End-to-End Inter-domain Transport Network Slice Management Using DLT-enabled Cloud-based SDN Controllers

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Abstract: This paper discusses the advantages and challenges of multiple architectures that consider the negotiation of inter-domain transport network slices using blockchain technologies. To this end, we presents results obtained using cloud-native ETSI TeraFlowSDN controller.

1. Introduction

SDN leads towards a centralization of the control and management tasks to a logically centralized SDN controller, which at certain level becomes inefficient and so, multiple transport domains are required. The co-existence of multiple transport domains helps on the overall resources management, increasing their security (e.g., isolating [1] one domain from the other in front of threats) and performance.

From an End-to-End (E2E) point of view, it is necessary that all SDN transport domains may interact among them to be part of inter-domain transport Network Slices deployments. At this point a new issue might appear, how to have a trust-based relationship among transport domains from different transport operators/owners without the need to centralise the E2E management [2] and depend on third party entity. A possible solution may be the use of a Distributed Ledger Technology (DLT), for example a Blockchain system.

A Blockchain [3] is a geographically distributed database in which all peers (i.e., participants) create a network among them and have an equal copy of all the stored data, avoiding a central point of failure to access and store new and updated data. Blockchain works based on a Peer-to-Peer (P2P) system in which all the peers are equal in terms of decision and transparency: a) no peer has more authority than the others (i.e., they must reach an agreement to add or update information), and b) all peers have the same exact copy of the stored data (i.e., stored data becomes immutable without a peer majority to add/change new/stored information). In the scenario with multiple transport SDN domains, Blockchain is a possible solution to assist on a cooperative and collaborative management of transport network slices.

Blockchain works by gathering a set of transactions (i.e., a piece of information) and store them in blocks that are linked one to another using the hash of the prior block, and so a chain of blocks is created. For each new block to be added, all peers need to validate it and agree using the consensus mechanism (e.g., Proof of Work, Proof of Stake, etc.) defined in the Blockchain system which may be either permissioned (i.e., only selected entities have access) or permissionless. The main strengths offered by a Blockchain system are: a) balance between privacy and transparency, b) no need of a central authority, c) secure with timestamped, tamper-proof and immutable data, d) verifiable, integrity and trustworthyand d) the use of Smart Contracts (SCs). Finally, the main challenges faced by Blockchain are: scalability and energy efficiency and its technological youth.

This paper describes different architectures and use cases on how DLT (i.e., Blockchain) might be used on the management of different aspects related to the creation and management of E2E Inter-domain Transport Network Slices and the advantages and challenges of the proposed architectures.

2. Blockchain-based Inter-domain Management Models

Among the different solutions proposed in this article, all the transport controllers are part of a Permissioned Distributed Ledger (PDL), this avoids the possibility that any non desired entity may become part of the whole network and become a threat without the peers to know. Based on this and as Fig. 1 illustrates, the two models were designed based on the possibilities that Blockchain may offer using each transport domain SDN controller as the peer participating in the Blockchain network.

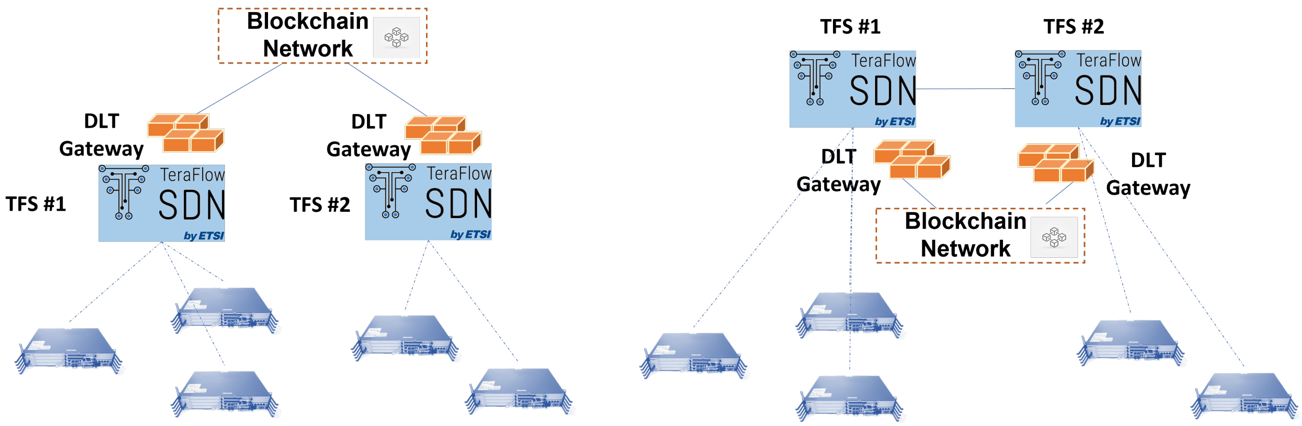

Fig. 1. PDL proposed architectures, Full PDL (left); Complementary PDL (right)

The first model (Fig.1-left), called "Full PDL", uses Blockchain as the key element in any interaction [4] among the transport SDN controllers (TeraFlowSDN elements in Fig.1). In this model Blockchain takes care to store and distribute all the information among the peers, moreover the use of SCs may remove easy and repetitive tasks from the transport SDN controllers solutions, making the Blockchain technology an even more integrated element within the inter-domain actions. While having all the information within the Blockchain brings positive advantages in terms of security and immutability, it is not the best solution due to certain restrictions in terms of latency. As presented in [5], this model needs to be carefully implemented taking into account possible issues in terms of latency. This is because the validation and acceptance of new/updated information within the Blockchain may take a minimum of some seconds, which is a high delay compared to certain SDN actions that can be done in less than a second.

To solve the previous issue, a second model (Fig.1-right) called "Complementary PDL" was designed. In this case, the Blockchain technology is placed in a second term and it is used to store and distribute specific information samples, leaving the communication among peers to other existing P2P communication protocols. In this model, Blockchain acts as a database for specific sets of information. Two possible use cases for this second model are: a) the topology export and b) elements traceability. In the first case and as similarly done in [5], Blockchain is used only to store and distribute the static information related to the SDN topology using abstraction models. In the second case, as there is no central authority on top of all domains, the use of Blockchain focuses on the immutability and transparency offered in order to check, if necessary, the owner of used resources or the responsible of a committed element (i.e., Service Level Agreement).

Both models should not be considered as opposites (e.g., hierarchic vs. mesh) but as two possibilities that may be implemented depending on the necessities of the scenario and in the future evolutions of the Blockchain. For this reason, the transport SDN controllers should be adaptive enough to be implemented in both models as it happens with the TeraFlowSDN Controller [6], with its cloud-native-based architecture illustrated in Fig.2 (left). TeraFlowSDN architecture based on micro-services allows the quick prototyping of the proposed use cases, as demonstrated for providing end to end connectivity in [7], or inter-domain connectivity using Full PDL architecture as demonstrated in [8].

The main module that gives the adaptation capability to this SDN controller is the "DLT" component. Due to the cloud-native nature of the architecture, any module is able to interact with the the other modules and so the two previous use cases (i.e., topology export, traceability) can be easily configured as the workflow to interact in the Blockchain is always the same (Fig.2-right). First, each DLT domain has to subscribe to the Peer (i.e., Blockchain system) to accomplish the "initialization" phase. Then, for each new data to record (i.e., Record$\{X\}$), the module owning the outcome (e.g., Inter-domain or Context) sends it to the DLT, which triggers the transaction with the "RecordtoDlt" and "DltRecordStatus" requests using the Peer. Then, the Peers (i.e., Blockchain) synchronize the data and after it, an event is generated to distribute the record identifier (record_id) among all domains. Finally, the DLT of each domain obtains the Record$\{X\}$ information and passes it to the the corresponding module (Context or Inter-domain).

3. Analysis and evaluation of Blockchain-based TeraFlowSDN architectures

In this section we analyse the previously presented architectures and use cases, while considering a qualitative analysis of significant topics into consideration, such as Setup delay, security, energy consumption and scalability of the

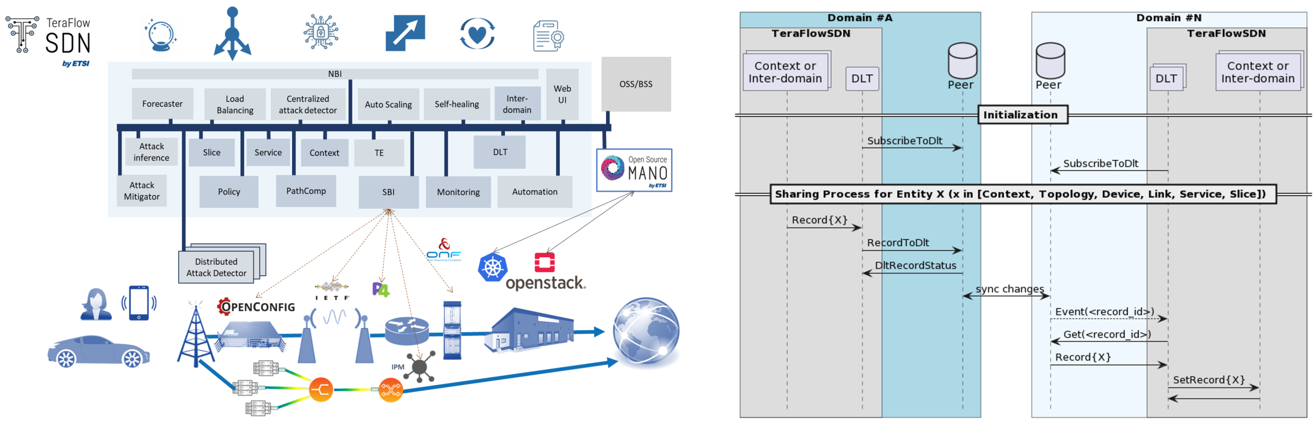

Fig. 2. ETSI TeraFlowSDN release 2 architecture (left); Sequence diagram for DLT usage (right)

proposed solutions.

Full PDL is able to provide high security bur at the cost of lower level of scalability and higher energy consumption and setup delays. For the complementary PDL, the results might depend on if the PDL is used in an initial exchange only (such as in the use case of topology export), or if the PDL is used dynamically for storage (such as for element traceability). Table 1 provides the expected quantative results.

	Full PDL	Complementary PDL topology export	Complementary PDL element traceability
Setup Delay	High	Low	Low
Security	High	Medium	Low
Energy consumption	High	Low	Medium
Scalability	Low	Medium	High

Table 1. Advantages and challenges of the proposed PDL architectures and scenarios

4. Conclusions

We have presented and analyses multiple architecture for blockchain applicability into inter-domain provisioning of transport network slices.

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