A Blockchain based Framework for Secure Data Offloading in Tactile Internet Environment

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***Abstract*—The rapid increase in the number of mobile devices across the globe has brought a new challenge to the forefront, one of mobile traffic management. The ever-increasing number of mobile devices leads to the generation of a large amount of data and computationally intensive applications, which contributes heavily to cellular network congestion. To solve this issue, we propose a mobile data offloading scheme based on a distributed ledger technology (DLT). Existing mobile data offloading schemes based on DLT employ conventional blockchain to set up a peer-to-peer (P2P) network of mobile users. Although these schemes have gained ground in improving the Quality of Experience (QoE) for end-users, they lack efficiency and scalability. Furthermore, generic blockchain does not provide timestamp ordering of events, which is necessary to ensure the computation of delay-sensitive tasks. To overcome these challenges, we propose the use of a directed acyclic graph (DAG) data structure for mobile data offloading. Finally, to ensure time and cost optimality, a game-theoretic approach has been proposed in this paper.**

***Index Terms*—Directed Acyclic Graph, Mobile Offloading, Consensus mechanism, Blockchain**

I. INTRODUCTION

The exponential increase in the number of mobile devices and consequently, computation-intensive mobile applications, such as video streaming and face recognition, presents a major challenge for mobile network providers. This is primarily due to the increase in mobile traffic that these applications cause while aiming to increase the end user's QoE. A recent Cisco report states that there has been an exponential increase in the number of mobile users around the globe, and consequently, an unprecedented surge in mobile data traffic [1]. A secure network with ultra-low-latency will, therefore, be needed to enhance the end user's QoE. One promising solution to this problem that has emerged in recent years is the mobile data offloading strategy, which enables the use of different network techniques to deliver the requested data [2]. In addition to reducing the operational costs of the network provider, mobile data offloading enhances the QoS delivered to the end-users.

There have been various attempts in the field of mobile data offloading, including WiFi offloading, Small Cell Networks (SCN), heterogeneous and opportunistic networks [3]. The SCN approach involves developing a vast number of small base stations in heavy mobile traffic areas. The significant drawback of this approach is its requirement of infrastructure expansion and high capital. The WiFi-based techniques offload the high computation task to the nearby WiFi access points [4]. However, these access points are not available everywhere and have a limited range. The concept of mobile-to-mobile communication is used in the upcoming heterogeneous and opportunistic networks [5]. Gouju gao et al. in [6] have explored the process of offloading in such opportunistic networks. Although such networks do not require infrastructure expansion, they lack mechanisms to motivate the users to engage themselves in the network pro-actively [7], [8].

In this paper, we propose a DLT-based approach to set up a P2P network of mobile users to securely offload the high computation task to other nodes in the network at a low-cost [9]. In recent times, a few attempts have been made to use a blockchain-based algorithm for enabling a P2P network of mobile users [10], [11]. Even though blockchain is a tamper-proof, distributed, and open data structure, it lacks scalability and efficiency. Furthermore, blockchain imposes a transaction fee on every transaction to encourage miners to add blocks in the chain. Offloading tasks often involve micro-transactions and adding them to the blockchain is not a viable option since transaction fees in such transactions are higher than the actual transaction value [12], [13]. Also, the prevalent forking and pruning issues reduce the efficiency of the traditional blockchain-based frameworks [14]. Over and above, since most of the offloading activities

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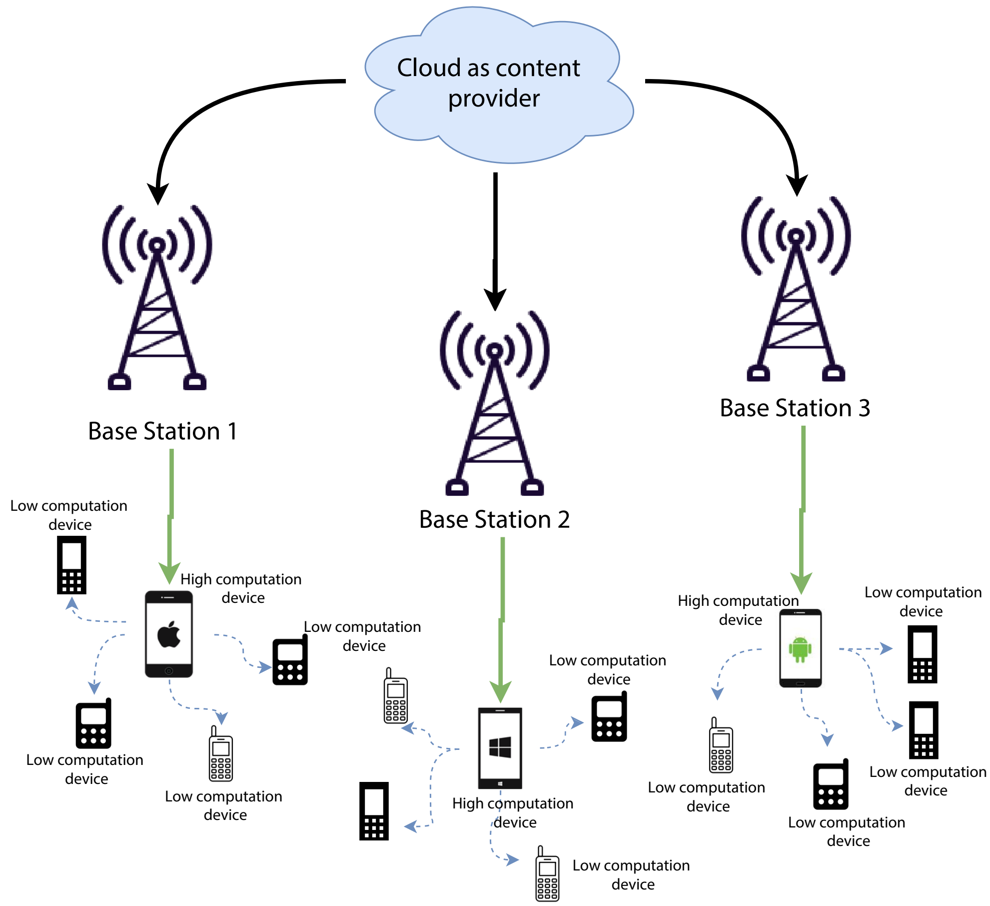


Fig. 1. Mobile Data Offloading Scenario

are delay-sensitive, requests that are closer to the deadline need to be processed first. To overcome these challenges, in this paper, we propose a DAG-based P2P network of mobile users.

II. Proposed Model for Mobile Data Offloading

For recording and processing a large number of frequent microtransactions that take place during mobile data offloading, DAG-based Hashgraph is a feasible option. Hashgraph provides features such as consensus timestamps, high speed, and Asynchronous Byzantine Fault Tolerance (ABFT) security mechanism [15]. In this work, a Hashgraph-based distributed network of mobile users is created for distributed mobile data offloading. The low computation mobile devices can submit a request to DAG in the form of a transaction. Users of high computation mobile devices can then submit the cost and time for the offloading task. Post this, a suitable price for offloading the task is determined using an iterative auctioning process.

A. *Digital Identity*

Every user willing to enter the network is assigned a global account id, a public key, and a private key. Global account id is required to uniquely identify the user [16], [17]. The two keys are used to securely perform all the exchanges that occur among the nodes in the proposed network. To initiate a transaction, a user has to digitally stamp the message or information via his/her unique private key. Other nodes in the network can validate this information by signing the message using their public key and further sending it to other users via the gossip protocol [18].

B. *Hashgraph Consensus Algorithm*

In any distributed ledger technology (DLT), there is a need to establish trust between the unknown nodes and, consequently, to achieve reliability in the network. To ensure this, consensus algorithms are put in place. The Hashgraph consensus algorithm makes use of the gossip protocol to reach a final agreement from all the network nodes on the order of the offloading requests. The gossip protocol requires much less bandwidth and time as compared to the traditional method of actually sending and validating the messages at all the nodes. As the hashgraph consensus algorithm does not send votes or details over the network, it is faster and much more efficient. Hashgraph uses the ABFT security mechanism, which ensures that no grouping among the nodes can influence the final output of the algorithm. Further details about the hashgraph DLT are provided in [15].

III. Proposed Network Model

Consider a distributed network comprising of multiple mobile devices. Let the set of mobile devices be denoted by $\mathcal{X} = \{\mathcal{X}_1, \mathcal{X}_2, ..., \mathcal{X}_m\}$. These devices may either choose to transfer the high computation work to other mobile devices or may volunteer to perform the work of mobile devices with low computation capability. The following section evaluates the time and cost involved with mobile data offloading.

Offloading Data Items

Data offloading aims to reduce the computation cost of computationally intensive tasks by offloading them to a high computation device while taking into account the ordering of events in the hashgraph and the deadline constraint of all the tasks. Let $\mathcal{I}$ = $\{\mathcal{I}_1, \mathcal{I}_2, ..., \mathcal{I}_n\}$ represents the count of items or tasks that need to be offloaded by each low computation device. Let $\mathcal{Z} = \{\mathcal{Z}_1, \mathcal{Z}_2, ..., \mathcal{Z}_n\}$ represent the computation capability required to compute these data items.

All the n data items present in any mobile device, $\mathcal{X}_i \in \mathcal{X}$, need to be computed before the deadline time denoted by $\delta = \{\delta_1, \delta_2, ..., \delta_n\}$. Mobile devices can either offload the data item through wireless networks such as WiFi or directly through a cellular network. Let σ_{wifi} and $\sigma_{cellular}$ denote the costs associated with data offloading through a WiFi and a cellular network, respectively. Let θ = $(\mathcal{T}, \Lambda, \varepsilon)$ be the offloading opportunity to offload the computation tasks. Here, $\mathcal{T}$ is the minimum time required by an offloading opportunity to offload the task, Λ is the probability of the availability of a WiFi network to perform offloading service, and ε is the total capacity of the ability of an opportunity to perform the offloading. Let $\Theta = \{\theta_1, \theta_2, ..., \theta_p\}$ denote the set of all the offloading opportunities where any $\theta_k \in \Theta$ can offload a data item only if the following constraints are satisfied:

$$\mathcal{T} \leqslant \delta, \mathcal{Z} \leqslant \varepsilon \tag{1}$$

Algorithm 1 Task Offloading Algorithm

Input: Offloading Solution, $\Gamma = (\Gamma_1, \Gamma_2, ..., \Gamma_t)$
Output: The Cost $\mathcal{C}$ associated with offloading n tasks

for $t = 1 : t$ **do**
  for $n = 1 : n$ **do**
    for $p = 1 : p$ **do**
      if $\delta_n \geq \mathcal{T}_p$ **then**
        $\Gamma_t \leftarrow 1$
      end if
      if $\Gamma_t = 1$ **then**
        Call Procedure 1
        if $\mathcal{Z}_n \leq \varepsilon_p$ **then**
          Call Procedure 2
        end if
      else if $\Gamma_t > \Gamma_{t-1}$ **then**
        $\Gamma_{t-1} \leftarrow 1$
        $\varepsilon_p \leftarrow \varepsilon_p + \mathcal{Z}_{n-1}$
        if $\mathcal{Z}_p \leq \varepsilon_p$ **then**
          $\varepsilon_p \leftarrow \varepsilon_p - \mathcal{Z}_n$
          $\Gamma_t \leftarrow 0$
        end if
      end if
    end for
  end for
end for

Offloading solution vector Γ stores a particular offloading opportunity θ_p for $p \in (1, p)$ and its associated data item $\mathcal{I}_n$. Let t be the total number of offloading solutions.

The probability and welfare function of offloading a data item through an offloading opportunity is represented by $\mathcal{U}_n(\Gamma)$ and $\mathcal{W}_t(\Gamma)$ respectively and mathematically modeled as:

$$\mathcal{U}_n(\Gamma) = 1 - \chi \tag{2}$$

$$\mathcal{W}_t(\Gamma) = \sum_{n=1}^{n} \mathcal{Z}_n * \mathcal{U}_n(\Gamma) \tag{3}$$

where

$$\chi = \prod_{p:(\mathcal{I}_n, \theta_p) \in \Gamma} (1 - \Lambda_p) \tag{4}$$

Procedure 1

procedure Calculate utility and welfare
  $\chi \leftarrow \prod_{p:(\mathcal{I}_n, \theta_p) \in \Gamma} (1 - \Lambda_p)$
  $\mathcal{U}_n(\Gamma) \leftarrow 1 - \chi$
  $\mathcal{W}_t(\Gamma) \leftarrow \sum_{n=1}^{n} \mathcal{Z}_n * \mathcal{U}_n$
end procedure

The objective function of the proposed model is to offload the data items in a way that eventually increases the value of welfare function. The mathematical formulation of the offloading cost via cellular network is given as follows.

$$\Phi_t^{cellular}(\Gamma) = \sigma_{cellular} \sum_{n=1}^{n} \mathcal{Z}_n (1 - \mathcal{U}_n(\Gamma)) \quad (5)$$

Similarly, the cost of offloading a data item through the WiFi network Φ_t^{wifi} can be formulated as:

$$\Phi_t^{wifi}(\Gamma) = \sigma_{wifi} \sum_{n=1}^{n} \mathcal{Z}_n * \mathcal{U}_n(\Gamma) \quad (6)$$

Based on Eqn. 5 and 6, Let $\mathcal{C}$ denote the final cost for offloading a data item, and is represented as follows.

$$\mathcal{C} = \Phi_t^{cellular}(\Gamma) - \Phi_t^{wifi}(\Gamma) \quad (7)$$

Procedure 2

procedure CALCULATE OFFLOADING COST
- $\gamma \leftarrow \sum_{n=1}^{n} \mathcal{Z}_n (1 - \mathcal{U}_n(\Gamma))$
- $\Phi_t^{cellular}(\Gamma) \leftarrow \sigma_{cellular} * \gamma$
- $\Phi_t^{wifi}(\Gamma) \leftarrow \sigma_{wifi} * \mathcal{W}_t(\Gamma)$
- $\mathcal{C} \leftarrow \Phi_t^{cellular}(\Gamma) - \Phi_t^{wifi}(\Gamma)$
- $\varepsilon_p \leftarrow \varepsilon_p - \mathcal{Z}_n$
- $\Gamma_t \leftarrow 0$

end procedure

IV. GAME THEORY FOR BARGAINING COST AND TIME

In this section, we establish a game-theoretical model for the low computation devices to negotiate the costs associated with offloading their computation requirements to the high computation devices.

Consider any low computation device $\mathcal{X}_m$ that wishes to offload its computation work to some other device in $\mathcal{X}$ with high computation capability. Let $\alpha^i = \{\alpha_1^i, \alpha_2^i, ..., \alpha_j^i\}$ and $\beta^i = \{\beta_1^i, \beta_2^i, ..., \beta_j^i\}$ be the vectors storing the costs and time respectively given by j high computation devices to satisfy the requests of low computation devices respectively. The price offered by $\mathcal{X}_m$ for computing its n tasks is given by $\mathcal{C}$, as shown in Eqn. 7. To ensure a fair price for both the parties, the value of $\mathcal{C}$ must be close to the median value in the cost vector α. In a scenario that the price offered by low computation devices, i.e., the devices intending to offload their tasks, differs vastly from the price sought by the high computation devices, the value of $\mathcal{C}$ is incremented iteratively:

$$\mathcal{C} = \mathcal{C} + \epsilon \quad (8)$$

until the value of $\mathcal{C}$ is approximately equal to ζ_i:, i.e.,

$$\zeta_{median} - \mathcal{C} \approx 0 \quad (9)$$

where ϵ is a small constant and ζ_{median} is the median cost value in the vector α^i.

To compare the bids of all the j devices, we formulate a separate value Ω that considers both the parameters, namely, cost and time. If $\mathcal{C}_t$ and $\mathcal{C}_c$ represent the weight of time and cost parameters assigned by the devices that need to get their task offloaded, then Ω can be calculated as,

$$\Omega_k^i = (\mathcal{C}_c * x_k^i) + (\mathcal{C}_t * y_k^i) \quad (10)$$

where x_k^i and y_k^i are the normalized numerical values of cost and time offered by the k^{th} high computation device during the i^{th} iteration. The values of x_k^i and y_k^i for all the j devices can be computed using the following equations:

$$x_k^i = \frac{\alpha_k^i - min(\alpha^i)}{max(\alpha^i) - min(\alpha^i)} (\kappa - \iota) + \iota \quad (11)$$

$$y_k^i = \frac{\beta_k^i - min(\beta^i)}{max(\beta^i) - min(\beta^i)} (\mu - \nu) + \nu \quad (12)$$

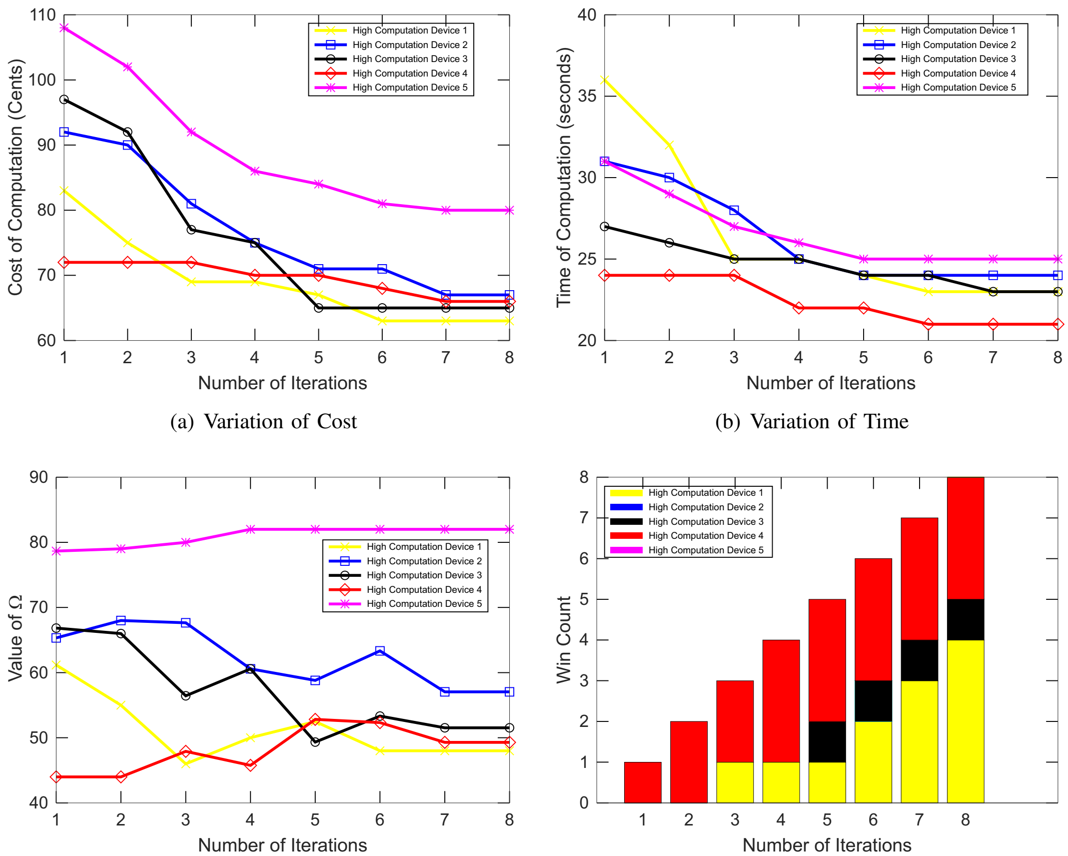
In eqn. 11, κ and ι denote the maximum and minimum permitted cost values. Similarly, in eqn. 12, μ and ν indicate the maximum and minimum permitted values of time.

Vector $\Omega = \{\Omega_1, \Omega_2, ..., \Omega_j\}$ stores the objective values for each high computation device calculated using eqn. 10. For each offloading task, the device which has the minimum value of Ω is announced as the winner. Vector Δ stores the win counts of all the j devices based on which, the final winner is declared. In a case where Ω vector has multiple minimum values, all the devices with this value are declared as winners. To succeed in obtaining the offloading tasks, other high computation mobile devices lower their expected cost and time values over z number of iterations as long as their cost and time values do not fall below their minimum threshold values. The minimum threshold values are those values of cost and time below which the high computation devices cannot perform offloading.

The last iteration of the bargaining model occurs when the difference in cost and time values of all j high computation devices is negligible, i.e.,

$$(\Omega_k^i - \Omega_k^{i-1}) \leq \varrho, \ \forall k \in (1, j) \quad (13)$$

where ϱ is a very small constant. The final win count of all the high computation devices determines which high computation device is ultimately allotted to a low computation mobile device $\mathcal{X}_m$.



(a) Variation of Cost

(b) Variation of Time

(c) Variation of Objective Values ω

(d) Cumulative Win Count

Fig. 2. Game Theoretic Bargaining Model over Several Iterations

V. Numerical Analysis

This section analyses the simulations performed to demonstrate the efficiency and performance of our proposed mobile data offloading algorithm.

A. Simulation Settings

Consider a low computation device that wants to compute a task requiring multiple operations for which the data requirement is in the range of $[120, 200]$ kilobytes (KBs). Local execution of the task would be more costly and require more time as compared to the scenario in which the task is offloaded to a high computation mobile device. The offloading cost over the cellular network is assumed to be 3 dollars while the cost associated with task offloading over the WiFi network is assumed to be 70 cents. We take the value of j as 5, i.e., 5 high computation devices act as participants in our game-theoretical model. We assume that the cost given by the low computation device is in the range of $[60, 110]$ cents, while the specified time is considered to be in the range of $[20, 40]$ seconds. The values of cost parameter $(\mathcal{C}_c)$ and time parameter $(\mathcal{C}_t)$ are taken to be 0.6 and 0.4 respectively.

B. Performance Evaluation

The variation in the time and cost values offered by the high computation devices to win the task offloaded by a low computation device is shown in fig. 2(a) and 2(b). For each iteration, the device with the least objective value (Ω) is announced as the winner. From the graphs 2(a), 2(b) and 2(c), it can be noticed that the all high computation devices that do not win a particular iteration update their cost and time values in subsequent iterations to win the task. Fig. 2(d) shows the cumulative win count of all the high computation devices after each iteration. It can be seen from the graph that once the stopping condition is achieved, high computation device 1 has the highest win count and therefore wins the task.

VI. Conclusion

This paper proposes a secure data offloading strategy based on the hashgraph consensus mechanism that takes into consideration the deadline constraint. A peer-to-peer network of mobile users is created in which the users may either choose to offload their tasks to other high computation devices or may choose to perform the computation task on behalf of other low computation devices. A game-theoretic bargaining model has also been implemented to ensure task computation in a cost-optimal and time-efficient manner. The results obtained confirm the effectiveness of the proposed offloading model.

VII. Acknowledgement

This work is supported by DST-SERB (Science and Engineering Research Board (SERB)) funding under Project Grant File no. ECR/2018/001479.

References

[1] Cisco, "Cisco Visual Networking Index: Global mobile data traffic forecast update," https://www.cisco.com/, online; accessed 18 Feb 2019.

[2] Y. Li, G. Shi, W. Yin, L. Liu, and Z. Han, "A distributed admm approach with decomposition-coordination for mobile data offloading," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 3, pp. 2514–2530, 2017.

[3] H. Zhou, H. Wang, X. Li, and V. C. Leung, "A survey on mobile data offloading technologies," *IEEE Access*, vol. 6, pp. 5101–5111, 2018.

[4] D. Liu, L. Khoukhi, and A. Hafid, "Prediction-based mobile data offloading in mobile cloud computing," *IEEE Transactions on Wireless Communications*, vol. 17, no. 7, pp. 4660–4673, 2018.

[5] S. Yu, R. Langar, X. Fu, L. Wang, and Z. Han, "Computation offloading with data caching enhancement for mobile edge computing," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 11, pp. 11 098–11 112, 2018.

[6] G. Gao, M. Xiao, J. Wu, K. Han, L. Huang, and Z. Zhao, "Opportunistic mobile data offloading with deadline constraints," *IEEE Transactions on Parallel and Distributed Systems*, vol. 28, no. 12, pp. 3584–3599, 2017.

[7] H. Shah-Mansouri, V. W. Wong, and J. Huang, "An incentive framework for mobile data offloading market under price competition," *IEEE Transactions on Mobile Computing*, vol. 16, no. 11, pp. 2983–2999, 2017.

[8] K. Wang, F. C. Lau, L. Chen, and R. Schober, "Pricing mobile data offloading: A distributed market framework," *IEEE Transactions on Wireless Communications*, vol. 15, no. 2, pp. 913–927, 2015.

[9] 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, April 2020.

[10] W. Tang, X. Zhao, W. Rafique, and W. Dou, "A blockchain-based offloading approach in fog computing environment," in *2018 IEEE Intl Conf on Parallel*. IEEE, 2018, pp. 308–315.

[11] N. Zhao, H. Wu, and Y. Chen, "Coalition game-based computation resource allocation for wireless blockchain networks," *IEEE Internet of Things Journal*, pp. 1–1, Mar 2019.

[12] 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, July 2019.

[13] V. Hassija, G. Bansal, V. Chamola, V. Saxena, and B. Sikdar, "Blockcom: A blockchain based commerce model for smart communities using auction mechanism," in *2019 IEEE International Conference on Communications (ICC) Workshops*, Shanghai, China, May 2019, pp. 1–6.

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

[15] M. H. Leemon Baird and P. Madsen, "Hedera: A Public Hashgraph Network and Governing Council," https://www.hedera.com/whitepaper, online; accessed 09 Feburary 2019.

[16] M. A. Rahman, M. S. Hossain, G. Loukas, E. Hassanain, S. S. Rahman, M. F. Alhamid, and M. Guizani, "Blockchain-based mobile edge computing framework for secure therapy applications," *IEEE Access*, vol. 6, pp. 72 469–72 478, 2018.

[17] M. Dabbagh, B. Hamdaoui, M. Guizani, and A. Rayes, "Exploiting task elasticity and price heterogeneity for maximizing cloud computing profits," *IEEE Transactions on Emerging Topics in Computing*, vol. 6, no. 1, pp. 85–96, Jan 2018.

[18] Z. Yang, W. Lang, and Y. Tan, "Fair micropayment system based on hash chains," *Tsinghua Science and Technology*, vol. 10, no. 3, pp. 328–333, June 2005.