MOTIVE: A Decentralized V2X Framework for Trusted Vehicular Services and Micropayments

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***Abstract*—The connected and autonomous vehicles are expected to rely heavily on connectivity to exchange data and computation services with other vehicles and remote infrastructure, including road-side units and other edge infrastructure. For increased autonomy, vehicles perceive the world around them through sensors and exchange that information with other vehicles to expand their immediate view resulting in greater safety, coordination, and more comfortable experience for their human occupants. For vehicles to obtain data, computation, and other services from other vehicles or road-side infrastructure, a V2X framework capable of delivering desired services despite the challenges posed by mobility and ephemeral interactions is desired. We present MOTIVE, a trusted and decentralized framework that allows vehicles to make peer-to-peer micropayments for data, computation, and other services obtained from other vehicles or road-side infrastructure within radio range. The framework utilizes blockchain and distributed ledger technologies, including smart contracts to enable the autonomous operation and trusted interactions between vehicles and nearby entities.**

***Index Terms*—V2X, Micropayments, Connected and autonomous vehicles, blockchain, edge computing**

I. Introduction

The automotive industry is moving towards autonomous driving [1], [2], connectivity [3], and electrification [4] to increase driver comfort, safety and eco-friendly driving. Modern day vehicles are increasingly being equipped with sensors, cameras, artificial intelligence and machine learning algorithms to assist the drivers, or in some cases, the technologies are making decisions for the drivers. The ongoing developments in artificial intelligence technologies are expected to further propel the adoption of such technologies in the race for the realization of connected and autonomous vehicles. Thus, applications such as electric vehicle charging and real-time traffic prediction are expected to exchange data and computation using vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication [5].

Connected vehicles, in the future, can communicate with other vehicles on the road to help the driver make informed decisions when crossing intersections, changing lanes, or driving under adverse weather conditions. In applications such as Advanced Driver Assistance Systems (ADAS), each vehicle can exchange information such as the speed and their distance with other vehicles, among other things, to calculate the safe driving speed and distance. Similarly, the vehicles can communicate and coordinate with road-side infrastructure to navigate through intersections by controlling their speed based on the traffic condition. Such applications require aggregation and processing of sensor data from multiple vehicles and the road-side units. In summary, the V2V and V2I (referred to as V2X from now on) applications require communication and computation services from nearby vehicles and road-side units in a dynamic environment.

The V2X applications exchange data and compuation services between devices and infrastructures owned by multiple users and organizations while operating in transient conditions. In such scenarios, a trust mechanism is necessary to consume and provide services in the V2X application domain as the vehicles and the drivers may be misguided by the dishonest devices since the interactions between devices cross the trust boundaries. Besides, the introduction of micropayments encourage vehicles and infrastructure nodes to contribute resources including data and computation, allowing them to gain monetary benefit for their service contributions while allowing the vehicles autonomously pay for services such as parking and the use of toll roads. It is essential to create a V2X platform with built-in mechanisms to guarantee trust and manage micropayments for exchanging data and compuation services. Such a V2X platform has the potential to enable what we call "financially autonomous vehicles". Another problem in the V2X application scenario is that each vehicle stays in contact with other vehicles or the road-side units for a short amount of time. Thus, the service agreements between devices have to be made based on the contact duration for reliable transaction.

In this paper, we introduce MOTIVE (an acronym coined from "Micropayments fOr Trusted vehIcular serVicEs"), a novel V2X platform with support for trust and identity management, micropayments, and mechanisms to provide and consume data and computation services with other vehicles and road-side units following a decentralized architecture. MOTIVE incorporates a link prediction algorithm which allows the vehicles to calculate the contact duration based on the destination of the vehicles, speed, and the traffic conditions of the environment. MOTIVE is a blockchain and protocol agnostic framework for V2X involving blockchain and distributed ledger technologies. Our preliminary implementation and evaluation show the practicality of the proposed approach. Lastly, the MOTIVE simulator allows the application developers to validate the processing time and the performance of the entire framework, including the blockchain-based identity management and rating framework and the payment handler.

Section II discusses the related work. The architecture of MOTIVE is presented in Section III. Research challenges and design choices of MOTIVE are presented in Section V. Section VI discusses our preliminary implementation of this framework. Finally, we conclude the paper with pointers for future work in Section VII.

II. Related Work

The application of blockchain to V2X are already discussed in the literature. ChargeItUp [6] uses micropayments for fuel recharging using layer-2 state channel mechanism. Leiding *et al.* [7] present an architecture for a self-managed blockchain-based platform for V2X based on smart contracts. These works illustrate the benefits of using blockchain and distributed ledger technologies to V2X applications. The Chorus framework [8] also explains the benefits of applying blockchain to V2X applications while contributing a technical architecture illustrating the components of the blockchain-based platform for V2X applications. Our work is complementary to [8] [7], except that the MOTIVE framework is more generic and it consists of components of link prediction and trust management. Zhaojun *et al.* contribute BARS [9], a trust management platform for V2X, which is one of the critical challenges in decentralized applications. BARS manages and estimate trust rating based on the historical behavior of the users and the indirect information collected from other vehicles in the vicinity.

Communication: The 5G Automotive Association (5GAA) is standardizing 5G cellular technology for V2X and ITS applications [10], which is expected to advance connected vehicle technologies. A secure communication scheme for V2X applications is presented in [11], which proposes a ring-based signature scheme in combination with multi-party smart contracts to ensure secure data sharing in a V2X environment. Merlin [12] contributes a file sharing protocol for intermittently connected vehicles in V2X applications. Ahn *et al.* [13] contribute a file dissemination protocol for dual radio vehicular platform, which calculates the optimal content dissemination model for V2X applications. The literature on communication [10], [11] and data dissemination [12], [13] emphasizes the need to manage the data and service exchanges within the short contact duration. To these, our work contributes a novel link prediction algorithm as well as the use of trust-based micropayments.

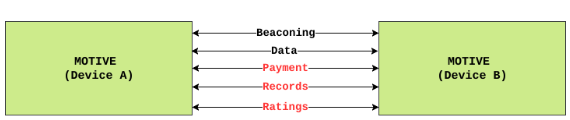

Fig. 1. Channels between MOTIVE Instances.

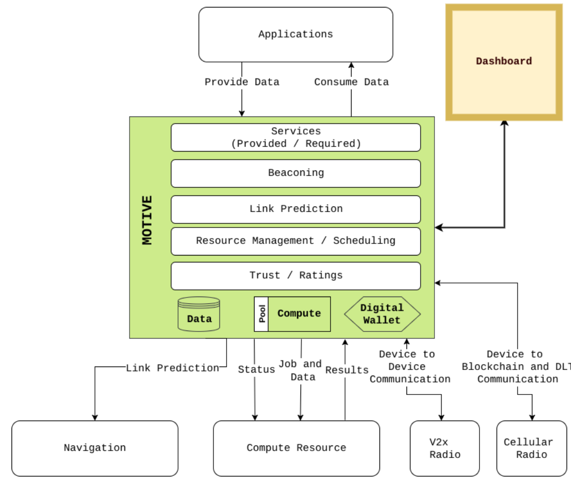

Fig. 2. Architecture of MOTIVE.

III. MOTIVE Architecture

MOTIVE enables vehicles and infrastructures to exchange data and compuation services in a peer-to-peer network, with built-in support for trust and micropayments. Figure 1 shows the different communication channels that exist between two MOTIVE instances. Each MOTIVE instance is:

- Capable of **beaconing** the provided and required data and compuation services to other MOTIVE instances in the neighborhood using a V2X radio.
- Able to exchange **data**, including sensor reading, computation tasks, inputs, and results, with other MOTIVE instances.
- Storing the **records** of all the transactions in a distributed ledger or a blockchain platform.
- Attached to a digital wallet for paying or receiving **payments** for the services consumed or provided respectively.
- Able to **rate** the other MOTIVE instance based on the transaction experience.

A. System Description

Figure 2 shows the architecture and the building blocks of MOTIVE. Each MOTIVE instance is capable of advertising the services it can provide and the services it requires to other MOTIVE instances using the V2X radio. Note that the MOTIVE instances can be running on both the vehicles and the road-side infrastructure.

All the MOTIVE devices in the operational environment can receive beacons and process the information in the beacon to understand the provided and required services. The decision to offer the service to the other devices are made based on how long the two devices will stay in contact along with the rating and the account balance in the wallet. MOTIVE consists of a link prediction algorithm, which compuations the contact duration based on the navigation data, traffic situation, distance between the vehicles, wireless communication range of the radio, and the speed limit. When the contact duration is well within the duration required to complete the transaction, the reputation of the device is above the acceptable threshold, and the account has sufficient balance to pay for the requested service, the service agreement is made between devices. The service provider then schedules the services by allocating the desired computation and storage resources and serve the peer in return for micropayment. The key building blocks of MOTIVE are described below:

Beaconing: Each MOTIVE instance advertises the services provided and required through a V2X radio. The device beacons as long as it has resources to provide and consume services.

Services: Each MOTIVE instance can provide and consume data and computation services.

- **Data services** include information such as the number of vehicles in the vicinity or the electric charge available in the charging stations in a freeway. For example, a speed recommendation application can consume data from other cars in the neighborhood to estimate the desired speed for the current road condition.
- **Computation services** include off-loading either a computation task to a road-side unit or other cars in the neighborhood. We propose two computation models in such a scenario. The first model consists of a set of predefined computation tasks for a set of well-known V2X applications. For example, a vehicle requiring the object recognition computation service can send the image frame and the task name associated with the object recognition to the vehicle providing the computation service, which in return would send the objects present in the frame. Creating a set of standard computing tasks for the known application scenarios would not only reduce the communication overhead but also increases the efficiency of the off-loading process. The second model enables any MOTIVE instance to off-load any computation task to neighboring vehicles or road-side units. This model follows our prior work, SmartEdge [14], which supports the execution of arbitrary computation tasks.

Trust and Ratings: The services provided and consumed through MOTIVE instances help drivers to make an informed decision or to gain monetary benefits. Vehicles and road-side units running the MOTIVE instance may behave dishonestly, wherein the devices may deliberately share false information about the contact duration or violate the service agreement by abruptly leaving the neighborhood while the service is being executed. To identify bad actors in the MOTIVE ecosystem, we propose a blockchain-based identity management system. The blockchain-based decentralized applications run either on public or private blockchain platforms. On the one hand, the public blockchain platforms allow any user in the network to run a node without necessarily revealing their identity. The private blockchain platforms (also called as permissioned blockchain platforms) typically consist of a registration set up wherein the users are required to create an identity in the platform by sharing personally identifiable information, which is defined by the consortium or enterprise that run the application. MOTIVE runs in a permissioned setup, wherein each user (or vehicle owner) is required to register their driving license and plate information to the MOTIVE platform, and road-side infrastructure nodes also must register their identity.

For a MOTIVE instance to interoperate with other vehicles and road-side units, the vehicle owners and the service providers at the edge are required to register their instance to the MOTIVE ecosystem. The registered MOTIVE instances can then exchange data and computation services with each other. Besides, the MOTIVE ecosystem maintains a rating framework to rate the behavior of the users. Each user is rated based on their behavior by the other party after each transaction. Users are required to maintain a trustworthy rating to participate in the MOTIVE transaction. When the rating of the device drops below a certain threshold, the user may be removed from the platform or subject to other penalties.

Link Prediction: The link prediction algorithm estimates the contact duration for the vehicle before providing or consuming services. This algorithm uses the navigation data, traffic situation, distance between the vehicles, wireless communication range of the radio, and the speed limit for estimating the duration for which the two vehicles will stay in contact. Our algorithm maintains the minimal contact duration needed to provide or consume each service in its registry. Thus, the scheduling of services is done when the contact duration is sufficient for the requested services. The contact duration topic is extensively addressed in literature. On the one hand, we have studies that predict contact duration by modeling the expected behaviour using probability in simulations [15], a large data set to reach an empirical result [16], using the traffic light delay to the model [17] and using neural networks [18]. On the other hand, other works focused more on reducing the contact duration via packet hopping between vehicles [19] or using backup caches in the vehicular network [20]. Unlike these approaches, our approach considers the Cartesian coordinates of each vehicle in combination with the navigation system information to estimate the contact duration based on the instantaneous position of each vehicle. We present our link prediction algorithm in Section V-B.

Resource Management and Scheduling: The scheduling of resources for a given service depends on the contact duration, rating of the user, and the account status, as shown in Pseudocode 1. When the scheduling criteria are met, the MOTIVE instance handles the service request by allocating the necessary computation, storage, and communication resources. We do not want to integrate a heavyweight scheduling framework as we do not plan to queue services due to the transient nature of peers. In our future work, we plan to develop a QoS-aware scheduler to schedule services based on their QoS requirements.

IV. Operation of MOTIVE

Pseudocode 1 presents the operation of MOTIVE at a high level. We have divided the process into three stages. At stage

1, each MOTIVE instance beacons while listening for a beacon from other MOTIVE instances. Note that the beacon message includes the service provided and required by each instance. When an instance receives a beacon, stage 2 of the process is invoked. In this stage, the MOTIVE instance checks whether the instance has a valid identity on the MOTIVE ecosystem before checking the availability of the requested service. If the requested service is available, then the framework validates the rating and the payment balance of the other MOTIVE instance. The requested service is scheduled if the instance has an acceptable rating and the sufficient account balance in its wallet. In Line 13, *T* refers to the predefined acceptable threshold for rating, while *B* refers to the minimum balance needed in the wallet to participate in a MOTIVE transaction. When the instance does not satisfy any of the conditions, the service request is declined, and the system goes back to the beaconing stage. However, if the service is scheduled, then the MOTIVE system executes the service and deliver the results to the remote MOTIVE instance. Upon receiving the result, the system enters into the final stage in which the instance that received the service is charged through the *Handle_Payment()* function. After handling the payment process, both the instances rate each other to complete the transaction. This rating process terminates the service execution, and the system goes back to Stage 1, where it starts beaconing to either advertise its services or request services from other MOTIVE instances.

Pseudocode 1 Pseudocode of MOTIVE. We refer the reader to the following video demonstration to better understand the different stages: https://youtu.be/qBkDRzxOUrA

```
1:  STAGE 1: Beaconing
2:
3:  while True do
4:      Transmit Beacon every X Seconds
5:      Beacon_Heard=Received_Beacon_Interrupt()
6:      if Beacon_Heard then
7:          Invoke Rating_and_Balance_Validation_function
8:      end if
9:  end while
10:
11: STAGE 2: Rating and Balance Validation, Contact
    Duration Estimation and Scheduling
12:
13: if Rating(M) > T and Account_Balance(M) > B then
14:     Contact_Duration = Get_Contact_duration() (See Pseu-
        docode 2)
15:     if Contact_Duration > Service_Delivery_Time then
16:         Schedule_Service()
17:     end if
18: else
19:     GoTo Stage 1
20: end if
21:
22: STAGE 3: Handle micropayment and rate transaction
23:
24: //Wait for the completion of the service
25: Handle_Payment()
26: Rate_Transaction()
27: GoTo Stage 1
```

V. Link Prediction Analysis

This section explains how MOTIVE instances estimate contact duration.

A. Initial Assumptions

The contact duration of two MOTIVE instances depends on the V2X communication protocol employed by MOTIVE and its performance characteristics such as delay, throughput, and reliability. We assume that the wireless transceivers are identical and have a uniform wireless range (R). For simplicity, we assume that the communication protocol has built-in mechanisms to handle issues such as wireless interference and multi-path fading. Besides, we assume that a MOTIVE instance, running on a vehicle, has access to the vehicle's computing unit (CU) and other onboard peripherals such as the navigation system and sensors. Finally, the transactions can happen either between two vehicles (V_{local} and V_{remote}) or between a vehicle (V_{local}) and an edge infrastructure or roadside unit (I_e).

B. Contact Duration of V2X Communication

At this preliminary stage, we considered an efficient way to obtain the contact duration time by using each agent's geographical coordinates based on their navigation course. The instance is expected to report the navigation information periodically, including their current and future position. The estimation of the contact duration time depends on the following equations:

$$\text{If } R = \sqrt{(X_{\mathrm{V}_{(t_0)}} - X_{\mathrm{V}_{e(t_0)}})^2 + (Y_{\mathrm{V}_{(t_0)}} - Y_{\mathrm{V}_{e(t_0)}})^2 + (Z_{\mathrm{V}_{(t_0)}} - Z_{\mathrm{V}_{e(t_0)}})^2}, \quad then \quad T_{\mathrm{i}} = t_0 \tag{1}$$

$$\text{If } R > \sqrt{(X_{\mathrm{V}_{(t_1)}} - X_{\mathrm{V}_{e(t_1)}})^2 + (Y_{\mathrm{V}_{(t_1)}} - Y_{\mathrm{V}_{e(t_1)}})^2 + (Z_{\mathrm{V}_{(t_1)}} - Z_{\mathrm{V}_{e(t_1)}})^2}, \quad then \quad T_{\mathrm{f}} = t_1, for\ t_1 > t_0 \tag{2}$$

$$T_{\mathrm{int}} = T_{\mathrm{f}} - T_{\mathrm{i}} \tag{3}$$

The algorithm proceeds to analyze from the moment both agents are within range R, after which it estimates the contact duration roughly based on the instantaneous position of each agent according to their navigation system until one of the vehicles move away from the radio range of the other connected vehicle. Once both times are estimated, we obtain the interaction time. We must add that this current approach has some limitations such as the lack of a path loss analysis which consider the impact of environmental effects, the assumption that the agents will do exactly as the navigation system estimated without considering traffic lights or other vehicles on the road. These additional effects will be addressed in a later study. The contact duration algorithm is presented in Pseudocode 2.

To check the performance of this algorithm, we implemented a scenario using SUMO [21], an open source traffic simulation package, in which we have a reference vehicle and four other vehicles that interact with it so that we estimate the contact duration using our algorithm. In Figure 3, we present a circular road that was used for this sample scenario with each vehicle being represented with a yellow triangle. For this study, each vehicle was defined with the same transmission range. However, we randomized the appearance of the agents on the road as well as the speed and acceleration to simulate a real-life scenario. Figure 4 shown the contact duration obtained from the algorithm between the vehicle (V) and each of the four remaining vehicles in the y-axis as well as the time when the link prediction algorithm is triggered in the x-axis. We can see that the contact duration is different regardless of the agents involved and independently of the moment it was generated.

Pseudocode 2 Pseudocode of Link Prediction Algorithm

Input: V:X,Y,Z;V_e:X,Y,Z
Output: T_{int}
Initialization :
While True
if (R $>=$ Distance($V(t_0)$,$V_e(t_0)$)) **then**
  $T_i = t_0$
  Break
end while
While True
if (R $<$ Distance($V(t_j)$,$V_e(t_j)$)) **then**
  $T_f = t_j$
  Break
end while
Calculate T_{int}
return T_{int}

An even more complex scenario than the one shown in Figure 3 occurs when the vehicle (V), which decides to use the MOTIVE system, realize there are three different agents within range which can be possibilities for a $V2X_{comm}$: vehicle V_{e1} going at same speed as V, vehicle V_{e2} going at a faster speed and a static edge infrastructure I_e. The system will give a recommendation based on the following priority:

1) Edge vehicle agents (V_e)
   - V_e with the longest T_{int}.
   - V_e with the second longest T_{int} and so on.
2) Edge infrastructure agents (I_e)
   - I_e with the longest T_{int}.
   - I_e with the second longest T_{int} and so on.
3) In case no viable option exist , service will be offloaded to the cloud.

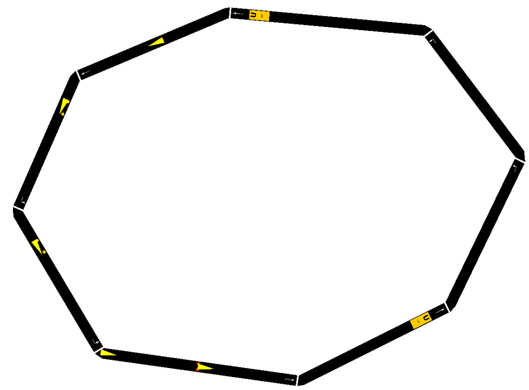

Fig. 3. Simulated Traffic Route in SUMO.

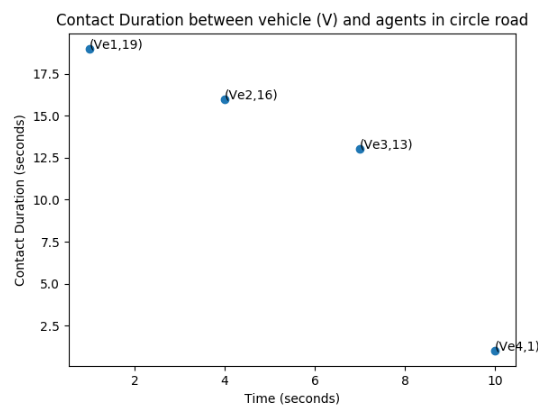

Fig. 4. Contact Duration between Reference Vehicle and Agents in Seconds.

Therefore, the system will initially recommend the V_{e1} since their trajectory in the near future will be the same as V. The next option would be V_{e2} since it will move outside of the range earlier than the previous agent and, even if the interaction time is long enough to make it a viable option, it is safer to consider the former agent than the current one. Finally, out of the three agents in range, the recommendation system will be leaving the I_e since it is static and, most likely, the interaction time between this agent and V will be either barely enough for the service or not viable. As mentioned in the priority list, in case none of the option is viable, MOTIVE will provide to the user the option to offload the required service to the cloud. Note that the cost increases as the vehicle connects with other edge vehicle, edge infrastructure, and the cloud in that order, where the processing in the cloud costs more money and result in slower response, while the neighbouring vehicle may be able to provide the service with low latency subject to the contact duration.

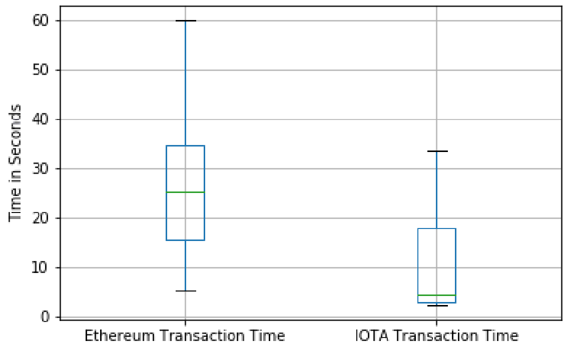

Fig. 5. Payment Transaction Time on Ethereum and IOTA Blockchain and Distributed Ledger Platforms.

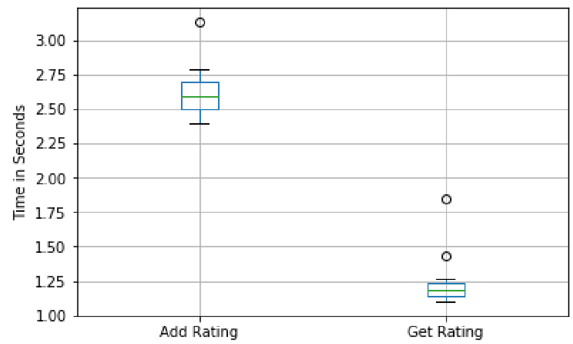

Fig. 6. Transaction Time for Adding a Rating to and Reading a Rating from Ethereum Smart Contract.

VI. Preliminary Implementation and Early Results

We have developed a simulator to demonstrate the different building blocks of MOTIVE. Note that our simulator does not execute the contact duration algorithm and instead it prompts the user to enter when a vehicle would come into contact and how long the vehicle stays in contact (i.e., contact duration) other vehicle (or MOTIVE instance). The simulator, identity and ratings smart contract, and the payment libraries are made available as open-source software at the following link: https://github.com/ANRGUSC/MOTIVE. In addition, a video demonstration of MOTIVE simulator is available at the following link: https://youtu.be/qBkDRzxOUrA [1].

We have estimated the time needed to add and read ratings, and the payment processing to show the importance of contact duration. We have collected 1000 samples each for rating and payment functionalities. Our MOTIVE framework is agnostic to the underlying blockchain platform. MOTIVE can work with cryptocurrency platforms such as Ethereum and IOTA or the fiat currency payment frameworks such as Stripe. The Ethereum version of MOTIVE was evaluated using Ropsten test network, which is functionally similar to the Ethereum main net. Similarly, the transaction duration of IOTA was estimated using the IOTA test net. We would like to emphasize that the decentralization is achieved in MOTIVE through the use of blockchain and distributed ledger technologies to manage identities, rating, and the payment processes.

A. Identity and Ratings Smart Contract

The **identity and ratings** smart contract was developed and deployed in Ethereum to manage the identities and the ratings of the members in the MOTIVE ecosystem. The smart contract consists of three functions to add a new user to the MOTIVE ecosystem, get the rating of an existing user, and rate an user after a transaction. We have evaluated the execution time of *read rating* and *add rating* functions. Each function was invoked 1000 times to estimate the average execution times. As shown in Figure 6, the *add rating* function takes an average *2.5 Seconds* whereas the *read rating* has the maximum delay of *1.25* Seconds.

B. Performance of Payment Channel

Figure 5 presents the payment transaction times for Ethereum and IOTA blockchain platforms. The blockchain platforms execute a consensus algorithm and record the transactions in a distributed ledger technology. Therefore, the payment transaction time depends on the processing duration of the consensus algorithm. Besides, the user has to pay a transaction fee in Ethereum, which at the time of writing, fell between *0.0021 USD (1 gwei)* and *51.71 USD (12500 gwei)* according to https://ethgasstation.info/.

The MOTIVE framework is agnostic to the underlying blockchain platform, although our proof-of-concept implementations are carried out on particular platforms, namely IOTA and Ethereum. In its present form, MOTIVE technically only requires blockchain platform with support for rating, record, and payment functionalities. We are currently implementing the contact duration and plan to evaluate the complete framework using mobile robots (or drones) and edge devices. Besides, we are optimizing the payment and rating transaction channels to speed up the overall process since the vehicles are already operating in transient conditions with limited contact duration in the order of tens of seconds.

VII. Conclusion

The growing interest in connected and autonomous vehicles and the latest technological advancements in 5G enable vehicles to connect with other vehicles and road-side units to exchange data and computation services. In this work, we have presented MOTIVE, a decentralized V2X platform with support for data and computation services in return for micropayments. Besides, the link prediction algorithm of MOTIVE allows the vehicle to estimate the contact duration before scheduling the services. The identity and rating mechanism used in MOTIVE enable the vehicle to verify the reputation of other vehicles for a trustworthy peer-to-peer transaction. Besides, our MOTIVE simulator allows the application developers to validate the transaction times of different processes, including the ratings and the payment handling functionalities.

[1] We are presenting the video demonstration of MOTIVE at MobiSys-2019 in Seoul on June,2019.

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