V. Vasilakos, "Multimedia services in cloud-based vehicular networks," *IEEE Intell. Transp. Syst. Mag.*, vol. 7, no. 3, pp. 62–79, 2015.
- [10] A. Ali, H. Liu, A. K. Bashir, S. El-Sappagh, F. Ali, A. Baig, D. Park, and K. S. Kwak, "Priority-based cloud computing architecture for multimedia-enabled heterogeneous vehicular users," *J. Adv. Transp.*, vol. 2018, pp. 1–12, Sep. 2018.
- [11] S. A. Hussain, M. Iqbal, A. Saeed, I. Raza, H. Raza, A. Ali, A. K. Bashir, and A. Baig, "An efficient channel access scheme for vehicular ad hoc networks," *Mobile Inf. Syst.*, vol. 2017, pp. 1–11, 2017.
- [12] J. Md Piran, Y. Cho, J. Yun, A. Ali, and D. Y. Suh, "Cognitive radio-based vehicular ad hoc and sensor networks," *Int. J. Distrib. Sensor Netw.*, vol. 10, pp. 1–11, 2014.
- [13] K. Wang, H. Yin, W. Quan, and G. Min, "Enabling collaborative edge computing for software defined vehicular networks," *IEEE Netw.*, vol. 32, no. 5, pp. 112–117, Sep. 2018.
- [14] E. Lee, E.-K. Lee, M. Gerla, and S. Oh, "Vehicular cloud networking: Architecture and design principles," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 148–155, Feb. 2014.
- [15] S. Bitam, A. Mellouk, and S. Zeadally, "VANET-cloud: A generic cloud computing model for vehicular ad hoc networks," *IEEE Wireless Commun.*, vol. 22, no. 1, pp. 96–102, Feb. 2015.
- [16] Y. Agarwal, K. Jain, and O. Karabasoglu, "Smart vehicle monitoring and assistance using cloud computing in vehicular ad hoc networks," *Int. J. Transp. Sci. Technol.*, vol. 7, no. 1, pp. 60–73, Mar. 2018.
- [17] M. Sadou and L. Bouallouche-Medjokoune, "Efficient message delivery in hybrid sensor and vehicular networks based on mathematical linear programming," *Comput. Electr. Eng.*, vol. 64, pp. 496–505, Nov. 2017.
- [18] N. Cordeschi, D. Amendola, and E. Baccarelli, "Resource-management for vehicular real-time application under hard reliability constraints," in *Proc. IEEE/ACM 18th Int. Symp. Distrib. Simul. Real Time Appl.*, Oct. 2014, pp. 219–226.
- [19] N. Cordeschi, D. Amendola, M. Shojafar, and E. Baccarelli, "Distributed and adaptive resource management in cloud-assisted cognitive radio vehicular networks with hard reliability guarantees," *Veh. Commun.*, vol. 2, no. 1, pp. 1–12, Jan. 2015.
- [20] R. I. Meneguette and A. Boukerche, "A cooperative and adaptive resource scheduling for vehicular cloud," in *Proc. IEEE Symp. Comput. Commun. (ISCC)*, Jul. 2017, pp. 398–403.
- [21] R. I. Meneguette and A. Boukerche, "SERViTES: An efficient search and allocation resource protocol based on V2 V communication for vehicular cloud," *Comput. Netw.*, vol. 123, pp. 104–118, Aug. 2017.
- [22] S. Midya, A. Roy, K. Majumder, and S. Phadikar, "Multi-objective optimization technique for resource allocation and task scheduling in vehicular cloud architecture: A hybrid adaptive nature inspired approach," *J. Netw. Comput. Appl.*, vol. 103, pp. 58–84, Feb. 2018.
- [23] R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. F. De Rose, and R. Buyya, "CloudSim: A toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms," *Software: Pract. Exper.*, vol. 41, no. 1, pp. 23–50, Jan. 2011.
- [24] T. Goyal, A. Singh, and A. Agrawal, "Cloudsim: Simulator for cloud computing infrastructure and modeling," *Procedia Eng.*, vol. 38, pp. 3566–3572, Jan. 2012.
- [25] Y. Sun, X. Guo, S. Zhou, Z. Jiang, X. Liu, and Z. Niu, "Learning-based task offloading for vehicular cloud computing systems," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2018, pp. 1–7.
- [26] A. Ashok, P. Steenkiste, and F. Bai, "Vehicular cloud computing through dynamic computation offloading," *Comput. Commun.*, vol. 120, pp. 125–137, May 2018.
- [27] T. Limbasiya and D. Das, "Secure message confirmation scheme based on batch verification in vehicular cloud computing," *Phys. Commun.*, vol. 34, pp. 310–320, Jun. 2019.
- [28] L. Nkenyereye, Y. Park, and K.-H. Rhee, "Secure vehicle traffic data dissemination and analysis protocol in vehicular cloud computing," *J. Supercomput.*, vol. 74, no. 3, pp. 1024–1044, Mar. 2018.
- [29] Q. Huang, Y. Yang, and Y. Shi, "SmartVeh: Secure and efficient message access control and authentication for vehicular cloud computing," *Sensors*, vol. 18, no. 3, pp. 1–16, 2018.
- [30] P. Dong, T. Zheng, X. Du, H. Zhang, and M. Guizani, "SVCC-HSR: Providing secure vehicular cloud computing for intelligent high-speed rail," *IEEE Netw.*, vol. 32, no. 3, pp. 64–71, May 2018.
- [31] K. N. Qureshi, F. Bashir, and S. Iqbal, "Cloud computing model for vehicular ad hoc networks," in *Proc. IEEE 7th Int. Conf. Cloud Netw. (CloudNet)*, Oct. 2018, pp. 1–3.

- [32] L. Vigneri, T. Spyropoulos, and C. Barakat, "Quality of experience-aware mobile edge caching through a vehicular cloud," in *Proc. 20th ACM Int. Conf. Modelling, Anal. Simulation Wireless Mobile Syst.*, Nov. 2017, pp. 91–98.
- [33] M. Tahmasebi and M. R. Khayyambashi, "An efficient model for vehicular cloud computing with prioritizing computing resources," *Peer-to-Peer Netw. Appl.*, vol. 12, no. 5, pp. 1466–1475, Sep. 2019.
- [34] S. K. Bhoi, S. K. Panda, S. R. Ray, R. K. Sethy, V. K. Sahoo, B. P. Sahu, S. K. Nayak, S. Panigrahi, R. K. Moharana, and P. M. Khilar, "TSP-HVC: A novel task scheduling policy for heterogeneous vehicular cloud environment," *Int. J. Inf. Technol.*, vol. 11, no. 4, pp. 853–858, Dec. 2019.
- [35] A. Ali, M. E. Ahmed, F. Ali, N. H. Tran, D. Niyato, and S. Pack, "Non-parametric Bayesian channels clustering (NOBEL) scheme for wireless multimedia cognitive radio networks," *IEEE J. Sel. Areas Commun.*, vol. 37, no. 10, pp. 2293–2305, Oct. 2019.
- [36] A. Ali, L. Feng, A. K. Bashir, S. El-Sappagh, S. H. Ahmed, M. Iqbal, and G. Raja, "Quality of service provisioning for heterogeneous services in cognitive radio-enabled Internet of Things," *IEEE Trans. Netw. Sci. Eng.*, vol. 7, no. 1, pp. 328–342, Jan. 2020.
- [37] A. Ali, K. S. Kwak, N. H. Tran, Z. Han, D. Niyato, F. Zeshan, M. T. Gul, and D. Y. Suh, "Raptor Q-based efficient multimedia transmission over cooperative cellular cognitive radio networks," *IEEE Trans. Veh. Technol.*, vol. 67, no. 8, pp. 7275–7289, Aug. 2018.
- [38] A. Ali, L. Abbas, M. Shafiq, A. K. Bashir, M. K. Afzal, H. B. Liaqat, M. H. Siddiqi, and K. S. Kwak, "Hybrid fuzzy logic scheme for efficient channel utilization in cognitive radio networks," *IEEE Access*, vol. 7, pp. 24463–24476, 2019.
- [39] H. Gao, Y. Duan, L. Shao, and X. Sun, "Transformation-based processing of typed resources for multimedia sources in the IoT environment," *Wireless Netw.*, pp. 1–17, 2019, doi: [10.1007/s11276-019-02200-6](https://doi.org/10.1007/s11276-019-02200-6).
- [40] H. Gao, Y. Xu, Y. Yin, W. Zhang, R. Li, and X. Wang, "Context-aware QoS prediction with neural collaborative filtering for Internet-of-Things services," *IEEE Internet Things J.*, early access, Dec. 2, 2019, doi: [10.1109/JIOT.2019.2956827](https://doi.org/10.1109/JIOT.2019.2956827).
- [41] H. Gao, W. Huang, and X. Yang, "Applying probabilistic model checking to path planning in an intelligent transportation system using mobility trajectories and their statistical data," *Intell. Autom. Soft Comput.*, vol. 25, no. 3, pp. 547–559, 2019.



MUHAMMAD HAMEED SIDDIQI received the bachelor's degree (Hons.) in computer science from the Islamia College, Chartered University, Peshawar, KPK, Pakistan, in 2007, and the master's and Ph.D. degrees from the Ubiquitous Computing (UC) Laboratory, Department of Computer Engineering, Kyung Hee University, Suwon, in 2012 and 2016, respectively. He was a Graduate Assistant with Universiti Teknologi PETRONAS, Malaysia, from 2008 to 2009. He was a

Postdoctoral Research Scientist with the Department of Computer Science and Engineering, Sungkyunkwan University, Suwon, South Korea, from March 2016 to August 2016. He is currently an Assistant Professor with the College of Computer and Information Sciences, Jouf University, Sakaka, Saudi Arabia. He published more than 50 research articles in highly reputable international journals and conferences. His research interests include image processing, pattern recognition, machine intelligence, activity recognition, and facial expression recognition. He is also a Reviewer of different journals and conferences.



MADALLAH ALRUWAILI received the bachelor's degree (Hons.) from Jouf University, Sakaka, Saudi Arabia, in 2005, the M.S. degree from the University of Science, Malaysia, in 2009, and the Ph.D. degree from Southern Illinois University, Carbondale, IL, USA, in 2015. The Ph.D. dissertation entitled Enhancement and Restoration of Dust Images. He is currently an Assistant Professor of computer engineering and networks with Jouf University. He is also the Dean of the College of

Computer and Information Sciences. His research interests include image processing, image quality analysis, pattern recognition, computer vision, and biomedical imaging.



AMJAD ALI received the B.S. and M.S. degrees in computer science from the COMSATS Institute of Information Technology, Pakistan, in 2006 and 2008, respectively, and the Ph.D. degree from the Electronics and Radio Engineering Department, Kyung Hee University, South Korea, in June 2015. Since July 2015, he has been serving as an Assistant Professor with the Department of Computer Science, COMSATS University Islamabad, Lahore Campus, Pakistan. From February 2018 to

February 2019, he was a Postdoctoral Research Scientist with the UWB Wireless Communications Research Center (formerly the Key National IT Research Center), Department of Information and Communication Engineering, Inha University, South Korea, and with the Mobile Network and Communications Laboratory, School of Electrical Engineering, Korea University, Anam-dong, Seoul, South Korea. He was a recipient of the Excellent Research Award from the UWB Wireless Communications Research Center and from the Mobile Network and Communications Lab during his Ph.D. studies. His main research interests include cloud computing, multimedia transmissions, cognitive radio networks, machine learning, the Internet of Things, smart grid, and vehicular networks.



SYED FAWAD HAIDER received the B.S. and M.S. degrees in computer science from the University of Gujrat, Pakistan, in 2012 and 2015, respectively. He is currently working as a Junior Programmer with the University of Gujrat. His primary research interests are multimedia cloud computing, vehicular ad-hoc networks, network architecture, network security, the IoT, and future Internet.



FARMAN ALI received the B.S. degree in computer science from University of Peshawar, Pakistan, in 2011, the M.S. degree in computer science engineering from Gyeongsang National University, South Korea, in 2015, and the Ph.D. degree in information and communication engineering from Inha University, South Korea, in 2018. He is currently working as a Postdoctoral Fellow with the UWB Wireless Communications Research Center, Inha University, South Korea. He is also working

as an Assistant Professor with the Department of Software, Sejong University, Seoul, South Korea. His current research interests include data mining, deep learning, sentiment analysis, recommendation system, healthcare monitoring system, ontology, information extraction, information retrieval, and fuzzy logic.



MUDDESAR IQBAL received the Ph.D. degree from Kingston University, in 2010. He is currently a Senior Lecturer in mobile computing with the Division of Computer Science and Informatics, School of Engineering. He is also an established Researcher and expert in the fields of the Internet of Things, mobile cloud computing, and open-based networking for applications in disaster management and healthcare, community networks, and smart cities. He was a recipient of an EPSRC

Doctoral Training Award, in 2007. He received the dissertation titled Design, development, and implementation of a high performance wireless mesh network for application in emergency and disaster recovery, for his Ph.D. degree, in 2010. He has been a Principal Investigator, a Co-Investigator, a Project Manager, a Coordinator, and a Focal Person of more than ten internationally teamed research and development, capacity building and training projects, with total funding of approximately over a million pounds from different international organizations.