EdgeChain: Blockchain-based Multi-vendor Mobile Edge Application Placement

He Zhu  
Systems and Computer Engineering  
Carleton University  
Ottawa, ON, Canada  
hzhu@sce.carleton.ca

Changcheng Huang  
Systems and Computer Engineering  
Carleton University  
Ottawa, ON, Canada  
huang@sce.carleton.ca

Jiayu Zhou  
Computer Science and Engineering  
Michigan State University  
East Lansing, MI, USA  
jiayuz@msu.edu

Abstract—The state-of-the-art mobile edge applications are generating intense traffic and posing rigorous latency requirements to service providers. While resource sharing across multiple service providers can be a way to maximize the utilization of limited resources at the network edge, it requires a centralized repository maintained by all parties for service providers to share status. Moreover, service providers have to trust each other for resource allocation fairness, which is difficult because of potential conflicts of interest. We propose EdgeChain, a blockchain-based architecture to make mobile edge application placement decisions for multiple service providers. We first formulate a stochastic programming problem minimizing the placement cost for mobile edge application placement scenarios. Based on our model, we present a heuristic mobile edge application placement algorithm. As a decentralized public ledger, the blockchain then takes the logic of our algorithm as the smart contract, with the consideration of resources from all mobile edge hosts participating in the system. The algorithm is agreed by all parties and the results will only be accepted by majority of the mining nodes on the blockchain. When a placement decision is made, an edge host meeting the consumer’s latency and budget requirements will be selected at the lowest cost. All placement transactions are stored on the blockchain and are traceable by every mobile edge service provider and application vendor who consumes resources at the mobile edge.

Index Terms—Mobile edge computing, blockchain, placement.

I. INTRODUCTION

The rapid advance of mobile edge computing (MEC) has been the last mile of enabling a shared, low-latency computational environment for multi-vendor mobile edge applications. MEC performs computing offloading, data storage, caching and processing, request distribution and service delivery from the mobile edge to end users. Applications with low latency tolerance, such as augmented reality (AR), video streaming, and online gaming, can deploy their services on the edge hosts at a cost, to achieve lower latency and better user experience.

As the market gets mature, there will be multiple 5G service providers (SPs) provisioning MEC services to cover the same area: bigger wholesale players will invest in infrastructure to actually build mobile edge base stations, while there will also be mobile virtual network operators (MVNOs) renting resources from the former. These SPs can collaborate with each other in several ways for better utilization of the resources at the edge: virtual SPs have to place mobile edge (ME) applications on one of the rented edge hosts, preferably with lower cost, regardless of SPs. On the other hand, MEC base stations from different SPs can share resources with each other to process bursting requests.

For encouraging SPs to enroll their eligible MEC base stations and hosts in resource sharing, it is common to give incentives to SPs for contributing their resources of the hosts for hosting edge applications. Following the changing demand of end users, certain types of edge applications need to be deployed on, migrated to, or removed from an edge host, in order to meet the service requirement. By deploying the edge applications at the right places, the edge application provider will save costs, while providing high-quality service with low latency to the end users. Meanwhile, the edge host will collect incentives for its resources effectively used.

Clearly, the edge computing framework needs a placement service to dynamically check the user needs and the available edge hosts, and determine the placement or removal of edge applications. In datacenters, virtual machine (VM) placement has been well investigated, mainly with the focus of more efficient resource utilization and lower operational expense (OPEX). However, the collaboration of multiple SPs and mobile edge applications vendors are posing new challenges for ME application placement from the following aspects:

- A placement model has to make transparent and consistent selections of the best host for each request for edge computing resources. Moreover, the model has to take into consideration that a mobile edge application may require multiple services chained together at the edge.
- A trusted party is required to determine the best place for application deployment. When an edge application is deployed on a mobile edge host, the application vendor needs to pay for the usage of the host. The placement algorithm has to avoid affiliation to either SP to ensure a neutral decision is made strictly according to the resource and the cost. It may create conflicts of interest to put any SP involved into the position of making placement decisions: placing mobile edge applications onto the SP’s own hosts would bring revenue for renting their resources.
- The application placement service needs to be steadily available. Both the mobile edge hosting service providers...
and the mobile edge application providers can constantly change. The placement service provider must remain in service regardless of the joining or quitting of vendors.

The challenges above urge a comprehensive solution uniting all SPs and their edge hosts without bias. In this paper, we present an architecture combined with its algorithm, namely EdgeChain, to create a decentralized placement service for mobile edge application that does not require trust to any party, i.e., trustless placement service. Compared with current placement solutions, EdgeChain has the following contributions:

- A cost model is presented as a stochastic programming problem, factoring in the pricing of edge hosts, latency, and service chaining.
- We develop a heuristic placement algorithm based on the proposed cost model with the consideration of efficiency for running by the blockchain.
- We introduce blockchain technologies to the MEC resource orchestration framework with two considerations: the first is to store the global resource availability, allocation, and consumption information that helps our algorithm make optimized decisions based on the global resource information. The second consideration is to have a decentralized public ledger for ensuring the neutrality of the placement decisions.
- The EdgeChain framework is presented to run our algorithm for making placement decisions. In our design, SPs and mobile edge application vendors participate in the maintenance of the blockchain. An EdgeChain client is embedded in the network function virtualization (NFV) framework to determine the placement based on the existing information on the blockchain. To our best knowledge, this is the first work that leverages blockchain to coordinate SPs for MEC application placement.
- Simulation results of our placement algorithm show its effectiveness in mobile edge host resource sharing among SPs. We also implement the EdgeChain by leveraging VeChain [3], an enterprise-level blockchain-as-a-service framework derived from Ethereum [4].

We divide the contents into the following sections. The related work is illustrated in Section II. Section III formulates the problem. Section IV proposes the heuristic EdgeChain placement algorithm based on the problem formulation. Then the simulation results are shown in Section VI. Section VII concludes the paper.

II. RELATED WORK

The research directions in network service chaining (NSC) were discussed in [5]. For security considerations, the authors highlighted the difficulty of bringing short-lived network services to targeted users in a single subscriber network by using the current security schemes. The potential security problems in SFC were stated in RFC7498 [6], including service overlay security, trusted classification policy, and secure SFC encapsulation. We investigated a placement problem in MEC with the consideration of application availability in [7].

Xiong et al. proposed a pricing strategy for offloading the blockchain’s resource-consuming proof-of-work tasks to edge computing nodes [8]. A two-stage Stackelberg game model was presented with both the edge computing service provider and the miners involved. A hierarchical distributed control system was built using Hyperledger Fabric blockchain [9]. The hosting locations of cloud and fog of blockchain were compared in [10] for IoT networks with the conclusion that fog nodes were better as network latency was the dominant factor.

Nakamoto introduced the concept of blockchain and implemented Bitcoin [11], a decentralized cryptocurrency that first resolved the double spending problem. Blockchains are based on Merkle trees [12] to efficiently allow multiple documents to be saved together in a block. As a decentralized public ledger,
MEApps used blockchain to store smart contracts that support building blockchains can serve beyond cryptocurrencies. Ethereum used blockchain to store smart contracts that support building blockchains can serve beyond cryptocurrencies. Ethereum (4) scenario in Table I. The problem is formulated from a

| Party       | Description                                                                 |
|-------------|------------------------------------------------------------------------------|
| Users       | Subscribers of applications and services over 5G networks with MEC enabled.   |
| MECSPs      | MEC service providers, who deliver MEC hosting services that can run MEApps at the network edge, close to end users. Examples include telecommunication companies like Rogers and Telus in Canada. |
| MEApps      | Mobile edge application vendors, who provide MEApps and services to end users. For instance, a company selling AR services. |
| MEHosts     | Servers that belong to different MECSPs to provide hosting service of MEApps. |
| HostLinks   | Network links between hosts, regardless of which MECSP they belong to.        |
| AppLinks    | When MEApps are chained together, virtual links will be established for data transmissions traveling through the chain. |

blockchains can serve beyond cryptocurrencies. Ethereum used blockchain to store smart contracts that support building virtually any decentralized application.

### III. Problem Formulation

We first list all parties involved in a MEC placement scenario in Table II. The problem is formulated from a MEAV's point of view: MEApps are direct consumers of the computing resources in the MEC environment, because a MEAV needs to pay MECSPs for hosting its applications in order to serve their users and meet the latency requirement. Each MEApp is equivalent to a virtual machine (VM) deployed on a MEHost. MEApps provided by different MEAV can be combined as a service chain to provide comprehensive services. A service chain may span multiple MEAVs. In this case, revenues generated by the service chain can be distributed according to the usage of each MEApp on the service chain. For instance, a full-fledged AR service can load real-time navigation information from an online map application, while it can also load promotions of a shopping mall nearby from the mall’s application. The navigation data is collected by the online map application, and the shopping mall application gets paid if the user "clicks" the links of the promotions.

The notations used in formulating the problem is shown in Table III. Define a chained service $s$ as a forwarding graph (13) $G_s = (V_s, L_s)$, where $V_s$ is the set of all MEApps contributing to the service, and $L_s$ is the set of all AppLinks connecting applications together. A MEApp is denoted by $v \in V_s$, and an AppLink between two MEApps is denoted by $l \in L_s$.

The chained service is deployed on a graph of connected MEHosts $G_h = (H, E)$, where $H$ is the set of all MEHosts owned by various MECSPs and $E$ is the set of all HostLinks. A MEHost is denoted by $h \in H$, and a HostLink between two MEHosts is denoted by $e \in E$. The HostLinks can be either physical or virtual links with fixed capacities and latencies.

Suppose in a certain service area, there are $n_s$ users from various MECSPs requesting the same chained service $s$ from a MEAV. We use $m$ to denote a MECSP and $h_m$ for a MEHost that belongs to $m$. Define an assigning function $x_{v, h_m}$, whose value is 1 if VM $v$ is assigned to Host $h_m$, 0 otherwise.

$$x_{v, h_m} \triangleq \begin{cases} 1, & v \text{ is deployed on } h_m; \\ 0, & \text{otherwise.} \end{cases}$$ (1)

Define a binary indicator of an AppLink between two chained MEApps in $s$, denoted by $L(v_{h_1}, v_{h_2})$, such that

$$L(v, v') \triangleq \begin{cases} 1, & l \in L_s \text{ exists between } v \text{ and } v'; \\ 0, & \text{otherwise.} \end{cases}$$ (2)

Also, we use $e_{ij}$ to represent the HostLink between $h_i$ and $h_j$. The cost of deploying $s$ is the sum of the cost of deploying each MEApp $v$ of the service and the cost of the traffic between each two adjacent MEApps in the service chain. It can be shown by

$$c_s = \sum_{h_m \in H} \sum_{v \in V_s} c_{v, h_m} x_{v, h_m} + \sum_{h_i, h_j \in H, v, v' \in V_s} c_{v, v', h_i} x_{v, h_i} x_{v', h_j} L(v, v'),$$ (3)

where $c_s$ represents the cost of deploying $s$ and $c_{v, h_m}$ is for the cost of a MEApp $v$ deployed on a MEHost $h_m$. We assume that the pricing scheme for the same MECSP is the same across all of its hosts. For a MEHost $h_m$, define its basic unit resource price, which is the unit price of serving its own subscribers, as $\gamma_m$. When $h_m$ is serving users of other MECSPs, it charges a premium of $\delta_m$ for its unit resource, as the return for doing
The following two parameters will determine \( \zeta_{e_{ij}} \), the unit price of a HostLink \( e_{ij} \), denoted by \( \zeta_{e_{ij}} \), is then defined to describe how much to use the HostLink \( e_{ij} \). The first parameter is \( L(v_{hi}, v_{hj}) \) as defined in Eqn. (2). The more AppLinks a HostLink carries, the more vital and expensive it becomes. The reason behind this ranking parameter is the potential consequence of migration: failure of a HostLink used by many VMs would lead to massive migration of all MEApps connected by that HostLink, which would be more disruptive to the service chain.

The other parameter \( B_V(e_{ij}) \) is the total bandwidth consumed by traffic between MEApps on the two hosts. It is selected because larger bandwidth usages would cause challenges at the time of migration: it can be hard to find another link with enough capacity.

\[
B_V(e_{ij}) \triangleq \sum_{v_{hi}, v_{hj}, h_i \neq h_j} B(v_{hi}, v_{hj}) \tag{5}
\]

Combining the two parameters, we define the unit price \( \zeta_{e_{ij}} \) of a HostLink \( e_{ij} \), as the factor of the number of AppLinks between two hosts times the factor of traffic flowing through these links:

\[
\zeta_{e_{ij}} = \frac{\sum_{v_{hi}, v_{hj}, h_i \neq h_j} L(v_{hi}, v_{hj}) B_V(e_{ij})}{B(e_{ij})}, \tag{6}
\]

where \( N_{e_{ij}} \) is the maximum number of virtual links possible on \( e_{ij} \). Therefore, \( \zeta_{e_{ij}} \in [0, 1] \). The value of \( \zeta_{e_{ij}} \) will rise to mark up a link’s importance given it is either occupied by more pairs of VMs, or there is more traffic assigned to \( e_{ij} \), or both. The cost of any two MEApps is then the sum of the cost serving users that belong to the MECSps owning \( h_i \) and \( h_j \) and the cost serving other users timed by the price factor \( \kappa_{e_{ij}} \):

\[
c_{v_{hi}, v_{hj}} = n_s \zeta_{e_{ij}} [P_{m_{h_i}} + P_{m_{h_j}}] \kappa_{m_{h_i}m_{h_j}} + n_s \zeta_{e_{ij}} [(1 - P_{m_{h_i}} - P_{m_{h_j}}) (\kappa_{m_{h_i}m_{h_j}} + \sigma_{m_{h_i}m_{h_j}})]
\]

\[
= n_s \zeta_{e_{ij}} ([P_{m_{h_i}} + P_{m_{h_j}}] \kappa_{m_{h_i}m_{h_j}} + (1 - P_{m_{h_i}} - P_{m_{h_j}}) (\kappa_{m_{h_i}m_{h_j}} + \sigma_{m_{h_i}m_{h_j}})]. \tag{7}
\]

The second parameter is \( \kappa_{e_{ij}} \), the latency of the link \( e_{ij} \) to be \( t_{e_{ij}} \). For a service chain \( s \), the total latency \( t_s \) is then

\[
t_s = \sum_{h_i, h_j \in \mathbb{H}} \sum_{v_{hi}, v_{hj} \in \mathbb{V}_s} L(v_{hi}, v_{hj}) x_{v_{hi},v_{hj}} t_{e_{ij}}, \tag{8}
\]

In the equation above, \( t_{e_{ij}} \) is a constant depending on the particular \( e_{ij} \). If \( h_i = h_j \), then we consider the latency to be 0, since no actual HostLink is used for data transmission between the two MEApps. Define the maximum latency allowed for the service chain \( s \) is \( T_s \). Then there must be \( t_s \leq T_s \) to meet the latency requirement.
C. Stochastic Programming Formulation

The problem is formulated as a stochastic programming optimization. Define $V_h$ as the set of all MEApps deployed on the MEHost $h$. The objective is to minimize the total cost of the service chain $s$ to provide service with the lowest cost to the end user. As discussed in Section III, the optimization is to minimize the costs on MEHosts and HostLinks for all MEApps of $s$.

Minimize

$$c_s = \sum_{h \in V} \sum_{v \in V_s} c_{vh,m} x_{vh,m} + \sum_{h_i, h_j \in V, v, v' \in V_s} c_{vh_i,v'h_j} x_{vh_i,v'h_j} L(v, v')$$

$$= \sum_{h \in V} \sum_{v \in V_s} x_{vh,m} h_s(C_v + M_v)[\gamma_m + (1 - P_m)\delta_m] + \sum_{h_i, h_j \in V, v, v' \in V_s} n_{h_i,v} \epsilon_{e_{ij}} ((P_{mh_i} + P_{mh_j})\kappa_{mh_i,mh_j} + (1 - P_{mh_i} - P_{mh_j})(\kappa_{mh_i,mh_j} + \sigma_{mh_i,mh_j})) L(v, v'), \quad \text{(9)}$$

$s.t.$

$$B(e_{ij}) \geq \sum_{v_h, v_{h'}, h_i \neq h_j} B(v_h, v_{h'}), \quad \text{(10)}$$

$$C_h \geq \sum_{v \in V} C_v, \quad \text{(11)}$$

$$M_h \geq \sum_{v \in V} M_v, \quad \text{(12)}$$

$$\sum_{h_i, h_j \in V, v, v' \in V_s} x_{vh_i,v'h_j} L(v, v') \leq T_s. \quad \text{(13)}$$

Remarks

- Function (9) is the objective function. It minimizes the cost of all MEApps and AppLinks by using less hosts, while not exhausting them.
- Constraint (10) is the HostLink bandwidth capacity bounds between each two hosts. Traffic transmitted between any two hosts $h_i$ and $h_j$ must not exceed the corresponding bandwidth capacity $B(e_{ij})$.
- Constraints (11) and (12) are the CPU and memory capacity bounds for each MEHost. The CPU and memory used by MEApps coordinating with each other and by intra-host communications must not exceed $C_h$ and $M_h$.
- Constraint (13) is the latency requirement of the service chain $s$ to ensure that the total latency of $s$ must not exceed the maximum latency allowed $T_s$.

IV. THE EDGECHAIN PLACEMENT ALGORITHM

The formulation presented in the previous section is a stochastic programming problem. Problems of this type been proved to be NP-hard [14]. It may not be computationally feasible when attempting to solve it in large scale. To apply our model to real-world scenarios, we design a heuristic algorithm called EdgeChain to achieve suboptimal results by applying a hybrid strategy of best-fit and first-fit decreasing algorithm. The pseudo code of the algorithm is shown in Algorithm 1.

Algorithm 1: EdgeChain Placement Algorithm

Data: $host\_list$: list of candidate MEHosts
Data: $app$: requested MEApp to be placed, including its max latency allowed, stored in latency
Data: $max\_latency$: max latency allowed for the service chain

Result: The best MEHost in host\_list to place app, or none if no valid host is found

```
1 begin
2 sort by percentage of users of the service chain descending
3 if multiple MEHosts found then
4 sort host\_list by the locations of app’s last-hop MEApps
5 if still multiple MEHosts found then
6 sort by the latency of the HostLinks to the previous MEApps in the service chain ascending
7 end
8 end
9 for $h \in host\_list$ do
10 latency ← all latencies added together if app placed on $h$
11 if latency ≤ $max\_latency$ then
12 $cpu\_left$ ← calculate remaining vCPU by $C_h$ and $C_v$ of each MEApp placed on $h$
13 $mem\_left$ ← calculate remaining memory by $M_h$ and $M_v$ of each MEApp placed on $h$
14 if $cpu\_left$ ≥ 0 and $mem\_left$ ≥ 0 then
15 end
16 else
17 return none
18 end
19 else
20 end
```

A. Processing Order and selection of MEHosts

The EdgePlace algorithm runs on each mining node based on the Ethereum platform. The algorithm retrieves its input information from the blockchain, as all transactions and updates are recorded on the blockchain. The EdgePlace algorithm will select the MEHosts following the steps below.

1) Users: Sort all MEHosts by the percentage of users of the service chain. For each MEApp on the service chain, consider which MECSP has most users using it. Then MEHosts with the same MECSP will have higher ranks to deploy this MEApp. Since all MEHosts of the same MECSP have the same unit resource cost, the MEApp can be placed on any of the MEHosts that belongs to the best MECSP, to avoid the situation that too many MEApps are concentrated on one MEHost.
2) Last-hop MEApp: For MEHosts given higher priority in the previous step, sort by the locations of last-hop MEApps. MEHosts hosting the previous-hop MEApps will be considered first. This step is to reduce the traffic cost between different MECSPs.

3) Latency: For MEHosts given higher priority in the previous step, sort by the latency of the MECSPs first. This step is to reduce the traffic cost between different MEApps in the service chain. MEHosts with lower latency will be considered first.

After the list of candidate MEHosts are sorted according to the steps above, the algorithm iterates the list and pick the first valid MEHost that has enough resources to place the MEApp, as well as meeting the latency requirement of the service chain.

V. EdgeChain Design and Implementation

In this section, we introduce the design and implementation of EdgeChain, a blockchain-based system that integrates with the existing MEC architecture for MECSPs and the scheduler of MEAV. There are mainly two reasons the blockchain is used in the system:

- The blockchain acts as a public ledger that stores all useful information and transactions made during the placement process. Exposure of the information would help the placement algorithm make optimized decisions considering the global resource demand and allocation. The blockchain enables such centralized resource information, in a decentralized implementation.
- As a public ledger applying proof-of-work verifications, the blockchain makes it nearly impossible to tamper the history stored in the blockchain. The EdgeChain algorithm will be downloaded by all mining nodes and they will execute the same algorithm with the same input. The placement result will only be accepted by the system if majority of the mining nodes reach agreement on the output. This will ensure the neutrality of the placement decisions.

The system takes requests to place MEApps from MEAVs, and the placement algorithm runs as the smart contract on the blockchain to select the best MEHost from all candidates. The NFV orchestrator of the related MECSP receives and enforces the placement decision, while posting the transaction onto the blockchain for recording. While this paper is written, the blockchain is implemented based on VeChain [3], an enterprise-level blockchain-as-a-service framework derived from Ethereum.

A. Data Entities

As Fig. 3 shows, there exist 6 types of data entities on the blockchain and they are related to each other to represent the status of MEHosts and placement decision of running MEApps. The descriptions of these data entities are illustrated below. Each data entity record has a unique Ethereum address for other to locate it on the blockchain. All types of data entities can be created, updated and deleted, while the blockchain will keep the audit trail of every change.

1) MECSP: When a MECSP record is registered to EdgeChain, a record of this MECSP is added with the Ethereum addresses pointing to the records of all its eligible MEHosts and HostLinks. A MECSP record is updated whenever there is change to any MEHost or HostLink.

2) MEHost: A MEHost record registers under an existing MECSP to the blockchain. In a record, the vCPU and memory capabilities can be found, along with the Ethereum addresses pointing to the records of all MEApps placed onto it.

3) HostLink: Similar to MEHosts, a HostLink is under a registered MECSP, which contains the two MEHosts it connects, and the bandwidth of the HostLink.

4) SvcChain: A service chain is registered by a user to the blockchain to reflect the resource consumption of a chained service, including that from MEApps and the corresponding AppLinks. The service chain can have MEApps from multiple MEAVs.

5) MEApp: A MEAV will submit a record of a MEApp whenever it needs to spin up one. A record stores the vCPU, memory usage of the MEApp.

6) AppLink: AppLinks describe chained relationship between two MEApps. The source and destination MEApps are stored in an AppLink record, as well as network bandwidth requirement of this link.

B. EdgeChain Work Flow

A typical EdgeChain work flow can be demonstrated by Fig. 4 where there are three parties participating in the entire process: MECSPs, MEAVs, and mining nodes. We use circled numbers and alphabets to define the work flow in sequence.

1 A user requests a service chain from the blockchain. Such requests will be sent to the blockchain every time a user requests a service chain.

2 The request for the service chain is recorded. When the request is synced to the mining nodes, it will be broken into requests for MEApps. The mining nodes will run the logic to break down the service chain creation request. Then
Based on its user demand, if the result points to a MEHost, the request of creating a new MEApp arrives at a MECS through its Ethereum client. The Ethereum client running the MEApp Scheduler decides to create a new instance of MEApp and pass the request to the Ethereum client of the MEAV.

The Ethereum client running the EdgeChain service sends the request to the blockchain, creating records for the request of placing a new MEApp.

The request of creating a new MEApp arrives at a MECS through its Ethereum client.

For every MECS, the Ethereum client requests the NFV Orchestrator (NFVO) to call the EdgeChain placement algorithm downloaded to the resource manager for the decision of the placement. This will ensure that the placement algorithm is executed by different parties for verifying the results. The placement result returned by the next step will only be accepted if majority of the parties return the same placement result.

The NFVO calls the EdgeChain placement algorithm for the placement decision. Note that the decision can be a hash representing any MEHost within the entire MEC network. If the result points to a MEHost which does not belong to the current MECS, then no actual placement will be done. Instead, only the result along with the algorithm’s hash will be returned to the Ethereum client for verification.

If the result points to a MEHost of the current MECS, then the NFVO will send the request to place the MEApp to the VNF Manager (VNFM). Also, a transaction shown in Fig. 4 will be posted to the blockchain to record that placement actually occurs.

The VNFM sends the request to the NFV Infrastructure (NFVI) to deploy the MEApp onto the target MEHost.

The mining nodes periodically perform the mining process to verify the blockchain, as well as earning Ethers for requesting placement services. Meanwhile, the resource manager periodically synchronizes with the NFVI for the up-to-date resource usage and availability, and then posts the updated information to the blockchain.

Fig. 4. Typical workflow of EdgeChain. MECSs, MEAVs, and mining nodes participate in the process. Steps of the workflow are marked by circled numbers and alphabets with details documented in Section V-B.

Fig. 5. A placement transaction in EdgeChain. A state transition happens upon a transaction. As this figure shows, MEApp-4 is to be placed with the requirement of 2 vCPUs and 4096 MB of memory. The input of the EdgeChain placement algorithm is the current state of the two MEHosts.

VI. NUMERICAL RESULTS

In this section, we illustrate the numerical results of the MEC placement cost changes based on varying mobile edge application user cases using CloudSim [15]. To clearly demonstrate the focused trends, the following assumptions are made to simplify the modeling of the problem without losing generality. We first discuss the placement results output by the EdgeChain algorithm for the same service chain on the same set of MEHosts.

1) The unit costs of the CPU and memory of all hosts for the same MECS are the same.
2) Costs of network bandwidth for all links follow the same unit price.
3) One mobile edge application includes the same type of VMs with the same CPU, memory and network bandwidth requirements.
4) A request from the user will be processed by one VM, while the VM may communicate with other VMs to exchange information.

A. Parameters

With the assumptions above, we choose parameters for our placement model to evaluate the performance and the facts under different circumstances. First, we choose a MEC service scenario of 3 MECSs $m_1, m_2,$ and $m_3$, each with 3 MEHosts, where $h_1, h_2, h_3$ belong to $m_1$, $h_4, h_5, h_6$ belong to $m_2$, and $h_7, h_8, h_9$ belong to $m_3$.

Three identical requested service chain, each with 5 MEApps is to be placed. The MEApps of each service chain are denoted by $v_1, v_2, v_3, v_4,$ and $v_5$. The service chain starts from $v_1$ and ends at $v_5$: $v_1 \rightarrow v_2 \rightarrow v_3 \rightarrow v_4 \rightarrow v_5$. We assume that all MEApps have the same CPU, memory and
bandwidth requirements, which are shown in Table III along with other parameters.

| Parameter | Value |
|-----------|-------|
| $C_v$     | 2 vCPUs |
| $C_h$     | 64 vCPUs |
| $\gamma_{m_1}$ | 1.0 |
| $\sigma_{m_1}$ | 0.2 |
| $\gamma_{m_2}$ | 0.5 |
| $\sigma_{m_2}$ | 0.3 |
| $\gamma_{m_3}$ | 1.2 |
| $\sigma_{m_3}$ | 0.3 |
| $n_4$     | 100 users |
| $B(v_1)$  | 10000 Mbps |
| $t_{e_1}$ | 15 ms |

**TABLE III**

**PARAMETERS FOR THE MEC SCENARIO**

B. Placement trends with changing unit resource premium

The placement decision changes by the increase of $\delta_{m_1}$ under different user distributions are shown in Fig. 6, where $\delta_{m_1}$, the unit resource premium payable to the MECSP for hosting MEApps for others, increases from 0.1 to 0.6. For comparison, in Fig. 6(a), most users are from $m_1$. There is $P_{m_1} = 0.5$ and $P_{m_2} = P_{m_3} = 0.25$. Meanwhile, in Fig. 6(b), most users subscribe services from $m_3$ as $P_{m_1} = P_{m_1} = 0.25$ and $P_{m_3} = 0.5$.

From the results of the two scenarios, we learn that the MEHosts with lower combination of unit resource base price ($\gamma_{m}$) and unit resource premiums ($\delta_{m}$) will be selected first. The MEHosts of the MECSP will have more weight upon consideration if there are more users from that MECSP.

C. Placement trends with changing user distribution

To further demonstrate the impact from the distribution of the users, we simulate various scenarios with different percentages of users for $m_1$ and $m_2$, while there is no user for $m_3$. Users of $m_1$ increase from 0% to 100%, while those of $m_2$ decrease from 100% to 0%. The results have shown the trends of MEApps migrating to MEHosts owned by the MECSP that has more active users to avoid premiums charged by other MECSPs. However, resource sharing still takes place ($m_3$ hosting MEApps for $m_1$ and $m_2$) when needed for better latency results and service quality.

VII. CONCLUSIONS

In this paper, we have presented the architecture and the algorithms for mobile edge applications placement for multiple mobile edge computing service providers, leveraging the blockchain-based system called EdgeChain. Future work will be considering multiple service chains initiated by multiple users, to achieve lower overall costs for the entire system.

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