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Multi-Channel Blockchain Scheme for Internet of Vehicles

LIMING GAO [1], CELIMUGE WU [1] (Senior Member, IEEE), TSUTOMU YOSHINAGA [1] (Member, IEEE), XIANFU CHEN [2] (Member, IEEE), AND YUSHENG JI [3] (Senior Member, IEEE)

[1] Graduate School of Informatics and Engineering, The University of Electro-Communications, 1-5-1, Chofugaoka, Chofu-shi, Tokyo 182-8585, Japan
[2] VTT Technical Research Centre of Finland, Oulu FI-90571, Finland
[3] Information Systems Architecture Research Division, National Institute of Informatics, 2-1-2, Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, Japan

CORRESPONDING AUTHOR: CELIMUGE WU (e-mail: celimuge@uec.ac.jp).

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ABSTRACT With the development of advanced information and communication technology, the traditional centralized service model alone no longer meets the increasing demand of data exchange in intelligent transportation systems (ITS). While Internet of Vehicles (IoV) technology has been introduced to achieve more advanced ITS, there are still some unsettled issues such as flexibility and fault tolerance. The conventional centralized approach for ITS is vulnerable to the single point of failure, and lack of flexibility due to its dependence on a trusted third party (TTP). The emergence of blockchain technology provides a potential direction to address these problems. However, due to varying vehicle densities, it is challenging to select the best blockchain parameters to satisfy the application requirements. In this paper, we propose a multi-channel blockchain scheme that can use the best parameters in accordance with the vehicle density. The proposed scheme first defines multiple blockchain channels where each channel is optimized for a certain vehicle density level. Then, the system selects the best channel according to the vehicle density, and the application requirements on the transaction throughput and latency. We use extensive simulations to show that the proposed blockchain scheme achieves a significantly better performance as compared with existing baselines.

INDEX TERMS Blockchain, IoV, hyperledger fabric, channel management.

I. INTRODUCTION

With the development of wireless communication, data sensing/processing, computing, and control technology, the Internet of Vehicles (IoV) has become a promising solution to intelligent transportation systems (ITS) [1]–[4]. ITS is a comprehensive integration of a large number of advanced technologies to improve efficiency and reliability of the transportation system. It combines cloud computing, edge computing and IoV to establish a fully connected transportation system with real-time efficient communication, monitoring and control [5].

Current ITS applications utilize cloud computing technology and distributed communications among the vehicles and infrastructures to provide global traffic management services. In ITS, there is a large number of devices and applications connected to the network, and most applications have high requirements on the network throughput and latency [6]. Due to limited communication resources, it is difficult for cloud servers to coordinate all the devices and applications in a totally centralized approach.

Applying vehicular ad hoc network (VANET) technologies makes the distributed communications possible at the network layer [7], but when it comes to the exchange of user data, the interoperability of the devices and applications from different manufacturers and service providers in ITS is still a problem that needs to be solved [8]. The vehicles from different manufacturers do not want to share data with each other unless we design a proper reward mechanism to incentivize the participants to share resources or data. We have to establish a platform that is trusted by every participant.

However, the conventional approach based on a trusted third party (TTP) faces some challenges in IoV. First, the conventional centralized approach is vulnerable to the single point of failure. Computer systems are vulnerable to cyber-attacks as anyone in the system might be malicious [9]. In IoV, vehicles periodically exchange safety beacon messages (SBMs) which contain much important information like identity, speed, and location. By collecting and mining the SBMs, malicious nodes can get the private information of the users. Conventional ITS system verifies the user's identity by introducing a third-party certification authority (CA). However, sometimes these third-party CAs are not completely credible. Furthermore, CAs are usually centralized entities that must bear the risk of the single point of failure [10]. Second, since the conventional approach is not flexible enough to support a large number of emerging applications due to its dependence on the TTP. Therefore, it is important to find an approach that can achieve a quick establishment of a new system that can be trusted by every participant.

These complicated and interdisciplinary challenges have hindered the further development of ITS. Fortunately, the emergence of blockchain technology provides a new approach for breaking through the bottleneck of the centralized intelligent transportation systems [11], [12]. Blockchain technology is a new distributed ledger technology (DLT) which is first introduced by Satoshi Nakamoto in 2008 to serve as the fundamental framework of the bitcoin, a well-known cryptocurrency. A blockchain is a growing chain of blocks that contain the transaction data in a digital ledger. The main contribution of blockchain technology is that it enables value transfer in a decentralized manner without a third-party certification authority [13]. At the same time, it can provide an effective incentive mechanism to promote the peers in a distributed system to make the right decision.

The characteristics of blockchain technology have attracted great attention from a large number of researchers. The combination of blockchain technology and IoV has the potential to overcome many obstacles of the traditional vehicular networks [14]. However, there are still some technical problems that need to be addressed. First, the blockchain system needs to handle a large amount of data and transactions under a highly dynamic network topology due to the high mobility of the vehicles in the network [15]. This characteristic of the vehicular network limits the efficiency of the block propagation. Different vehicle densities result in different amounts of transaction requests, which incurs different requirements on the blockchain system. Therefore, it is important to design a blockchain scheme that is able to handle the varying density of vehicles. Second, the heterogeneity of the vehicular network makes it hard for all the nodes in the network to play a purely equal peer-to-peer role since they all have different functions and objectives. The nodes in the vehicular network have different communication and computing capabilities [16]. The computing and power resources of the vehicles are typically not enough to support a proof-of-work (PoW) mechanism to achieve the consensus across the network [17]. Vehicles in one city or area have no necessity to verify the transaction from another city or area since it will also cause a huge delay that is intolerable in some vehicular scenarios. This motivates us to consider the heterogeneity of devices in the blockchain system.

In this paper, we propose a blockchain scheme for IoV to solve these problems. The main contributions of this paper are as follow:

1) We propose a multi-channel blockchain scheme for IoV. The proposed scheme defines multiple channels with different block sizes, and selects the best channel based on the vehicle density. By using different channels based on the number of vehicles using the blockchain, the blockchain scheme is able to satisfy the application requirements including transaction throughput and delay.
2) The proposed scheme employs a new three-layered blockchain architecture where the network nodes are divided into three layers, namely, cloud layer, infrastructure layer, and vehicular layer. The cloud layer provides ordering service and certification authority (CA) service. The nodes in the infrastructure layer such as roadside units (RSUs) and base stations are configured as endorsement and commitment nodes to provide transaction verification and ledger storage service. Vehicles generate transactions but do not participate in the consensus process. By performing different functionalities at three different layers, the computational and communication resources at each node can be used more efficiently.
3) We conduct extensive experiments based on Hyperledger Fabric and caliper to evaluate the performance of the proposed scheme. To the best of our knowledge, this is the first work to design and simulate a blockchain-based scheme for IoV on a benchmark with multiple peers and a realistic blockchain transaction sending rate.

The rest of the paper is organized as follows. Section II introduces the related work. Section III describes the details of the proposed blockchain scheme. The experimental results are presented in Section IV. Finally, conclusions and future work are given in Section V.

II. RELATED WORK

In this section, we present the overview and recent advances of the related technologies including IoV, blockchain technology, and the use of blockchain in IoV.

A. ITS AND IOV

As advanced information technology develops, people realized that efficient integration of some recently booming computer technologies can achieve a more accurate, intelligent, and real-time cyber-physical system (CPS) [18]. As an outstanding example of the rapidly developing CPS technology, ITS has attracted more and more attention from researchers.

ITS is an integration of various traffic management devices and applications. The ITS aims to provide large-scale and all-around services to traffic management using the data collected from various devices including smart vehicles, infrastructures, and pedestrians. With the continuous efforts of developers for decades, various ITS applications have been designed to provide a wide range of services on traffic management, such as emergency notification systems, electronic toll collection systems, traffic control systems, and data collection systems [19].

Recently, as one of the key components of realizing ITS, IoV has emerged to accelerate the evolution of transportation systems. In IoV, vehicles, devices, and infrastructures are connected in a distributed way through the vehicle-to-everything (V2X) communications including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-device (V2D), and vehicle-to-pedestrian (V2P) [20] communications. The smart vehicles in IoV are equipped with sensor units (camera, radar, etc.), control units, computational units, and communication units. Smart vehicles gather the data from various sensors through wired (controller area network, etc.) or wireless communications and send the data to the computational units for further processing.

Moreover, the development of edge computing and vehicular communication technology have further promoted the implementation of ITS. In some emergency conditions, the delay of cloud service is too high for the vehicles to take necessary action in time. Usually, RSUs in ITS are configured as the edge nodes to provide the edge computing services to reduce the latency. Besides, a distributed vehicular network called vehicle ad hoc networks (VANET) has been proposed by the researchers to improve the communication between vehicles and infrastructures. VANET is a substantial implementation of the mobile ad hoc network (MANET) in vehicular environments. All vehicles in a VANET system periodically receive SBMs from the nearby vehicles or sensors to learn about the current traffic status [21].

B. BLOCKCHAIN TECHNOLOGY

Blockchain technology has attracted huge attention from both academia and industry as the fundamental technology of Bitcoin. Generally speaking, blockchain is a new type of distributed ledger technology that helps decentralized systems to reach a consensus without a third-party certification authority. The ledger in blockchain consists of a growing list of data records that are linked in chronological order. The ledgers are stored on many independent nodes in a decentralized way so that no one can temper the ledger without the alteration of most of the ledgers [22].

Blockchain technology is an interdisciplinary technology that integrates several existing technologies such as cryptography, distributed systems, game theory, smart contract, and communication technology [23]. With an effective combination of these technologies, blockchain technology enables data recording and value transfer in a decentralized manner and prevents the double-spending problem which is a big challenge in a decentralized system.

There are mainly two types of blockchain, namely, permissionless and permissioned blockchain. The permissionless chain is also known as the public chain. In a permissionless blockchain, because of its efforts on solving the hash puzzles, there is no need to set any access control, and all the peers can join the network and participate in the consensus process freely without any approval [24]. On the contrary, in permissioned blockchain, only those peers that are granted with special privileges can participate in the network activity. Having an access control mechanism, the permissioned blockchain does not need to worry about the Sybil attack [13]. However, the peers in the permissioned chain are not equally privileged. The network initiator (mostly big organizations) constitutes a consortium and vets the authentication of the participants [25]. Therefore, permissioned blockchain is also called consortium blockchain.

Another valuable innovation of blockchain technology is the consensus algorithm and incentive mechanism that are used to encourage the distributed peers to record the most valid data. Those nodes that record problematic data do not get any rewards. Although the PoW mechanism used by Bitcoin is often accused of wasting power resources, it is still an efficient, reliable, and unprecedented consensus mechanism for decentralized systems [26]. In recent years, various consensus mechanisms with less power consumption, such as proof-of-stake (PoS), delegated proof-of-stake (DPoS), and practical Byzantine fault tolerance (PBFT), have been proposed [27].

C. BLOCKCHAIN FOR IOV

For the last decade, with the joint efforts of researchers in the related areas, blockchain technology has made great progress, and has been applied to many fields, such as governance, finance, energy, healthcare, smart city, and Internet of Things. A comprehensive survey on blockchain for IoV was presented in [28].

The studies on blockchain for IoV mainly focus on three aspects, namely, identity management, incentive mechanism, and performance improvement. In terms of the identity management aspect, blockchain is usually used for trust management and privacy protection. Lei *et al.* [29] proposed blockchain-based key management to reduce the security key exchange time when a handover happens in vehicular networks. Gao *et al.* [30] indicated the advantages of combining blockchain and SDN for the VANET systems and also designed an SDN-enabled trust management model to prevent malicious activities. Feng *et al.* [31] proposed a blockchain-based trusted cloaking area construction using identity pseudonym to protect privacy in location-based services. In [31], the edge computing technology was employed to facilitate the calculation of trust value for each vehicle with short latency.

Most studies on the incentive mechanism focus on solving the challenges for efficient collaboration among heterogeneous devices from different manufactures and service providers. Xiong *et al.* [32] designed a Stackelberg game based incentive mechanism to economically optimize the resource utilization of the blockchain-enabled mobile networks. In [33], a blockchain consensus algorithm called proof-of-collaboration (PoC) was proposed. PoC simplifies the computational process of the PoW algorithm to adapt to the limited resources of the edge devices. Chen *et al.* [34] proposed a quality-driven incentive mechanism based on a reverse auction model for sharing data in vehicular networks. Both the on-chain and off-chain scenarios are considered to optimize social welfare and reduce the cost. Iterative double auction mechanism was used in [35] to improve the trading efficiency and encourage more users to participate in the resource sharing among vehicles. Several other studies have proposed incentive mechanisms for vehicular resource allocation and data storage using blockchain technology [36]–[38].

The performance study of blockchain systems under different situations has also attracted great attention from researchers. In [39], the impact of vehicle mobility on the blockchain network performance was investigated. The author showed that the performance of a blockchain system was influenced by vehicle mobility tremendously. Nguyen *et al.* [40] presented a comprehensive analysis for the impact of network delay on the blockchain performance. The authors installed blockchain applications on cloud servers that were located in France and Germany and tested the impact of the network latency on the blockchain system under different situations. Sharma *et al.* [41] proposed an optimized blockchain architecture called Fabric++ based on Hyperledger Fabric, a well-known blockchain platform. Fabric++ shows a significantly higher throughput and lower latency as compared with the conventional Fabric architecture. While many studies discussing the use of blockchain in IoV, the problem of how to ensure the transaction throughput and latency in dynamic vehicular environments is still underexplored.

III. PROPOSED SCHEME

A. PROBLEM DESCRIPTION AND OVERVIEW

Blockchain applications in IoV can be classified into two different categories, namely, the throughput sensitive and latency sensitive applications, which have different requirements on the blockchain transaction throughput and latency. In IoV, the vehicle density also changes with the time domain, which makes the optimal parameters for the blockchain system change accordingly. Since the block size of a blockchain system is a dominant factor, in this paper, we discuss the problem of how to optimize the blockchain system in IoV by putting special focus on dynamically adjusting the block size according to the vehicle density.

We propose a multi-channel blockchain scheme that predefines multiple channels with different block sizes that are optimized for different levels of vehicle densities. The system then dynamically chooses the best channel for transactions based on the current number of vehicles in a specified region and the performance (throughput and delay) requirements of the corresponding transaction.

B. ARCHITECTURE

In IoV, considering the security and privacy protection, all participants must be identifiable [45]. Therefore, in our proposal, we adopt a well-known permissioned blockchain platform called Hyperledger Fabric in our proposal. As shown in Fig. 1, there are three layers in the proposed blockchain scheme, namely, the cloud layer, infrastructure layer, and client layer.

1) **Cloud layer:** This layer contains application servers and blockchain components including ordering and CA servers. The application servers are responsible for providing various ITS services and the maintenance of the blockchain database. Each organization in the network, such as the traffic management department or electronic toll collection (ETC) system, has its own CA server which is an intermediate CA that is connected to the root CA server of the blockchain network. The application servers store the ledger of those channels they have joined. The orderer peers store complete ledgers of all channels.
2) **Infrastructure layer:** This layer is comprised of infrastructures with stable connections and powerful resources, such as RSUs and base stations. They can be configured as the access point (AP) or edge node to provide communication, storage, offloading, and caching services to the nodes in the vehicular layer. The nodes in this layer store a complete duplicate of the blockchain ledger and the world state of the blockchain (a database that holds the values of ledger states and their version numbers). The RSUs in this layer also collect the SBMs and calculate the vehicle density.
3) **Vehicular layer:** This layer is comprised of all kinds of vehicles and devices. The vehicles in this layer are equipped with OBU to enable V2X communications and they periodically send SBMs to the surrounding vehicles and RSUs to inform others about their statuses. Each vehicle joins multiple channels which are preconfigured in the network to provide redundant channel services for the vehicles under different vehicle density situations.

In the initialization stage, each vehicle joins multiple channels. The world state of the blockchain is shared among these channels. The RSUs in the network collect the SBM from the network and inform the vehicles about the current traffic condition. Then, vehicles in the network select the most suitable channel according to the vehicle density and the requirement (throughput sensitive or latency sensitive) of the application that initiates the message to achieve better resource utilization and system performance. Different from the existing studies that mostly focus on how to utilize the trust management function or incentive mechanism of the blockchain technology [42]–[44], we focus on the vehicle density difference between different hours in a geographical area, and then design a new scheme to improve the performance of the blockchain system.

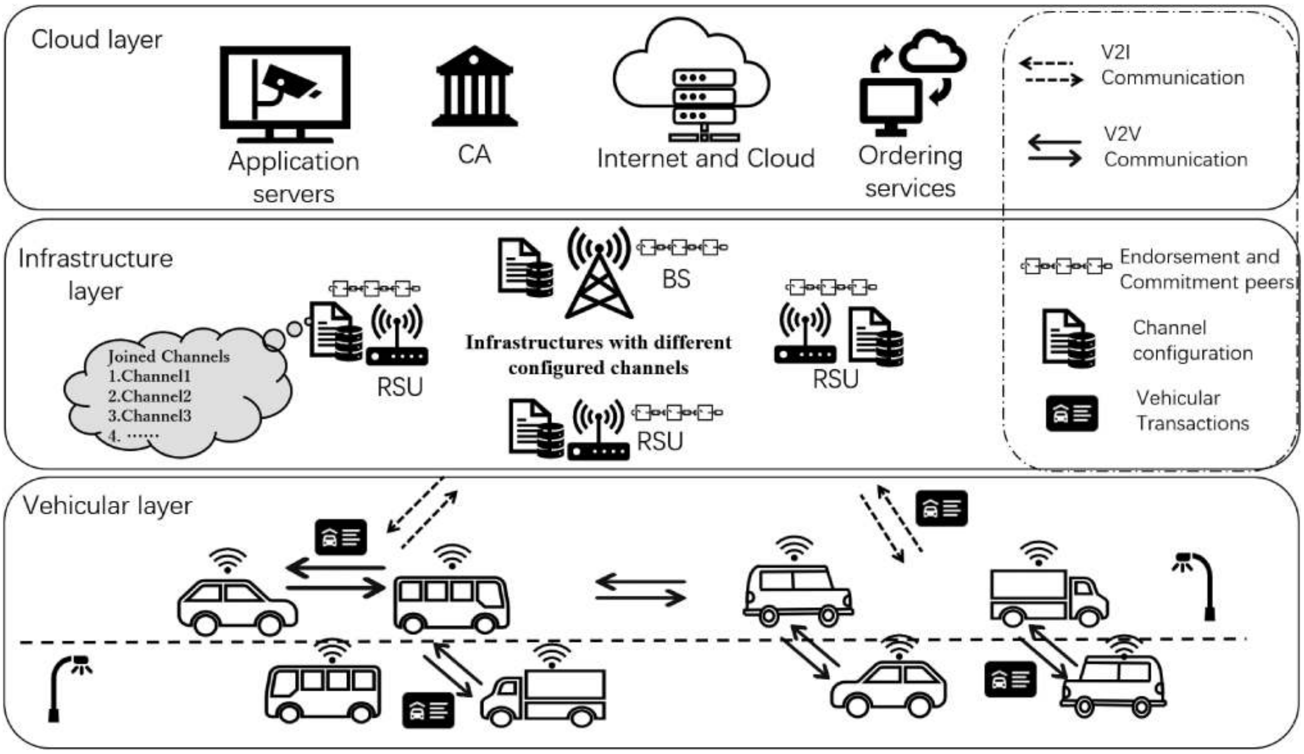

FIGURE 1. Layered architecture of the proposed blockchain scheme.

C. BLOCKCHAIN SETUP

Here, we explain three main procedures in the proposed blockchain scheme.

1) **Blockchain set-up:** During this stage, all the nodes in the network install corresponding blockchain applications according to their roles. The vehicles only install client applications and do not participate in the consensus process due to the limited resource and unstable connectivity. Those nodes in the infrastructure layer are configured as endorsing peers and committing peers as shown in Fig. 2. Every infrastructure layer node joins multiple channels with different configurations to provide adaptive services under different vehicle densities.
2) **Registration of vehicles:** The registration process of the system is shown in Fig. 3. First, all the infrastructure layer nodes register as administration nodes and get enrollment certificates (ECerts) from the CA server. When a vehicle wants to join the blockchain network, it first sends a registration request with its user-specific information to the RSU. Then the RSU registers the vehicle ID to the CA server, and the CA server returns a user-specific secret to the RSU that is in charge of the corresponding geographical region. When the vehicle receives the user-specific secret from the RSU, it enrolls in the CA server with the vehicle ID and user-specific secret, and gets its transaction certificates from the CA server.
3) **Transaction flow):** As shown in Fig. 4, there are four stages in the transaction flow of the proposed scheme.
   - **Stage 1:** Simulation stage. A vehicle signs and initiates a transaction proposal to one or more RSUs for executing some functions in a certain chaincode which is a smart contract in Hyperledger Fabric. The RSUs will verify the format, signature, and authorization of the transaction. If all the above verifications are passed, the RSUs will input the proposal as the parameter of the called chaincode function, simulate the chaincode on the current world state database and return the execution result (read-write set) signed by the RSUs to the vehicle. After collecting the required amounts of execution results, the vehicle generates a new transaction that contains the original proposal, the channel ID selected by the channel selection algorithm, and all the execution results and signatures from the RSUs, then sends the new transaction to the ordering service.
   - **Stage 2:** Ordering stage. The ordering service receives transactions from all channels and sorts them chronologically by channel without inspecting the content of the transactions, and creates blocks for each channel. The ordering service then distributes these blocks to all RSUs for the next step.
   - **Stage 3:** Validation stage. When an RSU receives a new block, it verifies the endorsements, signatures of

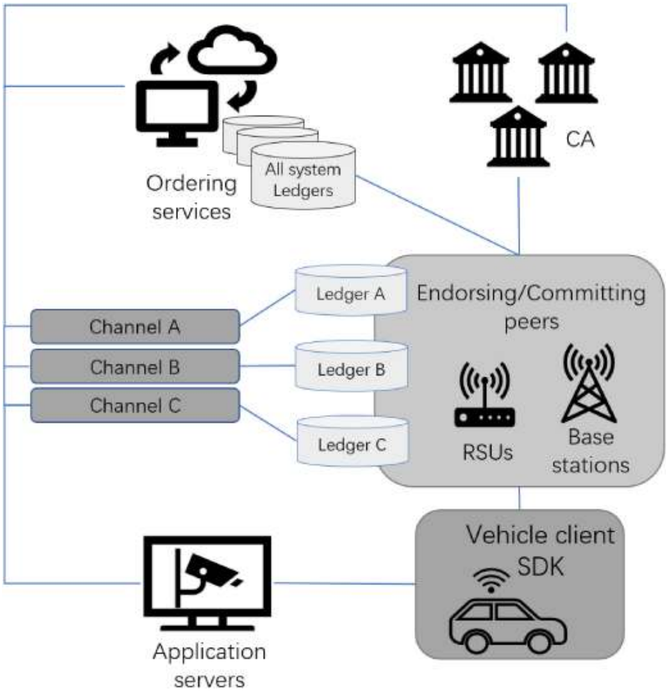

FIGURE 2. Blockchain network setup.

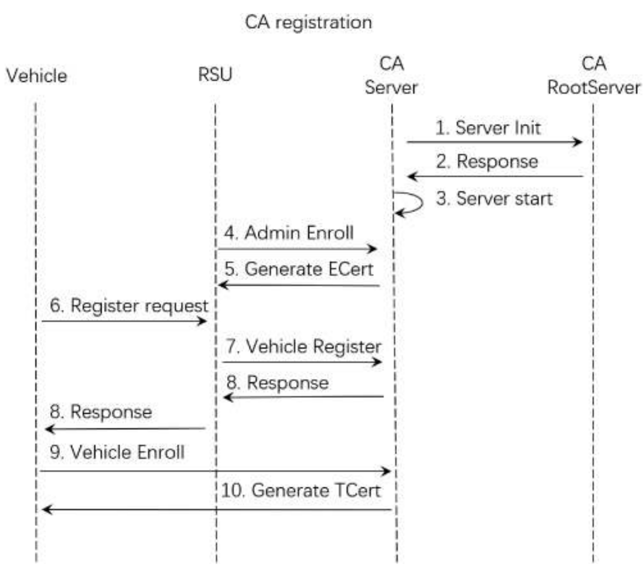

FIGURE 3. Sequence diagram of registration procedure.

the transactions in the block as well as the version number of the world state value for serialization conflicts to ensure the validity of the transactions.

- **Stage 4:** Commit stage. In the commit phase, each RSU appends the block to its local copy of the blockchain ledger. Additionally, each RSU applies all changes made by the valid transactions to its current world state.

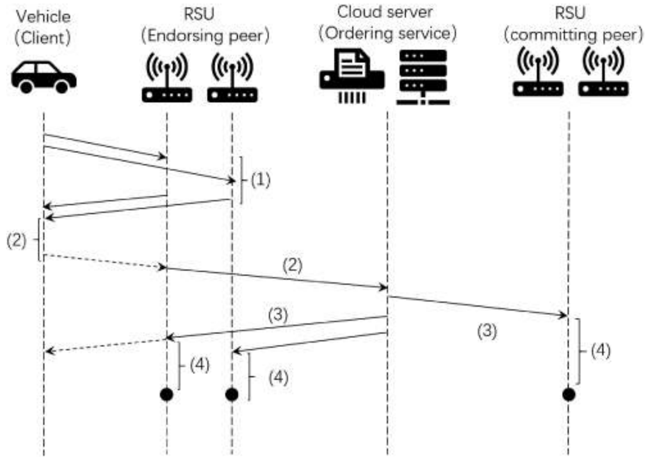

FIGURE 4. Transaction flow.

D. CHANNEL SELECTION ALGORITHM

As a part of the proposed blockchain scheme, we design a channel selection algorithm for blockchain. Algorithm 1 presents a summarized pseudo-code of how to select a suitable channel according to the density of the vehicles for the next transaction. In the proposed scheme, RSUs monitor the vehicle density and inform the vehicles periodically. Each RSU can join multiple channels with preconfigured channel ID during the network setup stage. We assume that all the vehicles initiate the same amounts of transactions in a certain period so that the density of the vehicles is proportional to the sending rate (of blockchain transaction). For example, when vehicles send a safety beacon message every 10 seconds [46], and there are 1000 vehicles in a certain area, the sending rate will be 100 transactions per second. The transaction sending rate varying from 100 to 200 transactions per second is equivalent to the number of vehicles changing from 1000 to 2000. We have tested a set of different configured channels and defined the most suitable channel for different traffic conditions as shown in Table I. We defined six channels, namely, $Channel1$, $Channel2$, $Channel3$, $Channel4$, $Channel5$, and $Channel6$ with 100, 200, 300, 400, 500, and 600 transactions per block (TRX / block), respectively. When a vehicle wants to send a transaction, it checks the table first to decide which channel to send the transaction. We consider two types of applications in our algorithm, namely, throughput sensitive and latency sensitive applications. Every blockchain transaction initiated by a vehicle has a $ChannelID$ in it that indicates which channel the certain transaction is sending to. As shown in Algorithm 1, each vehicle selects the most suitable channel to send the transaction according to the application requirement and the current vehicle density. As shown in Table I, when the number of vehicles is between 1000 and 1100, $Channel5$ is the best. When the number of vehicles is less than 1000, the performance difference of the block network under different channel configurations is

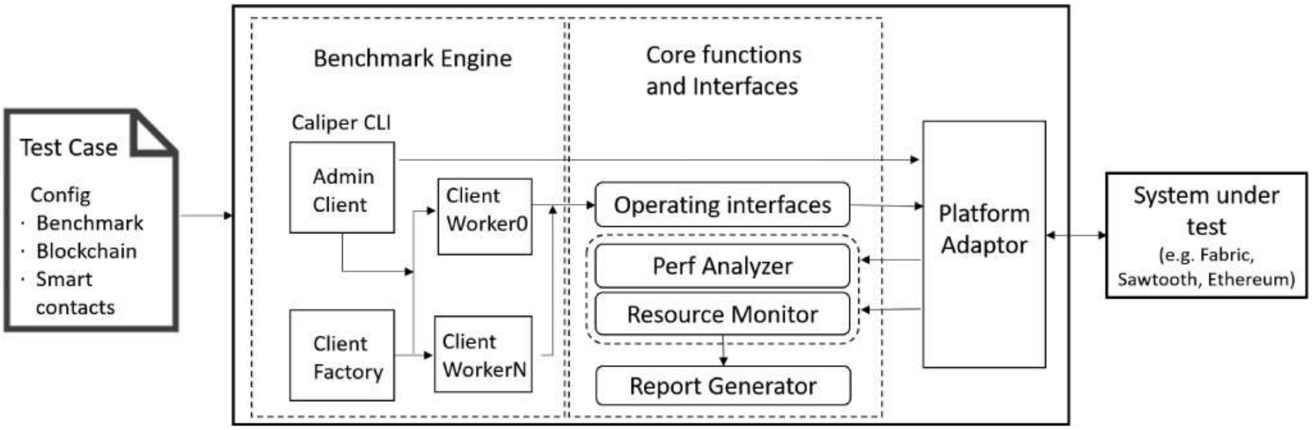

FIGURE 5. Architecture of Caliper.

TABLE 1. Channel Mapping Table (Best Channels for Different Sending Rates and Message Types)

Sending rate (transactions/s)	Throughput sensitive	Latency sensitive
100	$Channel5$	$Channel5$
110	$Channel2$	$Channel2$
120	$Channel2$	$Channel2$
130	$Channel3$	$Channel3$
140	$Channel3$	$Channel4$
150	$Channel3$	$Channel3$
160	$Channel2$	$Channel2$
170	$Channel3$	$Channel1$
180	$Channel3$	$Channel4$
190	$Channel4$	$Channel1$
200	$Channel4$	$Channel1$

very small. Therefore, we use $Channel5$ when the number of vehicles is smaller than 1100. Similarly, we use $Channel4$ (for throughput sensitive application) or $Channel1$ (for delay sensitive application) when then number of vehicles is larger than 2000.

IV. PERFORMANCE EVALUATION

The performance evaluation of the proposal is presented in this section. We evaluate the performance of the proposed scheme in terms of the throughput, latency, and transaction success ratio. We compare the proposed scheme with the baselines with different numbers of transactions per block (TXN / block). We first introduce the simulation settings and then show the simulation results and the corresponding discussions.

A. SIMULATION SETTINGS

Our simulation is conducted on a Desktop that has an Intel i3-8100 CPU running at 3.6 GHz, an 8 GB DDR4 RAM, and a GeForce 1050 M display card. The operating system is 64-bit Arch Linux with kernel version 4.17. We adapt Hyperledger Fabric 1.4 as our simulation platform, and the database of Fabric is set to LevelDB. In terms of the workloads, we employ caliper, a blockchain benchmark that is originated from the Hyperledger project to simulate the workloads of vehicular networks. Fig. 5 shows the architecture of the caliper benchmark.

The simulation topology is an area of 1000 m $\times$ 1000 m with 3 horizontal roads and 3 vertical roads, forming 4 square blocks. Every block has an RSU in it and all the vehicles on these roads can at least communicate with one of the RSUs directly. We assume that the maximum capacity of this area is 2000 vehicles.

We assume that all the vehicles initiate the same amounts of transactions in a certain period. In our simulation, we evaluate the scheme for different numbers of vehicles. In IoV, applications have different functions, and their priority requirements for transactions are also different. For example, emergency notification applications are latency sensitive, and environment monitoring applications are usually throughput sensitive [47]. Therefore, we simulate both the latency sensitive scenario and throughput sensitive scenario to observe the impact of the proposed scheme under different service requirements.

B. SIMULATION RESULT

We test two types of transactions in the simulations, namely, the registration transactions, and transfer transactions to evaluate the throughput, latency, and transaction success ratio of the proposed scheme under different scenarios. Registration transactions help the vehicle to open an account in a blockchain world state database and transfer transactions are used to transfer the value of the world state database between two accounts.

The effect of the vehicle density is simulated by changing the sending rate of the workload. In our simulation, we evaluate the proposed scheme for different sending rates, varying from 100 to 200 transactions per second, which is equivalent

Algorithm 1: Channel Selection Algorithm of The Proposed Scheme

Input: Current number of vehicles D_0 and application type M_t

Output: Selected $ChannelID$

Import the Channel Selection Table I

Calculate R, the sending rate of the vehicle transactions as follows.

$$R = \begin{cases} 100 & if\ D_0 < 1100 \\ 110 & if\ 1100 \leq D_0 < 1200 \\ 120 & if\ 1200 \leq D_0 < 1300 \\ 130 & if\ 1300 \leq D_0 < 1400 \\ 140 & if\ 1400 \leq D_0 < 1500 \\ 150 & if\ 1500 \leq D_0 < 1600 \\ 160 & if\ 1600 \leq D_0 < 1700 \\ 170 & if\ 1700 \leq D_0 < 1800 \\ 180 & if\ 1800 \leq D_0 < 1900 \\ 190 & if\ 1900 \leq D_0 < 2000 \\ 200 & if\ D_0 \geq 2000 \end{cases}$$

// Set BestChannel according to Channel Selection Table.

if Application type is "throughput sensitive" then **Switch** (R)

Case 100: $BestChannel \leftarrow Channel5$;Break;

Case 110: $BestChannel \leftarrow Channel2$;Break;

Case 120: $BestChannel \leftarrow Channel2$;Break;

...

Case 200: $BestChannel \leftarrow Channel4$;Break;

else if Application type is "latency lensitive" then **Switch** (R)

Case 100: $BestChannel \leftarrow Channel5$;Break;

Case 110: $BestChannel \leftarrow Channel2$;Break;

Case 120: $BestChannel \leftarrow Channel2$;Break;

...

Case 200: $BestChannel \leftarrow Channel1$;Break;

end if

$ChannelID \leftarrow BestChannel$

return

to 1000 to 2000 vehicles. The amounts of channels that the RSUs join can be adjusted as needed.

1) THROUGHPUT-SENSITIVE SCENARIOS

In throughput-sensitive scenarios, when a vehicle wants to send a transaction, it makes the throughput the first priority and selects the channel with the highest throughput under current vehicle density.

First, we test the performance of the registration transaction. The results are shown in Fig. 6 and Fig. 7. As the vehicle density increases, the system throughput also increases. At around 1380 vehicles, the throughput reaches the saturation

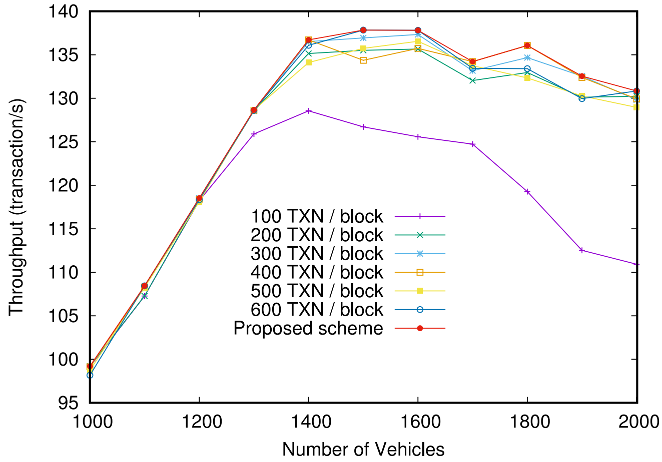

FIGURE 6. Throughput of registration transactions in throughput sensitive scenarios.

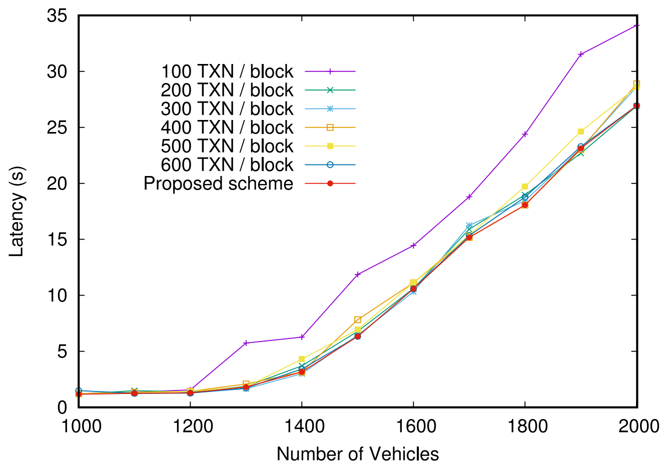

FIGURE 7. Latency of registration transactions in throughput sensitive scenarios.

point. Our scheme applies a smaller block size when the vehicle density increases before the saturation point to maximize the network utilization. Along with the increase of the vehicle density, we choose a larger block size to get a higher throughput. This is due to the fact that the usage of larger blocks results in a lower communication overhead. The throughput of the scheme keeps staying at the highest among all the other configurations under different numbers of vehicles.

The latency of the baselines with different block sizes is only slightly different from each other and increases significantly after the vehicle density reaches the saturation point. This is because, when a peer receives an ordered transaction, it invokes the validation system chaincode (VSCC) to determine the validity of the transaction. During the VSCC phase, the number of validation requests can grow rapidly, which impacts the commit latency of the transactions significantly. Although we take throughput as our first priority, the latency performance of the proposed scheme still keeps at a low level,

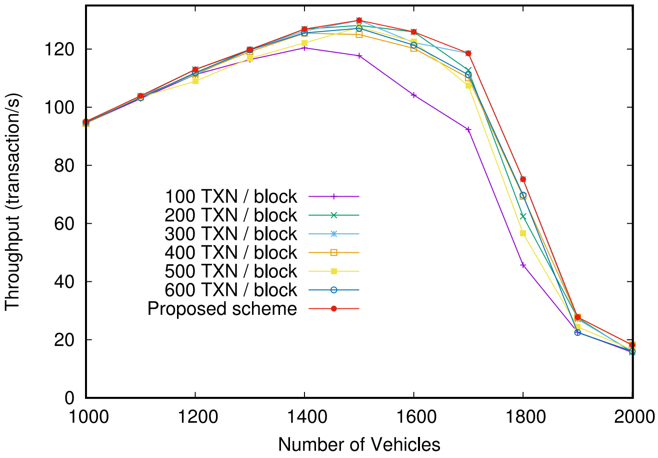

FIGURE 8. **Throughput of transfer transactions in throughput sensitive scenarios.**

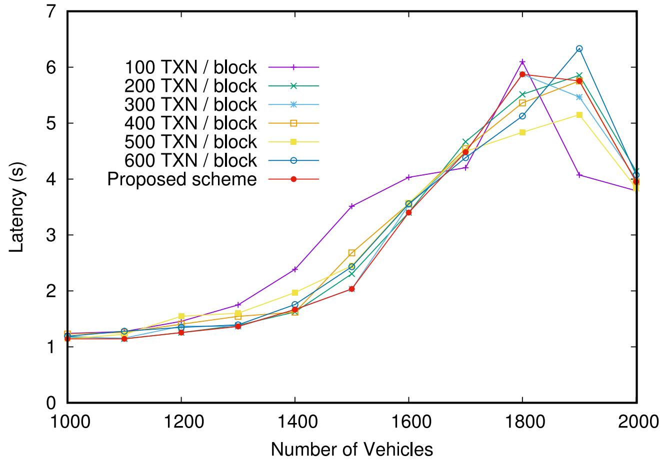

FIGURE 10. **Latency of transfer transactions in throughput sensitive scenarios.**

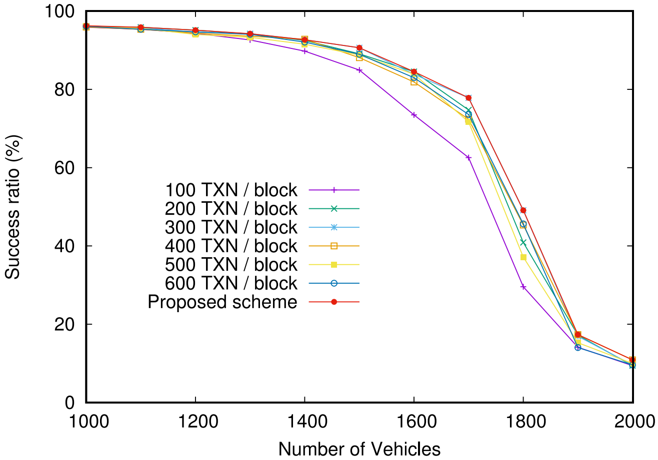

FIGURE 9. **Success ratio of transfer transactions in throughput sensitive scenarios.**

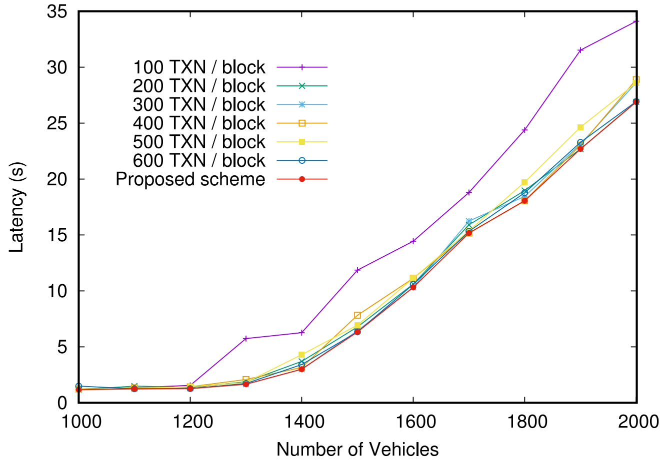

FIGURE 11. **Latency of registration transactions in latency sensitive scenarios.**

which is only slightly higher than the optimal value at each point.

The results of the transfer transaction under throughput sensitive scenarios are shown in Fig. 8, Fig. 9, and Fig. 10. In our simulation, we only take those transactions which are recorded into the blockchain ledger into account. Therefore, under a certain vehicle density, the throughput is proportional to the success ratio of the system. As it is shown in Fig. 8 and Fig. 9, the throughput and the success ratio of the transfer transaction decrease dramatically after the number of vehicles exceeds 1500. This is due to the multi-version concurrency control (MVCC) technique which is employed by Fabric to prevent two or more transactions update the same key (or value) at the same time. Although our proposal selects the most suitable channel to send the transactions under different numbers of vehicles to achieve the highest throughput, the latency performance is not always the best as it is shown in Fig. 10. This is a tradeoff process. When the service of an application is throughput sensitive, the system ensures throughput at first, and thus we cannot achieve both the highest throughput and the lowest latency under the same configuration.

2) LATENCY-SENSITIVE SCENARIOS

In latency-sensitive scenarios, we take latency as the first priority. The proposed blockchain scheme always chooses the channel with the lowest latency under the current vehicle density. The results of registration transactions under latency-sensitive scenarios are shown in Fig. 11 and Fig. 12. The latency of the transactions increases linearly to the increase of the vehicle density because of the VSCC mechanism. However, since the registration transaction only registers an account in the world state and generates an initial value for the vehicle, and this process does not involve value transfer between two accounts, there will be no transactions flagged as invalid by the MVCC mechanism. As a result, the throughput of the registration transactions will not drop dramatically as it

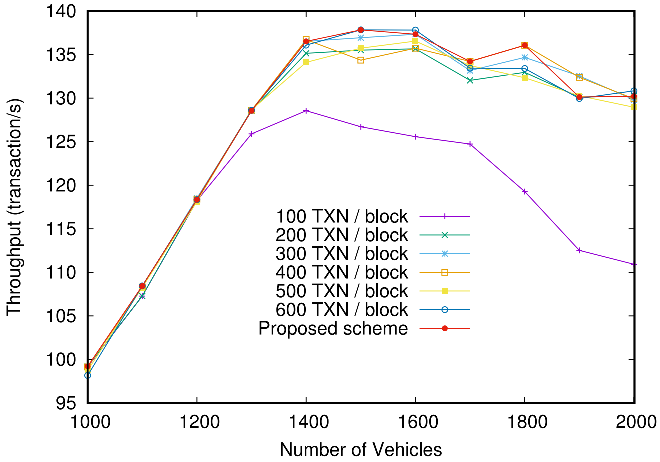

FIGURE 12. **Throughput of registration transactions in latency sensitive scenarios.**

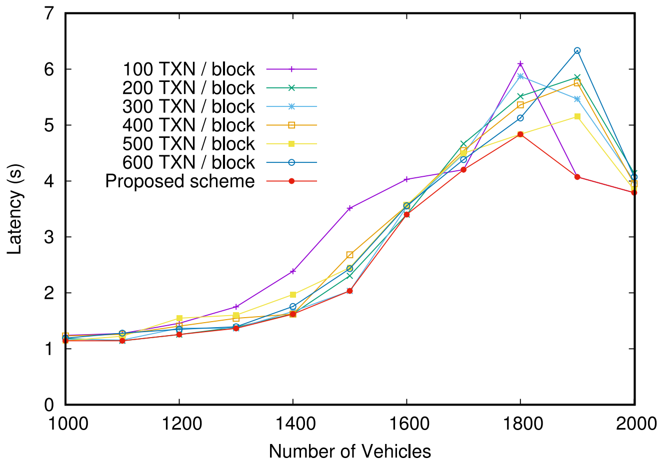

FIGURE 13. **Latency of transfer transactions in latency sensitive scenarios.**

is in transfer transactions. The improvement by the proposed scheme on the latency performance is not as significant as the throughput. However, the proposed scheme shows the lowest latency. In a latency-sensitive situation, when the vehicle density is high, we need to sacrifice throughput to a considerable extent to achieve the lowest latency.

The results of transfer transactions under latency-sensitive scenarios are shown in Fig. 13, Fig. 14, and Fig. 15. We can observe from Fig. 13 that our scheme reduces the latency of transfer transactions significantly. No matter what the speed is, our scheme can guarantee that the message is sent to the channel with the lowest delay.

It is shown in Fig. 14 and Fig. 15 that the throughput and the success ratio of the transfer transaction under this scenario still keep staying at a high level comparing to the others before the number of vehicles exceeds 1500 under all different scenarios. As the vehicle density increases further, the throughput of the system reaches the saturation point. When two or more transactions try to update one value frequently, some transactions already encapsulated in a block are invalidated due to

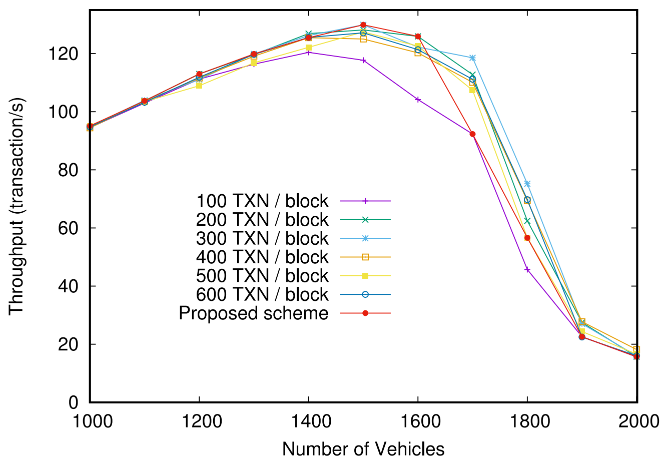

FIGURE 14. **Throughput of transfer transactions in latency sensitive scenarios.**

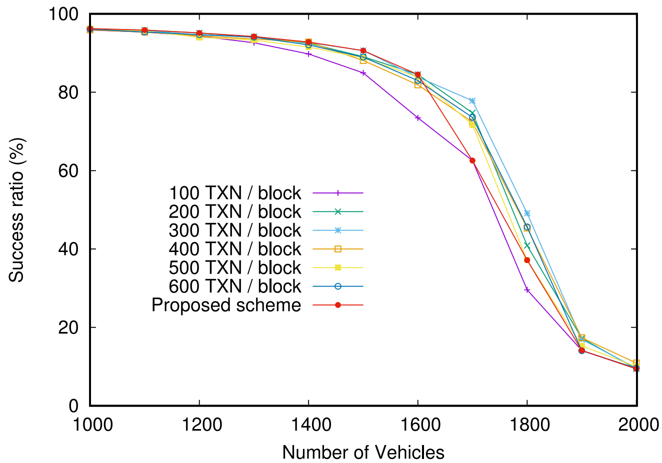

FIGURE 15. **Success ratio of transfer transactions in latency sensitive scenarios.**

the MVCC mechanism. Since we need to stick to the channel with the lowest latency, the throughput and success ratio of the system are inevitably affected.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed a multi-channel blockchain scheme for IoV where each channel is optimized for a certain level of vehicle density and application requirements. The proposed scheme uses the best channel for blockchain transactions according to the vehicle density and application requirements. We evaluated the performance of the scheme under the Hyperledger Fabric, a permissioned blockchain platform, by varying values assigned to configurable parameters. Simulation results show that the proposed scheme can significantly increase the performance of the blockchain system for different number of vehicles in terms of the throughput, latency, and transaction success ratio.

Since the proposed blockchain scheme and the channel management algorithm are independent of the consensus mechanism of the system, it is generally applicable in different kinds of blockchain platforms, including public blockchains such as Ethereum, and consortium blockchains such as Hyperledger Fabric. In future work, we will test multiple platforms to further evaluate the generality of the proposed scheme. Moreover, during our experiment, we find that caliper cannot fully satisfy our requirements. Therefore, we plan to build a customized benchmarking scheme to evaluate our scheme in a more realistic blockchain based vehicular network environment.

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LIMING GAO received the B.E. degree from China Agricultural University, Beijing, China and the M.Sc. degree from Coventry University, Coventry, U.K. He is currently working toward the Ph.D. degree with The University of Electro-Communications, Chofu, Japan. His current research interests include blockchain technology, vehicular networks, and IoT.

CELIMUGE WU (Senior Member, IEEE) received the M.E. degree from the Beijing Institute of Technology, Beijing, China, in 2006 and the Ph.D. degree from The University of Electro-Communications, Chofu, Japan, in 2010. He is currently an Associate Professor with the Graduate School of Informatics and Engineering, The University of Electro-Communications. His research interests include vehicular networks, edge computing, IoT, intelligent transport systems, and application of machine learning in wireless networking and computing. He is an Associate Editor for the IEEE Open Journal of the Computer Society, IEEE Transactions on Network Science and Engineering, IEEE Transactions on Green Communications and Networking, and IEEE Access. He is the Chair of IEEE TCGCC Special Interest Group on Green Internet of Vehicles and IEEE TCBD Special Interest Group on Big Data with Computational Intelligence. He was the recipient of the IEEE Computer Society 2019 Best Paper Award Runner-Up.

TSUTOMU YOSHINAGA (Member, IEEE) received the B.E., M.E., and D.E. degrees from Utsunomiya University, Utsunomiya, Japan, in 1986, 1988, and 1997, respectively. From 1988 to July 2000, he was a Research Associate with the Faculty of Engineering, Utsunomiya University. From 1997 to 1998, he was also a Visiting Researcher with Electro-Technical Laboratory. Since August 2000, he has been with the Graduate School of Information Systems, The University of Electro-Communications, Chofu, Japan, where he is currently a Professor. His research interests include computer architecture, interconnection networks, and network computing. He is a Fellow of IEICE and a Member of ACMand IPSJ.

XIANFU CHEN (Member, IEEE) received the Ph.D. degree (with hons.) in signal and information processing from Zhejiang University, Hangzhou, China, in 2012. He is currently a Senior Scientist with the VTT Technical Research Centre of Finland, Espoo, Finland. His research interests include various aspects of wireless communications and networking, with emphasis on human-level and artificial intelligence for resource awareness in next-generation communication networks.

YUSHENG JI (Senior Member, IEEE) received the B.E., M.E., and D.E. degrees in electrical engineering from the University of Tokyo, Tokyo, Japan. In 1990, she joined the National Center for Science Information Systems, Japan. She is currently a Professor with the National Institute of Informatics, and SOKENDAI (the Graduate University for Advanced Studies). Her research interests include network architecture, resource management, and quality of service provisioning in wired and wireless communication networks. She is the Editor of IEEE Transactions on Vehicular Technology, a Symposium Co-chair of IEEE GLOBECOM 2012, 2014, and the Track Co-chair of IEEE VTC2016-Fall and VTC2017-Fall.