DAGIoV: A Framework for Vehicle to Vehicle Communication Using Directed Acyclic Graph and Game Theory

Vikas Hassija, Vinay Chamola, Guangjie Han, *Senior Member, IEEE*, Joel J. P. C. Rodrigues, *Fellow, IEEE*, and Mohsen Guizani, *Fellow, IEEE*

***Abstract*—Data sharing and content offloading among vehicles is an imperative part of the Internet of Vehicles (IoV). A peer-to-peer connection among vehicles in a distributed manner is a highly promising solution for fast communication among vehicles. To ensure security and data tracking, existing studies use blockchain as a solution. The Blockchain-enabled Internet of Vehicles (BIoV) requires high computation power for the miners to mine the blocks and let the chain grow. Over and above, the blockchain consensus is probabilistic and the block generated today can be eventually declared as a fork and can be pruned from the chain. This reduces the overall efficiency of the protocol because the correct work done initially is eventually not used if it becomes a fork. To address these challenges, in this paper, we propose a Directed Acyclic Graph enabled IoV (DAGIoV) framework. We make use of a tangle data structure where each node acts as a miner and eventually the network achieves consensus among the nodes. A game-theoretic approach is used to model the interactions between the vehicles providing and consuming offloading services. The proposed model is proven to be highly scalable and well suited for microtransactions or frequent data transfer among the nodes in the vehicular network.**

***Index Terms*—Auction, consensus finality, directed acyclic graph, distributed applications, internet of vehicles, Nash bargaining, tangle.**

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V. Hassija is with the Department of CSE and IT, Jaypee Institute of Information Technology, Noida 201304, India (e-mail: vikas.hassija@jiit.ac.in).

V. Chamola is with the Department of Electrical and Electronics Engineering, Birla Institute of Technology and Science-Pilani, Pilani Campus 333031, India (e-mail: vinay.chamola@pilani.bits-pilani.ac.in).

G. Han is with the College of Engineering, Nanjing Agricultural University, Nanjing 210095, China, and also with the Department of Information Communication Systems, Hohai University, Changzhou 213022, China (e-mail: hanguangjie@gmail.com).

J. J. P. C. Rodrigues is with the Teresina – PI, Brazil and Instituto de Telecomunicações, Federal University of Piauí, Lisbon 13010, Portugal (e-mail: joeljr@ieee.org).

M. Guizani is with the Computer Science and Engineering Department, Qatar University, 2713, Qatar (e-mail: mguizani@ieee.org).

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I. Introduction

With the emerging Internet of Things (IoT) applications and Intelligent Transportation Systems (ITS), a large amount of data is getting generated in vehicular networks [1]. The vehicle to vehicle (V2V) communication is an important enabling factor in enhancing the driving safety and comfort of the users [2]. Various applications have been developed in recent years to avoid accidents, pileup crashes, vehicle platooning or traffic jams using V2V and Vehicle to Infrastructure (V2I) communication models [3]. Various big companies such as Audi (Germany), General Motors (U.S.), BMW (Germany), Volvo Cars (Sweden), Daimler AG (Germany), Toyota Motor Corporation (Japan), Qualcomm Technologies, Inc. (U.S.), Volkswagen (Germany) and AutoTalks Ltd. (Israel) are actively participating in funding and developing applications that support V2V communication [2]. The expected revenue of global Vehicle to Vehicle (V2V) communication Market by 2023 is predicted to be USD 24 Billion [1].

Additionally, a lot of research and implementation is going on in direction of automated driving [4], [5]. Various self driving vehicles are being developed in countries like Japan, U.S.A, Germany and so on. The inter vehicular communication becomes even more important in case of self driving vehicles [6], [7]. A lot of data needs to be shared and collected among vehicles to actually experience driving safety and improved Quality of Experience (QoE) [8], [9].

There have been various attempts in the recent years toward developing a robust framework for vehicular communication [10], [11]. However, most of these attempts are based on centralized network architectures [12]. There are various security and privacy issues involved in sharing data over these centralized servers and therefore the users are not highly motivated to share their data [13]. In addition, these centralized applications act as a single point of failure and some issues in the central server can paralyze the entire vehicular network [14]. Data theft and data manipulation are another area of concern in centralized applications. A Peer-to-Peer (P2P) communication model among vehicles can be a highly promising solution to avoid such issues related to centralized applications [15], [16]. However, a robust and reliable trust management system is required in a P2P network to be able to actually leverage its advantages [17], [18].

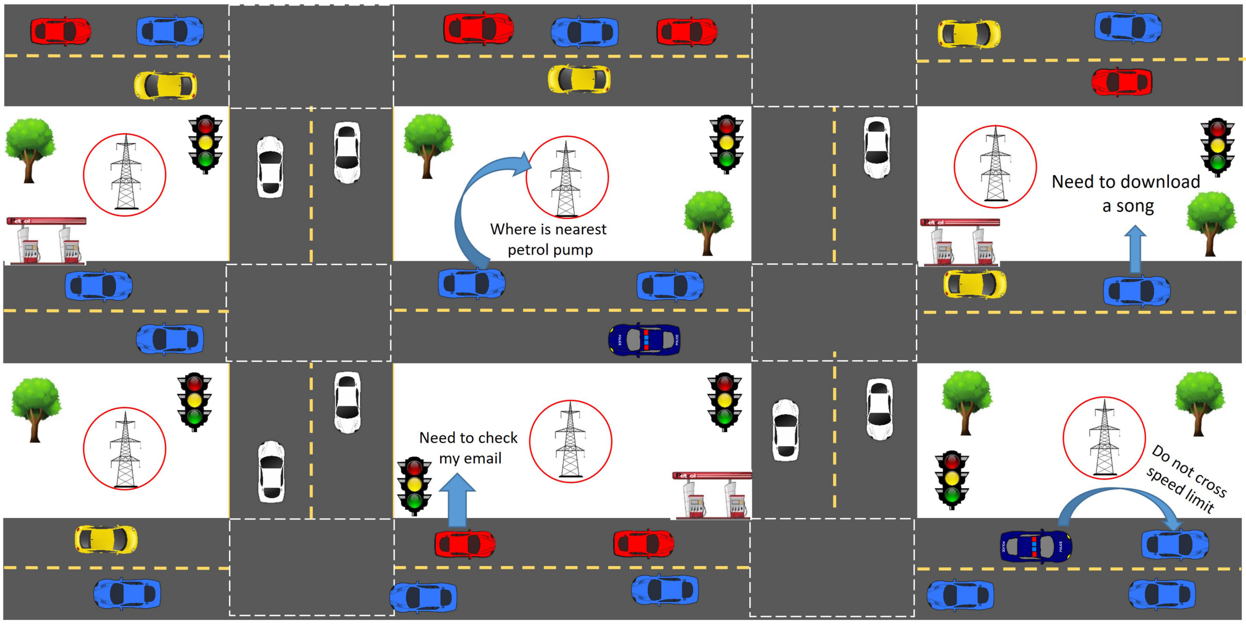

Fig. 1. Network of vehicles communicating among each other and Road Side Units (RSU).

Few attempts have been made toward integrating blockchain technology with vehicular communication to realize a secure peer-to-peer communication model [15], [19]. Although, blockchain can help in securely authorizing the peers to communicate in a vehicular network, there are some fundamental constraints in blockchain architecture that obstructs the scalability and efficiency of such frameworks [20], [21]. Blockchain basically depends on the Proof-of-Work (POW) consensus mechanism to reach to a consensus among the peers in the network [22], [23]. Various miners are involved in solving a mathematical puzzle and whoever is able to solve the puzzle first is allowed to attach the latest set of transactions to the main chain. The miners are incentivized in order to get motivated to participate in the mining process. The mining process involves a lot of computation power and the overall efficiency of the process is low because ultimately the work of only one miner for a particular transaction is kept in the main chain. Many miners parallely work on a single set of transactions and the blocks created by all the miners except one (miner whose block got added in longest chain) are eventually pruned from the main chain and are considered as the forks. Such pruning and forking greatly affects the efficiency of the process. Various alternative consensus algorithms have been proposed in recent years to avoid the issues related to POW mechanism such as proof-of-stake (POS), proof-of-burn (POB) and proof-of-reputation (POR) [24], [25]. However, the fundamental constraints of forking and lack of efficiency more or less continue to exist in these algorithms as well [26], [27]. Additionally, these algorithms do not support micro-transactions among the participating nodes [28], [29]. However, such small value transactions are an imperative part of a fast V2V communication model [30], [31].

In this paper, a fast, secure, and light-weight peer-to-peer communication model is presented for vehicular networks. The proposed model leverages the features of a tangle data structure used in IOTA to support frequent and small value transactions in a P2P network. The proposed model maintains all the benefits provided by blockchain and resolves the fundamental constraints introduced by blockchain. A game theoretic approach is used to map the service providers and consumers for performing offloading services in a cost-optimal way in vehicular network. Fig. 4 shows the pictorial representation of the V2V network. The vehicles communicate with each other as well as with the Road Side Units (RSUs) to get the required data or information. More specifically, the major contributions of this work are summarized as follows:

- A peer-to-peer vehicular network is proposed where vehicles can securely communicate and can perform data offloading.
- The directed acyclic graph (DAG) data structure is used to store and validate the transactions in the network and IOTA based consensus mechanism is used to bring the nodes to a final agreement about the order of transactions.
- A game theoretic model is presented to negotiate and choose the best service provider in a cost-optimal way.
- Simulation results demonstrate that our proposed model achieves the lowest communication cost and can support frequent micro transactions.

The rest of this paper is organized as follows. The recent works related to V2V communication models are presented in Section II. Some background information about the DAG chain and decentralized V2V communication model is presented in Section III. Section IV presents the optimal price formulation strategy for cost-optimal data offloading. In Section V the simulation results are presented and are compared with the existing models for data offloading in V2V communication. Section VI finally concludes the paper.

TABLE I
RELATED WORK ON VEHICLE TO VEHICLE COMMUNICATION

Year	Author	Contributions
2017	Yingyang chen *et al.* [32]	3-D massive MIMO channel model for V2V communication.
2017	Linjun zhang *et al.* [3]	Predict the behavior of the vehicles that are beyond line of sight.
2017	Myounggyu Won *et al.* [9]	Mitigating Phantom Jam Using Vehicle-to-Vehicle Communication.
2018	Ribal atallah *et al.* [33]	Deep reinforcement learning to schedule the operations of a connected vehicles.
2018	Wern-Yarng *et al.* [2]	Short-range vehicle to vehicle communication based on infrared-signal direction.
2018	Linjun Zhang *et al.* [34]	Regulate the longitudinal motion of connected and automated vehicles.
2019	Qin Wang *et al.* [35]	Pricing model for content sharing and media streaming among vehicles.
2019	Dusit Niyato *et al.* [15]	Blockchain-based internet of vehicles

II. Related Work

Various attempts are being made both in industry and academia to enhance the capabilities of V2V communication model, and to allow seamless and secure communication among vehicles. The authors in [33] have used deep reinforcement learning to schedule the operations of a connected vehicular network. A Q-network is used, which learns a scheduling policy from high-dimensional inputs and schedules the upcoming transactions accordingly. Authors of [8], [32] have proposed to use 3-D massive multiple input multiple output (MIMO) based model to support vehicular communication. A spherical wavefront is assumed in contrast to the regular plane wavefront in the traditional MIMO models.

The authors in [35] have proposed a pricing model for content sharing and media streaming among vehicles. An unmanned aerial vehicle (UAV) is placed between V2V users to assist inter cell communication. Authors of [2] have proposed a model for short-range vehicle to vehicle communication based on infrared-signal direction. Short-range communication is effective to avoid collisions in V2V communication.

The authors in [3] have proposed a model to predict the behavior of the vehicles that are beyond line of sight of the receiving vehicle to avoid future accidents. A causality detector is created to ensure the relevancy of the received information. Authors of [14] have discussed a Platooning technique to reduce the distance among the vehicles to avoid the probability of congestion. A power control mechanism and sub channel allocation schemes are discussed for V2V communications in a multi-platooning scenario. THe authors in [34] have discussed a model for cooperative adaptive cruise control (CACC) to monitor and control the movement of connected vehicles in mixed traffic.

All these works are more or less based on centralized network architectures. Few other recent attempts have been made toward creating a distributed architecture of V2V network based on blockchain [36]. A privacy preserving and trust management system based on blockchain for secure internet of vehicles is discussed in [37]. The proposed model removes the fundamental constraints in blockchain based network architectures. The model also allows iterative auctioning by the vehicles to gain the required amount of bandwidth for data offloading scenarios.

III. Network Model and Prelims

To minimize the computation and create a distributed network, IOTA based distributed ledger technology proves to be a highly promising solution. In IOTA, a directed acyclic graph (DAG) also referred as tangle is used as a data structure to store the transactions among the nodes in the network. Both vehicles and RSUs act as the nodes in the proposed model. It is assumed that each vehicle can directly communicate with other vehicles and RSUs in a range of 200 meters. The RSUs can also communicate with each other. The transactions that occur in the IOTA network contain vehicular data such as current global positioning system (GPS) coordinates, vehicle speed, acceleration and heading direction. Some other detailed information such as vehicle's brake status, data transmission state, path history, steering wheel angle, and path predictions can also be included if required. All this information is shared among vehicles and RSUs as per requirement. In this section the system model and the prelims for network model creation for V2V communication are discussed.

A. System Model

Fig. 2 shows the detailed steps involved in the proposed model to achieve cost-optimal data offloading in vehicle to RSU and vehicle to vehicle scenarios. Following are the steps that are being followed in the Figure to illustrate the system model of the proposed framework.

1) The first box shows the process of adding all the transactions in the IOTA tangle data structure. Here transaction refers to any communication or exchange between the vehicles or RSUs. The tangle data structure records all the events and all the new events are verified by the older events. The different colours in the tangle signify the status of verification of these transactions. The red colour events are not yet verified and the blue coloured transactions are been verified by other previous transactions. The transaction colour changes to green only when it reaches a state of consensus finality.
2) The second box shows the scenario of bandwidth auction between vehicles and RSUs as discussed in more detail in section IV-A. Here, the RSU gets the required data from the cellular network. The RSU has a fixed limited bandwidth and multiple vehicles demand for the data from

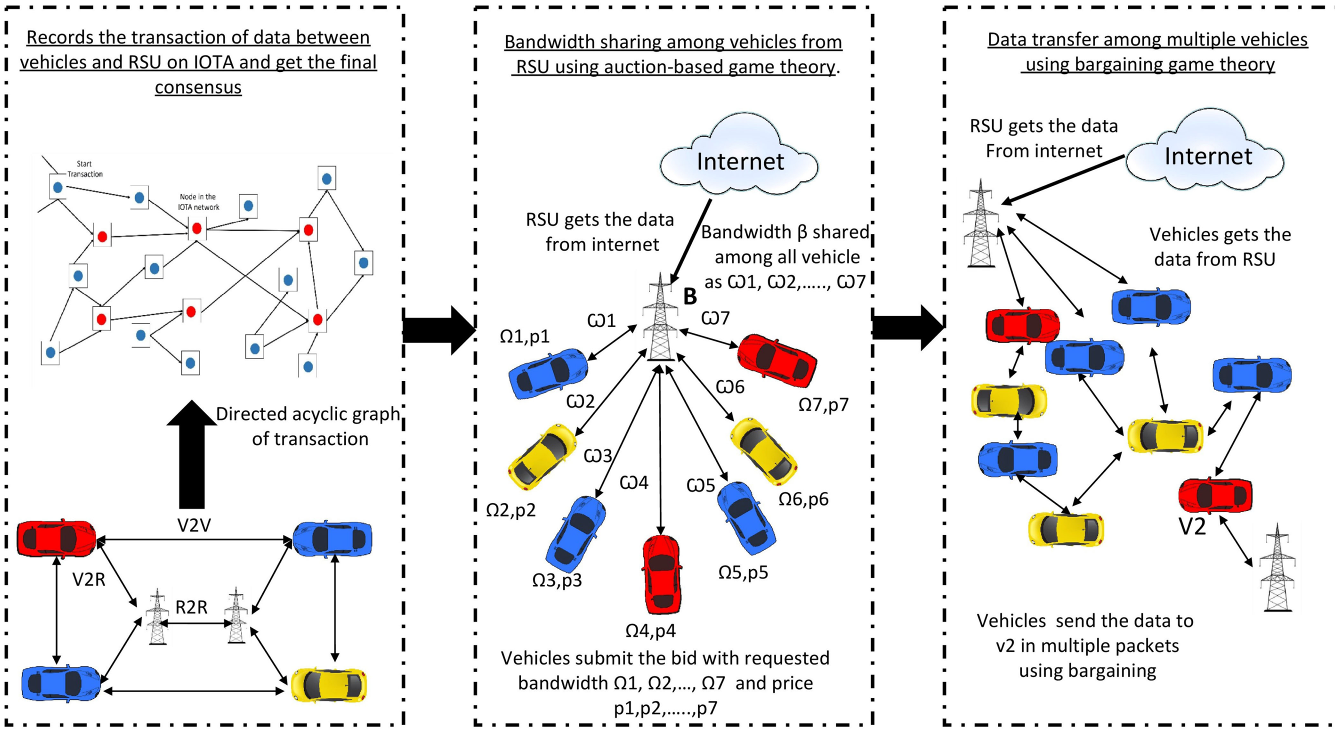

Fig. 2. Proposed model for vehicular communication using IOTA.

the RSU. An auction is done among the vehicles and RSU to provide best possible bandwidth to all vehicles as an optimal price.

3) The third box shows the scenario of bandwidth auction among vehicles. In this case the vehicle demanding the data is outside the range of the RSU that is carrying the data. Therefore, the RSU chooses to transfer the data in form of packets through other vehicles that are in the range of RSU. This scenario is also explained in good detail in section IV-B.

B. Digital Identity

Vehicles and RSUs act as nodes in the proposed network. Each node has a unique digital identity that is used to communicate with the other nodes in the network. Digital identity is the combination of the private key and the public address of the node [38]. To discuss about the key generation process, it is first important to discuss some basic terms such as seed, security level, and index. The seed, denoted by $\mathcal{S}$ is a type of secret identity of each node that is used to generate multiple unique addresses and signatures for all the transactions being issued in the network. Security level, denoted by $\mathcal{C}$ decides the length of the private key, higher the security level longer is the private key. The private key of vehicle is generated using Cryptographic Sponge Function (CSF) that takes input as seed, index, and security level as shown in Eqn. (1).

$$Privatekey = \mathcal{CSF}\left(\mathcal{S} + \mathcal{I} + \mathcal{C}\right) \quad (1)$$

Here index is an important parameter that helps in maintaining a unique identity for each vehicle along with the private seed. It is assumed that when any new node enters into the network it is assigned to a new index $\mathcal{I} = 1, 2, 3, 4, \ldots., N$ to maintain the uniqueness of identity. The private key generated from Eqn. (1) is further divided into key fragments. To create an address, the private key is split into 81 tryte segments. Then, each segment is hashed 26 times. A group of 27 hashed segments is called a key fragment. Key digest denoted by $K = k_1, k_2, k_3, k_4, \ldots., k_n$ is generated by passing the key fragments through a hash function. Further, the unique addresses for all transactions are generated by passing the different key digests through a CSF as shown in Eqn. (2).

$$Address = \mathcal{CSF}\left(\sum_{i=1}^{n} k_i\right) \quad (2)$$

C. Tangle Creation

Once the nodes get their digital identity they can start issuing transactions such as data request on the network. The nodes in the network are responsible for validating and issuing the transactions. If a new vehicle enters the network and issues a transaction then it must be directly or indirectly approved by the previous two transactions. After verification, the transaction can be added in the network and repeated addition of transactions results into a DAG like structure called the tangle. There is a start transaction or the first transaction in the network that is directly or indirectly approved by all the other transactions. The first transaction is responsible for creating the tangle graph that contains all the IOTA tokens. IOTA tokens are the specific cryptocurrency used in IOTA to perform seamless and immediate transactions between the nodes. Every time a transaction is added in the

TABLE II
NOTATION SUMMARY

Notation	Meaning
s	Seed for IOTA address
I	Index
c	Security level
K	Key digest
W	weight of transaction
c_w	Cumulative weight of transaction
$\mathcal{B}$	Total Bandwidth of RSU
β	Bids of vehicles
ω_i	Required Bandwidth by vehicle i
ϱ_i	Price offered by vehicle i to download the data
Ω_i	Bandwidth allocated to vehicle i
E_i	Quality of Experience of Vehicle i
ϕ	Valuation function of the vehicle
Λ_i	Cost function for vehicle i
τ_i	Time at which Vehicle is connect with RSU
τ_o	Time at which vehicle is out of region of RSU
Υ	Weight of data packets
$\varkappa$	Data transmission rate
ν	Data size of the packets being transferred
η	Function of Vehicle Satisfaction
Δ_i	Utility of vehicle
$\Psi_{i,j}$	Number of packets transmitted in given time
Δ_o	Utility of vehicle before Nash bargaining
φ	Nash bargaining solution

network it has to be validated by the previous two transactions and therefore there is no need to do any complicated puzzle solving to choose the miner. This is how the IOTA decreases the computational dependency as compared to blockchain.

D. Consensus Finality

Consensus is a sort of agreement for the validity of a transaction among the nodes in a distributed ledger [39], [40]. Consensus finality is referred to as a final agreement among all the network nodes. Blockchain never reaches to consensus finality due to the issues of forking and pruning. In generic blockchain network, where proof-of-work consensus is followed, different miners parallely work to mine a block. Whichever miner is able to present a successfully mined block in less time wins the competition and his block is accepted in the main chain. There are various instances when two or more miners simultaneously present a new block. In such cases, both the successfully mined blocks are accepted as two forks of the main chain. Gradually as the chain increases, one of the block becomes the part of longest chain and the other fork has to be pruned. The transaction that has reached consensus at one point of time, might be pruned in due course. Therefore, a stage of consensus finality is never reached, as the risk of pruning is always there [41].

The concept of weight associated with each node is used in IOTA network to eventually reach consensus finality. The weight of the node in the tangle is proportional to the amount of work that the issuing node invested into it. The value of the weight of the transaction is a multiple of three. The importance of the transaction is decided on the basis of weight associated with the transaction. The transactions with a higher weight are more important to be present in the network and vice-versa. To avoid any type of attacks and spam in the network it is assumed that in a short period of time any new node cannot create large number of transactions having a high weight value. The weight of the transactions gradually increases as and when the new transactions are verified by other existing transactions. Increased weight directly states that the transaction is more authentic. The IOTA tangle follows this process for reaching consensus without a transaction or mining fees as compared to the bitcoin consensus where the miners charge a fees to mine a block or validate a transaction. The cumulative weight of a transaction is the sum of the weights of the particular transaction and the weight of the transactions that validated it directly or indirectly as shown in Eqn. (3).

$$\mathrm{C_w} = \mathrm{w} + \left(\sum_{i=1}^{n} w_i\right) \tag{3}$$

IV. Proposed Optimal Price Formulation

A game theoretic approach is used to find the computation cost between vehicle to vehicle and vehicle to RSU. The price is assumed to be the computation power used by the vehicle to get the requested data such as the GPS location of other vehicle. Location is transferred from the vehicle to the RSU and further to the requesting vehicle from the RSU. The game theory is used to calculate the solution that involves minimum computation by the requesting vehicle. The requesting vehicle can get the data either from the RSU or directly from the nearby vehicle.

The game theoretic model is divided into two parts. The first part includes the division of bandwidth from the RSU to multiple vehicles in the range of RSU. The RSU will provide different bandwidth to different vehicles in its range based on the price offered by vehicles requesting the data. Auction based game theoretic approach is used here to allocate the bandwidth to multiple vehicles. Here RSU and the requesting vehicles act as auctioneer and bidders respectively.

The second part of the model comes into play when the RSU carrying the required data is out of the range of requesting vehicle. In such a case, the RSU transmits the requested data in form of packets to the vehicles in its range, which in turn transmits the packets to the requesting vehicle. This part of the game theoretic model includes the Nash bargaining process among multiple vehicles. The requesting vehicle checks for the vehicle having maximum information or the packets with highest weight and gets associated with that vehicle. The Nash bargaining approach helps the requesting vehicle to get the maximum requested data in least computation cost. The following two sub sections explain these two parts of the model in detail.

A. Game Theory Model for Bandwidth Auction Between Vehicles and RSU

In this model, we assume that at some location there are multiple vehicles and a single RSU. RSU is connected to the

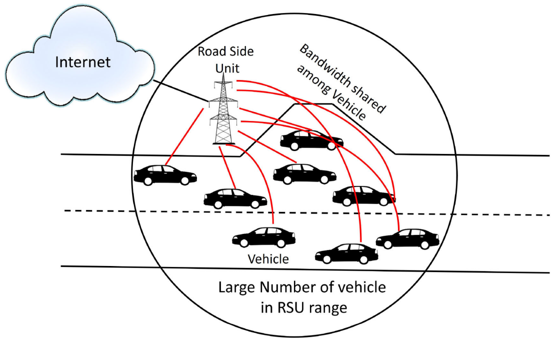

Fig. 3. Bandwidth sharing among vehicle from RSU using auction-based game theory.

internet to collect the useful information requested by the vehicles. Vehicles can request the RSU for any information such as traffic data, whether information data, GPS data of other vehicles or some multimedia data. The maximum bandwidth that the RSU can provide to the vehicles is limited. Therefore, get the data from RSU with maximum bandwidth or in minimum time there is a conflict among the vehicles as shown in Fig. 3. To solve this conflict between the vehicle to RSU communication, a game theoretic auction based mechanism is proposed. In this mechanism, auctioneers are the RSU and bidders are the vehicles.

Let us consider one RSU that is connected with the internet. When vehicles comes in the coverage area of RSU and request for data, then the bandwidth of RSU has to be divided among N number of vehicle. Total Bandwidth at RSU is denoted as $\mathcal{B}$. First of all, the bidders submit their bids i.e., β_i as shown in Eqn. (4). The bid includes the requested bandwidth and the offered price. Here ω_i denotes the bandwidth requested by the vehicle i and ϱ_i denotes the price offered by that vehicle to download the requested data. Please note that the requested bandwidth should always be less than the total bandwidth with the RSU (i.e., $\omega_i < \mathcal{B}$). After collecting the bids from all N vehicles, the amount of bandwidth allocated to each vehicle is Ω_i as shown in Eqn. (6). Here Γ is the summation of the prices offered by all the vehicles as shown in Eqn. (5) and $\mathcal{B}$ is the total bandwidth of the RSU. So the allocation of bandwidth is calculated based on the values of requested bandwidth and offered price as shown in Eqn. (6).

$$\beta_i = (\omega_i, \varrho_i) \tag{4}$$

$$\Gamma = \sum_{i=1}^{N} \varrho_i \tag{5}$$

$$\Omega_i = \min\left(\omega_i, \frac{\varrho_i}{\Gamma}\mathcal{B}\right), \ \forall \ \omega_i < \mathcal{B} \tag{6}$$

The bandwidth allocated to the vehicles by the RSU is not only dependent on the individual bid of the requesting vehicles but also depends on the bid from other vehicles. Each vehicle wants to optimize its bid to minimize the price and maximize its QoE in terms of allocated bandwidth. Based on the above information, non cooperative game (Auction based) is proposed to provide maximum possible bandwidth to the participating vehicles in minimum possible price. To minimize the price and maximize the bandwidth, we defile a QoE function E_i for the ith vehicle as follows [42].

$$E_i(\varrho_i, \varrho_{-i}) = \phi_i\left(\Omega_i(\boldsymbol{\beta})\right) - \Lambda_i\left(\Omega_i(\boldsymbol{\beta}), \varrho_i\right) \tag{7}$$

Here ϱ_{-i} denotes the vector of bidding prices of all vehicles other than vehicle i. The QoE is calculated as the difference between valuation and cost, where cost Λ_i is the product of the allocated bandwidth and price and the valuation is defined as the time interval during which the vehicle is in or out of the range of RSU. The valuation of a vehicle is calculated as the summation of time-in i.e., τ_i in which the vehicle is within the range of RSU and τ_o during which the vehicle is out of the range of RSU. The following equations are used to calculate the cost and valuation.

$$\Lambda_i\left(\Omega_i(\boldsymbol{\beta}), \varrho_i\right) = \Omega_i \varrho_i \tag{8}$$

$$\phi_i\left(\Omega_i(\beta)\right) = \tau_i \kappa \log\left(1 + \xi \Omega_i\right) + \eta(\tau_o) \tag{9}$$

where κ and ξ are logarithmic constants. The user satisfaction or η is defined as a function of time interval in which vehicle is not able to fetch the data from RSU. The following equation is used to calculate the value of user satisfaction.

$$\eta\left(\tau_o\right) = 1 - \frac{1}{1 + \exp\left(-\mu\left(\tau_o - \epsilon\right)\right)} \tag{10}$$

where μ and ϵ are constants. The best response of vehicle i is calculated as shown in the following equation.

$$\rho_i(\varrho_i) = \arg\max_{\varrho_i} E_i(\varrho_i) \tag{11}$$

where ρ_i is the best response of vehicle i. The Nash equilibrium is given as follows.

$$\varrho_i^* = \rho_i\left(\varrho_{-i}^*\right) \tag{12}$$

The Nash Equilibrium gives the appropriate values of price that deliver the maximum QoE to each vehicle.

In Algorithm 1, first the bid price of all vehicles in the RSU network is taken as the input. The bid price is taken in terms of required bandwidth and offered price per unit to download the data. Output of the algorithm is the price at which vehicles can get the maximum QoE. To get this, the values of bandwidth ω, cost Λ, valuation ϕ, user satisfaction η, and QoE E are calculated for all the vehicles and finally the price ϱ is declared at which the vehicles can get the maximum QoE E.

B. Game Theory Model for Bandwidth Auction Between Vehicles

In this model the requesting vehicle is assumed to be out of the range of serving RSU. The RSU divides the requested data into multiple packets. These packets are send to number of vehicle in the network of RSU. The requesting vehicle is allowed to access the data from multiple vehicles as they come in the range of requesting vehicle. It can improve both speed and reliability and thereby the cost of offloading.

We take a situation as shown in Fig. 4 where RSU in lane A wants to send the data to the vehicle in lane B. Let us assume that the size of data file is too large and the vehicle in lane B

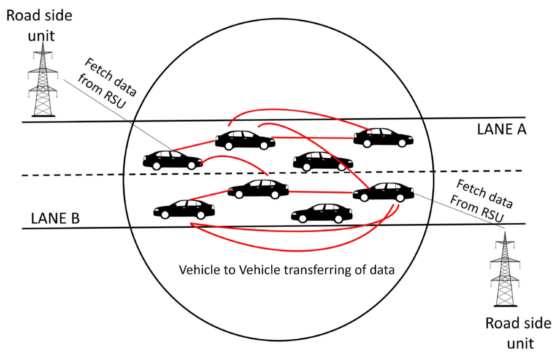

Fig. 4. Data transfer between Vehicle to Vehicle.

Algorithm 1: Auction Based Game Theoretic Model.

Input: Bid price $\beta_i = (\omega_i, \varrho_i)$ for all vehicles where ω_i = requested bandwidth and ϱ_i = bid price $\forall\, i \in \{1, 2, 3, .., N\}$
Output: ϱ_i at which QoE i.e., E is max
for $(i = 1 : n)$ **do**
  if $\Omega_i < \omega_i$ **then**
    Follow the below mentioned steps:
    1. compute allocate bandwidth Ω_i using: $\Omega_i = \min(\omega_i, \frac{\varrho_i}{\Gamma}\mathcal{B})$
    2. compute the cost Λ_i using: $\Lambda_i(\Omega_i(\beta), \varrho_i) = \Omega_i \varrho_i$
    3. compute the valuation ϕ_i using: $\phi_i(\Omega_i(\beta)) = \tau_i \kappa \log(1 + \xi\Omega_i) + \eta_l(t_i)$
    4. compute the user satisfaction η_i using: $\eta(t_i) = 1 - \frac{1}{1+\exp(\mu(t_i - \epsilon))}$
    5. compute the QoE E using: $E_i(\varrho_i) = \phi_i(\Omega_i(\beta)) - \Lambda_i(\Omega_i(\beta), \varrho_i)$
    6. compute ϱ_i at which E is max using: $\rho_i(\varrho_i) = \arg\max_{p_i} E_i(\varrho_i)$
  end if
end for

is not in the range of the RSU in lane A. Therefore, the RSU cannot send the data to the vehicle directly as the case discussed in Section IV-A. Therefore, the RSU sends the data in form of packets to the vehicle in the lane B via other vehicles. The RSU in lane A transmits the data to vehicles in same lane and these vehicles in both lanes exchange the data among themselves when they cross each other. In this manner the data is exchanged between vehicles. The data is divided into L packets having same size, and the requesting vehicle needs all the data packets. Each packet is denoted with some weight $\Upsilon(L)$. The number of packets n that can be transmitted between vehicles within time χ_0 is defined as follows.

$$n \leq (\varkappa * \chi_0)/\nu \tag{13}$$

where ν is data size and $\varkappa$ is transmission rate. The utility provided by vehicle i to the requesting vehicle j is the sum of weight of the n number of packets that vehicle i currently has

Algorithm 2: Information Transfer Between Vehicles.

repeat
1. **Locate Neighboring Vehicle**: Identify the Vehicle that are in range and have required packets
2. **Transfer Data Information**: The serving vehicles transmit the information of available data packets and their weight
3. **Bargaining Between Vehicle**: Bargaining for the information between vehicle is defined in Algorithm 3
4. **Transmission of Data**: Transfer the packet of data to the other vehicle based on results of bargaining algorithm

until Both vehicles have same data packets.

as shown in following equation.

$$\Delta_i = \sum_{L \in \kappa_i} \Upsilon_i(L) \tag{14}$$

where Δ_i is the utility, κ_i is the packet being shared between two vehicles and Υ_i is the weight of that particular packet. The utility function can also be considered as the vehicle satisfaction parameter.

The objective function is to maximize the utility between the requesting vehicle i.e., i and the vehicle carrying requested data i.e., j. We define an objective function φ which is defined as the mutual benefit which vehicle i and j gain from the bargaining, and it is expressed as follows.

$$Maximize : \varphi\,(\Delta_i, \Delta_j) \tag{15}$$

subject to the constraint

$$\sum_{L_1 \notin \kappa_i, L_1 \in \kappa_j} 1 + \sum_{L_2 \notin \kappa_j, L_2 \in \kappa_i} 1 \leq \Psi_{i,j} \tag{16}$$

where L_1 and L_2 are packets of vehicle i and j respectively and $\Psi_{i,j}$ is the number of packets that can be transmitted within time period χ_0. φ is function that define that how both vehicle can get benefits from bargaining. The constraint specified in Eqn. 16 specifies that the data packets with the servicing vehicle i must be different from the requesting vehicle j. If the requesting vehicle already has all the packets carried by the servicing vehicle then there would be no benefit in data transmission between these two vehicles.

For bargaining we adopt Nash bargaining solution. In Nash bargaining algorithm ϑ is feasible region, Δ is the utility after the bargaining and Δ^o is utility before the data transfer between vehicles. $\varphi(\vartheta, \Delta^o)$ is the Nash bargaining solution that maximizes the utility of both vehicles.

$$\varphi\,(\vartheta, \boldsymbol{\Delta}_o) = \arg \max_{\boldsymbol{\Delta} \geq \boldsymbol{\Delta}_o, \boldsymbol{\Delta} \in \vartheta} \prod_{z=i,j} (\Delta_z - \Delta_z^o) \tag{17}$$

The algorithm for information transfer between vehicles is defined in Algorithm 2. First of all the requesting vehicle locates the other vehicles in its communication range i.e., 200 meters. Among all vehicles in the range, the data is exchanged with the vehicle having data with maximum weight. Next we calculate the

Algorithm 3: Bargaining Algorithm.

Input: weight, Υ for the available packets with vehicle 1 and vehicle 2 as

$\Upsilon_i = [\Upsilon_i(1), \Upsilon_i(2), \ldots, \Upsilon_i(L)]$ from v_1.

$\Upsilon_j = [\Upsilon_j(1), \Upsilon_j(2), \ldots, \Upsilon_j(L)]$ from v_2.

Output: Nash bargaining solution between $v_1$and v_2 i.e., (Ψ_i^*, Ψ_j^*)

1. Sort packets by weight i.e., $\Upsilon_i(1) < \Upsilon_i(2) < \cdots < \Upsilon_i(L)$
2. Define a set of transmitted packet by vehicle i and j as (Ψ_i, Ψ_j) where, $\Psi_i = \{0, \ldots, \Psi_{i,j}\}$, and $\{\Psi_j = \Psi_{ij} - \Psi_i\}$
3. Calculate utility from $\Delta_i = \sum_{L \in \kappa_i} \Upsilon_i(L)$
4. Obtain Nash solution in form of (Ψ_i^*, Ψ_j^*) from $\arg\max_{(\Psi_i, \Psi_j)} (\Delta_i(\Psi_i) - \Delta_i^0) \times (\Delta_j(\Psi_j) - \Delta_j^0)$

number of packets that are can be transmitted between vehicle i and j in time χ_0 as $\Psi_{i,j}$. When the vehicles are connected, each vehicle transfers information of weight of data and summary of data packet to other vehicles. The bargaining algorithm 3 is run between the vehicles to search for the best possible association. The data transfer is done based on the results of the bargaining algorithm until both the vehicles have same data packets. The steps for the data transfer are also explained in Algorithm 2.

V. Numerical Analysis

A. Simulation Settings

Consider a distributed network of V2V and vehicle to RSU. For the evaluation of vehicle to RSU model, we have considered four vehicles having different time-in and time-out in the network. Time-out of vehicle is calculated as difference of total time and time-in of vehicle. The time-in of vehicles is assumed to be in the range of [10, 50] minutes in the frame window of 60 minutes. The required bandwidth of four vehicles while entering in the network is assumed to be $\omega_i = \{6, 12, 18, 24\}$ bits per second and the corresponding price of each vehicle is taken as $\varrho_i = \{30, 40, 50, 60\}$ cents. For every iteration, we increase the number of vehicles in the network and consider the change in QoE of the four vehicles under consideration. Finally, each vehicle is allocated its required bandwidth at minimum price having maximum QoE. It is assumed that the RSU can provide bandwidth to more then one vehicle simultaneously, hence if multiple vehicles are assigned to one RSU then all can get the required bandwidth. In the model of V2V communication we have considered three vehicles. Number of packets transferred between two vehicles are $L = \{1, 2, 3, 4, 5\}$ and on the basis of proposed model, the utility between the vehicles is calculated. One vehicle calculates the utility with two other vehicles and decides to get the information from one having a higher utility.

B. Performance Evaluation

Fig. 5 shows that the allocation of bandwidth by RSU to vehicle 1 is varying as the bid price by vehicle increases or the number of vehicles in the network increase. It can be observed that with the increasing of the number of vehicle in the network, the allocation of bandwidth to vehicle 1 is decreasing and when bid price of vehicle 1 is increasing the allocation of bandwidth is also increasing. The values on the colour map indicate the change in the values of the allocated bandwidth. The dark blue colour indicates the minimum value of allocated bandwidth and the dark orange colour indicates the maximum value of the allocated bandwidth.

Fig. 6 shows that with the with the increase in the number of vehicles in the network, allocation of bandwidth to different vehicles by the RSU decreases. This is so because the bandwidth at RSU is fixed and is divided among the vehicles that are in the network of RSU.

Similarly, Fig. 7 shows the effect on the QoE of vehicles as the network size is changing. The QoE not only depends on the

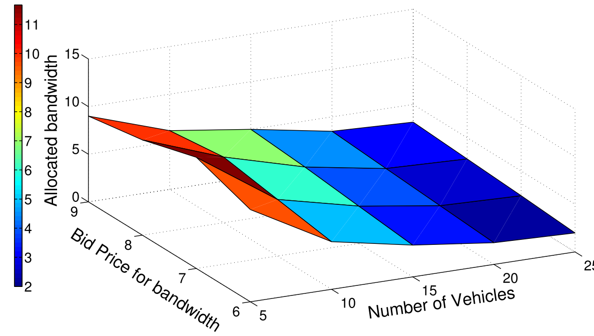

Fig. 5. Variation in allocated bandwidth based on bid price and network size.

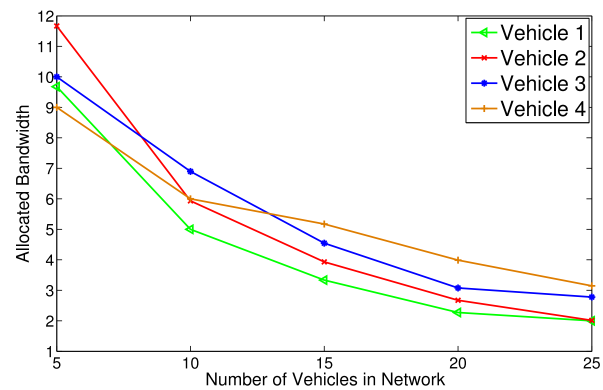

Fig. 6. Variation in allocated bandwidth‘ based on network size.

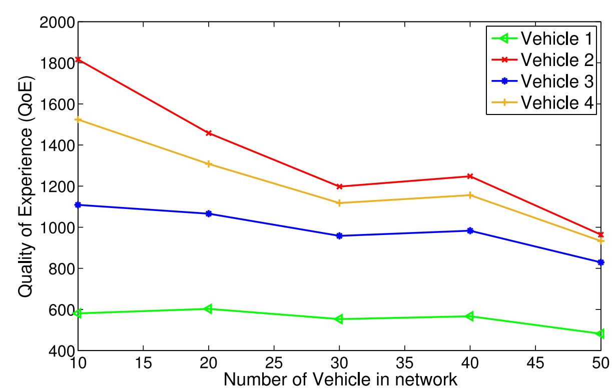

Fig. 7. Variation in QoE with increase in network size.

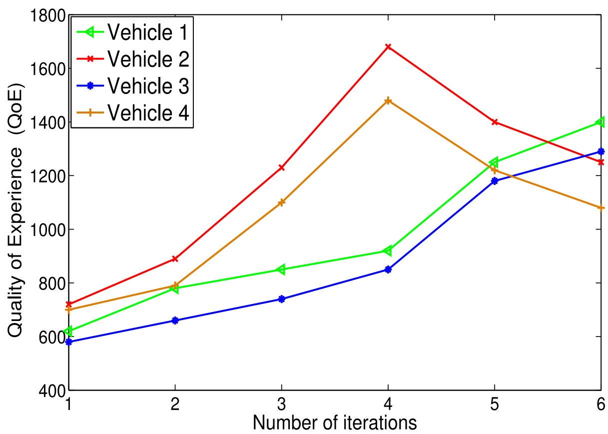

Fig. 8. Variation in QoE with number of iterations.

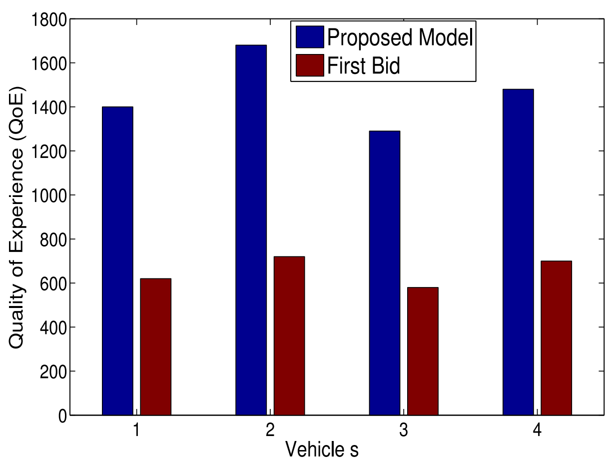

Fig. 9. Comparison of QoE of vehicles in proposed model and first bid model.

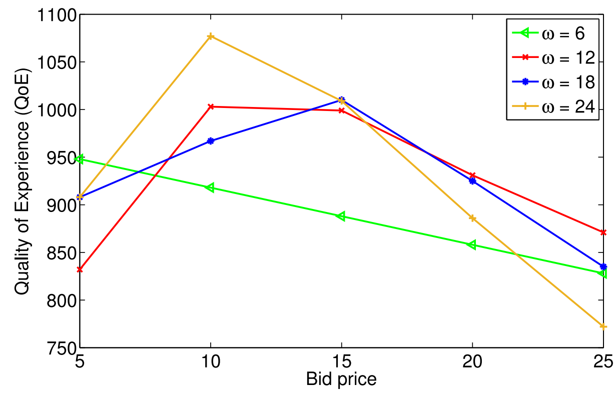

Fig. 10. variation in QoE with change in bid price and fixed bandwidth requirement.

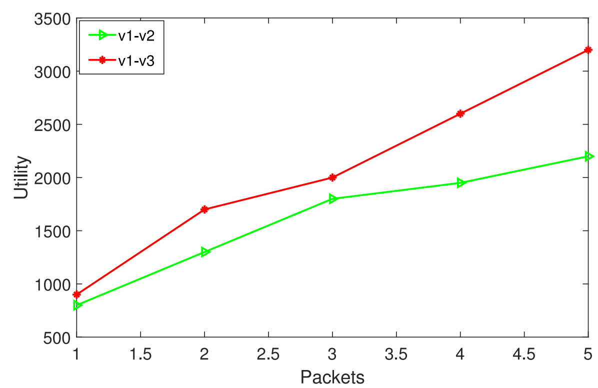

Fig. 11. variation in utility when vehicles 1 exchanges data with vehicle 2 and 3.

time in which the vehicle was in the range of RSU, valuation and cost but it also depends on the size of the network i.e., number of vehicles in the range of RSU. As the number of vehicles increases the QoE of vehicle decreases. It can be observed that the QoE is sometimes increasing in between in Fig. 7. This is so, because the QoE parameter is dependent on multiple parameters as discussed above and the decisions taken by other vehicles effects the QoE of one vehicle.

Fig. 8 shows the variation of the vehicle QoE with the change in the bid values by the vehicles. As the vehicles go on increasing the bid amount, the allocated bandwidth foes on increasing and hence the QoE. We assume that the requested bandwidth by each vehicle is fixed. The QoE will increase with increasing the bid price only till the allocated bandwidth is less than or equal to the requested bandwidth. As soon as the requested bandwidth becomes equal to the allocated bandwidth, the QoE decreases with increase on bid price. This is so, because the user is already getting the maximum requested bandwidth and there is no benefit of further increasing the price. It can be observed that for vehicle 2 and 4 in Fig. 8 the allocated bandwidth becomes equal to the requested bandwidth at iteration 4 and thereafter the QoE value is declining if the bid price is increased.

Fig. 9 shows the comparison of the proposed model in terms of vehicle QoE with the first bid mechanism. In proposed model vehicles increase the bid value over iterations to get the required amount of bandwidth and high QoE. It can be observed that the QoE of all the vehicles is comparatively higher in the proposed model as compared to the first bid auction model.

Fig. 10 shows variation in QoE due to variation in amount of bandwidth required and bid price. As the bid price increases, QoE of vehicles increases or decreases depending on the bids of other vehicles. This is so, because the QoE of vehicles depends on the bid decision taken by all the vehicles in the network. At some point, vehicles get the highest QoE depending on the required bandwidth. After this point even if the vehicle chooses to increase the bid price, the allocated bandwidth does not increase and therefore the value of QoE decreases.

Fig. 11 shows the utility comparison of exchange of packets between vehicle 1 and 2 or between vehicle 1 and 3. The utility of exchange between vehicle 1 and 3 is high as compared to vehicle 1 and 2. Therefore, vehicle 1 decides to communicate and exchange packets with vehicle 3 instead of vehicle 2. Here, utility refers to gathering maximum amount of data in minimum number of communications.

VI. Conclusion

In this paper, we have proposed two models 1) vehicle to RSU auction based model 2) vehicle to vehicle nash bargaining model. IOTA consensus algorithm is used to reach to a consensus in the vehicular network. The auction based model is used to allocate the required amount of bandwidth with maximum quality of experience (QoE). The Nash bargaining algorithm is used to get associated with the vehicle with maximum utility. The simulations results prove that the proposed algorithms to maximize QoE and utility of every vehicle in network are better than its counterparts.

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REFERENCES

[1] M. A. Masrur *et al.*, "Military-based vehicle-to-grid and vehicle-to-vehicle microgrid—System architecture and implementation," *IEEE Trans. Transp. Electrific.*, vol. 4, no. 1, pp. 157–171, Mar. 2018.

[2] W. Y. Shieh, C. C. J. Hsu, C. H. Lin, and T. H. Wang, "Investigation of vehicle positioning by infrared signal-direction discrimination for short-range vehicle-to-vehicle communications," *IEEE Trans. Veh. Technol.*, vol. 67, no. 12, pp. 11 563–11 574, Dec. 2018.

[3] L. Zhang and G. Orosz, "Beyond-line-of-sight identification by using vehicle-to-vehicle communication," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 6, pp. 1962–1972, Jun. 2017.

[4] R. He *et al.*, "Vehicle-to-vehicle radio channel characterization in crossroad scenarios," *IEEE Trans. Veh. Technol.*, vol. 65, no. 8, pp. 5850–5861, Aug. 2016.

[5] S. Kwon, Y. Kim, and N. B. Shroff, "Analysis of connectivity and capacity in 1-D vehicle-to-vehicle networks," *IEEE Trans. Wireless Commun.*, vol. 15, no. 12, pp. 8182–8194, Dec. 2016.

[6] M. Azimifar, T. D. Todd, A. Khezrian, and G. Karakostas, "Vehicle-to-vehicle forwarding in green roadside infrastructure," *IEEE Trans. Veh. Technol.*, vol. 65, no. 2, pp. 780–795, Feb. 2016.

[7] S. Garg, K. Kaur, G. Kaddoum, F. Gagnon, N. Kumar, and Z. Han, "Sec-IoV: A multi-stage anomaly detection scheme for Internet of vehicles," in *Proc. ACM MobiHoc Workshop Pervasive Syst. IoT Era*, 2019, pp. 37–42.

[8] H. Jiang, Z. Zhang, J. Dang, and L. Wu, "A novel 3-D massive MIMO channel model for vehicle-to-vehicle communication environments," *IEEE Trans. Commun.*, vol. 66, no. 1, pp. 79–90, Jan. 2018.

[9] M. Won, T. Park, and S. H. Son, "Toward mitigating phantom jam using vehicle-to-vehicle communication," *IEEE Trans. Intell. Transp. Syst.*, vol. 18, no. 5, pp. 1313–1324, May 2017.

[10] B. Fan, H. Tian, S. Zhu, Y. Chen, and X. Zhu, "Traffic-aware relay vehicle selection in millimeter-wave vehicle-to-vehicle communication," *IEEE Wireless Commun. Lett.*, vol. 8, no. 2, pp. 400–403, Apr. 2019.

[11] Y. Bi, G. Han, C. Lin, Q. Deng, L. Guo, and F. Li, "Mobility support for fog computing: An SDN approach," *IEEE Commun. Mag.*, vol. 56, no. 5, pp. 53–59, May 2018.

[12] H. Jiang, Z. Zhang, L. Wu, and J. Dang, "A non-stationary geometry-based scattering vehicle-to-vehicle MIMO channel model," *IEEE Commun. Lett.*, vol. 22, no. 7, pp. 1510–1513, Jul. 2018.

[13] Y. Yao, X. Chen, L. Rao, X. Liu, and X. Zhou, "Lora: Loss differentiation rate adaptation scheme for vehicle-to-vehicle safety communications," *IEEE Trans. Veh. Technol.*, vol. 66, no. 3, pp. 2499–2512, Mar. 2016.

[14] H. Peng, D. Li, Q. Ye, K. Abboud, H. Zhao, W. Zhuang, and X. Shen, "Resource allocation for cellular-based inter-vehicle communications in autonomous multiplatoons," *IEEE Trans. Veh. Technol.*, vol. 66, no. 12, pp. 11 249–11 263, Dec. 2017.

[15] J. Kang, Z. Xiong, D. Niyato, D. Ye, D. I. Kim, and J. Zhao, "Toward secure blockchain-enabled Internet of Vehicles: Optimizing consensus management using reputation and contract theory," *IEEE Trans. Veh. Technol.*, vol. 68, no. 3, pp. 2906–2920, Mar. 2019.

[16] A. Yassine, M. S. Hossain, G. Muhammad, and M. Guizani, "Double auction mechanisms for dynamic autonomous electric vehicles energy trading," *IEEE Trans. Veh. Technol.*, vol. 68, no. 8, pp. 7466–7476, Aug. 2019.

[17] F. Tang, Z. M. Fadlullah, N. Kato, F. Ono, and R. Miura, "AC-POCA: Anti coordination game based partially overlapping channels assignment in combined UAV and D2D-based networks," *IEEE Trans. Veh. Technol.*, vol. 67, no. 2, pp. 1672–1683, Feb. 2018.

[18] F. Tang, Y. Kawamoto, N. Kato, and L. Jiajia, "Future intelligent and secure vehicular network towards 6G: Machine learning approaches," *Proc. IEEE*, vol. 108, no. 2, pp. 292–307, Feb. 2020.

[19] K. Kaur, S. Garg, G. S. Aujla, N. Kumar, J. J. Rodrigues, and M. Guizani, "Edge computing in the industrial Internet of Things environment: Software-defined-networks-based edge-cloud interplay," *IEEE Commun. Mag.*, vol. 56, no. 2, pp. 44–51, Feb. 2018.

[20] V. Hassija, V. Chamola, V. Saxena, D. Jain, P. Goyal, and B. Sikdar, "A survey on IoT security: Application areas, security threats, and solution architectures," *IEEE Access*, vol. 7, pp. 82 721–82 743, 2019.

[21] K. Kaur, S. Garg, G. Kaddoum, M. Guizani, and D. N. K. Jayakody, "A lightweight and privacy-preserving authentication protocol for mobile edge computing," 2019, *arXiv:1907.08896*.

[22] T. Alladi, V. Chamola, B. Sikdar, and K.-K. R. Choo, "Consumer IoT: Security vulnerability case studies and solutions," *IEEE Consum. Electron*, vol. 9, pp. 6–14, Nov. 2019.

[23] G. S. S. Chalapathi, V. Chamola, C.-K. Tham, S. Gurunarayanan, and N. Ansari, "An optimal delay aware task assignment scheme for wireless sdn networked edge cloudlets," *Future Gener. Comput. Syst.*, vol. 102, pp. 862–875, 2020.

[24] V. Hassija, G. Bansal, V. Chamola, V. Saxena, and B. Sikdar, "Blockcom: A blockchain based commerce model for smart communities using auction mechanism," in *Proc. IEEE Int. Conf. Commun. Workshops*, China, May 2019, pp. 1–6.

[25] G. K. Verma, B. Singh, N. Kumar, and V. Chamola, "CB-CAS: Certificate-based efficient signature scheme with compact aggregation for industrial Internet of Things environment," *IEEE Internet Things J.*, to be published, doi: 10.1109/JIOT.2019.2944632.

[26] V. Hassija, V. Saxena, and V. Chamola, "Scheduling drone charging for multi-drone network based on consensus time-stamp and game theory," *Comput. Commun.*, vol. 149, pp. 51–61, 2020.

[27] T. Alladi, V. Chamola, J. J. Rodrigues, and S. A. Kozlov, "Blockchain in smart grids: A review on different use cases," *Sensors*, vol. 19, no. 22, 2019, Art. no. 4862.

[28] T. Alladi, V. Chamola, R. M. Parizi, and K.-K. R. Choo, "Blockchain applications for industry 4.0 and industrial IoT: A review," *IEEE Access*, vol. 7, pp. 176935–176951, 2019.

[29] G. Bansal, V. Hassija, V. Chamola, N. kumar, and M. Guizani, "Smart stock exchange market: A secure predictive decentralised model," in *Proc. IEEE Globecom*, Waikoloa, USA, Dec. 2019, pp. 1–6.

[30] Y. Bi, G. Han, C. Lin, M. Guizani, and X. Wang, "Mobility management for intro/inter domain handover in software defined networks," *IEEE J. Sel. Areas Commun.,* vol. 37, no. 8, pp. 1739–1754, Aug. 2019.

[31] Y. Bi, G. Han, S. Xu, X. Wang, C. Lin, Z. Yu, and P. Sun, "Software defined space-terrestrial integrated networks: Architecture, challenges, and solutions," *IEEE Netw.*, vol. 33, no. 1, pp. 22–28, 2019.

[32] Y. Chen, L. Wang, Y. Ai, B. Jiao, and L. Hanzo, "Performance analysis of NOMA-SM in vehicle-to-vehicle massive MIMO channels," *IEEE J. Sel. Areas Commun.*, vol. 35, no. 12, pp. 2653–2666, Dec. 2017.

[33] R. F. Atallah, C. M. Assi, and M. J. Khabbaz, "Scheduling the operation of a connected vehicular network using deep reinforcement learning," *IEEE Trans. Intell. Transp. Syst.*, vol. 20, no. 5, pp. 1669–1682, May 2019.

[34] L. Zhang, "Cooperative adaptive cruise control in mixed traffic with selective use of vehicle-to-vehicle communication," *IET Intell. Transport Syst.*, vol. 12, no. 10, pp. 1243–1254, 2018.

[35] Q. Wang, Y. Chen, S. Yin, L. Tian, and Y. Guo, "Pricing based power control for inter-cell UAV-assisted vehicle-to-vehicle underlay communication," *China Commun.*, vol. 16, no. 1, pp. 57–68, 2019.

[36] X. Wang, P. Zeng, N. Patterson, F. Jiang, and R. Doss, "An improved authentication scheme for internet of vehicles based on blockchain technology," *IEEE Access*, vol. 7, pp. 45 061–45 072, 2019.

[37] Z. Yang, K. Yang, L. Lei, K. Zheng, and V. C. Leung, "Blockchain-based decentralized trust management in vehicular networks," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 1495–1505, Apr. 2019.

[38] A. Miglani, n. Kumar, V. Chamola, and Z. Sherali, "Blockchain for internet of energy management: A review, solutions and challenges, computer communications," *Comput. Commun.*, Jan. 2020.

[39] V. Hassija, V. Chamola, S. Garg, D. Nandu, G. Kaddoum, and N. Jayakody, "A blockchain-based framework for lightweight data sharing and energy trading in V2G network," *IEEE Trans. Veh. Technol.*, to be published, doi: 10.1109/TVT.2020.2967052.

[40] V. hassija, V. Saxena, and V. Chamola, "A mobile data offloading framework based on a combination of blockchain and virtual voting," *Softw.: Pract. Exp.*, Jan. 2020.

[41] G. Bansal, Naren, and V. Chamola, "Rama: Real-time automobile mutual authentication protocol using puf," in *Proc. IEEE ICOIN*, Barcelona, Spain, Jan. 2020, pp. 1–6.

[42] S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge, U.K.: Cambridge Univ. Press, 2004.