Research Report

Autonomous Agent-Based Negotiation Using Smart Contracts

THE BLOCKCHAIN TECHNOLOGY ENABLES ENTITIES TO QUERY AND ALTER INFORMATION WITHOUT TRUSTING A MIDDLE PARTY WHILE PROVIDING A SECURE DATA STORAGE IN A DECENTRALIZED MANNER. WE FOCUS ON AN IT DATA SUPPLY CHAIN SCENARIO WHERE MULTIPLE ACTORS NEGOTIATE A TENANCY AGREEMENT FOR VIRTUALIZED NETWORK RESOURCES. WE PRESENT OUR APPROACH, A BROKERLESS BLOCKCHAIN-BASED SYSTEM THAT USES SMART CONTRACTS AND A VIRTUAL NETWORK PARTITIONING ALGORITHM. WITH THIS APPROACH WE CAN OVERCOME THE INFORMATION DISCLOSER PROBLEM IN THIS SCENARIO.

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Introduction

Can a user/company always safely trust third-parties? Why not distributing these privileges among multiple users which co-operate for handling such complex tasks? Consider a service negotiation cycle in which different service providers (SPs) are willing to embed virtual nodes across multiple infrastructure providers (InPs) in order to provide wide-area network services. This process is called network virtualization or network slicing, in which typically the brokers, named virtual network providers (VNPs), are responsible for performing the service negotiation that enables the virtual network (VN) embedding. Since InPs are typically not willing to disclose detailed internal network information, even to the VNPs, this is a major deal breaker that hampers the efficiency of the service negotiation process.

For this reason, a blockchain architecture can enhance the process by removing the presence of these third-parties (VNPs) while maintaining a co-ordinated process that ensures a secure storage of data. This negotiation can be based on a time-limited auction where each virtual network request automatically creates a new smart contract on the blockchain that enables the bidding of the requested resources by the different service providers.

In our work, we focus on an IT data supply chain scenario where multiple actors negotiate a tenancy agreement for virtualized network resources (Rizk et al., 2018). The presented approach comprises of a brokerless blockchain-based system that uses smart contracts and a VN partitioning algorithm based on the Vickrey auction model (Vickrey, 1961).

The Design Approach

In the following, we introduce a conceptual design of a multi-provider virtual network embedding approach using an Ethereum blockchain as well as the underlying auction model.

In the presented scenario, a SP is willing to embed virtual nodes {A,B,C,D} across different InPs where the InPs are not willing to disclose detailed information about their resource availability or network topologies (see Figure 1). Here, the partitioning problem is treated as a cost minimization problem where the SP pursues the minimum embedding cost. Nevertheless, there is some information not considered confidential by the InPs, such as the location or the virtual node types offered by the peering nodes. For instance, in Figure 1, it is shown that InP1 has two peering nodes with locations in Germany and Switzerland that may embed virtual node types {A, B, D, E} and {F, G}, respectively. These virtual node types are used to classify the resources in different groups, each having common attributes, such as CPU, memory, storage, and network capability.

The proposed blockchain design consists of the following four main components. First, we have a private group of users, the InPs and the SPs. Only this group is allowed to access and alter the smart contract data. New users must ask for permission before joining the network. The second component, the user interface (UI), interacts with the blockchain through a given API. The blockchain itself, as the third component, is based on the Ethereum architecture. This allows the creation of smart contracts – the fourth part – that reflect the needs of the users into code and can be created or called either from another contract or simply by a user.

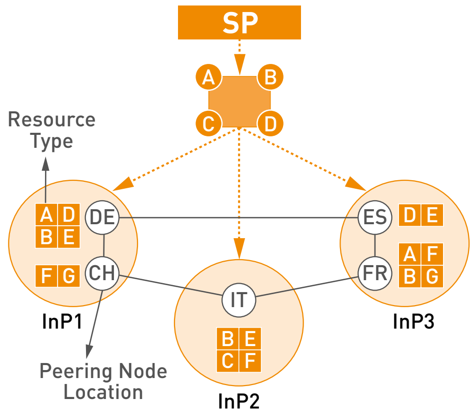


Figure 1: Virtual Network Embedding

In the following, we introduce the virtual network embedding (VNE) process itself. An SP requests a virtual network. A virtual network can be represented as a graph $G^R = (N^R, d^R)$, where N^R consists of a set of k virtual nodes, and d^R the set of all bandwidth demands between the virtual nodes. In our example, the graph consists of four virtual nodes {A,B,C,D} (see Figure 1). Moreover, each virtual node is formed by a collection of attributes, such as the desired location (l) or the upper bound cost (u) which may be the maximum amount that an SP is willing to pay for a virtual node.

Before the auction starts, the associated set of attributes (e.g., locations, bandwidth) of the requested virtual nodes is matched with the InPs entered data in the smart contract. For instance, virtual nodes {A, B} and {C, D} will be matched with InPs possessing physical nodes in Germany (DE) and Switzerland (CH), respectively.

Then the auction starts and a corresponding smart contract as a limited time auction is created. Since the bidding and the virtual network lifetime must terminate, the SP is required to specify a bidding period and a lifetime to the request.

After the new auction contract is created, the included InPs are notified. Before bidding, the SPs typically evaluate the requested requirements into their network, such that the set of physical nodes and physical links can fulfill the request. We assume that InPs are interested in serving requests at maximum profit and also note that a single InP may not be able to serve all of the virtual nodes requirements.

Once the auction has finished, each virtual node is assigned to the winning InP that minimizes the VN embedding cost. These winners are now publicly known by all participating users and thereupon, VN segment map ping and stitching between the InPs may be performed.

The proposed auction model makes use of a Vickrey auction model, in which it is known that if each bidder quotes the true cost of the service, bidder's expected utility is maximized. The Vickrey auction model has the particularity of corresponding to a sealed-bid auction, in which during the bidding time bidders do not know other bids and, eventually, how the auction is evolving. In addition, this auction model corresponds to a second-price tender where the bidders will offer a price for the service and the highest bid will win. Nevertheless, this service will be rendered at the second highest value. Thus, a Vickrey auction is considered a fair-price system since it provides a reasonable price to the buyer by motivating bidders to bid truthfully.

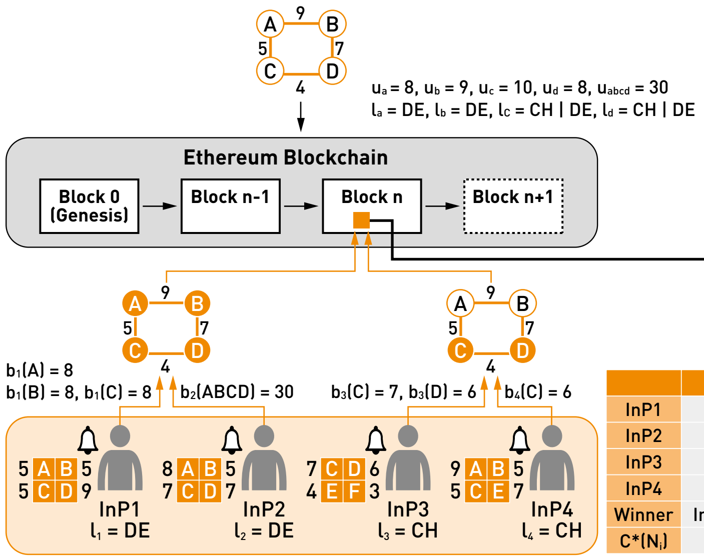
Virtual Network Embedding with Limited Information Disclosure

We adapted the auction model to the multi-provider VNE problem with limited information disclosure. Firstly, we seek an efficient virtual network partitioning where the requested virtual nodes are assigned to the participating InPs such that the VNE costs are minimized. However, we only consider the price quotes of the notified InPs to determine the minimum VNE cost. Hence, the InPs act as sellers who submit bids for the services requested by the SPs, and, once the auction finishes, the VN is split between the winning InPs. Since in our scenario SPs request the embedding of different virtual nodes, we are facing a multi-unit auction. Thus, before defining the minimum VN cost using the Vickrey auction, it is important to note that InPs can submit bids per virtual node or for a group of virtual nodes.

Consider the example from Figure 1. Now, four InPs compete for virtual nodes which are requested from a SP with: {A(u_a=8;l_a=DE), B(u_b=9;l_b=DE), C(u_c=10;l_c=CH or DE), D(u_d=8;l_d=CH or DE)} or {G(u_{abcd}=30;l_{ab}=DE and l_{cd}=CD or DE)}.

Here, an InP bids either for the entire virtual network G or for individual virtual nodes, depending on the number of paired resources. If all the virtual nodes' locations and types match with certain InP nodes, then the system enables that the InP bids for the entire virtual network. If not, an InP is only allowed to quote prices for the paired virtual nodes.

The bidding process gives the following result (see Figure 2): InP1 located in Germany is only able to bid for nodes A, B and C with equal cost of 8. InP2 is able to bid for the whole network G with cost of 30. InP3 bids for node C and D with cost of 7 and 6, respectively. InP4 only bids for node C at cost of 6. At the end of this auction, since the sum of the individual quotes is less than the package pricing min{30; 29}, the virtual network is partitioned across different InPs, i.e., A → InP1; B → InP1; C → InP4; D → InP3. In addition, the prices that the SP must pay to each InP (C*(N_i)) are the ones resulting from the low-bidding second-price auction as one can see from the table in Figure 2.



	A	B	C	D	ABCD
InP1	8	8	8	∞	∞
InP2	∞	∞	∞	∞	30
InP3	∞	∞	7	6	∞
InP4	∞	∞	6	∞	∞
Winner	InP1	InP1	InP4	InP3	–
C*(N_i)	8	8	7	6	–

Figure 2: The Auction Algorithm: Four InPs Bid for One VN Request

Since network virtualization is a real-time process where the demand and availability of the resources are constantly changing, our approach encourages that users apply dynamic pricing models. A dynamic pricing model is a strategy where the prices are flexibly adapted to the current market demands. In our approach, InPs can consider the current SP demands and the current availability of the resources to optimize their bids. In our scenario, this demand is related either with the computing or the bandwidth requirements, and the supply with the resource utilization.

Evaluation

In our work, we evaluate the efficiency of the proposed brokerless inter-domain virtual network embedding system. We introduce a pricing model used for the InPs to dynamically quote their services, as well as a performance comparison of different consensus algorithms that are used in the deployed blockchain (Rizk et al., 2018).

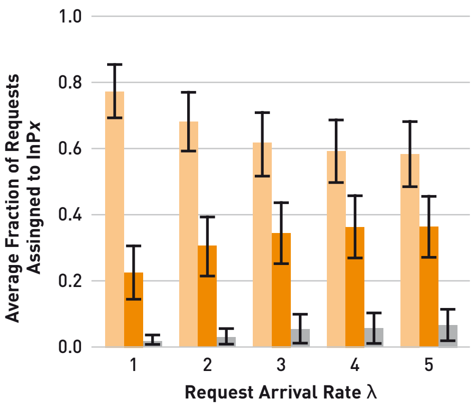


Figure 3: Average Fraction of VN Requests Assigned to Each InP with Different Profit Margins at Varying Request Arrival Rates λ [request/sec]

The main goal of our evaluation is to show the feasibility of the introduced approach and to demonstrate its potential. To this end, we are using the following metrics:

Acceptance rate: Based on our approach and the proposed pricing model, we examine the VN embedding efficiency through its acceptance rate. This VN acceptance rate is the percentage of embedded virtual nodes from the total incoming VN requests.

Bidding strategy: The bidding strategies are evaluated based on how the profit margins employed by the different InPs produce significantly different revenues in certain scenarios.

Blockchain performance: The blockchain performance will be verified basically in terms of the block generation time (mining) and the number of forks. The former is an accurate method to express the speed of the transactions since each block contains multiple transactions. The latter expresses the amount of useless work and the possibility of non-synchronized state among the nodes.

Our evaluation shows that the *average acceptance rates* depend on the lifetime of the virtual network request, but that in all cases the system reaches steady state as the number of VN requests grows.

The evaluation results for the bidding strategy can be seen in Figure 3. It shows the average fraction of requests assigned to each InP. The InPs are heterogeneous with different profit margins (InP1 < InP2 < InP3). We observe that for low arrival rates (λ) the fractions differ significantly as the resources are not yet fully occupied. Hence, the InP with lower profit margins, in this case InP1, embeds most of the VN requests. In contrast, for larger λ, the second InP starts to gradually increase the number of embedded VN requests since the resources of InP1 are now more utilized, which affects its bidding strategy. Finally, the fraction of InP3 increases in the same vein. With large arrival rates λ, InPs with higher profit margins start to embed more virtual network requests.

Regarding the *blockchain performance*, we have evaluated the proposed proof of elapsed time (PoET) consensus model. We showed how it depends on the number of InP miners in the system and that increasing this number with all other parameters being fixed increases the transaction throughput, i.e., decreasing the block generation time, but also increases the number of blockchain forks which is highly undesirable. We note that this trade-off has to be subtly designed when fixing the system parameters.

Conclusions

In this article, we have shown the design, implementation, and evaluation of an approach that uses the blockchain technology to enable a brokerless supply chain for inter-domain virtual network embedding.

The main idea behind came from observing the lack of a single solution that provides distributed trust and management to solve the VNE problem given limited information disclosure of the participating parties. By introducing a blockchain, it was achieved to get a scalable system with reduced set up complexity, lower maintenance costs, distributed trust and decentralized management, and data confidentiality. The results show that the defined approach is fair in terms of cost and embedding distribution across the InPs. Finally, we do not claim that our approach is the only viable way of performing VN partitioning, however, thanks to smart contract's flexibility we now provide brokerless inter-domain virtual network embedding in an automated way under limited information disclosure.

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