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A Lightweight and Secure Vehicular Edge Computing Framework for V2X Services

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***Abstract*—Vehicle-to-everything (V2X) communications over cellular networks have a great potential for enabling intelligent transportation systems (ITSs), and supporting advanced services such as autonomous driving. However, such services have stringent QoS and security/privacy requirements. Even though the use of blockchain can ensure security and privacy for V2X services, blockchain-based solutions suffer from the issues of high latency, low scalability, and high computation power for mining. To overcome these challenges, we propose a lightweight and secure vehicular edge computing framework. The LS-VEC framework leverages directed acyclic graphs (DAGs) for recording transactions for edge resource allocation and micro-transactions for pricing VEC resources. In addition, an auction theory-based game-theoretic approach is proposed for allocation and pricing of edge resources used for supporting computation offloading.**

***Index Terms*—5G, VEC, V2X, DAG.**

I. Introduction

Vehicle-to-everything (V2X) communications involve interactions between vehicles and road-side units (RSU) for enabling advanced applications such as fully autonomous driving (FAD), highly autonomous driving (HAD), tele-operated driving, cooperative sensing, safety services, high-density platooning, infotainment services, and so on [1]. Such critical applications have stringent quality of service (QoS) requirements. Vehicular edge computing (VEC) provides an efficient solution for hosting data and compute intensive tasks while satisfying the strict QoS requirements for advanced V2X applications [2].

Further, ubiquitous vehicle connectivity and seamless access to edge resources call for strict security and privacy mechanisms to prohibit unauthorized access to sensitive vehicle and personal data (e.g., critical data for autonomous driving systems and mission-critical applications). However, conventional solutions handling security at the application layer involve high overheads and hence fail to provide the strict timeliness required in V2X environments [3], [4].

Recent works have investigated the blockchain (BC) technology to address these issues for VEC [5]. However, blockchain-based solutions for interactions between the vehicles and edge servers lack scalability, and involve high computational overheads for mining of blocks to verify the transactions [6]. Moreover, provisioning VEC resources for V2X will involve a large number of micro-payments, and hence, paying a transaction fee greater than the value being transferred is not acceptable.

To address these challenges, we propose a lightweight and secure VEC (LS-VEC) framework for emerging V2X services. LS-VEC leverages IOTA for recording transactions for accessing VEC resources, as well as micro-transactions for pricing VEC resources [7]. To issue a transaction, a user must verify two previous transactions, and thus the miners are eliminated from the verification process that leads to enhanced decentralization and scalability. In addition, we present a game-theory based auction mechanism for efficient resource allocation and pricing of VEC resources, with an aim of maximizing the edge service quality.

II. LS-VEC Framework

The LS-VEC framework leverages IOTA for secure and efficient provisioning of VEC resources for V2X communication. We consider a scenario where edge resources provisioned by 5G network operator are used for storing and processing the data generated by on-board units and roadside units (RSUs). In IOTA, the transactions among various nodes in the network are saved using tangle data structure (i.e., a directed acyclic graph (DAG)) [8].

The overview of the LS-VEC framework is depicted in Figure 1. Each vehicle and things (e.g., RSU and pedestrian) are treated as nodes in the system and assigned a unique digital identity, created by combining the node's public address and the private key. Private keys as well as addresses for all the transactions can be generated using cryptographic sponge functions taking parameters such as a unique index and security level [6] into consideration. All the data transactions for accessing VEC resources, as well as micro-transactions for pricing the edge resources are recorded as transaction on the tangle, issued by different nodes in the system. Unlike traditional blockchains, there are no miners in IOTA and thus any issued transaction must be approved by at least two previous transactions before it is added to the network to form a DAG structure [8], as illustrated in Algorithm 1. Consequently, the latency and computational overheads related to the mining process in the traditional blockchains can be overcome, and these transactions can be issued without any additional fees.

Further, the LS-VEC framework combines IOTA with a game-theoretic method for efficient pricing and resource allocation. We consider the vehicles and things as bidders that bid for VEC resources (e.g., virtual machines (VMs) of the VEC server), based on their sensitivity to latency. We follow

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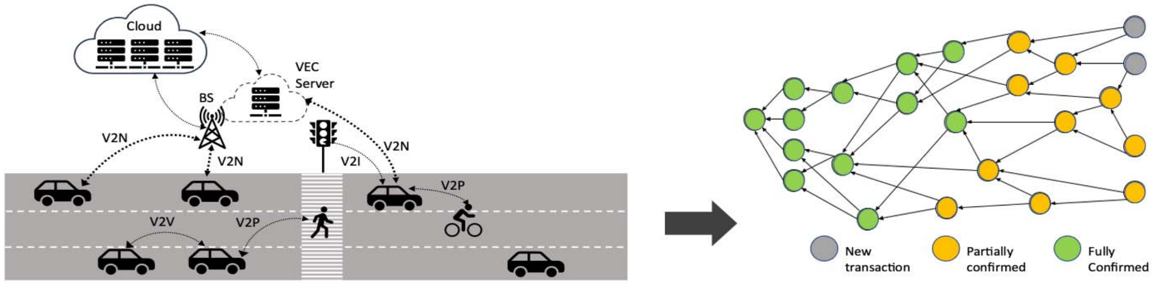

Fig. 1: System model: The transactions corresponding to interactions between nodes for VEC are recorded on DAG.

Algorithm 1 DAG-based VEC Transaction Creation

Input: The input transaction (Tx_i) <address, signature, value, tag>; Node i creating the transaction Tx_i.
Output:Broadcasting input Tx_i to Tangle.

1: Construct the Tx_i or a bundle in case of multiple transactions.
2: **if** Tx_i has value transfer **then**
3:     Sign the Tx_i inputs with personal private key.
4: **else**
5:     Simply send the Tx_i.
6: **end if**
7: Choose two unconfirmed transactions using Markov chain Monte Carlo algorithm.
8: Execute the Proof of Work and check for any conflicting transactions.
9: Update the nonce of Tx_i object.
10: Broadcast Tx_i to the Tangle.

Algorithm 2 Dynamic Game-Theoretic Pricing

Input: Bid of node i, $B_i = (v_i, p_i)$ defined in terms of amount of virtual resources v_i and offered bid price p_i; total resources with VEC V; allocated resources va_i; valuation α_i of user i; user welfare w_i; QoS Q;
Output: QoS maximizing bid price p_i

1: Firstly N bidders submit their bids such that $v_i < V$.
2: Collect bid from all N nodes
3: **for** $i = 1$ to N **do**
4:     Compute allocated resources va_i as $va_i = min(v_i, \frac{p_i}{\rho}V)$, $\rho = \sum v_i$
5:     Calculate the cost $C_i(v_i, p_i) = va_i * p_i$.
6:     Calculate the valuation $\Lambda_i(v_i, p_i)$, as $\Lambda_i = \mu_{i,v} - \mu_{i,\phi}$, where $\mu_(i, v)$ is the expected QoS achieved by serving user i with v resources and $\mu_{i,\phi}$ is the default expected QoS.
7:     The edge service quality Q can be expressed as: $Q = \Lambda - C$
8:     Hence, the best (QoS maximizing) response of node i, σ_i can be calculated as $\sigma_i(p_i) = argmax_{p_i} Q(p_i)$.
9: **end for**

a sealed-bid second-price auction where the bidders submit sealed bids in terms of the amount of the VEC resources required and the price they are willing to pay. After that, the VEC server acts as auctioneer and allocates the VMs based on the bids offered and the VM requirements of different nodes. The detailed auction-based resource allocation method is illustrated in Algorithm 2.

Based on Algorithm 2, the Nash Equilibrium, indicating the suitable value of price delivering the maximum QoS to each user i can be expressed as $\sigma_i^* = p_i(\sigma_{-i}^*)$. Algorithm 2 takes the bid prices of all the nodes, expressed as a combination of required VMs and the offered per unit price, as input. Based on it, the valuation and cost are calculated, and the edge service quality Q is expressed as their difference. Finally, the best response of each node, representing QoS maximizing the response is expressed as σ_i. All these transactions for edge resource allocation and pricing, as well as for data exchange between the nodes are recorded on tangle, as explained in Algorithm 1.

III. Conclusion

In the LS-VEC framework, all the transactions are recorded to form a DAG structure and the IOTA consensus algorithm is used for transaction verification. The game-theoretic pricing method is used to allocate the required resources while maximizing the achieved QoS, based on the offered price. As a result, the LS-VEC framework provides a lightweight and secure solution for edge-assisted V2X communication. Our future work entails the extension of the LS-VEC framework for multiple VEC service providers and detailed evaluation using real-world data traces.

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References

[1] H. Zhou, W. Xu, J. Chen, and W. Wang, “Evolutionary v2x technologies toward the internet of vehicles: Challenges and opportunities,” *Proceedings of the IEEE*, vol. 108, no. 2, pp. 308–323, 2020.

[2] A. Moubayed, A. Shami, P. Heidari, A. Larabi, and R. Brunner, “Edge-enabled v2x service placement for intelligent transportation systems,” *IEEE Transactions on Mobile Computing*, vol. 20, no. 4, pp. 1380–1392, 2021.

[3] M. Hasan, S. Mohan, T. Shimizu, and H. Lu, “Securing vehicle-to-everything (v2x) communication platforms,” *IEEE Transactions on Intelligent Vehicles*, vol. 5, no. 4, pp. 693–713, 2020.

[4] A. G. Tasiopoulos, O. Ascigil, I. Psaras, and G. Pavlou, “Edge-map: Auction markets for edge resource provisioning,” in *WoWMoM 2018*, 2018, pp. 14–22.

[5] D. C. Nguyen, P. N. Pathirana, M. Ding, and A. Seneviratne, “Blockchain for 5g and beyond networks: A state of the art survey,” *Journal of Network and Computer Applications*, vol. 166, p. 102693, 2020.

[6] V. Hassija, V. Chamola, G. Han, J. J. P. C. Rodrigues, and M. Guizani, “Dagiov: A framework for vehicle to vehicle communication using directed acyclic graph and game theory,” *IEEE Transactions on Vehicular Technology*, vol. 69, no. 4, pp. 4182–4191, 2020.

[7] W. F. Silvano and R. Marcelino, “Iota tangle: A cryptocurrency to communicate internet-of-things data,” *Future Generation Computer Systems*, vol. 112, pp. 307–319, 2020.

[8] S. Popov, “The tangle,” *White paper*, vol. 1, no. 3, 2018.