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Blockchain-empowered Secure Spectrum Sharing for Next Generation Train Networks

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ABSTRACT The integration of private mobile networks (PMN) driven by next generation train networks (NGTNs) require a paradigm for a secure spectrum sharing with mobile network operators (MNOs) to provide privacy driven architecture. For such unprecedented performance expectations, a fine-grained spectrum sharing PMN is required to address secure communication with volume, time, and usage area parameters. In this article, we study a novel vision for empowering secure spectrum sharing for NGTNs with MNOs using blockchain technology by using smart contracts. In particular, blockchain key features and its integration along with the anticipated challenges and potential benefits of the proposed architecture are discussed. Finally, we have also highlighted potential NGTN use-cases to address the outlined challenges. This would unlock several practical scenarios and critical applications to meet rising business demands. From the implementation perspective, this article would exploit a conceptual blockchain-driven intelligent network that is ready to satisfy a number of NGTN applications that need privacy preservation.

INDEX TERMS Blockchain, Intelligent Transport Systems, Next Generation Train Networks.

I. INTRODUCTION

THE fifth generation (5G) advancement have leapt into a modern digital world that interconnects heterogeneous network (HetNet) to a distributed network infrastructure ubiquitously [1], [2]. It is expected to have more heterogeneity in future mobile networks where support for beyond 5G (B5G) applications are possible including pervasive intelligence, virtual, augmented, and extended reality (VR/AR/XR), ubiquitous instant communications, and the Internet of Skills [2], [3]. However, with advancement of mobile networks proliferation of ultimate number of additional small cells (SCs) with freedom of more capacities, the complexity of spectrum allocation, network management, and service orchestration will increase drastically. Similarly, mobile network operators (MNOs) face difficulties in managing next generation train networks (NGTNs) due to the complexities of bulky train infrastructure and available resources such as, a complex and multi-disciplinary engineering system involving MNOs coverage to the underground train tunnels and regulating the whole train infrastructure independently. This is where MNOs need to reach out to NGTN for every single deployment, change, and upgrade. Existing mobile networks that are serving train infrastructure, are mostly idle on average when there is no traffic, yet still unable to meet the traffic demands during peak and off-peak hours [2]. This inefficiency forces MNOs to increase the operational expenses (OPEX) in order to provide coverage to train networks. This is due to the service level agreement (SLAs) between the MNOs and train companies with expensive license fees and associated running expenses such as redundant bandwidth, and ever-increasing costs of infrastructure deployment and maintenance [4]. The participating members in the blockchain ecosystem allocate some shares of resources to host the blockchain network nodes. Through these agreed resources, computing capacity is observed which plays a vital role in executing smart contracts and the consensus protocol. In addition, infrastructure costs, operational benefits, and the overall economic feasibility of the networking infrastructure to allow communication between blockchain nodes belonging to different members, is observed. These decisions have direct implications on costs and the security of the blockchain ecosystem [5]. Therefore, it is inevitable for the NGTNs to establish their own decentralised business model for more flexibility driven by spectrum sharing infrastructure where more capacity would be dealt with enhanced security.

Thus, in the foreseeable future, there would be either private mobile networks (PMNs) to serve NGTNs, or NGTNs would appear to indulge flexibility in business models in order to respond to market and user demands. Such a paradigm requires robust decentralised spectrum allocation in real-time along with a dynamic resource utilisation across time and space [6]. Therefore, there is a need for a trusted, preserved, and scalable solution to ensure infrastructure sharing and growing capacity & enhanced security demands, among MNOs and NGTN-driven PMNs. This is where SLAs covenant is required to be improved and prospected when NGTN-driven PMN locally keep the record of all transactions and consequently share them to MNOs via blockchain.

For decentralised applications and distributed edge intelligence, blockchain is leading the momentum as a promising technology. Blockchain is a distributed ledger technology (DLT) based on a digital system for recording the transaction of assets. It provides a flexible decentralised platform that can permanently record and verify transactions and their details are recorded in multiple places simultaneously. Distributed ledgers don't have central data store or administration functionality like traditional platforms [6]. The additional key features of blockchain technology are transparency of the transactions along with anonymity and immutability. It is preserved by a privacy mechanism with a short transaction time. Importantly, underpinned by smart city economics and governance mechanisms, blockchain can legislatively improve mobile network market by enabling trusted spectrum and infrastructure sharing between MNOs and NGTNs. For example, NGTN driven dynamic MNO switching by end users can be possible via smart contracts, borderless roaming, and quality control. This can be done by using blockchain-driven wallet ID works on a principle of embedded universal integrated circuit card (eUICC) to each end user with a unique access as an identifier across all MNOs. The eUICC is the software component that allows the remote SIM provisioning of multiple network profiles under one umbrella [7], [8]. Doing so, users would benefit with the seamless coverage, resources, handovers, more capacity, and flexible change in a temporary subscription. Consequently, with the use of NGTN-driven PMN, plans and contracts are downloaded directly via eUICC profiling. Due to this benefit, connecting passengers' devices and getting online would take seconds once all the devices are registered onto the NGTN [7], [8].

Some interesting studies have considered blockchain as an integration part for B5G and 6G networks where most of the works discussed specific blockchain solutions with limited feasibility. This included, block creation, ledger distributions, mining, and consensus algorithm [9]. The merits of blockchain technology and the benefits of integrating it with 5G networks are explained in [10], where mobile network operation is reviewed against a variety of blockchain applications. A concept of Ethereum platform in relation to the blockchain's processing transaction's time and a mechanism to evaluate text type operations on Ethereum network is discussed in the works [11]. On the other side, some authors, such as, Igboanusi et al. in [12] investigated the high latency overhead of the blockchain network. In the Industry 4.0 automation, data-driven intelligent manufacturing concept is presented by authors in [13], using a decentralised blockchain paradigm for big data-driven cognitive computing (D2C). In terms of road safety and security, embedding blockchain in edge-based vehicular networks is proposed to resolve computation of data challenges [14]. Furthermore, implementation of blockchain-enabled private transactions based on off-chain peer-to-peer (P2P) confidential data messaging, and broadcast transactions that contain hashes of private data to verify immutability and integrity [15]. The blockchain-based framework to provide reliability of important data, and jointly optimise caching content probability and redundancy rate in order to maximise the secure transmission probability, is presented in [2], [16].

As mentioned above, most of works considered specific blockchain problems, such as spectrum and infrastructure sharing, SLA management, and privacy preservation of end users [17]. However, to the best of our knowledge, there are currently less or even no works related to blockchain implementation as a core element that provide secure spectrum sharing among NGTN-driven train PMN (regulated by a train organisation), and MNOs as a whole. Therefore, we propose a novel vision for empowering secure spectrum sharing for a NGTN using blockchain where the main driver is a train organisation (such has Transport for London, TfL) that would act as an owner for all MNOs and users. For this, we utilise blockchain to empower a highly distributed and virtualised NGTN by using smart contracts and SLAs. This would simplify the financial transactions and related agreements between NGTN-driven PMN, and spectrum owners i.e., MNOs. The contributions of this article are as follows:

- Potential need for Blockchain in NGTN architecture.
- Blockchain key features and its likelihood of integration into NGTN.
- A novel concept of blockchain-empowered secure spectrum sharing for NGTN architecture and technical modelling.
- NGTN-empowered Blockchain and Smart-Contracts workflow.

II. POTENTIAL NEED FOR BLOCKCHAIN IN NGTN

A novel Beyond 5G vision to support NGTN is proposed in this article with blockchain-empowered network architecture that simplifies mutual agreements between shared spectrum ledgers based on smart contracts. The potential need for Blockchain is to provide safety against vulnerable shared

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spectrum that is shared between multiple entities, identification and memorise passengers' movement in train network for intelligent decisions, a scalable and cost-effective solution to store and distribute AI models, and end-to-end channel resilience [1], [18]. Out of all mentioned needs, the vital use-case to use Blockchain in NGTN architecture is to effectively use shared spectrum with low number of overheads through transactions between different entities/ledgers. This is shown in Fig. 3 workflow process which depicts, (i) how the number of transactions are reduced while reporting intelligently, and (ii) how spectrum trading is performed using multiple ledgers in one single NGTN. These potential needs are detailed below.

a: Robust Security

Blockchain can enable applications in a secure and safe manner that require end-to-end user data, such as tracking, personalised ads, or videos based on location (since the path of the user is known) [5], [6]. Public information tracking in the current train networks is useful to monitor end-to-end paths of moving passengers. Also, with the known passenger trajectories, enhanced security measures are highly essential for diffusing such situations in the interest of public safety. Public safety applications utilising intelligent solutions using blockchain consortium in a decentralised fashion can help in the predicament of daily travel against the threat of lost trajectories, financial constraints, and monitoring passenger commutes [11], [15]. In addition, when more passengers are commuting, there is a need to address such capacity crunches by enhancing security in order to protect the user data.

b: Traffic and Crowd Management

Passenger's and traffic flow congestion due to high traffic activities, may cause disruptions, and loss of revenue for the train companies. For transport businesses, any form of disruption or congestion in their services directly or indirectly affects their CAPEX and OPEX while causing harm not only to the business operations but also to the reputation of the company. Identification of passenger movement in train network contributes to high energy consumption and subsequent failure of effective optimisation measures for mobile networks [2]. Therefore, with the shared and collective data from MNOs, blockchain privacy preserved consortium can address numerous traffic management application issues while keeping a closer look at the traffic patterns and inferring decisions in smarter ways [16].

c: Planning and Costing

Emerging NGTN technologies within the train infrastructure are extremely beneficial to derive existing methods to AI-based archetypes. However they bring in deployment and sustainability related costs. Several strategies and techniques have been developed for the planning and costing of densely populated networks and energy-efficient systems, but they fail to address many challenges. Planning regulations are required to be in compliance with the active development procedures. Using blockchain intelligence, a scalable and cost-effective solution to store and distribute AI models providing an audit trail, and pairing, can enhance data planning, costing, and security [4], [16]. AI can rapidly and comprehensively read, understand and correlate data at incredible speed, bringing a new level of intelligence to blockchain-based business networks.

d: Resilience

The NGTNs to be built upon resilient networking environment where daily/hourly trusted platform forecasting is possible between the regulator, the owner/designer, and end users. The end-to-end channel must be resilient to extreme threats such as cyber-attacks and malicious activities, revealing IDs to unknown parties, or even personal passengers data breach must have the capability of resilience as proposed in the resilient design of distribution using blockchain and smart contract in [19]. This study proposed an AI-based approach where blockchain and smart contract ensure to visualize core functions. Therefore, with a distributed private network employing blockchain at many facets, security on the untrusted platforms is highly important.

III. BLOCKCHAIN KEY FEATURES AND ITS INTEGRATION INTO NGTN

A. FEATURES OF BLOCKCHAIN

Based on non-centralised ledger concept, a distributed ledger, blockchain keeps the record of information transference for its network state along with the tracking of changes. Any correspondence in the blockchain has proved to be privacy preserved providing effective security layer to untrusted parties signing mutual contracts [6]. Therefore, in this article we consider blockchain as a core technology to empower decentralised secure spectrum sharing for NGTNs and mutual agreements between different entities of mobile and train networks. Below, we describe the key features that make blockchain attractive for B5G and 6G networks.

a: Immutability

Due to the robust nature of blockchain does not allow the deletion of any confirmed transactions (i.e., agreement between MNOs). This leads to the satisfaction of untrusted parties for simple agreements without causing disputes between MNOs, and users regarding violations of unintended user transactions.

b: Decentralisation

Blockchain possesses a consensus mechanism for the verification of decentralised transactions and maintain the correct spectrum allocation state of the system end-to-end.

c: Anonymity

Blockchain has unique cryptographic hash for each block of transactions to verify the correctness of the information. This integrates hash of the previous block to the transaction data of the hash coming ahead, for entire chain process. This feature does not allow modification of past transactions (e.g., SLAs).

d: Smart Contracts

Through this feature, multiple transactions would be executed automatically under defined software based algorithms, making the use of automatic executions according to the defined conditions. Smart contracts can unleash the future of SDN in B5G and 6G networks for dynamic management and flexible agreements between MNOs, and NGTN-led PMN [2].

B. ADVANTAGES & POTENTIAL OF BLOCKCHAIN IN NGTNS

a: Spectrum Sharing

With the reservations of real-time spectrum tracking and irregularity, existing spectrum sharing procedures do not possess automation and intelligence. As such, there is high risk of complexities inherited in multiple bands (either licensed and/or unlicensed), for different wireless standards. Furthermore, the lack in dynamic spectrum sharing with incentive based real-time agreements leads to the complex nature of overall management. However, with the proposed NGTN architecture using blockchain technology, automated spectrum trading framework can be designed to either permit or restrict MNOs spectrum usage on the private software level. Such a framework yields agreement of smart contract usage among MNOs and NGTN-led train network. This is where NGTN controls mobile network services with a full swing, recording all transactions, and sharing it with MNOs on regular basis. With this approach NGTN would benefit MNOs by sending less transaction's overhead which may/may not be needed on every unnecessary transaction, this, saving resources, time, volume, and resilience [16]. On the contrary there would be a risk of overall network overhead for NGTN local transactions.

b: Infrastructure Sharing and Network Slicing

There are always challenges between entities when spectrum sharing is concerned despite being a straightforward concept in comparison. However, these challenges can be fixed by using infrastructure sharing using blockchain technology which not only hold tracking of MNOs infrastructure usage, but also, provides opportunity to MNOs to slice the network with corresponding cost management between MNOs by using cryptocurrencies. Furthermore, with the intelligent use of smart contracts, resources in need can be locked/booked in advance. Private entities with binding smart contracts, integrate into blockchain for splitting expenses (i.e., transactions, electricity, Internet provider, and real estate) With this, NGTN led PMN and all MNOs, can utilise the intelligent technology with correct proportions [9].

c: Service Level Agreements

In modern mobile and train networks, SLAs are major contributors of the overheads today that have OPEX costs to run the contract and network. This often involves a trade-off between price, coverage footprint, quality of service (QoS), and quality of experience (QoE). Due to the trade-off, user's satisfaction is not always possible due to more flexible demands. However, using blockchain, can guarantee important parameters availability, is by negotiating and enabling flexible SLA smart contracts between, (i) NGTN-driven PMN and MNOs, and (ii) PMNs and end-users [16].

d: Authentication and Authorisation

Mobile networks work on a principle of subscriber identity module (SIM) cards for radio parameters activation onto user handset. If end user likes to move from one MNO to another, he either changes SIM card (physical or electronic) or using porting authorisation code (PAC) facility to transfer. However, blockchain brings wallet ID concept to each end user with a unique access as an identifier across all MNOs via MNO profiling method [16].

e: Local Area Mobile Networks

The existing infrastructure deployment from centralised model perspective has a complex way of maintaining large MNOs and train networks. However, decentralised concept to MNOs and PMNs by using blockchain technology makes tradings smarter and easier by providing NGTN-empowered local spectrum trading. In real-time, blockchain smart contracts can provide an opportunity to seamlessly utilise unused spectrum for specific amount of time as a tenant. All other radio parameters such as, coverage area, capacity shift, resources, can be adjusted and agreed between MNOs and PMNs.

f: Intelligent Networking

The existing terminologies of B5G and 6G networks are based on SDN, virtualization, and network slicing. This brings slightly complex structure into place where mobile networks require AI integration by relying on self-organised networks (SON) paradigms. By retrieving well-structured, validated, and complete data from blockchain, AI can be trained to solve specific tasks in mobile and train networks collectively [16].

g: Intelligent Entities Control

Blockchain can empower high level regulators, such as the Federal Communications Commission (FCC), European Telecommunications Standards Institute (ETSI), or Ofcom, for mutually enabling high-level policies and spectrum usage tracking. Through this hybrid spectrum market fashion, NGTNs can trade parts of the spectrum using MNOs to regulate spectrum usage in order to avoid interference or unnecessary wastage (e.g., military, unwanted off-peak resources). Blockchain, in addition, holds administration to a level where governments can avoid economic malpractices such as cartel agreements [16].

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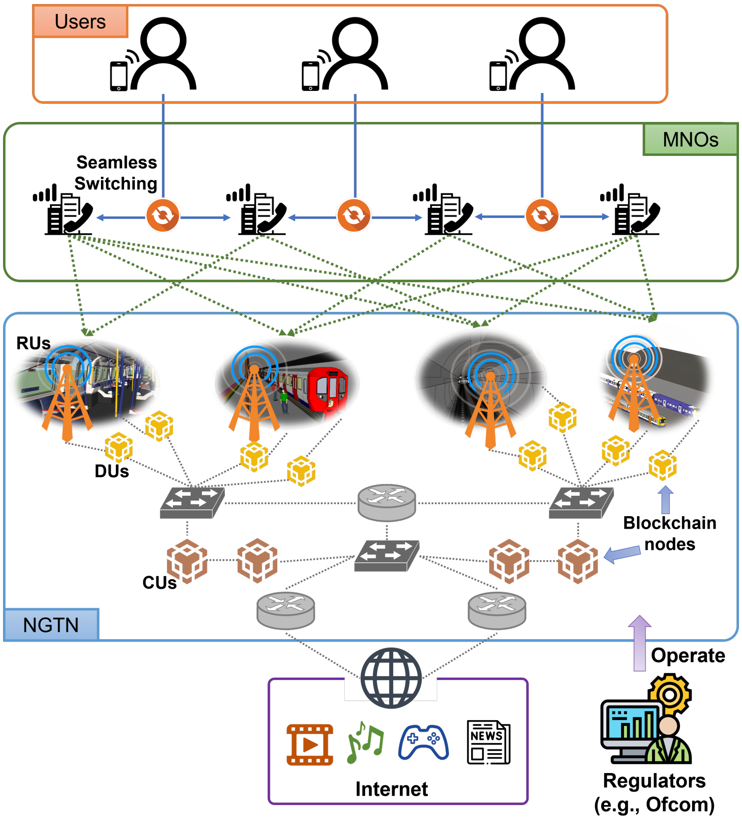

FIGURE 1. Next Generation Train Network (NGTN) architecture.

h: Green and Low Carbon

By using Blockchain technology, NGTN can also be benefited by adopting less overhead transactions and executing them when necessary. Transactions between NGTN and MNOs occur frequently to solve their local queries, and only send the overall transaction record at the end when it decides to switch from one MNO to another. This is a huge benefit to consume less carbon by reducing the number of unnecessary transactions. In other words, blockchain supports secure transactions intelligently through Smart Contracts agreement when necessary in order to reduce carbon emissions. The application of our novel approach can help to reduce the energy consumption of stations, trains and locomotives, making railway transportation greener and low carbon.

i: Security to NGTN transactions

Adopting blockchain into NGTN would bring more security into transactions as every transaction has a cryptographic principle that ensures high data integrity and authentication. However, this comes with expense of high latency and costs mainly caused by the consensus among blockchain nodes verifying new transactions. Hence, some fast consensus mechanisms have been discussed in Table 1 that would potentially support high transaction throughput reducing latency and costs. All of the consensus algorithms mentioned in the Table 1 have high security, low throughput and low scalability which shows that Proof of Works (PoW) and Proof of Stake (PoS) are not able to fulfill throughput requirements to support transactions entirely in a decentralized mobile network. However, the security these algorithms provide is more important than the throughput and scalability. Also, traditional fault tolerant consensus, i.e., crash fault-tolerant (CFT) and Practical Byzantine Fault Tolerance (PBFT) specially, for CFT, Paxos and Raft are widely considered as a guide to train networks [20]. When we consider NGTN dynamics and its characteristics, two things are highly important, i.e., the dynamic link (e.g., communication channel), and the dynamic configuration (i.e., different participants, join/leave). This is where wireless PBFT consensus plays a vital role [20]. For the dynamic configuration of the NGTN, CFT or PBFT needs to be dynamically configured to cope with complex tasks, especially when decentralisation is needed. However, if the system has an authority, the reconfiguration process might be simplified. Message dissemination protocol with fault tolerance where, Gossip and Epidemic are often discussed. They are suitable for large-scale distributed systems with frequent changes or dynamic membership. In the NGTN, these algorithms can be used for disseminating real-time updates or notifications across multiple nodes, such as station information boards or mobile applications [20]. Gossip-based algorithms are fault-tolerant, scalable, and can handle network partitions and node failures. But one thing needs to be noticed, these

TABLE 1. Consensus Algorithms that can be used in NGTN

Consensus algorithm	Number of transactions per second	Confirmation latency
Proof-of-Work (PoW)/Bitcoin, Ethereum	Tens	6–60 min
Proof-of-Stake (PoS)/Peercoin	Tens	10–60 min
Practical Byzantine fault tolerance (PBFT) Hyperledger	Tens	1–60 s
Gossip and Epidemic	Tens	0-60 min
Raft	Tens	0-60 min
Delegated Proof-of-Stake (DPoS)/EOS	Tens	<1 s
Proof-of-Formulation (PoF)/FLETA	Tens	<1 s

protocols are usually very heavy in communication overhead, and might cause latency issues. Due to a fast blockchain model that can support high transactions with low latency, we require fast consensus mechanisms such as FLETA in which consensus is made on block mining procedure and blocks are generated in designated order. Moreover, other non-mining consensus mechanisms with high transaction throughput such as Raft and Hotstuff [9], [11], could be promising blockchain solutions to NGTN.

In this article, we have proposed a proof of concept by using blockchain in NGTN architecture that can be further taken into deep dive research by comparing consensus algorithms against throughput and latency which is beyond the scope of this article.

j: Seamless International Roaming

Due to the intelligent reliance of blockchain onto Internet connections, it is seamless compared to traditional methods specially when transactions are concerned. This is where cryptocurrencies can be transferred around the globe with quick response time leaving virtually no difference to either domestic or international transactions with negligible fees This helps in the mobile roaming when one user is beyond the domestic borders eliminating existing highly constrained international roaming limitations [17]. However, this whole process still require maturity to run transactions without delays by using ultra-high consensus mechanism.

IV. BLOCKCHAIN-EMPOWERED SECURE SPECTRUM SHARING NGTN ARCHITECTURE

We propose a blockchain-empowered framework for a decentralised NGTN 6G architecture to facilitate spectrum sharing cooperation and network management by multiple MNOs in Fig. 1. The proposed framework relies on the following elements.

a: The Regulator

is the government body (such as Ofcom in the UK) who has the following responsibilities of spectrum regulation within mobile and train network, issuing spectrum licenses among MNOs to operate onto the train infrastructure, harmonising between multiple emerging wireless technologies and standards, controlling transmission power and interference, regulation of spectrum sharing and trading management, etc.

b: The Owner

would be NGTN with a license to run PMN where all MNOs are integrated through smart contracts. This body would keep the record of all transactions taking place in the train network, and consequently share those transactions to MNOs via blockchain technology. With the NGTN-driven PMN, passengers moving within a train carriage, can share their available resources based on smartphones device-to-device communications (D2D). This would help passengers to use their phones in the time of not available balance/credit. Discussion on D2D credit sharing concept under the umbrella of NGTN-led PMN is another research which is beyond the scope of our proposed model. This approach can encourage new business models in which stakeholders invest in the NGTN and gain profit by sharing with MNOs via the blockchain platform.

c: The Spectrum and Infrastructure Owners

are MNOs that not only hold spectrum license from the spectrum regulator, but also posses network infrastructure ownership such as macrocells, small cells, blockchain nodes, and servers deployment. They also have complete responsibility to maintain the quality and manage the mobile infrastructure. The MNOs being infrastructure owners, can share their idle resources with other MNOs based on smart contracts principle via NGTN. In addition, blockchain nodes jointly invested by different MNOs and regulators into NGTN can be managed by NGTN mainly, and MNO when needed.

d: End users

are user equipments (UEs) or passengers within NGTN that use unique blockchain identifiers (BIDs) recognised by all MNOs. This enables passengers to dynamically switch between MNOs when necessary, while travelling. This is done by negotiating SLA smart contracts in the blockchain technology. For example, end users can dynamically use other mobile networks to share resources, utilise other MNO services, and coverage footprints for better use of the mobile coverage, handovers (HOs), and capacity [1].

V. TECHNICAL MODELLING OF BLOCKCHAIN-BASED NGTN ARCHITECTURE

Beyond any limits, mobile and train network information is stored in the distributed ledger irrespective of complexity, scalability, privacy, and security. Therefore, networking information can be privately processed within the NGTN via blockchain to keep reasonable number of nodes, complexity, train timetables, and passengers traffic flows. Also, passengers movement information would be available in the entire NGTN that can be accessed by authorised personnel.

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The regulator spectrum ledger contains information about each MNO bands, such as the frequency range, licensing, primary owner MNO, currently assigned MNO/MNOs, uplink/downlink duplex mode, and so on.

The NGTN blockchain consortium infrastructure ledger contains information about each next generation nodeB (gNB) in terms of passenger location, passenger trajectory, spectrum band, gNB transmission power limits, currently assigned MNOs, supported radio technologies, etc.

The spectrum/infrastructure MNO ledger contains information about each MNO, such as operational area, radio resource token (RTT), infrastructure resource token (IRT), national cryptocurrency (NC) balance, and supported SLAs.

The blockchain public UE ledger contains information about each passenger, such as blockchain identifiers, national cryptocurrency, and tracking area in train station, platforms, and tunnels. Passenger tracking information can only be seen by the NGTN who is responsible for the ownership of critical information. Passengers would share their tracking information by trusting the owner for mobility management purposes. MNOs can access only certain piece of information that is allowed to ensure better quality and a more personalised user experience.

The SLA ledger keeps the record of past, current, and future that were agreed between NGTN-led PMN, MNOs and UEs. This ledger is controlled by NGTN itself for current, past, and estimated future transactions based on Machine Learning. Therefore, each SLA is defined for a specified execution time frame and price.

A modification of any record in the distributed ledger is called a transaction. Transactions are analysed and assembled by the smart contracts in the form of blocks, which are then verified in the blockchain as shown in Fig. 2. The contract service has a front-end and an application programming interface (API) to interact with the regulator, MNOs, and passengers. A contract engine translates smart contracts into blocks of transactions for further verification by other nodes.

Mobile networks perform numerous transactions on daily basis, depending on the network requirements associated with mobility of users. Similarly, in the train environment, MNOs can have thousands of transactions per second when passengers move from stations to stations to complete their journeys. This is to ensure necessary resources are available for the passengers to utilise. Also, consensus among different MNOs or trust issues between them require a systematic NGTN paradigm to perform according to the share of MNOs obtained from the regulator.

In our case, we assumed NGTN require a fast blockchain model that can support high transactions throughput, ultrafast connections, low latency data downloads, and the ability to handle millions of connections forming a rapid autonomous system. This can be done by enabling one of the fast consensus mechanisms such as FLETA in which consensus is made on block mining procedure and blocks are generated in designated order. This allows block's dissemination range to be reduced, resulting in faster block generation and dissemination. Moreover, other non-mining consensus mechanisms with high transaction throughput such as Raft and Hotstuff [9], [11], could be promising blockchain solutions to NGTN. In addition, the transaction latency also depends on the network scale. Hence, the usage of blockchain in NGTN is not to process all data packets but only for billing and MNO switching so the number of network nodes is not big to limit the network scale.

There are several consensus mechanisms used to achieve agreement, trust, and security across a decentralized computer network as mentioned in [5]. For our proposed model, one of the fast consensus mechanisms to enable procedure of block mining. In this way blocks are generated with low latency in the designated order avoiding unnecessary delays. This allows block's dissemination range to be reduced, resulting in faster block generation and dissemination. However, some transaction delays will impact the blockchain network, as it needs time for all the nodes to reach a consensus and push the block to the chain. Similarly, due to the high block verification delays, spectrum sharing, and seamless roaming are also affected which would require ultra-low latency consensus mechanism such as FLETA [5] which will have following benefits,

- All five ledgers would work under one single consensus mechanism with ultra-low latency and high security.
- The permissioned NGTN-led PMN blockchain network is constructed for spectrum sharing which can greatly realize the high throughput, low cost of trading, and short delay.
- This is where NGTN administers the whole environment and acts as authorised body to authenticate multiple entities before joining in the constructed permissioned blockchain.

Using blockchain technology's strength in our NGTN architecture allows trustworthy functioning by enabling an ecosystem of participants in order to serve blockchain nodes. This applies to all blockchain applications (Hyperledger, Ethereum, R3 Corda Quorum, etc.) that are able to independently utilise blockchain framework cost effectively. Using [21] as a reference for our proposed model, blockchain as a service (BaaS) is expected to reach USD 24.94 billion by 2027 which put cloud providers in competitive market share by offering it as a service. Utilising Hyperledger Fabric platform of the BaaS, our NGTN architecture would offer no on-boarding cost for the passengers and administration. In addition, this will be a plug and play deployment where the owner (NGTN) controls the ecosystem. The infrastructure costs, operational benefits, and the overall economic feasibility can be calculated for NGTN architecture using Hyperledger Fabric platform which is optimal cost-effective solution for our NGTN architecture where main control in the hands of the owner due to sensitive train data and strict governance around it. Our aim is to highlight estimated costs based on [21] where detailed quantitative analysis is out of the scope of this study.

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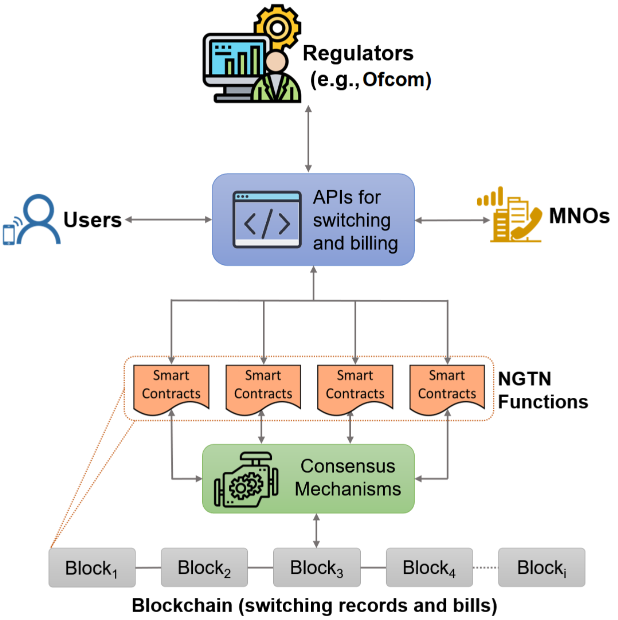

FIGURE 2. Technical diagram of blockchain-empowered NGTN services.

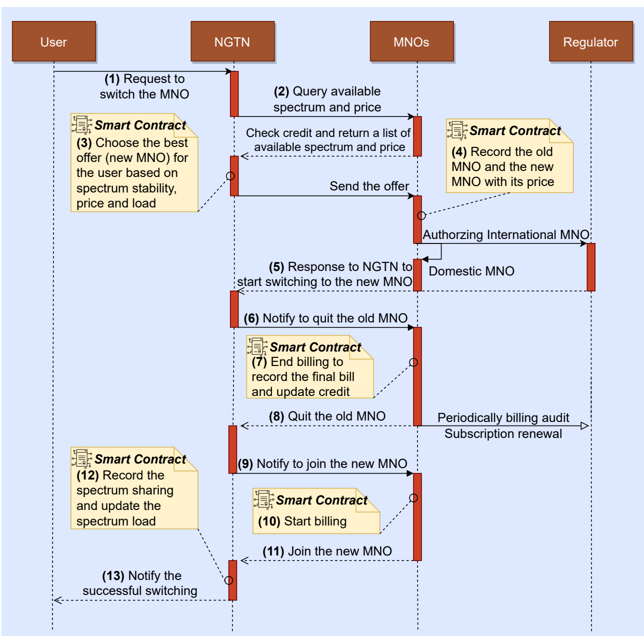

FIGURE 3. Protocol diagram of the proposed blockchain-based spectrum trading workflows.

VI. PROPOSED WORKFLOW FOR BLOCKCHAIN-BASED SMART CONTRACTS

This section focuses on the application of Blockchain-based Smart Contracts between different entities by highlighting the automated process with less overhead and a reduced number of transactions as shown in Fig. 3. In addition, NGTN-empowered spectrum trading is discussed and implemented as a proof of concept to evidence our proposed scheme is cost effective compared to other trading schemes when number of UEs are concerned. This is shown in Fig. 4.

A. SMART CONTRACT FOR SERVICE PROVISIONING

Fig. 3 shows the protocol diagram of the smart contract between the regulator (a government body), the owner (NGTN), spectrum/infrastructure owners (MNOs), and end users. Initially, a passenger connects to any available node (gNB or a Wi-Fi AP), and gets his registration completed in the NGTN via blockchain. This is where a unique identifier has been assigned to the passenger entering into the station. Then the passenger negotiates the SLA with the owner by submitting the service request along with the reference signal received power (RSRP) values of the visible nodes to the smart contract service API. The user throughput is defined as a function of two arguments such as, bandwidth and link spectral efficiency. From link spectral efficiency, the NGTN derives a required bandwidth for each passenger on the move. Therefore, the SLA price depends on the required bandwidth and profit margin of the MNOs being used by the end users. Finally, the passengers evaluates the utility function [3] and selects the necessary smart contract among all available offers. When the smart contract is invoked, according to the scheduling procedure defined in 3rd Generation Partnership Project (3GPP) Release 15, the regulator provides service for the passengers with the agreed-upon SLAs.

B. NGTN-EMPOWERED SPECTRUM TRADING

As the baseline, we assume the spectrum trading strategy observation to resemble with conventional spectrum licensing. This is where each spectrum/infrastructure owners purchase a specific spectrum license for coverage deployment from the regulator. Our proposed paradigm differentiates with conventional spectrum licensing where the owner (NGTN) purchases a separate license to run a PMN integrated with MNOs via blockchain. This process involves twofold blockchain transactions between UE ledger to the owner (NGTN) ledger followed by NGTN ledger to spectrum/infrastructure owners (MNOs) ledger. Distributed ledger stores all transactions along with the validation by all nodes. Thus, only authorised MNOs which have signed SLAs with the owner would use this particular spectrum band. The main benefit of this procedure is to limit the number of required transactions where spectrum trading agreements are already purchased and known by spectrum/infrastructure owners (MNOs) for long timescales. In this process, traffic demands have priority over network parameters. Therefore, MNOs are often forced to fulfil the user demands by sacrificing their resources. This often increases the price offered to end users for the same throughput which can be seen in Fig. 4.

In our NGTN-driven spectrum trading strategy, NGTN requests MNOs to estimate the total bandwidth needed to satisfy all requests from the users. Each MNO checks the availability of their spectrum in terms of bandwidth, coverage, and capacity, with a price in the spectrum ledger back to the NGTN. After that, the corresponding SLAs are offered to the users. Once a UE chooses the best offer based on

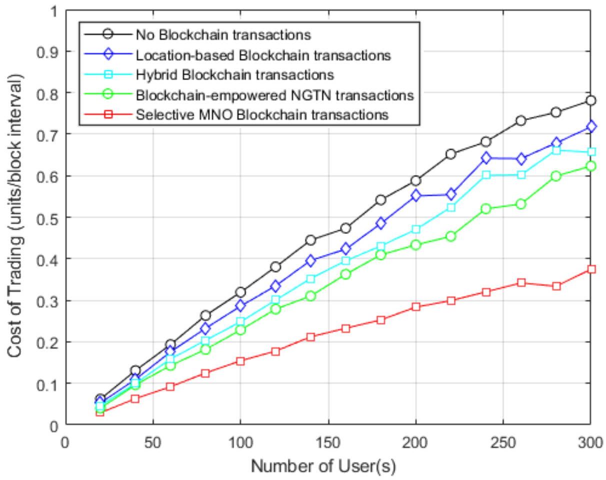

FIGURE 4. Simulation result, Cost of Trading vs. number of Users.

spectrum stability and price, the owner (NGTN) sends the offer to the regulator with the corresponding modifications of the spectrum ledger, MNO ledger, UE ledger, and SLA ledger. The regulator records the switching demand from old to a new MNO along with a new price and return a response to NGTN accordingly. Now, the owner NGTN, based on the regulator response, decides to switch a UE from one MNO to another by fulfilling user demands, and sends a notification to the regulator with corresponding MNO switchover. The corresponding amount of a switchover is recorded in the NGTN ledger and transferred to the regulator to end billing with the existing MNO and generate a final bill. The regulator sends a 'quit' notification to the respective MNO followed by the MNO's successful quit notification to the NGTN. Now, the NGTN notifies the regulator of new MNO selection so that its billing would be started. After registration of new billing, the regulator sends a notification to the new MNO of its services being utilised. The new MNO confirms the successful connection back to the NGTN. Finally NGTN records the execution of the successful transition and notifies the user. This strategy ensures that bandwidth is effectively utilised according to the traffic demand.

In Fig. 4, five different scenarios have been compared to identify preliminary results with the cost of trading against UEs. This simulation provides the cost of multiple trading strategies to satisfy number of transactions as a proof of concept of the proposed research. Detailed analysis by considering key indicators such as throughput, capacity, latency, etc would be presented at later research articles. In the No Blockchain trading, as its name shows, all MNOs directly provide mobile coverage and their services to the UEs without involving the proposed workflow shown in Fig. 3. This way all MNOs don't have insight of the effective bandwidth utilisation and security threats. In order words, each MNO is unable to estimate the total bandwidth needed to satisfy all requests from the UEs. Hence the cost of trading is high. In the Location-based Blockchain trading, the transactions are performed on the basis of user movements and trajectories. For instance, if certain train stations have high number of users than others. This scenario brings latency issues and some overhead problems where the owner (NGTN) have to keep the record of high density stations vs low density ones. Hence, the cost of trading gets impacted as shown in the Fig. 4. In Hybrid scheme of trading, out of all train stations, there are fewer stations take part in the blockchain implementation. This is because of different station types, such as Underground vs. Overground. However, this strategy creates a higher overhead in the blockchain because the number of transactions required to modify the spectrum ledger according to station types will grow exponentially with user demand. In our proposed scheme, Blockchain-empowered NGTN trading, NGTN requests MNOs to estimate the total bandwidth needed to satisfy all requests from the users. Then each MNO checks their bandwidth availability in the spectrum ledger and responds to NGTN to agree on the offered SLAs. Once the best option is chosen by the UE, the owner(NGTN) sends an offer to the regulator with the corresponding modifications of the spectrum ledger, MNO ledger, UE ledger, and SLA ledger. This strategy ensures that bandwidth is effectively utilised among serving MNOs without wasting the spectrum. Therefore, the NGTN dynamic strategy provides a lower cost of trading compared to most of the other trading scenarios. Finally, in the Selective MNO Blockchain trading scheme, only one MNO is allowed to share its resources without intelligent approach. Hence, the cost of trading is controlled due to non-shared spectrum. This scheme is not very effective in the modern shared spectrum due to blockchain capabilities are not fully utilised.

There are some trade-offs which can be considered in order to leverage the potential of AI in spectrum trading. The NGTN-driven blockchain keeps every transaction and transition records that can be used to train the AI engine. In [1], the findings indicate that AI can predict traffic demand with effective percent accuracy in the customised mobility model. With AI-driven traffic monitoring and predictions, further enhancements can be done to the proposed framework in order to minimise the number of transactions while maintaining the high spectrum utilisation efficiency. This can be achieved by adapting the spectrum trading strategy to according to the traffic flow demand variation.

VII. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

With the exploitation of NGTN-driven PMN, we have studied the advantages of blockchain integration into B5G and 6G networks. This includes, improved privacy on the spectrum and infrastructure sharing, flexible SLAs, intelligent authentication and authorisation, and seamless roaming. The framework has a novelty to empower an NGTN using blockchain technology with a specific tokenisation model used for applying privacy on spectrum and infrastructure trading among multiple MNOs. Providing trust-worthy platform to the

NGTN would benefit, (a) sharing of idle resources (mobile network resources) through smart contract agreements, (b) passengers can demand available resources based on smart phones D2D communication, and (c) end users can dynamically use other mobile network. The distributed ledger usage in NGTN and MNOs has been discussed while exploiting its transactions in the blockchain consortium. The integration of blockchain into B6G networks along with NGTN, clearly has great potential and wide prospect. The blockchain is shifting its paradigm toward a future decentralised and digitised economy. The concept we have discussed in this article can be expanded in various economic and technical directions. Such as; MNOs can ensure their profit margins regardless of the deployment area, rural or urban; careful spectrum pricing; more suitable consensus algorithms; and more robust smart contracts.

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