An Efficient Cluster Based Resource Management Scheme and Its Performance Analysis for V2X Networks

FAKHAR ABBAS1, (Student Member, IEEE), GANG LIU1,2, (Member, IEEE), PINGZHI FAN1, (Fellow, IEEE), AND ZAHID KHAN3, (Member, IEEE)

1School of Information Science and Technology, Southwest Jiaotong University, Chengdu 610031, China
2National Mobile Communications Research Laboratory, Southeast University, Nanjing 210096, China
3Robotics and IoT Labs, Prince Sultan University, Riyadh 12435, Saudi Arabia

Corresponding author: Fakhar Abbas (fakhar@ieee.org)

This work was jointly supported by NSFC key project under Grant No. 61731017, 61971359, the 111 Project under Grant No. 111-2-14, Sichuan Science and Technology Program (Grant No. 2019YJ0248), and the open research fund of National Mobile Communications Research Laboratory Southeast University (No. 2019D05).

ABSTRACT As the demand for VANETs data transmission continues to increase, the defined cellular band becomes a bottleneck to meet the demands for all vehicle-to-everything (V2X) users. To deal with this problem, an efficient cluster based resource management scheme and its performance analysis for V2X networks is suggested to discover exceptional needs for various types of VANETs connections, namely vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) connections, and to enhance the efficiency of cellular user with respect to sum ratio, packet received ratio and average throughput for V2I connections whereas maintaining constancy for each V2V link. To deal with the fast channel deviations because of high mobility, we developed an efficient cluster based resource management technique to attain spectrum sharing and power control that relies on large scale fading. In addition, we have also examined the resource management problem of VANETs and V2X users to minimize data communication effects. Primarily, the total cellular sum ratio of every V2I connections is employed as an analysis target to enhance the throughput and to minimize end-to-end latency of the whole V2I link. Moreover, efficient resource management and cluster head selection algorithms are developed which grant the optimum resource distribution. According to our results, the proposed scheme with efficient resource management improves cellular user sum rate, average packet received ratio and throughput in comparison with existing schemes.

INDEX TERMS Cluster, cellular-V2X, vehicle-to-vehicle communication and resource management.

I. INTRODUCTION

Intelligent transportation systems (ITS) have been evolved for years to assist different kinds of safety critical and traffic efficient applications. Recently, the solution concept of cellular vehicle-to-everything (C-V2X) communication has drawn immense attention in the industrial and academic fields, including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and so on [1]–[3]. At the same time, safety-critical information often requires that safety-related messages be disseminated in the neighboring vehicles either in event triggered or a periodic manner. As a result, it is normally assisted over the V2V connections that demand rigorous stability and timeliness conditions. The conventional IEEE 802.11p standard depicts inadequacies in assisting highly steady and accessible vehicular networks, whereas the V2V assisted C-V2X networks have gained contemporary demand in facilitating such goals [1]. Widely extensive C-V2X communication networks provide essential services for V2I links, whereas the dense V2V connections are appropriate for cellular networks [4], [5]. The C-V2X Rel. 14, complements cellular connectivity between vehicles and networks/cloud (V2N) with connectivity between vehicles and other vehicles (V2V), road side infrastructure (V2I) and also pedestrians (V2P). In particular, enabling direct V2V and V2I communications in and off network coverage as well as the availability of a proven evolution of cellular network generations are essential steps to support all ITS use cases with a single VOLUME 8, 2020 This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/ 87071

Received April 19, 2020, accepted May 1, 2020, date of publication May 6, 2020, date of current version May 20, 2020. Digital Object Identifier 10.1109/ACCESS.2020.2992591
cellular network technology, keeping the costs in the vehicle at a minimum. V2V, V2I, and V2P on “PC5” interface, operating in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network. PC5 operates on 5.9GHz.

Based on V2V and V2I communication, a major work has been developed based on a special traditional protocol namely IEEE 802.11p, that uses legacy CSMA/CA techniques to moderate gain control [6]. As the contention based CSMA technique was not primarily aimed for VANETs networks with rapid mobility, special V2V traffic can cause uncertain transmission latencies and cannot meet their reliable timeliness requirements of ITS Application [7]. In contrast, V2V communication, which allows direct communication in close associated links [8], offers an optimistic solution for stable VANETs connections [7]. Compared with ad-hoc V2V solutions, V2V links may easily achieve reliable message delivery and organized resource employment by investigating the extensive existence of a centralized intelligent V2X infrastructure [9]. However, the presence of the V2V link, supplemented by a central V2X structure, will offer direct nearby message propagation, significantly reducing power consumption and latency, hence appropriate for latency based V2V communications [10]. Therefore, the V2V based cellular network is an optimistic solution to achieve highly stable and effective vehicles communications.

The motivations of this work can be explained in detail below. First, due to changes in wireless assistance, different vehicles may have unique access demands. Second, the current dedicated short range communication (DSRC) or IEEE 802.11p develop for limited range vehicular communications, which drives it complicated for the employment of V2V communications that demands immense link range and wide area of coordination.

In the literature, majority of existing work on radio resource management (RRM) assumes that channel state information (CSI) is accessible over eNodeB, which is unrealistic in vehicular situation due to high mobility. For example, [11]–[15], in which only slow fading transmission is needed, design power estimation does not take into account the impact of fading and consequently will not indicate the existing power efficiency of the V2X communication networks which may lead higher power consumption and high latency. Therefore, the developments of resource management methods are usually suboptimal. This study an extension of our previous work [43], wherein, a cluster based resource distribution scheme was proposed. However, the channel detection and power management mechanism were ignored. Herein, we consider channel detection and power management mechanism. Moreover, additional theoretical and simulations experiments have been performed by considering more performance metrics such as cumulative distribution function (CDF), packet received ratio and throughput.

In this work, we propose an efficient cluster based resource management system and its performance analysis for V2X networks based on existing work [15], [27], [28] to assist all vehicles connections namely, V2V and V2I connections. During the cellular-based V2V structure, the V2V connection is supported through identified V2V-assisted link to get the advantages of cellular-based V2V vehicular networks. The designed V2X technique groups all vehicles within clusters in a context of an optimum vehicle named cluster head (CH) vehicle. The CH is selected on the basis of cluster members (CM). The CM connect with CH through IEEE 802.11 or V2X interface and the CHs connect with other CHs and pedestrians through V2X. We recognize and incorporate above mentioned quality of service (QoS) differentiation issues, and rely on large-scale fading structures to formulate spectrum and power management algorithms to achieve synchronous V2I and V2V communication, thereby greatly reducing transmission costs and network interference. In this work we have examined the combined performance of V2V and V2I connections jointly in V2X networks. Simulation experiments reveal the promising performance of proposed scheme compared with existing scheme. The main contributions are summarized as follows.

- An efficient cluster based resource management system and its performance analysis for V2X networks for spectrum and power management is proposed to enhance reliability, throughput and latency performance.
- The resource management problem is considered to obtain the assignment of set of radio resource blocks (RB) and power level for V2V and V2I users.
- We estimate the interference of VANETs users by cellular users by constructing a vehicle interference analysis technique to take advantage of the unlicensed spectrum, whereas the interference is analyzed within the area brought by the cellular users.
- An analysis technique is considered to model the intended reliability and latency requirements for V2X communications, which are based on random fast fading impacts, into analysis constraints that are measurable over slowly changing channel state information (CSI) only.
- The clusters based algorithms are presented which gives the best resource allocation. The experimental results demonstrate promising performance of proposed scheme compared with existing scheme.

The paper is structured as follows. Section II presents the state of the art. The system model and problem formulation are described Section III. Section IV presents the Channel Distribution and Power Management Scheme. The simulation results and analysis are given in section V and section VI concludes the paper.

II. STATE OF THE ART

The cellular-V2X communications have been the matter of current research efforts [17], [27]. V2V users can use two different methods: reuse method and allocated method, where V2V users distribute the similar resources as the cellular user and keep allocated resources separately. Dedicated method is easy to apply because it does not cause interference to...
current cellular users, and reuse patterns can help to enhance spectral efficiency. An efficient resource management (RM) strategy is needed to correctly manage mutual interference among V2V and cellular users in a reuse pattern.

Current work on V2V based communications, while providing valuable insight toward channel distribution and power restraint has one major limitation: majority of them consider single-hop transmissions in cellular networks. It is noted that single-hop transmission actually has some limitations in network capacity, latency, and spectral efficiency. The authors [18] introduced a spectrum resource distribution scheme that allows users to maintain for band resources to find D2D links, thereby effectively improving performance. In [19], authors designed a resource distribution method on the basis of sequential secondary value auctions to indicate that their attainable throughput is relatively 85% of the optimum resource management method. An effective resource distribution system for distributed energy in [20] is proposed to study the trade-off among spectrum efficiency and energy efficiency in D2D communication in vehicular networks. Subsequently, authors designed an energy efficient resource distribution algorithm over joint channel selection and power allocation to enhance quality of service (QoS) performance in [21]. Furthermore, a three-level method proposed [22], [23] to design power control and band management to extend plan throughput by least SINR assurance to both V2V and cellular users connections.

It can be imagined that high mobility in the automotive environment will cause wireless channels to rapidly change by time [24]–[26], [45]–[49]. Hence, the conventional RRM method for D2D communication under the assumption of the complete channel state information (CSI) is not any more appropriate because it is difficult to trace channel diversities in short time period. Therefore, employing V2V technology to assist vehicle communication requires further research on new RRM strategies to address rapid vehicle channel changes. The authors in [24] proposed a model including vehicle organization and power control to amplify the total or minimum feasible value of D2D users whereas suppressing the overall interference to the cellular network. In [14], it not only allows multiple resource blocks to be shared among V2V and cellular users, as well as allows distributing between different V2V-enabled vehicular communications.

The authors in [16] presented the resource allocation algorithm for VANETs networks to optimize the total capacity. The authors consider joint problem of band sharing and power management by examining full channel state information (CSI) at the eNodeB, which can be used for only slow fading CSI at the eNodeB. This assumption is especially good for high speed scenarios wherein only statistical information of rapidly changing small-scale fading can be obtained. Secondly clustering was ignored in the existing studies.

Y. Wang et al. [28] presented cooperative power management and user pairing for channel capacity gain scheme in V2V-enabled communications to maximize the total cellular rate during an access time. The objective of proposed scheme was to maximize the throughput during access period. This model have some constraints. First, authors only considered the capacity rate optimization. Moreover, the clustering is not studied to select the optimum vehicle to communicate with cellular eNodeB or RSU which may raise the end-to-end latency substantially when traffic is highly dynamic.

A new scheme is proposed by Liu et al, in which eNodeB and users communicate mutually within single-hop method or dual-hop method in downlink [29] and uplink [30] D2D overlay cellular networks. They determined range probability and data packet rate under distinct parameter setup, and determined that D2D communication can substantially improve vehicular network execution. In [15] authors investigate the joint power control and band allocation issue for V2X communications on the basis of LTE-U technology in vehicular environment. To get the fairness between the V2V and cellular users, authors proposed a resource distribution strategy to address spectrum distribution and power distribution problem. However, the above mentioned works have not studied V2I and V2V connectivity jointly and distinguished QoS demands for V2V and V2I links have not been acknowledged.

**FIGURE 1. System model.**

**III. SYSTEM MODEL AND PROBLEM FORMULATION**

**A. VEHICULAR SYSTEM MODEL**

We consider a multi-lane road of distance $M$ as shown in Figure. 1. Where $N$ number of vehicles requiring stable V2V and V2I communications, wherein clusters head (CH) vehicle to eNodeB connection is identified as cellular connection, and group of cluster members vehicles (CM) communications are identified as V2V connections. It is noted that every vehicle is suitable for operating V2V and V2I links jointly, i.e. vehicles are equipped with different radios interfaces namely V2X and 802.11p. The vehicles on the highway are supposed to follow Poisson distribution [35]–[38] whereas the speed of each vehicle is formed as Normal distribution. The vehicles are located in the broadcast range $R$ of CH, and the vehicles can be directly connected to CH. In a given cluster, all CMs use IEEE 802.11p to communicate.
with other CMs and cellular eNodeB via V2X. The CH can communicate with pedestrians directly or indirectly through the cellular eNodeB.

It is assumed that, all connected vehicles are mobilized with two radios. Identify the cellular users CH vehicle as \( n = \{1, \ldots, N\} \) and the V2V users CM vehicles group as \( l = \{1, \ldots, L\} \). It is assumed that V2X users can use dedicated frequency bands through orthogonal frequency domain carrier. The radio bandwidth of the determined cellular band is divided into \( q \) subchannels, defined as \( q = \{1, \ldots, Q\} \). Consequently, the data communication of V2X users desires to follow the V2X paradigm in the unlicensed band, which can be divided within \( Q \) sub-channels by the cellular eNodeB, expressed as \( Q_o = \{Q + 1, Q + 2, \ldots, Q + q\} \) to facilitate various V2X users simultaneously.

The time-line is divided towards several subframes towards cellular data communications, each sub-frame has length \( T_p \). A scheduling frame consists \( L \) subframes, defined as \( l = \{1, \ldots, L\} \). Essentially, vehicles are granted cellular spectrum in each subframe to manage signal communication to guarantee the consistency. Let a V2X users transmits information at a determined power defined by \( P^c \) on a determined unlicensed sub-channel. In addition, it is assumed that the lowest received power needed is \( P^d \). The obtained signal by vehicle CM\(_1\) from CH\(_1\) is described as

\[
Z_{CM_1} = H_{CH_1,CM_1}X_{CM_1} + N_{CM_1}
\]

wherein \( H_{CH_1,CM_1} \) is the channel gain, \( X_{CM_1} \) is the signal provided through V2X user CH\(_1\), and noise \( N_{CM_1} \) follows independent gaussian distribution by 0 mean and \( \sigma^2 \) variance.

We determine a free space path-loss model with Rayleigh fading [24] to simulate the channel gain between V2X user, \( P = P_e.(d/E)^{-\beta}.|H_e|^2 \), where \( P_e \) and \( P \) shows signal power calculated at \( d_e \) and \( d \) aside from the source appropriately. \( \beta \) is the free space path loss exponent, and \( H_e \sim CN(0, 1) \) is a convoluted random normal variable illustrating Rayleigh fading. Moreover, the obtained power \( P_e \) at \( d_e = 1 \) is assumed to be the transmitting power \( P^e \). Whilst the mobility of vehicles can strictly affect the distance between them, the speed information is used to estimate the distance between V2X users CH\(_1\) and CM\(_1\). The obtained signal power of the vehicle CH\(_1\) on one sub channel is defined as

\[
P_{CH_1,CM_1}^c = P^c.|H_{CH_1,CM_1}|^2
\]

and the channel gain \( H_{CH_1,CM_1} \) from vehicle CH\(_1\) to vehicle CM\(_1\) can be written as

\[
|H_{CH_1,CM_1}|^2 = O.|d_{CH_1,CM_1} + V_{CH_1,CM_1}.c_t X|^{-\beta}.|H_e|^2
\]

whereas \( O \) is the constant power gain component obtained by antenna, \( d_{CH_1,CM_1} \) is the area vector with V2X user CH\(_1\) to user CM\(_1\), \( V_{CH_1,CM_1} \) is the relative velocity of vehicle CH\(_1\) to vehicle CM\(_1\), and \( t_x \) is the latency time between the time period once the data to forward is ready and the duration when the significant data transmission started. In order to enhance the spectrum effectiveness, orthogonal allocated spectrum of cellular users is re-utilized by the V2V users whereas uplink resources are less widely utilize and noise to the eNodeB is feasible to handle. The power gain \( x_{n,C} \) between the CH\(_n\) user and the cellular eNodeB [15] is described as

\[
x_{n,C} = q_{n,C}F_{n,C}DM_{n,C}^{-\gamma} = q_{n,C}H_{n,C}
\]

wherein \( q_{n,C} \) is the fast fading power part and assumed to be distributed in units of average exponents, \( D \) is the path loss constant, \( M_{n,C} \) is the distance between the \( nth \) user CH\(_n\) and eNodeB, \( \gamma \) is the decomposition index and \( F_{n,C} \) is the logarithmic normal shadow fading in random variation with a standard deviation \( \Delta \). The channel \( x_l \) between the \( lth \) V2V pair, interference channel \( x_{n,l} \) from the \( lth \) V2V user to the user CH\(_n\) and interfering channel \( x_{n,l} \) from \( nth \) CH\(_n\) user to the \( lth \) V2V are equally determined.

### B. INTERFERENCE ANALYSIS OF V2V AND V2I USERS

Herein we have analyzed the interference of V2I and V2V users. The cellular V2V and 802.11p users employ channels in distinct ways, such as the 802.11p user use the whole channel, whilst V2V users share channels with splitting the channel into multiple sub-channels. When a cellular user utilizes this channel, the efficiency of vehicular user is influenced. Therefore, to analyze the deterioration of vehicular users performance, we identify the interference area of CH\(_1\) users to the vehicular users as the range from the V2V user whose received power cross a predefined threshold value \( P^r \). The interference level of the CH\(_1\) user, defined by \( S_{CH_1} \), is identified by channel fading and the least suitable obtained power \( P^r \) is defined as below

\[
S_{CH_1} = \log_\beta \left[ \frac{P^d |O|}{P^r} \right]
\]

Once a new V2V user CH\(_1\) access the unlicensed band, the total interference area is probably to rise. Just the extra interference range of the user CH\(_1\) is examined, that is computed as the area of the user CH\(_1\) interference circle as shown in Figure.2.

**FIGURE 2. Interference of V2X user to VANETs users.**

Let \( d_{CH_1,CM_1} \) is the distance among V2V users CH\(_1\) and CM\(_1\) are the set of V2V users which employ unlicensed sub channels. To best describe the size of the extra interference zone carried by V2V user CH\(_1\) given the continuation of V2V user.
C. PROBLEM FORMULATION

It is assumed that the path loss, large-scale fading factor of the channel and shadowing of all links are well-known at the eNodeB since they normally rely on the position of the vehicle and vary at a slow speed [22]. This information can be evaluated at the eNodeB for the links between cellular users $CH$, V2V users $CM$ and eNodeB. Whereas for links among vehicles, i.e., $u_l$ and $u_{nl,l}$ the parameters are computed at the V2V receiver and transmitted to the eNodeB continually. In the meantime, every deployment of fast fading is not accessible at the eNodeB because it varies rapidly in vehicular network with high mobility and it is assumed that its statistical analysis has been noticed. The obtained SINRs at the $n$th cluster head (CH) [16] is described as follows

$$\text{SINR}_n^l = \frac{S_n^d x_{n,C}}{\sigma^2 + \sum_{l \neq l} \rho_{n,l} S_{l}^d x_{l,C}}$$

and at the $l$th V2V users cluster member (CM) vehicles can be determined as

$$\text{SINR}_l^l = \frac{S_l^d x_l}{\sigma^2 + \sum_{n \in N} \rho_{n,l} S_{n}^d x_{n,l}}$$

respectively, whereas $S_n^d$ and $S_l^d$ depict transmitted powers of the $n$th (CH) cellular and the $l$th V2V users accordingly, $\sigma^2$ is the interference power and $\rho_{n,l}$ is the spectrum distribution sign by $\rho_{n,l} = 1$ showing the $l$th V2V user reuses the spectrum of the $n$th cellular user and $\rho_{n,l} = 0$ else. The total cellular sum ratio capacity of the $n$th cellular users by the premise of Gaussian inputs is accordingly defined as

$$D_n = \mathbb{E} \left[ \log_2 (1 + \text{SINR}_n^l) \right]$$

wherein $\mathbb{E} \left[ . \right]$ is the expectation measured by the fast fading distribution.

D. CLUSTER FORMATION

Here, we employ the greedy iterative technique to model several V2V clusters in every cluster, which includes the subsequent vital steps as shown in Figure. 1.

- Initially, we obtain set $C$ for different vehicles based on the requested vehicles inside the cluster.
- We introduce a set of metrics to select the steady and optimal cluster head, where the metric group consists of three different metrics, namely vehicle velocity, link time period $X$ and the mean distance between transmitting vehicles.
- The metric for every vehicle is calculated on the basis of cellular eNodeB and the vehicle with the smallest group value is elected as cluster Head $CH$ vehicle.

The mathematical description of link transmission period [12] is describe as below

$$X_{u_{ad}} = \frac{-\Delta u_{ln} \ast \Delta V_{ln} + |\Delta u_{ln}| \ast R}{|\Delta u_{ln}|^2}$$

wherein $R$ illustrates the communication range of each vehicle. Based on the definition of $X_{u_{ad}}$ assume that all vehicles are traveling straight, $X_{u_{ad}}$ is the connection duration between any two connected vehicles $l$ and $n$, $\Delta u_{ln} = u_l - u_n$, $\Delta V_{ln} = V_l - V_n$, $ZS$ is the set of vehicles and $Z_l$ is the number of vehicles in $ZS$. The vehicle $l$ calculates the average $X_{avg}$, $\Delta u_{avg}$ is the average velocity of vehicles and $\Delta V_{avg}$ is the distance among the communicating vehicles [12], [35].

$$X_{avg} = \frac{1}{Z_l} \sum_{n \in ZS} X_{u_{ln}}$$

$$u_{avg} = \frac{1}{Z_l} \sum_{n \in ZS} \Delta u_{ln}$$

The algorithm 1 stated below calculates the set of metrics against all adjacent vehicles gradually and elects the best $CH$ vehicle with least value as presented in (10). The algorithm 1 elect the $CH_1$ containing lowest value among all $ZS$ vehicles.

Algorithm 1 Cluster Head (CH) Election Algorithm for V2X Communications

initialize

Input: Vehicles velocity $v_{CH_1, CM_1}$, vehicle selection $CH_1 CM_1 \leftarrow m$, $CH_1 \leftarrow m$

for $V_n \in S$ do

| \{ $V_n$ group of vehicles, $S$ is vehicles graph topology \} |

Transmit (request messages)

end

foreach $V_n \in S$ do

| \{ $V_n$ group of vehicles, $S$ is vehicles graph topology \} |

if $(CM_1, CH_1) = 1$ then

| \{$NS_{CM_1} \leftarrow CH_1$\} |

else

| $CH_1$ already in $ZS$ |

end

end

end

$CH.E(ZS, Z_l)$

while $CM_1 \in ZS$ do

| Avg $X_{CM_1, CH_1} \leftarrow Cal.X(CM_1, CH_1)$ |

| Avg $X_{CM_1, CH_1} \leftarrow CM_1 - CH_1$ |

end
users whilst taking into account the exclusive features of V2V-based VANETs. The proposed method depends on gradually varying large-scale channel parameters and only needs to be modified every some hundred milliseconds, thus minimizing signaling overhead compared to directly applying traditional resource management schemes in cellular-V2X communication networks. For multiple links, the extensive capacity of the V2I link and the better stability of the V2V link, we use the sum of the $N$ cellular users to cover the total sum ratio to guarantee a stable link for every V2V.

The stability of V2V users is assured over adjusting the possibility of an interrupt events, wherein it’s received SINR is under a determined threshold $\text{SINR}_d^c$. The sum ratio of cellular users is calculated over the extended average by the fast fading that shows the codeword length distances some coherent periods through the slow fading time scale. It is noteworthy that the performance of the solution is close to the sum rate, which mainly depends on the time deviation of the cellular channel and the acceptable waiting time. Faster changes result in additional channel conditions for a fixed period of time, which results in a system performance approach that calculates faster total sum rate because the codeword needs to traverse the largest channel conditions to average the fading consequences. The problem of resource distribution in V2X communication networks is [17] described as

$$\max_{\rho, l} \mathbb{E}[\log_2(1 + \text{SINR}_d^c)]$$

(12)

wherein $\text{SINR}_d^c$ is the lowest sum rate condition for the data rate demanding cellular users to build a steady link. $S_{\text{max}}^d$ and $S_{\text{max}}^e$ are the determined transmitting powers of the cellular-V2I users and V2V users appropriately.

The considered analysis problem depicts a novel formula that takes into account the special characteristics of time-varying channels for vehicle communications and the differentiated QoS requirements for V2I and V2V links. Though, because of its combined quality and complex objective function, this is a highly non-convex analysis problem. We try to solve the analysis problem in (12) in the two steps motivated by [24]. First, we utilize the separability of power distribution and band reuse mode design by observing that interference exists only in every V2V user reuse center. For each pair of V2V users, we study their optimum power distribution to extend the sum of cellular users and provide stability assurance for V2V users. Second, we examine the possibility of each V2V user pair and the sum rate of cellular users, eliminate infeasible pairs and form a two-sided graph to identify the best band sharing mode among the cellular user group and the V2V user using the Halls method [31]. We noted that the proposed technique will result in a globally optimum solution for resource management issues in (12), as it can find the best band sharing model between cellular users and V2V users in all possible ways, and produce the best power control method. Every reuse pair is in an efficient manner.

### B. CHANNEL DETECTION FOR V2X AND VANETs USERS

Herein, we have presented band sharing and channel detection technique for V2X users to distribute licensed bands properly with VANETs users. Unlike users in an integrated downlink method, VANETs users require to separately detect channel settings of their own data broadcasts, demanding particular technique to reduce data transmission conflicts. Furthermore, several safety applications have imposed rigorous latency requirements on the in-vehicle networks, so the duration of the test demands to be limited to a tolerable level. In addition, new constraints have been raised because of the existence of V2I communication compared to traditional VANETs networks. Managing interference among neighboring users is easy to control in licensed band. It can be used more efficiently since the operator can exercise more flexibility in organizing their network to manage interference. In this technique, robust duty cycles [24], [41], [42] are employed, which represent constant data communication periods for V2X users and VANETs users. As presented in Figure 3, every duty time is separated into a detection time and an accommodative communication time.

**FIGURE 3. The architecture of the duty time.**

During detection, the V2X user detects the channel to choose one of the licensed channel and occupies it. The V2X user firstly executes a test to choose the best appropriate licensed channel for communication. They evaluate the level of interference on every licensed channel by detection. If the interference value is below the detection threshold, the channel is considered idle. If exist a free channel, the V2X user will employ the licensed channel, else they will essentially distribute the channel with the lowest interference value with the VANETs user. Therefore to reduce data communication collisions among V2X users and VANETs users when sharing channels, V2X users will continue to detect unless the nominated channel is idle and then immediately take it. The channel detection technique observes the operational channel state and retains track of the best appropriate channel, for example, whenever the interference status of the operational channel exceeds a threshold value, and there is additional channel that detects that the interference status is lower than the operational channel. The V2X user will exchange to the lower interfered channel toward data communication.
C. POWER MANAGEMENT FOR CELLULAR-V2V USER PAIRS

Herein, we investigated the best power distribution for each potential cluster member (CM) V2V user and cellular user (CH) re-use pair. Considering any spectrum reuse mode, for example, to allocate \( n \)th cellular users to the \( l \)th V2V user and the power distribution problem on a single V2V set is decreased

\[
\max_{\{S^d_n\}} \sum_{n \in N} \sum_{l \in L} \ln(1 + \text{SINR}^d_n) \quad (13)
\]

wherein the sum ratio restraint to the cellular users is temporally excluded and can be estimated in the following step. We evaluate the stability limitations for the \( l \)th V2V users. The stability restraint over the \( l \)th V2V, i.e. in the proposed single pair power management problem in (13), can be denoted as

\[
S^d_n \leq \frac{u_k S^f_d}{\text{SINR}^f_{I\text{h},n,l}} \left( \frac{e^{-\text{SINR}^f_d a^2}}{1 - p_q} \right) \triangleq f(S^f_d) \quad (14)
\]

let \( S^d_n \geq 0 \) and from equation (7), we get the zero intersection point by considering \( f(S^f_d) = 0 \)

\[
S^f_d = \frac{-\text{SINR}^f_d a^2}{u_k \ln(1 - s_l)} \triangleq S^f_d_{\text{max}} \quad (15)
\]

It can be noticed from (14) that \( f(S^f_d) \) monotonically increases in the range according to the V2V users power, \( S^f_d \) in the range of \((S^f_d_{\text{max}}, +\infty)\). This observation is straightforward because the increase in V2V user power leads to a higher interference margin, which means that V2V users are more tolerant of interference from cellular users. The best power distribution explanation to analysis problem (13) is stated \( [28] \) as

\[
S^d_n^* = \min(S^d_{\text{max}}, S^d_{e,\text{max}}) \quad (16)
\]

Once the band is distributed over the \( l \)th V2V user, the closed statement of the overall sum ratio of the \( n \)th user describe as

\[
D_{n,l}(S^d_n, S^f_d) \triangleq E[\log_2(1 + \text{SINR}^d_n)] \quad (17)
\]

The channel sum rate \( D_{n,l}(S^d_n, S^f_d) \) of the \( n \)th cellular users when sharing band with the \( l \)th V2V user is \( [16] \) as follows

\[
D_{n,l}(S^d_n, S^f_d) = \frac{b}{(b - c)\ln 2} \left[ e^{\frac{1}{b} E_1 \left( \frac{1}{b} \right)} - e^{\frac{1}{c} E_1 \left( \frac{1}{c} \right)} \right] \quad (18)
\]

where \( b = \frac{S^d_n}{\sigma^2/c}, c = \frac{S^d_n}{\sigma^2/c} \) and \( E_1(y) = \int_y^{\infty} e^{-t} \frac{dt}{t} \) is the first order differential integral function. Replacing the optimum power management (16) in equation (17) gives the determined sum rate obtained while the \( n \)th cellular users shares its band by the \( l \)th V2V users, represented as \( D^*_{n,l} \).

\[
D^*_{n,l} \leq r^d_l \quad \text{moreover this combination cannot gather the least sum ratio conditions toward cellular users.}
\]

To determine the best solution toward resource distribution problem of vehicular transmission in (12) are outlined in Algorithm 2. The proposed resource management algorithm for V2X Communications depends on steadily varying wide scale channel parameters and only needs to be modified every few hundred milliseconds, thus significantly minimizing the total average end-to-end latency and signaling cost as compared to conventional resource management schemes.

Assuming \( N \geq R \) which is constantly reasonable in V2X communication system. The algorithm II can mitigate the computational cost by \( \frac{N}{R} \), by \( N \) according to vehicle speed and channel situation. The main computational overload of proposed resource distribution algorithm is to form a power matrix \( D^* \).

Algorithm 2: Efficient Resource Distribution Algorithm Based on V2X Communications

\textbf{Send:} Apply the Halls assignment method \([31]\) to discover the best joining set \( \{p^*_{n,l}\} \).

\textbf{Result:} Build ideal joining set \( \{p^*_{n,l}\} \) and power distribution \( \{S^d_n^*, S^f_l^*\} \) accordingly

\begin{algorithm}
\textbf{for} \( n = 1, 2, \ldots, N \) \textbf{do}
\textbf{for} \( r = 1, 2, \ldots, R \) \textbf{do}
\begin{enumerate}
\item Calculate the best transmit power \( (S^d_n^*, S^f_l^*) \) for V2X users \( n \) and V2X users \( r \) correspondingly on the basis of (16)
\item Substitute \( (S^d_n^*, S^f_l^*) \) into equation (17) to achieve \( E[\log_2(1 + \text{SINR}^d_n)] \) and \( E[\log_2(1 + \text{SINR}^f_l)] \) if \( E[\log_2(1 + \text{SINR}^d_n)] \geq \text{SINR}^d_l, E[\log_2(1 + \text{SINR}^f_l)] \geq \text{SINR}^f_l \), then
\begin{enumerate}
\item \( D^*_{n,l} = D_n(S^d_n^*, S^f_l^*) \)
\end{enumerate}
else
\item \( D^*_{n,l} = -\infty \)
\end{enumerate}
\textbf{end}
\textbf{end}
\end{algorithm}

V. THE SIMULATION RESULTS AND ANALYSIS

Herein, numerical results are presented to verify and validate the efficiency of suggested efficient cluster based resource management technique for V2X communication networks. We follow the simulation of the highway scenario described in 3GPP TR [32] and simulate a multilane highway running on cells in which the eNodeB is located. All simulations were performed using MATLAB in conjunction with Network Simulator NS3.26 (NS-3). In our simulations we have used NS3.26 and MATLAB jointly to see the performance of different metrics. For example, two metrics throughput and packet received ratio we have measured these two performances metric by using NS3.26 and other performance metrics such as cellular user sum rate, CDF of cellular users.
TABLE 1. Network simulation parameters.

| Parameter                        | Value                      |
|----------------------------------|----------------------------|
| Bandwidth                        | 10 MHz                     |
| $f_c$ carrier frequency          | 22 GHz                     |
| Traffic movement model           | Gaussian distribution      |
| Transmission range               | 250m-1000m                 |
| Cell range                       | 1000 m                     |
| eNB receiver gain                | 8 dBi                      |
| eNB receiver noise level         | 6 dB                       |
| Distance between eNodeB and highway | 40 m                  |
| Vehicular receiver gain          | 3 dBi                      |
| Vehicular receiver noise level   | 9 dB                       |
| $\lambda$ Vehicle density       | 60 veh/km                  |
| SINR threshold for V2V users $\gamma_q^*$ | 5 dB          |
| Capacity of V2V users $r_q^*$    | 0.5 bps/Hz                 |
| Noise power $\sigma^2$           | -114 dBm                   |
| Reliability for V2V $p_{rv}$     | 0.001                      |
| Number of V2V $L$ and cellular users $N$ | 20, 20            |
| V2V and cellular users transmitting power $P_{t,\text{max}}$ | 24, 16 dBm |

and cluster head duration over different vehicles velocity we have evaluated in MATLAB. The vehicles on the road follow a Poisson distribution and the vehicle density is provided by the vehicle speed. Between the formed vehicles, $n$ cellular users and $L$ V2V users are randomly elected, where V2V user pairs are continuously formed between nearby vehicles, and cellular users are assumed to have the same total bandwidth share. Table 1 lists the key simulation parameters [32], [33]. Average packet received ratio: Is the average ratio of successful received packets at destination vehicle over the total generated packets on the source vehicle.

It is noted that the vehicles are moving relatively close and within the same set of communication ranges. V2V and V2I communication via the PC5 interface is broadcast in nature and usually targets a single transmission. They are also connectionless: no signaling is needed on the side chain for connection establishment and neighbor discovery procedures. This is to ensure that messages related to critical data (for example, security alerts) are exchanged quickly in a dynamic environment, where the topology changes rapidly, so connectivity is short. For analysis we have considered data related messages (for example, security alerts) to see the effectiveness of proposed scheme as compared to existing scheme.

Figure. 4 shows the total cellular user sum ratio at distinct vehicle speeds on the road. It can be observed from Figure. 4, as the vehicle rapidly changes its speed, the cellular users total rate decreases. This is because of higher speed, as sparse traffic relying on the simulated scenario, which will increase the distance among the vehicles on average and lead to a less consistent V2V connection with low obtained power. As noted above, because of extreme transmission power limitation of V2V users, lowest interference between cellular users can be allowed, thereby minimizing the power distributed to cellular users and minimizing them together. It can be observed that the suggested efficient cluster based resource management scheme has better cellular user rate than existing algorithm. It is worthy observing that the determined raise in transmitting power has almost constant impact on the cellular user ratio of the existing and proposed algorithms.

In order to see the advantages of the proposed efficient cluster based resource management scheme when the cellular eNodeB can only access large-scale fading data, we examine the cumulative distribution function (CDF) of the fast total cellular user sum ratio implemented in the suggested algorithm. The technique presented in [28] is described in Figure. 5. The result shows that the proposed scheme performs better as compared to existing technique. The logic of the performance gain of the proposed efficient scheme is twofold. First, the proposed efficient cluster based scheme strictly manages the fading effect when calculating the V2I link and rate, i.e., calculating the total cellular user and rate, rather than using only large-scale fading parameters to evaluate the cellular user and rate. Second, the technique used
in the existing algorithm cannot achieve the specific SINR threshold of V2V connection.

The Figure. 6 depicts the average CH lifetime over distinct vehicle speeds. Because of the advanced 5G technology and cluster head metric selection features, the proposed efficient cluster based scheme has a longer lifetime than the existing scheme [28]. The extended communication boundary and the centralized location of the CH result in a long duration of resource management.

Figure. 7 shows the cellular sum rate at different SINR threshold $\text{SINR}_Q$. The performance degradation is due to reduced interference tolerance for the SINR threshold gain required by V2V users, which imposes stricter restrictions on the allowable transmission power of paired cellular users. Considering that all QoS constraints are met, reducing the transmit power of a cellular user directly translates into a reduction in cellular user sum rate.

Figure. 8 demonstrates the average throughput of proposed and existing scheme over different vehicles velocity. The simulation result show that the throughput in the proposed algorithm is higher as it is developed on V2X technique which is derived from semi-persistent scheduling (SPS) transmission during side link control information (SCI) which may not influence the performance through the message dissemination from sender to receiver vehicle. The advancement in technology from LTE to 5G V2X expands the available bandwidth, which not only deceases the end-to-end latency yet also boost the average throughput under different vehicle speeds. The throughput in the case of existing scheme is low because of store-and-catch-up (SAC) method which increases its end-to-end latency.
TABLE 2. Average packet received ratio for highway scenario.

| Range (m) | Existing Scheme | Proposed Scheme | Gain(%) | Existing Scheme | Proposed Scheme | Gain(%) |
|-----------|-----------------|-----------------|---------|-----------------|-----------------|---------|
| 10-30     | 0.883           | 0.925           | 4.8595  | 0.9182          | 0.9462          | 2.8743  |
| 50-70     | 0.805           | 0.855           | 6.8570  | 0.8907          | 0.9337          | 3.9554  |
| 90-110    | 0.730           | 0.785           | 8.2527  | 0.8738          | 0.9194          | 5.1038  |
| 130-150   | 0.655           | 0.725           | 10.1217 | 0.8487          | 0.9038          | 6.3602  |
| 170-190   | 0.585           | 0.665           | 14.4237 | 0.8225          | 0.8861          | 7.5625  |
| 210-230   | 0.525           | 0.611           | 16.9243 | 0.7905          | 0.8693          | 9.1204  |
| 250-270   | 0.465           | 0.551           | 19.1815 | 0.7665          | 0.8517          | 10.7165 |
| 290-310   | 0.425           | 0.545           | 29.0927 | 0.7405          | 0.8353          | 11.6382 |

The Figure 10 shows the comparison of total cellular users sum rate attained via proposed and existing schemes with respect to the maximum communication power $S_{\text{max}}$. It can be seen from the Figure. 10 that even though proposed scheme is based on the expectation in lieu of precise values of the sum rate, the performance remained fairly good with a loss of about 20 bps/Hz. Moreover, the computational cost of proposed efficient model is only 2% as compared to existing algorithm, which confirms that proposed scheme can significantly reduce the computational density at an acceptable cost of performance.
The Figure. 11 and Figure. 12 shows the average packet received ratio for vehicle speed at 60 km/h and 80 km/h respectively. From the simulation and Table 2, it can be noticed that the proposed scheme achieves better average packet received ratio performance as compared to existing scheme consequently reduced number of resource interface. Furthermore, as the vehicle density decreases, the interference effect as the vehicle speed increases from 60 km/h to a different speed due to resource collision.

VI. CONCLUSION
This paper investigates an efficient cluster based resource management scheme and its performance analysis for V2X networks whilst maintaining throughput, packet received ratio, latency and cellular user sum rate constraints. To trace rapid channel diversity because of high mobility, we examined common QoS demands of V2X and vehicular based transmissions and presented an analysis problem for an efficient resource distribution on the basis of large scale fading data. The optimum cluster head selection and resource distribution algorithms have been presented to utilize the total cellular users sum rate towards V2I links while ensuring stability, best average packet received ratio and throughput towards all V2V connections. The experimental results suggested that the proposed efficient resource management scheme attains good performance in various scenarios, particularly attaining best packet received ratio, total cellular users sum ratio during high density VANETs environment.

REFERENCES
[1] G. Araniti, C. Campolo, M. Condoluci, A. Iera, and A. Molinaro, “LTE for vehicular networking: A survey,” IEEE Commun. Mag., vol. 51, no. 5, pp. 148–157, May 2013.
[2] Cisco, “Cisco visual networking index: Forecast and methodology 2015–2020,” Public Cisco, San Jose, CA, USA, White Paper 2017-2022, Nov. 2018.
[3] 5GAA: Cellular Technology is Key Enabler for Smart Mobility of the Future, 5G Automot. Assoc., Frankfurt, Germany, Sep. 2017.
[4] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil, “Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions,” IEEE Commun. Surveys Tuts., vol. 13, no. 4, pp. 584–616, Jul. 2011.
[5] F. Abbas, P. Fan, and Z. Khan, “A novel reliable low-latency multipath routing scheme for vehicular ad hoc networks,” EURASIP J. Wireless Commun. Netw., vol. 2018, no. 1, Dec. 2018.
[6] X. Cao, L. Liu, Y. Cheng, L. X. Cai, and C. Sun, “On optimal device-to-device resource allocation for minimizing end-to-end delay in VANETs,” IEEE Trans. Veh. Technol., vol. 65, no. 10, pp. 7905–7916, Oct. 2016.
[7] X. Cheng, L. Yang, and X. Shen, “D2D for intelligent transportation systems: A feasibility study,” IEEE Trans. Intell. Transp. Syst., vol. 16, no. 4, pp. 1784–1793, Aug. 2015.
[8] Z. Zhou, K. Ota, M. Dong, and C. Xu, “Energy-efficient matching for resource allocation in D2D enabled cellular networks,” IEEE Trans. Veh. Technol., vol. 66, no. 6, pp. 5256–5268, Jun. 2017.
[9] N. Cheng, H. Zhou, L. Lei, N. Zhang, Y. Zhou, X. Shen, and F. Bai, “Performance analysis of vehicular Device-to-Device underlay communication,” IEEE Trans. Veh. Technol., vol. 66, no. 6, pp. 5409–5421, Jun. 2017.
[10] T. H. Luan, X. Shen, F. Bai, and L. Sun, “Feel bored? join verse! engineering vehicular proximity social networks,” IEEE Trans. Veh. Technol., vol. 64, no. 3, pp. 1103–1113, May 2015.
[11] W. Sun, E. G. Strom, F. Branstrom, K. C. Sou, and Y. Sui, “Radio resource management for D2D-based V2 V communication,” IEEE Trans. Veh. Technol., vol. 65, no. 8, pp. 6636–6650, Aug. 2016.
[12] S.-S. Wang and Y.-S. Lin, “PassCAR: A passive clustering aided routing protocol for vehicular ad hoc networks,” Comput. Commun., vol. 36, no. 2, pp. 170–179, Jan. 2013.
[13] F. Abbas and P. Fan, “Clustering-based reliable low-latency routing scheme using ACO method for vehicular networks,” Veh. Commun., vol. 12, pp. 66–74, Apr. 2017.
[14] F. Abbas, P. Fan, and Z. Khan, “A novel low-latency V2V resource allocation scheme based on cellular V2X communications,” IEEE Trans. Intell. Transp. Syst., vol. 20, no. 6, pp. 2185–2197, Jun. 2019.
[15] F. Abbas and P. Fan, “A hybrid low-latency D2D resource allocation scheme based on cellular V2X networks,” in Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops), Kansas City, MO, USA, May 2018, pp. 1–6.
[16] L. Liang, G. Y. Li, and W. Xu, “Resource allocation for D2D-enabled vehicular communications,” IEEE Trans. Commun., vol. 65, no. 7, pp. 3186–3197, Jul. 2017.
[17] D. Feng, L. Lu, Y. Yuan-Wu, G. Li, S. Li, and G. Feng, “Device-to-device communications in cellular networks,” IEEE Commun. Mag., vol. 52, no. 4, pp. 49–55, Apr. 2014.
[18] C. Xu, L. Song, Z. Han, D. Li, and B. Jiao, “Resource allocation using a reverse iterative combinatorial auction for device-to-device underlay cellular networks,” in Proc. IEEE Global Commun. Conf. (GLOBECOM), Anaheim, CA, USA, Dec. 2012, pp. 4542–4547.
[19] C. Xu, L. Song, Z. Han, Q. Zhao, X. Wang, and B. Jiao, “Interference-aware resource allocation for device-to-device communications as an underlay using sequential second price auction,” in Proc. IEEE Int. Conf. Commun. (ICC), Ottawa, ON, Canada, Jun. 2012, pp. 445–449.
[20] Z. Zhou, M. Dong, K. Ota, J. Wu, and T. Sato, “Energy efficiency and spectral efficiency tradeoff in device-to-device (D2D) communications,” IEEE Wireless Commun. Lett., vol. 3, no. 5, pp. 483–488, Oct. 2014.
[21] Z. Zhou, M. Dong, K. Ota, G. Wang, and L. T. Yang, “Energy-efficient resource allocation for D2D communications underlaying cloud-RAN-Based LTE–A networks,” IEEE Internet Things J., vol. 3, no. 3, pp. 428–438, Jun. 2016.
[22] P. Janis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler, and K. Hugl, “Interference-aware resource allocation for device-to-device radio underlaying cellular networks,” in Proc. VTC Spring - IEEE 69th Veh. Technol. Conf., Apr. 2009, pp. 1–5.
[23] L. Wei, R. Q. Hu, T. He, and Y. Qian, “Device-to-device(d2d) communications underlaying MU-MIMO cellular networks,” IEEE Trans. Commun., vol. 61, no. 8, pp. 3541–3551, Aug. 2013.
[24] Q. Wei, L. Wang, Z. Feng, and Z. Ding, “Wireless resource management in LTE-U driven heterogeneous V2X communication networks,” IEEE Trans. Veh. Technol., vol. 67, no. 8, pp. 7508–7522, Aug. 2018.
[25] Z. Zhao, X. Cheng, M. Wen, B. Jiao, and C.-X. Wang, “Channel estimation schemes for IEEE 802.11p standard,” IEEE Trans. Intell. Transp. Syst., vol. 7, no. 4, pp. 38–49, 2013.
[26] K. Wen and Y. Chen, “A resource allocation method for D2D and small cellular users in HetNet,” in Proc. IEEE ICC, Dec. 2017, pp. 628–632.
[27] A. Masmoudi, S. Feki, K. Mnaif, and F. Zarai, “Efficient radio resource management for D2D-based LTE-V2X communications,” in Proc. IEEE/ACIS 15th Int. Conf. Comput. Syst. Appl. (AICCSA), Oct./Nov. 2018, pp. 1–6.
[28] Y. Wang, Z. Yang, Y. Pan, and M. Chen, “Joint power control and user pairing for ergodic capacity maximization in V2 V communications,” in Proc. 9th Int. Conf. Wireless Commun. Signal Process. (WCSP), Nanjing, China, Oct. 2017, pp. 1–6.
[29] J. Liu, S. Zhang, H. Nishiyama, N. Kato, and J. Guo, “A stochastic geometry analysis of D2D overlaying multi-channel downlink cellular networks,” in Proc. IEEE Conf. Comput. Commun. (INFOCOM), Hong Kong, Apr. 2015, pp. 46–54.
[30] J. Liu and N. Kato, “Device-to-Device communication overlaying two-hop multi-channel uplink cellular networks,” in Proc. 16th ACM Int. Symp. Mobile Ad Hoc Netw. Comput. MobilHoc, 2015, pp. 307–316.
[31] D. B. West, Introduction to Graph Theory, vol. 2. Upper Saddle River, NJ, USA: Prentice-Hall, 2001.
[32] 3rd Generation Partnership Project, Technical Specification Group Radio Access Network; Study on LTE-Based V2X Services; (Release 14), document 3GPP TR 36.885 V2.0.0, Jun. 2016.
[33] WF on SLS Evaluation Assumptions for ev2x, document 3GPP TSG RAN WG1 Meeting #85, R1-165704, May 2016.
F. Abbas, Y. Fang, M. I. Zahoor, and K. Sultan, “Combined resource networks, Reliable routing schemes in wireless Ad-hoc networks, resource management scheme based on cellular-V2X,” China Commun., vol. 15, no. 7, pp. 55–66, Jul. 2018.

J. He, L. Cai, J. Pan, and P. Cheng, “Delay analysis and routing for two-dimensional VANETs using carry-and-forward mechanism,” IEEE Trans. Mobile Comput., vol. 16, no. 7, pp. 1830–1841, Jul. 2017.

F. Abbas, Y. Fang, M. I. Zahoor, and K. Sultan, “Combined resource allocation system for device-to-device communication towards LTE networks,” in Proc. MATEC Web Conf., vol. 56, 2016, p. 05001.

J. Guo, Y. Zhang, X. Chen, S. Yousefi, C. Guo, and X. Wang, “Spatial stochastic vehicle traffic modeling for VANETs,” IEEE Trans. Intell. Transp. Syst., vol. 19, no. 2, pp. 416–425, Feb. 2018.

E. Bjornson, E. A. Jorswieck, M. Debbah, and B. Ottersten, “Multiobjective signal processing optimization: The way to balance conflicting metrics in 5G systems,” IEEE Signal Process. Mag., vol. 31, no. 6, pp. 14–23, Nov. 2014.

G. Yu, Y. Jiang, L. Xu, and G. Y. Li, “Multi-objective energy-efficient resource allocation for multi-RAT heterogeneous networks,” IEEE J. Sel. Areas Commun., vol. 33, no. 10, pp. 2118–2127, Oct. 2015.

Gang Liu (Member, IEEE) received the Ph.D. degree in communication and information systems from the Beijing University of Posts and Telecommunications (BUPT), in 2015. He is currently an Associate Professor with the School of Information Science and Technology, Southwest Jiaotong University (SWJTU), Chengdu, China. He has coauthored more than 20 technical articles in international journals and conference proceedings. His current research interests include 5G cellular networks, connected vehicle networks, full-duplex wireless, network virtualization, resource management, cross-layer design, and protocol optimization. Dr. Liu has served as a reviewer/TPC member for numerous journals and conferences. He received the Excellent Doctoral Dissertation Award of BUPT, in 2015, the Best Paper Award in IEEE ICC’2014, and the Second Prize in the National Undergraduate Electronic Design Contest of China, in 2009. He is serving as the secretary and treasurer for IEEEComSoc, Chengdu Chapter.

Pingzhi Fan (Fellow, IEEE) received the M.Sc. degree in computer science from Southwest Jiaotong University, China, in 1987, and the Ph.D. degree in electronic engineering from Hull University, U.K. He has been a Professor and the Director of the Institute of Mobile Communications, Southwest Jiaotong University, China, a Visiting Professor with Leeds University, U.K., since 1997, and the Guest Professor with Shanghai Jiaotong University, since 1999. He has more than 290 research articles published in various international journals and eight books (incl. edited). He is the inventor of 23-granted patents. His research interests include vehicular communications, wireless networks for big data, and signal design and coding. He has served as a Board Member for the IEEE Region 10, IETF (IEEE) Council, and IET Asia-Pacific Region. He is a Fellow of IET, CIE, and CIC. He was a recipient of the U.K. ORS Award, in 1992, the NSFC Outstanding Young Scientist Award, in 1998, the Yisheng Mao Rail Sci and Tech Award, in 2017, the IEEE VTS Jack Neubauer Memorial Award, in 2018, and the IEEE SP Soc SPL Best Paper Award, in 2018. He has served as the General Chair or the TPC Chair for a number of international conferences. He is currently the Founding Chair of the IEEE VTS BJ Chapter, the IEEE ComSoc CD Chapter, and the IEEE Chengdu Section. He is also the Guest Editor or an Editorial Member of several international journals. He has been the IEEE VTS Distinguished Lecturer/Speaker, since July 2015.

Fahhat Abbas (Student Member, IEEE) received the M.S. degree in information and communication engineering from Harbin Engineering University, Harbin, China, in 2015. He is currently pursuing the Ph.D. degree with the Key Laboratory of Information Coding and Transmission, School of Information Science and Technology, Southwest Jiaotong University (SWJTU), Chengdu, China. He is also a Lecturer with the Computer Science Department, COMSATS University Islamabad (CUI), Pakistan. He has been a reviewer for several IEEE journals and major conferences. His research interests include 5G cellular networks, Reliable routing schemes in wireless Ad-hoc networks, resource management in 5G-V2X networks, and protocol optimization.