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A Blockchain-Based Network Slice Broker for 5G Services

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***Abstract*—With advent of 5G, the classical mobile network business model is shifting from a network-operator-oriented business to a more open system with several actors. In this context, the Network Slice provider will play the role of an intermediate entity between the vertical service provider and the resource provider. To deploy a network slice, the network slice provider will require a brokering mechanism, which allows it to lease resources from different providers in a secure and private way. In this paper we propose a broker design based on Blockchain technology, providing a mechanism that secures and ensures anonymous transactions.**

***Index Terms*—Network Slicing, 5G Network, Blockchain**

I. Introduction

5G represents the last evolution of mobile networks. It is not only about increasing the physical data rate, as the precedent generations did (3G and 4G), but provides a completely new vision of mobile networks. 5G aims at opening the mobile networks to vertical industries to unify and simplify the management of networks. In 5G, not only broadband services will be deployed, but also services that usually have their own network technology, which is proprietary and closed, such as automotive services, Internet of Things (IoT) based services, and industry 4.0.

To support these different type of services, which usually operate on a dedicated network, 5G relies on the concept of *Network Slicing*, which consists in sharing the same physical infrastructure by using several network substrates, known as *Virtual Networks*. The recent evolution of network architecture [1], known as *Network Softwarization*, will be the main enabler of Network Slicing. Network Softwarization consists in running network functions (Virtual Network Functions (VNFs)) as software components to be hosted in the cloud, inside Virtual Machines (VM) or containers. It is well established that a network slice will be composed of a set of VNFs and PNFs (Physical Network Functions), connected together to enable a network service, which requires computation and storage capabilities to be provisioned on a cloud infrastructure (including edge clouds to run delay-sensitive VNFs), but also radio resources from the Radio Access Network (RAN).

A Network Slice has to be managed as a classical network, requiring specific functions to handle its lifecycle (known as Life Cycle Management - LCM). The main difference with classical networks consists in the fact that a network slice may have a lifetime duration, according to the service needs, which requires additional orchestration functions to provision and decommission the virtual resources dedicated to it. Moreover, a network slice is a composition of sub-slices, which can be common or slice-specific [2]. When stitched together, the sub-slices create an end-to-end slice carrying a 5G network service. It should be noted that the resources of each sub-slice could be provisioned from different administrative or technological domains, also known as federation.

By enabling Network Slicing, 5G will change the current economical model by introducing new stakeholders. Indeed, the market will be composed not only by network operators and service providers, but it will see the appearance of verticals (or the slice owners) and slice providers. The latter will act as brokers, selling network slices to verticals and leasing resources from resource providers (such as network operators or cloud providers) to build end-to-end slices. In this context, the slice provider requires specific resource brokering mechanisms.

Samdanis *et al.* [3] described the need of a network slicing broker and its role be in future 5G. The authors also studied 3GPP standards towards easing the role of the resource broker. However, these solutions do not consider the economic model of the system as they present only technical solutions to expose mobile resources provided by an operator. Indeed, the slice broker needs to consider in the first place the business model of the slice provider and maximize its profit by using auctions or other trading mechanisms. The auction system should be *secure* and *anonymous*, in a sense where an offer from competitors should be known only by the broker. Furthermore, the propositions provided by competitors should be respected and followed by a Service-Level Agreement (SLA) signed with the slice provider. In this context, we consider Blockchain as a promising solution for the implementation of a brokering mechanism to be used by the network slice provider.

Blockchain technology [4], initially developed to be used in Bitcoin to provide a fully-distributed and secure ledger, has already been studied as an enabler for a diverse set of services. These range from automotive application scenarios [5] to content delivery, where Herbaut *et al.* [6] have explored the use of a distributed Blockchain to create smart contracts for CDN as a Service (CDNaaS). However, this model cannot be

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applied in the context of network slicing, as the latter is highly centralized around the slice provider.

In this work, we exploit Blockchain technology to enable the network slice provider to securely build end-to-end network slices, by using resources from different stakeholders involved in the 5G network. When a slice provider receives a request to build an end-to-end slice, it publishes in the Blockchain a request for resources regarding each sub-slice composing the end-to-end slice. After receiving the different offers for each sub-slice, the slice provider selects the best offer in terms of cost and the capabilities to meet the requested performance.

II. Background and motivation

A. Network Slicing in 5G

Network slicing [7] represents the main enabler to support 5G services. Different ongoing research projects, under the 5GPPP umbrella, aim to build the concept of network slicing by proposing reference architectures and enabling mechanisms. Standardization organizations, such as ETSI NFV and 3GPP groups, provide an architectural solution for the management and orchestration of network slices [8], [9]. Most known is the NFV model, which aims to build an ecosystem to orchestrate and manage network services that compose a network slice.

One common agreement so far is to classify 5G services into three categories of network slices: eMBB (enhanced Mobile Broadband), uRLLC (ultra Reliable and Low Latency Communications), and mMTC (massive Machine Type Communications), which allows to differentiate among the network slices and their requirements in terms of resources. For instance, uRLLC requires very low latency access for the deployed service, such as automated driving, while eMBB needs very high bandwidth and data rates to sustain the application quality, such as for Virtual and Augmented reality. Indeed, each type of slice requires a particular behavior of the network, which is translated into specific types of resources (e.g., VNF, PNF, CPU, storage, RAN resources, transport network, etc.). The sub-slices composing a network slice belong to different technological domains, which may be part of the same or different administrative domains. For example, a RAN sub-slice is dedicated physical Resource Blocks (pRB) [10] and dedicated eNB functions, which can be virtualized (in the form of VNFs) [2], while a Core Network (CN) sub-slice is exclusively composed by VNFs along with their computation resources (CPU, storage, memory). Stitched together, via specific interfaces [11], sub-slices will compose an end-to-end network slice that fulfills the requirements of the requested 5G service [12]. Accordingly, the resources composing a network slice could be provided by a single resource provider (i.e., all the sub-slices are provided by the same operator or domain), or from different resource providers (or administrative domains); in the latter case, we refer to a multi-domain end-to-end slice [11].

In 5G, a network slice provider is separated from a resource provider, which could be a network provider (for the RAN and transport network) or a cloud provider (for VNF deployment, including the CN functions). The network slice provider needs to select carefully the resources, on the one hand to reduce the cost and make a profit, and, on the other hand, to ensure the necessary resources for a specific slice to respect the SLA, which will be signed with the vertical or slice owner.

B. Blockchain Overview

Blockchain technology [13] was originally developed for use in Bitcoin to provide fully-distributed and secure transactions between anonymous participants without the need for a centralized entity. Blockchain is a distributed chain of blocks (ledger) that can be considered as a database of digital deals. Once a new block is created, it should be validated by peers before being added to the chain. This validation process is known as Proof-of-Work (PoW), which makes the system secure. Also, by adding a new block to the chain, it is not possible to change its content or remove it (immutability). Based on Blockchain's application, we distinguish two types:

- *Permissionless Blockchain*: This is also known as public Blockchain network, where every user is allowed to create transactions and add them to the ledger in a fully decentralized and anonymous fashion. Furthermore, any node can act as a miner to verify transactions. An example of this type is Bitcoin.
- *Permissioned Blockchain*: This is also known as private Blockchain network, where users are not free to join the network, consult transactions, or add new ones. This networks are centralized (e.g., organization, government, etc.).

For more information on the Blockchain concept, the reader may refer to [4].

III. Blockchain-based Resource Broker for 5G

A. System Description

We envision a sub-slice deployment brokering mechanism as a series of small contracts. Each contract has a unique identifier and some data fields, and can perform actions such as creating a new contract or updating the state of the Blockchain. Contract actions are triggered by on-chain data updates (i.e., the creation of a new contract). Each sub-slice generates a contract. The end-to-end slice is ready for the deployment once all the contracts regarding its sub-slices are negotiated and finalized.

Figure 1 describes the process of network slice creation from a business point of view. Here, we omit the technical details on the orchestration and management procedures. The vertical or the slice owner requests the creation of a network slice using a template or a blueprint. This template may contain high-level information.The slice provider will translate the template to specific slice resource requirements, such as the number and types of sub-slices, PNFs, VNFs, CPU, I/O, memory, storage, etc. As illustrated in the figure, the sub-slice components are translated to resources of a Technological Domain (TD). A TD can be a computing resource domain (such as CPU, I/O), a storage domain, a radio domain (eNB, Central Unit - CU, Distributed Unit - DU, Remote Radio Head - RRH / Remote Radio Unit - RRU), and transport domain

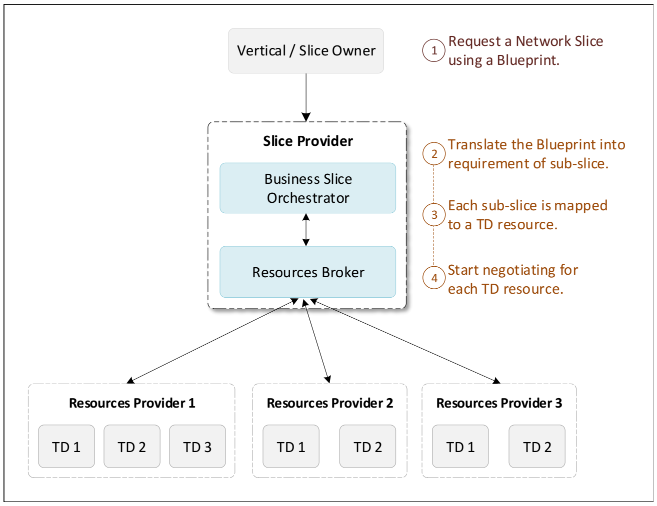

Fig. 1. Network Slice Creation Process.

(e.g., VLAN, VPN). We assume that a slice is composed by several TDs, noted as $NS = \{TD_1, TD_2, TD_3, \cdots, TD_n\}$. For each TD, the slice provider describes the needed resources according to the slice type. For instance, in the case of the computing resource domain, they could include the number of CPUs, VM instances, etc. For the radio domain, resources could be related with the functional split type [1], the MAC scheduler algorithm, the number of Physical Resource Blocks (PRB) and others. Transport domain resources, on the other hand, may include the type of a link (bandwidth, latency), number of VLANs, front haul link capacity, VPN links, QoS, etc. We define $R(TD_i) = \{p_1, p_2, p_3, \ldots, p_n\}$, as the set of parameters requested by TD_i.

B. Sub-Slice Brokering

Once each sub-slice is described in terms of resources (i.e., $R(TD_i)$), the request for each sub-slice is sent to the Blockchain (permission-less network). Each sub-slice will generate a contract to be negotiated. Once the query for a sub-slice arrives at the Blockchain, a Sub-Slice Contract (SSC) is created and published. This contract specifies the necessary resources needed by the sub-slice (i.e., $R(TD_i)$) and the duration of the sub-slice. The different resource providers are notified of the new SSC. Since all the SSCs are visible on the Blockchain, the resource providers respond by publishing Sub-Slice Deployment Costs (SSDC), which specify the cost that the resource providers are willing to charge for providing the necessary resources for each component of the sub-slice $R(TD_i)$. The original SSC collects all the related SSDC and arbitrates according to specific objectives (e.g., cheapest, best in terms of quality, or other criteria). All other contracts are terminated, and the winning contract is used to deploy the sub-slice components. All related information about the sub-slice deployment is recorded in a permissioned Blockchain managed by the slice provider.

Relevant information on the different interfaces allowing to access to the sub-slices, such as the stitching interface (the Resource Orchesrtator (RO) interfaces and their description), are compiled in a Sub-Slice Deployment (SSD) document.

C. Sub-Slice Deployment

Once the resources are negotiated and an agreement has been settled with the selected resource provider, the Slice Orchestrator (SO) handling the LCM of the deployed network slices, will use the RO interfaces indicated in each SSD to: (i) instantiate and create the sub-slice; (ii) stitch the sub-slice with the other sub-slices to build the end-to-end network slice. Note that each resource provider uses its domain RO to manage and orchestrate its resources. The resource provider exposes interfaces to allow other ROs or the SO to interact with the local RO. For further details on the orchestration of multi-domain resources and the stitching process, readers may refer to [11]. Finally, it is important to note that the RO needs to provide monitoring information on the resources used by the sub-slice in its domain. This allows the slice provider to verify that the resource provider is respecting the signed SLA included in the SSD.

IV. Proof of Concept and Evaluation

In order to evaluate the performance of the proposed architecture, we have implemented a prototype of the proposed mechanism using Python. We simulated requests coming from 20 verticals. We assume that 50 resource providers are available, where each one has from 2 to 3 TDs. We tested up to 20 parallel requests managed by the Blockchain, being confident that this number is a good representative of a case of a high number of requests coming from verticals. The slice broker uses only the cost as a criterion for selecting the resource provider. It is worth noting that other metrics, such as the requested type of slice (e.g., eMBB, uRLCC, or mMTC), the number of users, the targeted areas, the duration of the network slice and the applications provided for the slice users, could be considered; but do to space limitation, it is left for future work. We have implemented Hashcash as the PoW algorithm, similar to Bitcoin's PoW. However, other consensus mechanisms may also be used without altering the system design and objective (e.g., Proof of Stake, Proof of Burn, Proof of Retrievability, etc.) [14].Finally, the evaluation has been performed on Intel Xeon(R) CPU X5650 2.67GHz x 8 with 8 GB of RAM.

The evaluation focuses mainly on the time needed to negotiate the resources for a network slice, excluding the time taken by the ROs to deploy the sub-slices on their domain. As stated earlier, our main motivation for using Blockchain technology to build our brokering mechanism is to overcome the major challenges in terms of security, privacy, and anonymity. Indeed, the proposed Blockchain-based broker adds not only security, but also privacy and accountability.

In Figure 2, we illustrate the average time required to create a sub-slice contract and get the validated sub-slice deployment cost. It is worth to recall that a sub-slice is using only resources from a single technological domain (TD). We can notice that when the number of SSCs increases, the required time also increases, due to (i) the time needed to negotiate sub-slice resources with the different resources providers, and (ii) the complexity to validate the Proof-of-Work, i.e., the time to validate the transaction before adding it to the chain. The average time is linearly proportional to the number of parallel network

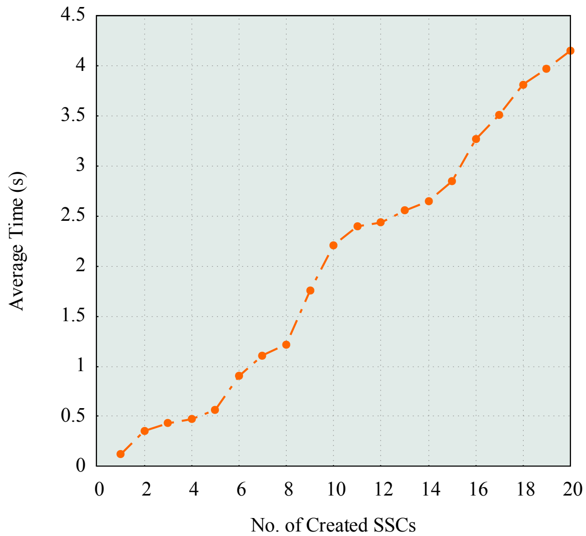

Fig. 2. Average time for Sub-Slice Contract creation and validation.

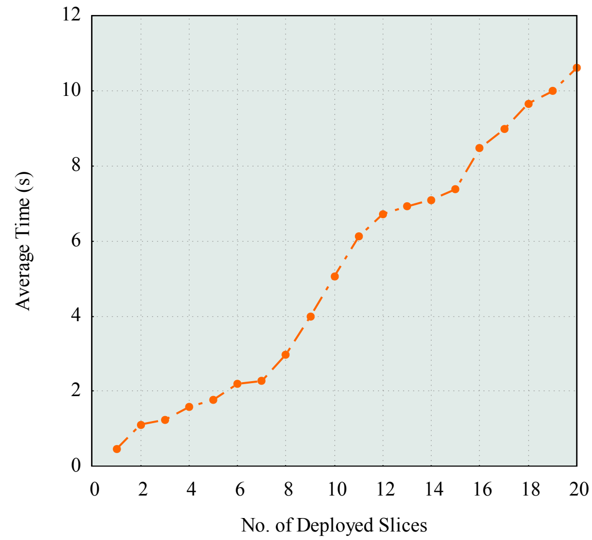

Fig. 3. Average time for slice deployment.

sub-slices created. Figure 2 shows only the instantiation of one sub-slice. In Figure 3 we present the average time to deploy a full end-to-end slice, that is, negotiating all resources and getting agreements with the resource providers. We assume that an end-to-end slice is composed of three sub-slices, i.e., three resource providers need to be selected. In this case, two main factors may affect the time of deployment: (i) number of allocated TDs, and (ii) the time to negotiate, satisfy, and validate each sub-slice contract among the slice requests. The complexity of the latter factor (PoW algorithm) has a direct effect on its performance, which is highly dependent on the configuration of the node which solves the PoW challenge. Furthermore, we see that in the case of 20 parallel requests, the time needed to deploy the slice is growing to up to 10 s. As for the precedent figure, we remark that the time of creation of a complete slice is proportional to the number of parallel requests. Although the time needed to instantiate a slice requires seconds to be deployed, it has no impact on the slice provider business, as slices are created offline.

Finally, Table I provides a qualitative analysis on different security and privacy features added by the proposed Blockchain-based broker compared to regular broker.

V. Conclusion

This paper explored Blockchain technology as a means of building a brokering mechanism to be used by a network slice provider in a 5G network. The slice provider is a new business entity included in 5G, which aims to select the resources from different resource providers to create end-to-end slices. A proof of concept has been developed to show the performance of the slice broker, has been evaluated focusing on the time to negotiate the resources. The obtained results show that the added security and privacy features of Blockchain do not have a significant impact on the performance of the slice broker. Future work will focus on (i) adding other parameters to the Blockchain, when selecting the RO, instead of using only the cost, and (ii) exploring other PoW algorithms.

TABLE I
COMPARISON OF DIFFERENT SECURITY AND PRIVACY FEATURES.

Properties	*Regular Broker*	*Blockchain-based Broker*
Secure contract negotiation	✗	✓
Secure auctions/trading	✗	✓
Secure end-to-end slice	✗	✓
Anonymous Transaction	✗	✓

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