Blockchain-Based Intelligent Network Management for 5G and Beyond

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***Abstract* — The concept of spectrum and infrastructure sharing appeared to solve the problem by allowing operators to cooperate between each other. However, the current architecture of mobile network, which is mostly based on the centralized management entities is not suitable for the spectrum and infrastructure sharing due to the complexity of billing procedure. Moreover, the operator oriented mobile network is slowing the overall technological development, because operators must balance between capital expenditures and profit margins. Such situation negatively affects users, because they are either experience lower quality of service or forced to pay higher price. In this paper, we propose a new intelligent network architecture, which leverage the blockchain technology to handle relationship between operators and users based on smart contracts. The new unlicensed spectrum sharing algorithm between operators using the virtual cryptocurrency has been developed based on game theory. Simulation results show that proposed algorithm achieves Nash equilibrium between operators within few seconds.**

Keywords—5G, AI, blockchain, spectrum sharing

I. Introduction

In the era of wireless digital world, the importance of reliable wireless connectivity with target performance increases exponentially. Regardless of the technological achievements of 5G networks, the physical constraints such as limited spectrum and infrastructure availability are still major limiting factors, which prevent operators to scale their services properly.

Spectrum limitation in wireless networks cause a lot of complexities for fast improvement of throughput and service quality. Operators are forced to invest large amount of money in their infrastructure, in order to maximize the capacity by network densification and higher frequency reuse factors. The dark side of such trend is that infrastructure becomes more expensive, spectrum price is getting higher and total cost of ownership for operator increases drastically [1].

In order to reduce the capital expenditure (CAPEX) and operating expenses (OPEX) of the mobile network operator, the concept of self-organizing network (SON) has appeared to improve the management of dense and complex heterogeneous network infrastructure in an autonomous fashion [2].

Nowadays, with the rise of big data and artificial intelligence, the applications of SON have been facilitated by use of new state-of-the-art algorithms for spectrum management, coverage optimization, mobility management, QoS (quality of service) control, and many others [3]. It is difficult to overestimate the impact of big data on the future ecosystem of artificial intelligence. Being "the electricity of mind," data are essential part of any intelligent network management algorithm.

The emergence of cloud computing has introduced scalable and powerful computing and storage infrastructures, which opened new opportunities for smarter algorithms. The cloud infrastructure provides a good platform for effective management of big data that allows handling of massive computing tasks and training more complex intelligent algorithms. This feature is helpful for network management, because more parameters can be optimized to achieve better performance from the 5G infrastructure. Moreover, the scalability of cloud systems provides flexible computational capacity, which can be adjusted for various types of 5G deployment and management scenarios [4-6].

In addition to technical limitations, there are also economic constraints, which prevent the fully autonomous network operation. For example, it is not yet clear how different operators will operate simultaneously in autonomous fashion, if they will be forced to share the spectrum or even infrastructure. Moreover, roaming between operators is still complex and expensive for all parties. We propose to utilize the latest advances of blockchain technology to simplify relationship between all parties it the mobile communications market [7].

Blockhain can disrupt traditional established relationships between end users and mobile network operators. Technically, blockchain is a continuously growing list of transaction records, i.e. blocks. Each new block is dependent on the previous one in a way that cryptographic hash of the previous block with timestamp, and transaction data is included in the new block. Such feature prevents data modification, because any attempt to create fake block will lead to the wrong hash in the following blocks on the chain, so that such transaction will not be accepted by other nodes. Thus, blockchain provides a distributed ledger that record transactions between two parties in a secure manner.

In this paper, we integrate blockhain and AI in the future intelligent mobile networks to open a door for various intelligent network management algorithms.

The remainder of the paper is organized as follows. Section II covers the detail description of the proposed blockchain-based intelligent mobile network architecture and proposed blockchain solutions for mobile networks. Simulation results and performance analysis are provided in Section III. Finally, we conclude the paper in Section IV.

II. BLOCKCHAIN-BASED INTELLIGENT NETWORK ARCHITECTURE

A. *LTE Network Architecture*

The major current limitation is that conventional network architecture based on LTE (Long Term Evolution) is not very suitable for purely autonomous intelligent operation. First of all, it is necessary to reconsider current core network, which is responsible for handling all data flows, which come from the wireless infrastructure. In current hierarchical architecture, each base station is connected to the mobility management entity (MME) and serving gateway (S-GW). S-GW establishes connection to the packed data network gateway (P-GW). All information about users is stored in HSS (Home Subscriber Server). P-GW is connected to the external IP network (i.e. Internet) and to P-GWs of other operators. Literally it means that data flow of user should pass the whole tree, depending on the particular location [8].

All entities in the can be virtualized by using Docker containers. Usually, EPC can be built within one container, while eNBs use separate containers. Technically, eNB can be combined with EPC in a single container. However, for our concept of distributed mobile network based on blockchain we keep them separate.

B. *Intelligent Blockchain-Based Distrubuted Mobile Network Infrastructure*

There are two mainstream applications of blockchain technology: cryptocurrencies and smart contracts. While cryptocurrency is purely an asset of financial market, the smart contract allows two parties to agree upon particular commercial relationships in the physical world. We exploit these two features of blockchain to improve the overall technical and economic aspects of the mobile networks.

First of all, we introduce following entities in the next generation wireless communications market (Fig.1).

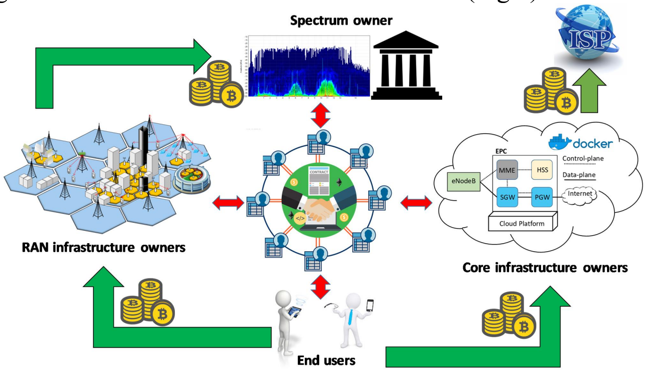

Fig. 1. LTE network architecture.

Spectrum owners. Wireless spectrum is key component of any wireless communication system. In conventional mobile market, spectrum is licensed by the government for particular technology (i.e. LTE, 5G, etc.). Such license can be purchased by mobile network operator in order to legally provide services to his users. In our model, we assume that spectrum market is open, i.e. no one can buy it exclusively. Instead, government body owns the entire spectrum and leases it to the infrastructure owners (i.e. mobile network operators) for specific price per time unit. Technically, such transactions can be implemented by using blockchain technology. For example, spectrum owner can issue tokens (i.e. cryptocurrency assets), which price is equal to 1 Hz/second, so that infrastructure owner will have opportunity to access the spectrum depends on the amount of tokens in his account.

Infrastructure owners. Currently, mobile network operators heavily invest money in their infrastructure. In our model, we propose to use open infrastructure market, so that anybody can invest money in the infrastructure and create his own mobile virtual network operator (MVNO). Since infrastructure consist of wireless base stations and core network, they can be separately owned by different entities. For example, one can invest in the base station deployment, while other will invest in the server which can accommodate virtual EPC (Evolved Packet Core), where all required functions will be virtualized in a form of virtual machines or Docker containers. In this case, they can share the revenues, which are paid by end users. Since base station owner needs to pay for the spectrum usage to the spectrum owner and core network owner needs to pay to the ISP (Internet Service Provider), they can set up their profit margins in a way that part of the revenue from end users comes directly to the spectrum owner and ISP, while pure profit is shared equally among them.

ISP owners. ISP owner provides Internet access to the infrastructure owners. Usually, such organizations offer monthly subscriptions for fixed price according to agreed SLA (Service Level Agreement). Such option is the best, because it is agnostic to the traffic volumes that allow to create more flexible data plans for the end users.

End users. In traditional mobile networks, end users are equipped with one or few USIM cards, with independent IDs, account balances and SLAs. In other words, users are limited to the infrastructure of the particular operator. In our network model, we assume that there will be tens or even hundreds of different MVNOs, instead of few in traditional mobile networks. Of course it will not be feasible for end users to manage agreements with so many different MVNOs. Therefore, application of blockchain smart contracts seems to be promising for such scenario. Each user will have his unique global ID and financial account. In the future, cryptocurrencies are likely to be adopted globally, so that conventional billing systems will be substituted by transactions of cryptocurrencies between users and infrastructure owners.

C. *Application of Smart Contracts for Mobile Networks*

A smart contract is a computer protocol intended to digitally facilitate, verify, or enforce the negotiation or execution of a contract between two parties. The main reason for smart contract is to enable trust between contractors and allow credible transactions without third parties [9].

Smart contract can provide the following benefits to the 5G and future 6G mobile networks.

Autonomy. Users will no longer be the “prisoners” of the operator, by being forced to choose the best data plan among the worst ones. Usually, operators offer some cheap option which includes very small limits for data and calls, and then very expensive one with vast amount of data and calls. In this situation, many users are forced to pay higher price for redundant services. With smart contracts each UE will have an intelligent agent, which will automatically negotiate the price and service conditions in real-time and switch between tens of different operators, while the user personally will not have any idea about it.

Trust. Once user and infrastructure owner agreed upon some conditions, they become immutable during the whole period of smart contract validity. All conditions are encrypted on a shared ledger, and there will be not any possibility for operators to modify of violate these conditions.

Safety. Blockchain provides the security of all transactions, so that it is impossible to hack the account of any user and steal his money.

Speed. Blockchain eliminates all paperwork requires to negotiate terms and conditions between users and operators, as well as between operators and government bodies. All tasks in a smart contract are automated by software code that allows to save hours of time for all business processes.

Savings. Smart contracts eliminate the need of complex and expensive billing systems that reduces the CAPEX of MVNOs, allowing them to enter the market much easier.

We specify two types of smart contracts. First type is the smart contract between user and MVNO (i.e. infrastructure owner). This contract can be created by the end user with his own request for connection to the mobile network, and then MVNOs offer their prices to satisfy this request. Then, smart contact will be executed in a way that user will connect to the operator who offers lowest price for the target QoS requirements.

Second type of smart contract is the contract between infrastructure owner and spectrum owner. This contract is simpler, because its conditions do not imply any quality policies. Infrastructure owner just pays for the used spectrum timely depends on the conditions specified in a smart contract.

D. Unlicensed Spectrum Sharing Based on Blockchain

Utilization of unlicensed spectrum has been widely welcomed due to the vast amount of resources, which are free to use and quite often available. One of the biggest problems for unlicensed spectrum utilization is the competition between mobile network operators. In [10] we have developed the coalitional spectrum sharing game with perfect information and updatable payoffs,

In this paper, we have further developed a coalitional game between operators for unlicensed spectrum sharing based on blockchain technology. In order to ensure the fair utilization of the spectrum, we introduce a virtual cryptocurrency, which has no value in any fiat currency, because unlicensed spectrum is free to use. Instead, value of one token will be equal to 180 kHz/s in unlicensed spectrum, which corresponds to the smallest bandwidth that can be allocated for mobile user in modern LTE mobile networks. Note that token value is a float non-negative number, i.e. values less than 1 are possible. The workflow of the proposed algorithm is described below.

Step 1. Initially, tokens are distributed equally among all mobile network operators, which are participating in the spectrum sharing.

$$m_k = \frac{M}{n},\ k \in [1,n]\,, \tag{1}$$

where m_k – initial number of tokens for network operator k,

Step 2. Each operator utilizes the unlicensed spectrum by spending tokens from his account.

$$m'_k = m_k - \omega_k \cdot p,\ k \in [1,n]\,, \tag{2}$$

where ω_k – is the amount of utilized spectrum, p – spectrum price per second.

Step 3. Tokens, which are spent by the operator are equally shared between all other participating operators by using blockchain transactions.

$$m'_k = \frac{\sum_{i \neq k} m_i - \omega_i \cdot p}{n},\ k,i \in [1,n]\,. \tag{3}$$

Proposed approach allows explicitly defining and executing the conditions of spectrum sharing, while preventing selfish behavior of the operator. Once, any operator attempts to utilize more resources than others, his account balance will be spent very quickly and he will end up with zero tokens. Since, everything is executed by blockchain, selfish operators will not be able to utilize the unlicensed spectrum until his balance will increase again.

Such scenario can be simply described in terms of game theory, where each operator acts as an independent player and choose his strategy of unlicensed spectrum utilization. By the strategy we assume how much bandwidth operator will try to utilize for his users. Considering the limited amount of tokens, the best strategy for operator is to balance his input and output flows of tokens. In order to achieve that, the best option is to use less or equal bandwidth with other operators. Thus, the Nash Equilibrium strategy of an operator will be:

$$\omega_k = \frac{W}{n},\ k \in [1,n]\,, \tag{4}$$

where n – is the number of mobile network operators participating in spectrum sharing, W – the total available bandwidth.

III. Simulations of the Proposed Blockchain-Based Spectrum Sharing Game

In order to study the performance of the proposed algorithm, we have developed spectrum sharing game in unlicensed spectrum. We use 540 MHz of spectrum in 5 GHz ISM band. For this case, we issue 1800 tokens, which is equal to the entire spectrum utilization during one minute. For simulations, we assume that network is saturated, so that all total spectrum usage of all operators is 100 percent. Fig. 2 shows the throughput for the case of random spectrum sharing between two operators. As we can notice from the Fig.2, the divergence of throughput is very high, e.g. there are period when one operator benefit from using the entire band, while other is not even able to communicate. For our proposed algorithm, we observe that initially, the same divergence of throughput between operators exists, but later operators are quickly balance it equally by using the transactions of virtual cryptocurrency (Fig.3). Fig. 4 shows how account balance of operators changes for the same timeframe as throughput. It is noticeable that while operator A use the bandwidth over his norm, his account balance decreases proportionally, because he sends cryptocurrency to operator B. Then, operator B appear to have more cryptocurrency, so that he starts to use more spectrum than operator A. Finally, divergence diminishes and both operators reach the Nash equilibrium, when they use equal amount of bandwidth and their income of cryptocurrency is balanced with spending.

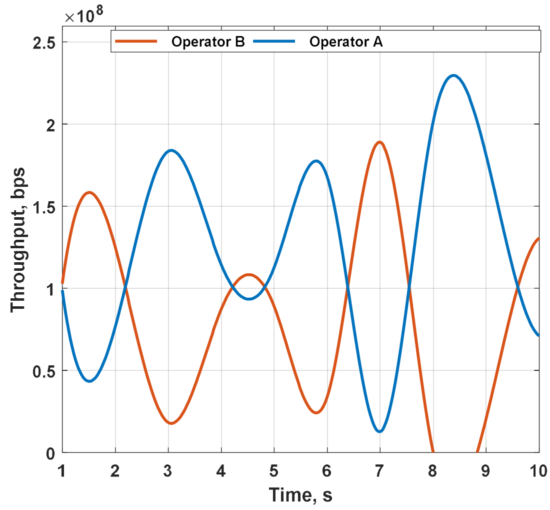

Fig. 2. Throughput in case of random spectrum sharing between two operators in unlicensed spectrum.

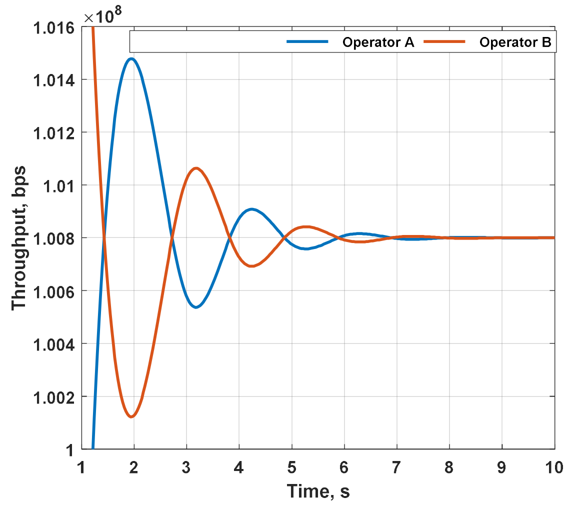

Fig. 3. Throughput in case of blockchain-based spectrum sharing between two operators in unlicensed spectrum.

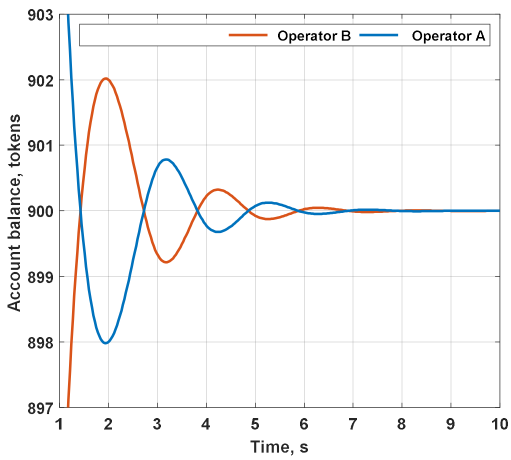

Fig. 4. Account balance in case of blockchain-based spectrum sharing.

Conclusion

In this paper, we propose a new architecture of blockchain-based intelligent mobile network operation. Proposed blockchain-based mobile network allows to perform all relationships between users and operators by using smart contracts. Moreover, relationships between operators will also be based on smart contracts and cryptocurrencies, which will simplify the spectrum and infrastructure sharing. Simulation results shows that proposed blockchain-based algorithm allows to achieve the fair utilization of unlicensed spectrum by each network operator.

Acknowledgment

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