Blockchain for 5G: Opportunities and Challenges

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***Abstract*—5G is a revolutionary technology in mobile telecommunications that promises to be 20x faster than today's 4G technology. The novel characteristics of 5G can be exploited to support new business models and services that require seamless interactions among multiple parties that may include mobile operators, enterprises, telecom providers, government regulators, and infrastructure providers. Meanwhile, blockchain technology has evolved as an enabling, disruptive, and transformational technology that has started to be adopted across many industry vertical domains. Blockchain has been increasingly used to register, authenticate and validate assets and transactions, govern interactions, record data and manage the identification among multiple parties, in a trusted, decentralized, and secure manner. In this paper, we discuss and highlight how blockchain can be leveraged for 5G networks. First, an overview of blockchain capabilities as well as smart contracts, decentralized storage and trusted oracles are presented. Second, potential opportunities in which blockchain features are used to enable 5G services are outlined. Third, examples of system integration architecture and sequence flow diagrams to illustrate how blockchain along with other supporting decentralized technologies can support and facilitate such opportunities are discussed. Finally, key challenges and open research problems are identified and discussed.**

Keywords—Blockchain; Distributed Ledger Technology (DLT); 5G Networks; Smart Contracts; Trusted Oracles

I. INTRODUCTION

Mobile data traffic is expected to increase by 46% by the end of 2020 [1]. This massive upsurge in mobile data has been attributed to (i) increase of mobile device usage (e.g. smartphones, tablets, embedded SIM cards in laptops), (ii) content availability and ubiquity in video-streaming service providers (e.g. Netflix, Youtube), and (iii) user-created contents being hosted on several social-cloud platforms for consumption by other end-users. This gives a big push for designing and standardizing the next generation of mobile networks [2], as that of 5G networks. Stringent efforts have been taken to create new requirements of the 5G-enabled service spectrum, that can be categorized as: (i) enhanced Mobile Broadband (eMBB), (ii) ultra-Reliable and Low Latency (uRLLC), and (iii) Massive Machine Type Communications (mMTC). 5G primary features include (i) user peak data rate of 10 Gbps, (ii) 1 Million devices per square kilometer, (iii) 10 Tbps per square kilometer, and (iv) 1 millisecond latency.

5G is also designed to leverage the network function virtualization (NFV) and software defined networking (SDN). SDN and NFV technologies allow the flexibility of accommodating diverse use cases at the same time. This will give rise to business models such as operator sharing i.e. multi-tenancy, providing Network-as-a-Service (NaaS), Telecom-as-a-Service (TaaS), Virtual Functions-as-a-Service (VFaaS), and Infrastructure- as-a-Service (IaaS) [3]. The concept of a *network slice* [4] will also be a key feature in 5G to enable such services and new functionalities.

To meet 5G stringent requirements and support mission critical applications, 5G will be operating at high frequencies i.e. *millimeter Wave (mmWave)* which operates beyond 30 GHz, resulting in signals that travel shorter distances. This requires higher number of cellular stations or sites to cover the same 4G area, resulting in high cost in infrastructure deployment. To reduce infrastructure deployment cost, newly emerging options have been considered. These options include (i) infrastructure crowdsourcing, (ii) roaming sharing, and (iii) spectrum sharing. Another key challenge is addressing the management and service capabilities of mMTC with a support requirement of at least 1 Million devices per square kilometer. Such massive number of distributed and heterogeneous Internet of Things (IoT) and mobile devices pose new challenges with respect to authentication and scalability of 5G networks. In this paper, we shed light and argue that blockchain can play an instrumental role in addressing these challenges and providing decentralized, trusted, and cost-efficient solutions.

Blockchain is the underlying technology of the cryptocurrency bitcoin, but blockchain is now seen as a new effective, robust, and cost-efficient technology (with the use of smart contracts) to govern interactions among multiple participants or devices in a secure, trusted, efficient, and decentralized manner [5]. Blockchain transactions are stored in a chain of blocks in an immutable manner. These blocks are validated and mined by thousands of mining nodes, in permissionless public networks such as Bitcoin and Ethereum, or created in private permissioned enterprise blockchain network as Hyperledger. It is expected that the number of implementations of the blockchain in the telecom sector will reach 1 billion USD by 2023 [6].

The primary contributions of this paper can be summarized as follows:

- Provide a background on blockchain technology and its enabling decentralization components including smart contracts, decentralized storage, decentralized applications, and trusted oracles.
- Highlight potential and novel opportunities and use cases (other than discussed in the literature) that arise from integrating blockchain with 5G networks.
- Provide technical details in the form of system integration architecture and sequence diagrams to show how blockchain along with supporting decentralized technologies can be leveraged for 5G.
- Identify and discuss key open research challenges for the research community to address and propose corresponding solutions to in order to fully leverage the

benefits of blockchain for the anticipated 5G networks and services.

The remainder of the paper is organized as follows. Section II gives a brief background pertaining to blockchain and decentralized enabling technologies. Section III discusses with technical details on how blockchain can be leveraged for 5G. Section IV outlines open research challenges. The conclusion is presented in Section V.

II. BACKGROUND

In this section, we give a brief background on blockchain along with key supporting decentralized technologies that can be leveraged to support and facilitate 5G networks and services.

1) Blockchain Technology: Blockchain is the underlying technology of the bitcoin cryptocurrency. It is a distributed ledger that can hold transactions and records in an immutable, trusted, secure, and decentralized manner, with no use of intermediaries or centralized authorities [5]. These records and transactions are stored in blocks that are validated by thousands of mining nodes, when considering public blockchain platforms.

2) Decentralized Storage: Blockchain is an expensive storage media, especially for large data storage. For this reason, several distributed peer-to-peer storage solutions are introduced, e.g. Interplanetary File System (IPFS) [7], Swarm [8], Filecoin [9], BigChainDB [10], and Storj [11]. The benefits of blockchain thus become very obvious which led to the development of Smart Contracts [12]. Ethereum is a blockchain platform that introduced programmability to the blockchain.

3) Smart Contracts and Decentralized Apps (DApps): A smart contract is a program that governs the interactions and agreed-on terms and conditions among participants. The execution outcome of the smart contract is validated and agreed on by all distributed and trusted nodes. Decentralized apps also known as DApps are frontend user apps that interact with the smart contracts by initiating transactions that call functions within the smart contract.

4) Blockchain Platform Types: Blockchain platforms can be of different types; namely: (i) Permission-less, which means that the blockchain network is public, (ii) Permissioned, which means that the blockchain network is private and access can be granted by specific participants, and management of the network is typically done by a known administrator, or (iii) Consortium, which is a hybrid of the both permission-less and permissioned [13]. Consortium, federated, or hybrid blockchains are similar to the permissioned networks; however, the management of the chain is carried out by more than one administrator. It is envisioned that future 5G mobile operators would benefit more by using a consortium or permissioned blockchain. A public blockchain can jeopardize privacy as customer and provider data are made publically available. This may violated GDPR and data privacy protection laws. A permissioned or private blockchain would be more appropriate if the operator uses the blockchain for its internal use cases. A consortium blockchain would be more appropriate in the use cases where the operators may offer telecom services to the vertical industries, roaming charges settlements involving multiple business partnerships.

5) Trusted Oracles: By design, smart contracts cannot fetch external information on their own. Oracles or source feeds must report external data and events to the smart contracts by calling certain functions within the smart contracts. A single oracle to report information cannot be trusted. Therefore, there is a need for multiple oracles to report feeds to the smart contracts. Smart contracts need to validate and check reported data from multiple oracles to verify the trustworthiness of the reported data. Decentralized mechanisms for reporting, consensus, and reputation are used for the oracles to ensure high level of trust for the reported data [14].

III. BLOCKCHAIN FOR 5G

This section discusses key opportunities offered by blockchain technology in 5G networks. Fig. 1 portraits a hierarchical classification of these opportunities. In addition, we also provide brief and high-level technical details of such opportunities.

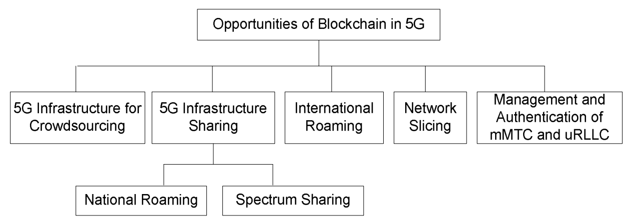

Fig. 1. Hierarchal classification of potential opportunities of blockchain in 5G

1) 5G Infrastructure for Crowdsourcing: Crowdsourcing allows smaller infrastructure investors to roll out cellular towers that will be part of the overall operator's infrastructure. These smaller investors need to be registered, certified, managed, and also automatically paid upon the use of their towers. The authors in [15] have proposed novel signatures that can be embedded in transmitted signals to form a coalition of cellular sites belonging to multiple owners with the objective of providing services in an area. The distributed cellular sites can be individually or jointly owned by the investors/operators in offering a telecommunication service to a specified area. Multiple coalitions can also exist in a particular geographical area [16], and a central authority would be required to manage the distribution of signatures for each coalition [15]. Blockchain and smart contracts can offer a practical solution for registering towers, managing used resources, and automatic charges, billing, and payment in crypto tokens, in a decentralized trusted manner, while at the same time ensuring traceability and transparency. This can be realized by the use of distributed orchestration, rather than a centralized entity. The authors in [17] have proposed a smart contract with the Service Level Agreements (SLA) terms to be used between the small cell providers and the telecom operators. Penalties and incentives can be used to enforce honest behaviors among the parties.

Fig. 2 presents a sequence diagram of applying smart contracts and oracles to the 5G infrastructure crowdsourcing.

The tower owners register their tower information to the smart contract with key attributes about its capabilities, hardware, pricing, availability, attestation and certification, as well as reputation history. Once a cellular tower is registered, the information is broadcasted as blockchain events to all the mobile operators (MO). Then, the interested MOs can select particular towers to lease. Off-chain negotiation can be initiated between the MOs and the selected tower owners. The tower owners can also evaluate the MOs, based on their reputation in the network. Once the negotiation is completed, the agreement can be recorded on the blockchain via smart contracts, and payment can be made automatically using crypto tokens based on the consumption and usage as long as there is no violation of Service Level Agreement (SLA) terms and conditions. SLA monitoring can be done by trusted oracles that report to the smart contract SLA violations. This will result in invalidating usage, and will block disbursement of payments. SLA violations would also result in giving poor reputation scores given to the tower owner.

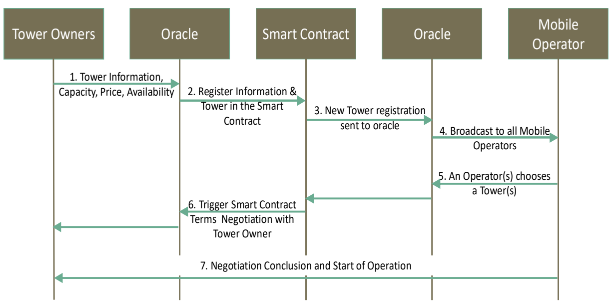

Fig. 2. A sequence diagram of utilizing smart contracts and oracles for infrastructure crowdsourcing

2) 5G Infrastructure Sharing: Infrastructure sharing in 5G is an obvious opportunity [18], in which a seller Mobile Network Operator (MNO) offers telecom services either (i) cellular towers or (ii) a subset of these towers. These two models are considered as *active sharing* [19]. In *active sharing*, an MNO offers its active elements, such as (i) Radio Access Network (RAN), also known as Multi-Operator Core Network (MOCN), or (ii) Core network elements, known as Gateway Core Network (GWCN) [20]. However, *passive sharing* occurs when an MNO shares the cellular tower mast, space, cooling, and the telecom rooms allocated in various buildings. Active sharing is considered as the most efficienltly used technique due to the realization of *network virtualization* [16] [21]. It refers to the abstracting and slicing of the physical and radio infrastructure resources into different virtual resources, each with separate functionalities, services, and goals different from each other [22]. Blockchain is anticipated to be extremely useful in managing and tracking the sharing and usage of resources (of 5G active and passive elements). With the use of smart contracts, an immediate and automated agreement sharing and payment disbursement can be made without any intermediaries.

a) National Roaming: Roaming sharing occurs when telecom operators act within a country with no sharing of 5G active or passive elements. However, the subscribers are always allowed to roam to host operator even if the home operator does not cover a specified geographical area [22]. Home Server Subscriber (HSS) model is proposed to share the subscriber information of the operators on a blockchain network so that seamless facilitation of roaming service can be achieved without the intervention of any central entities. Smart contract-based authorization and authentication methods are used, with automatic billing and payments [23]. A decentralized network access and authentication based on blockchain was also proposed in [24] that performs the autonomous roaming between the different network operators.

b) Spectrum Sharing: The spectrum in cellular networks has become a scarce and very expensive resource. Currently, operators pay large fees to spectrum regulators. Typically, an operator purchases a sub-band or several sub-bands from a regulator [25]. The operator then uses these sub-bands either for their own purposes or leases them to other operators. This model allows a telecom operator to fully utilize its resources and supports the newly entrant small operators to provide 5G services without paying large licensing fees. It is also known that most of the available spectrum bands are already occupied by the primary users, known as incumbent users. These bands include television, digital broadcast, government digital service, and satellites [26]. The use of the License Shared Access (LSA) scheme can improve this issue of spectrum scarcity. LSA provides a part of its unused spectrum to the incumbent user, whereby the LSA licensee is granted for using part of its incumbent spectrum. The regulating body only oversees the agreement terms between both of the parties and issues the LSA license. The terms of the agreement normally contain the Quality of Serivce (QoS) thresholds in order to guarantee the controlled interference operation. In addition, the agreement rules are pre-defined or converted into a dynamic one. The specified sharing dimensions generally span frequency, time, and location whereby allow the dynamic spectrum allocations by considering the Cognitive Radio Sensing (CRS) [26] using the dynamic agreement rules [23]. Other existing spectrum sharing schemes, such as Spectrum Access Sharing (SAS) [27] and Co-primary Shared Access (CAS) [28] are also available to fulfill this need. These schemes offer effective spectrum sharing mechanisms;however, seriously lack an end-to-end dynamic spectrum management and sharing process [28]. Blockchain and smart contracts can be leveraged to efficiently and securely provide these services in an automated, visible, and trusted manner without third parties or intermediaries. Moreover, coordinated control and spectrum management for 5G heterogeneous radio access networks (RAN) is required, firstly for; abstraction of physical and Medium Access Control (MAC) layers, network functions, topography, and connections (known as *infrastructure resource abstraction*), and secondly for the *network services abstraction* to applications and services that use service from the control plane [29]. Fig. 3 illustrates the architecture of the concept to allow for Dynamic Spectrum Sharing (DSS) and interactions between the network infrastructure and network slices. The figure shows that this concept has very close resemblance to the Software Defined Network (SDN) architecture [30].

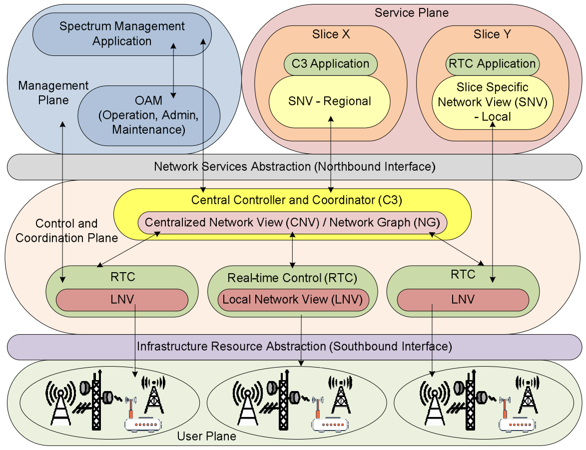

Fig. 3. Unified framework for dynamic spectrum sharing and network slicing

The spectrum sharing operates in a trustless environment where every entity competes for available resources. For this, blockchain offers a key role in tracking the usage, ownership, and management of resources, relationships, and interactions among the entities in a fully decentralized manner. A decentralized application (DApp) provisioned on the top of the blockchain network can hold all the available spectrums and rules which are closely related to each spectrum usage. An operator can request a spectrum usage through the DApp as per the long term or on-demand requirement. The DApp can help to settle all the payments autonomously between the spectrum owners, - that is regulators and the operators after the smart contract term ends. In this framework, an operator who already has leased a part of the spectrum can also offer it again through the deployed DApps.

Fig. 4 illustrates the utilization of blockchain for LSA sharing. The LSA licensee and associated incumbents are allowed to access the LSA repository and smart contract via the oracles. A reputation mechanism is devised to rate the licensees and the incumbents to check if they abide by smart contract rules and Spectrum Sharing Rules (SRR). The regulating authorities maintain the National Frequency Allocation Table (NFAT), which contains all the spectrum allocations of incumbents and licensees. Smart contracts are written to show the allocation of current registered owners and leasees of the spectrum. The regulating authorities enforce general sharing rules on the smart contract and any other relevant agreements among all participant. In [26, 31], cognitive radio networks (CRN) are combined with blockchain to offer a distributed MAC protocol for the secondary users of the 5G network. In [32], a blockchain-based spectrum sharing method is proposed to provide the virtualization of network resources under 5G network infrastructure. Another important aspect is that to provide the ultimate telecom services, the spectrum resources exist in a reserve pool and require automated trading and allocation via the blockchain platforms by incorporating the primary owners and virtual providers. The Federal Communications Commission (FCC) has also recommended the use of blockchain for spectrum management to realize the futuristic 6th generation (6G) technology [33].

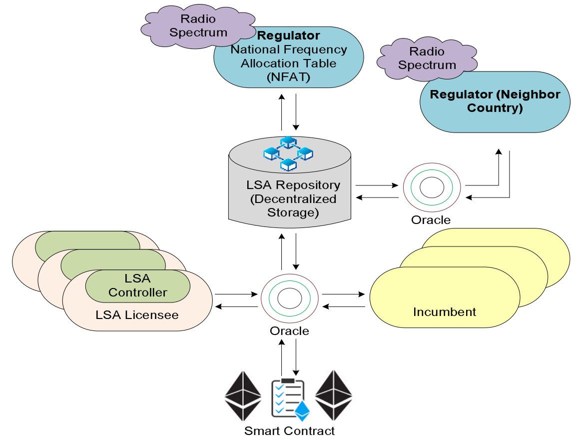

Fig. 4. Leveraging blockchain for LSA Sharing

3) International Roaming: Roaming is one of the challenging issues in the telecom sector as it involves brokers and third parties to settle down payment and charges rules among them. It is obvious that in 5G many parties are going to be involved for the usage of 5G networks. These parties may include multiple operators, intermediary international exchanges, and intermediary networks. In any of the cases, the roaming interconnections are settled either by direct or by international exchanges [34]. The international exchanges have some critical drawbacks, such as (i) single point of failure in the intermediary level, (ii) profit-cut (that these intermediaries regularly charge), and (iii) fraudulent activities (that may occur if the roaming subscriber usage is not directly exchanged). Smart contracts are implemented to accomplish a blockchain-based payment and roaming in which charges and consumption per usage is recorded and tracked. Subsequent payments are dispersed automatically in the form of cryptocurrency or tokens among the parties involved, in a trusted manner with no involvement of local or international third parties, brokers, or exchanges. Smart contracts capture the agreement conditions and logic from all parties and record, validate, and govern all their interactions so that they can be all traced, tracked, and audited by all the parties, in a cost-efficient way.

4) Network Slicing: In 5G, a network slice is defined as an instantiation of the physical infrastructure or the underlying network services and capabilities. 5G network slicing allows an operator to serve a wide variety of user services and applications by using the same network infrastructure. 5G network slices also facilitate active infrastructure sharing and spectrum sharing [21]. A Network Slice Broker (NSB) is typically used to perform the slicing by exposing the service capabilities of the mobile operator network. A blockchain smart contract with decentralized storage, like Storj or IPFS can be used to replace some or all NSB functionalities. The smart contract, upon predefined rules, allows different requestors to negotiate various contract terms autonomously and dynamically. In addition, the operator can also register and publish network slice capabilities on the blockchain. The payment can also be automated through the smart contract.

5) Management and Authentication of Massive Machine Communicaitons (mMTC) and Ultra Reliable Low Latenciy Communications (uRLLC): The *mMTC and uRLLC* are two key pillars of 5G, where millions of IoT devices are expected to be connected at less than one millisecond latency. The incorporation of such a large number of IoT devices opens up the possibility for new business models and services to be offered to the futuristic mobile customers. It is anticipated that 5G shall manage these IoT devices by trusted intermediary centralized operators [2]. The operator is expected to carry out the following tasks as the central authority: (i) manage subscriptions, payments, and data bundles to enable *mMTC and uRLLC,* (ii) anage multiple verticals and multiple enterprises, and (iii) manage device authentication. Blockchain smart contracts, with decentralized storage are more powerful and attractive alternatives to these centralized operators, in which such management functionalities can be performed in a decentralized manner, with superior trust, visibility, traceability, and automated payment.

IV. Open Challenges

This section highlights and discusses challenges that may hinder massive adoption and utilization of blockchain in 5G.

A. Scalability: The targeted end-to-end latency in 5G networks is less than 1 millisecond [2] for payload and carried data. This stringent requirement entails configuration and setup transactions at very high throughput rate. Currently, public blockchain networks, such as Bitcoins and Ethereum, can handle 10-14 TPS (Transactions per Second), whereas some private blockchain implementations can reach to as much as 3,000 to 20,000 TPS [35]. Therefore, novel blockchain architectures, sharding techniques, block size increase, consensus algorithms are being researched to increase the throughput of today's blockchain networks.

B. Smart Contracts: To date, there are approximately 10 million smart contracts deployed on the public Ethereum blockchain. The major challenge is how to transform these massive number of contracts into smart contracts for the 5G ecosystem. Particularly when considering the high granular level of IoT devices that will be present in a typical 5G network. The legality of the deployed smart contracts is another issue. Normally, the legal status of smart contracts depends on whether there is a binding contract and jurisdiction associated with it [17]. The security of smart contracts code is another a critical issue. Smart contracts code also may contain bugs and vulnerability that may lead to the exploitation of smart contracts by hackers. Development of secure and vulnerability-free code for smart contracts has become a critical task, and 5G smart contracts are not an exception. Moreover, by design, smart contracts are not patchable or upgradable. Once the smart contract is uploaded and used, it cannot be updated or patched if a vulnerability or bug is found. Therefore, there is a need to devise novel ways for upgrading smart contracts to fix previous issues, and ethical reporting of bugs and vulnerabilities need to be enacted and standardized.

C. Standardization and Regulations: To date, blockchain and smart contracts are highly de-standardized and de-regulated, at both national and international levels. For massive adoption of blockchain in 5G and telecom industry, local and international standardization, regulation, and governance must be enacted. The standardization can either happen within the telecom standard groups to target telecom-service-specific blockchain applications, or it can also be done completely independent of other aspects.

D. Transaction and Cloud Infrastructure Costs: Building and maintaining a private or consortium blockchain network have to account for cloud infrastructure costs to host the blockchain nodes, and this can be costly if not optimized. In a public blockchain network like Ethereum, fees must be paid gas units for every transaction. One unit of gas represents the computing and energy consumed for leveraging the smart contract when executed by the mining nodes. The transaction fees are relative to the function code to be executed by the smart contracts. If smart contracts functions and their respective codes require heavy computation, or not written in an efficient manner, large fees can be incurred.

F. Data Privacy: Data privacy has become a major concern for governments, businesses, and individuals. It is more critical for 5G operators that hold sensitive customer information that may include personal and identification details, such as credit card, address details, service and usage records, and payment history. With the advent of EU GDPR policy, privacy requirements have become more stringent in protecting users records and data, and in giving control and ownership of the data to users. By design, data stored or recorded on a blockchain cannot be deleted or forgotten, since blockchain data is immutable. On the other hand, when considering blockchain privacy design, no personal data shall be stored in blockchain, only has pointers of that information [23].

G. Interoperability: Seamless interoperability among different blockchain platforms is still a challenging issue. There are many types of blockchain platforms available today in which 5G stakeholders can be connected to. This is a key challenge that needs to be addressed and overcome by researchers. Moreover, interoperability within the 5G networks is yet another challenge. 5G comes with a set of new technologies that include mmWave, small cells, massive MIMO, full duplex, SDN, and beamforming. Each of these technologies works in a different fashion.

H. Naming, Registration, and Reputation: In order to manage many of the participants and entities which are part of the blockchain and 5G ecosystem, a decentralized registration system with trust, scalability, performance, and efficiency is needed. Such a system can be built with the use of smart contracts and decentralized storage. In addition, a decentralized identity registration is required to associate blockchain addresses, public keys, and accounts to legitimate identity for participants in a 5G network. These participants need to be linked to a decentralized reputation system, that can be built using smart contracts, and it will give aggregated reputation scores to all participants and oracles based on their historic behavior and provided services. Reputation scores can be reported by service users to a reputation smart contract that will calculate the aggregated score to enable, authorize and authenticate the 5G end users.

V. Conclusion

In this paper, we presented an overview of blockchain DLT technology along with its key features and supporting elements, such as smart contracts, decentralized storage, and trusted oracles which all can be leveraged to support decentralized 5G applications, services, and ecosystems. We outlined various opportunities and use cases for blockchain in 5G with high-level technical details including system designs and architectures. Furthermore, we identified several open research challenges that need to be addressed in order to efficiently utilize and integrate blockchain in 5G networks.

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