Blockchain-based Roaming and Offload Service Platform for Local 5G Operators

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***Abstract*—Local 5G Operator (L5GO) concept is one of the most prominent versatile applications of the 5G in the near future. The popularity of L5GOs will trigger a greater number of roaming and offloading events between mobile operators. However, existing static and the operator-assisted roaming and offloading procedures are inefficient for L5GO ecosystem due to poor service quality, data privacy issues, data transferring delays, excessive costs for intermediary parties and existence of roaming fraud. To address these challenges, we propose a blockchain / Distributed Ledger Technology (DLT) based service platform for L5GOs to facilitate efficient roaming and offload services. As the key contribution, blockchain-based smart contract scheme is proposed to establish dynamic and automated agreements between operators. By using smart contracts, we introduce several novel features such as universal wallet for subscribers, service quality based L5GO rating system, user-initiated roaming process and the roaming fraud prevention system to improve the operational quality of a L5GO. A prototype of the proposed platform is emulated with the Ethereum blockchain platform and Rinkeby Testnet to evaluate the performance and justify the feasibility of the proposal. Upon an extensive evaluation on the prototype, it was observed that the proposed platform offered benefits such as cost effective, more secure and reliable experience.**

***Index Terms*—Roaming, Offload, 5G, Local 5G Operators, Blockchain, Distributed Ledger Technology, Smart Contracts**

I. Introduction

Local 5G Operator (L5GO) is one of the prominent innovation in 5G which operates as a small scale mobile network within limited geographical area such as university, hospital, factory or shopping mall. L5GOs enable business entities to operate their own 5G communication ecosystem with distinguishing and custom requirements [1]. It will be a disruptive innovation of 5G networks to cater a diverse set of emerging applications [2]. The decentralization and locality oriented design of L5GOs ensure high reliability, context awareness, perimeter security and privacy management.

The roaming and offloading procedures maintain persistent connectivity of the subscribers across different networks and geographical regions. Roaming refers to the capability for a subscriber to access the mobile services offered by the Visited Public Mobile Network (VPMN) via the Home Public Mobile Network (HPMN), when moving out of the coverage range of HPMN [3]. Accordingly, L5GOs are able to provide connectivity for the Mobile Network Operator (MNO)'s customers when they reside outside geographical coverage area of its home network. Offloading allows MNOs to handover the network traffic load to other networks to boost the network efficiency of the system, minimize power consumption of base stations, achieve expected quality of service and maximize throughput. Since L5GOs offer better coverage inside their premises, MNOs can use these L5GOs to serve their subscribers when they reside in L5GO's coverage area. Most of the state-of-art roaming management systems suffer with limitations such as operational bottlenecks and fraudulent practices. Roaming frauds prevalent when a fraudulent user attempts to utilize the VPMN's resources after the session termination. In such circumstances, it may take some time to synchronize and identify the fraud due to data exchanging delay. Then, HPMN is incapable to charge the fraudulent user and yet compelled to pay for the delivered service. Roaming frauds are one of the most prevalent issue in telecommunication industry which cost over USD 38 billion annually [4].

Additionally, roaming processes lack the transparency, which results in the violation of static agreements and pre-agreements by network operators. Further, there is potential for a partner operator to access the users' information unlawfully and to charge roaming users unfairly which might generate bill-shocks to users. Eventually the customers would unhappy on the service [5]. Therefore, the mutual trust between operators must be maintained. Also, real-time network characteristics such as current load and bandwidth are not assessed in such agreements. Furthermore, the popularity of L5GOs will trigger more and more number of roaming and offloading instances, which increases the network traffic load in network operators. However, these issues expected to be rectified in the future evolution of 5G.

The blockchain / Distributed Ledger Technology (DLT) is another disruptive technology which is distributed and decentralized in the operational perspectives. The blockchain operates with decentralization which leverages the orientation and robust access control implementation to the user data. Otherwise the data is prone to malicious parties who commit frauds. The smart contract provides transparency in the execution logic, which enhances the trust between intervening parties [6]. Furthermore, the integration of distributed ledger maintains a transparent log of footprints of the activities

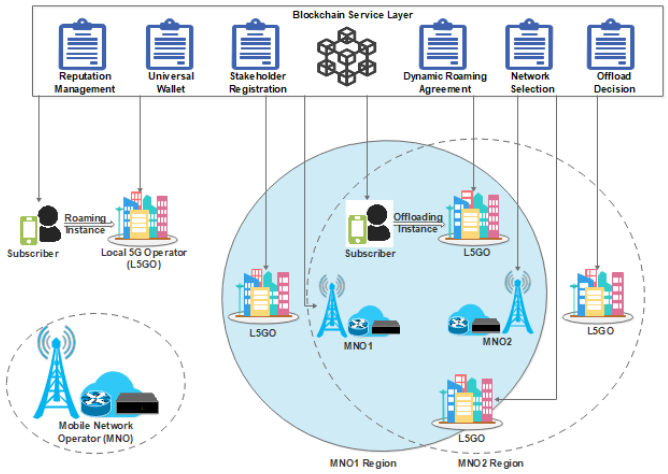

Fig. 1: The high-level view of the proposed model

by each party. The transparency of logs are important in case of dispute resolution scenarios to ensure non-repudiation and trust between the resolving parties. Furthermore, the logs attached to the distributed ledger are immutable which guarantees that none of the party can modify it. Researches are now urged to apply blockchain technology to overcome this situation [7], [8], [9] and [10]. However, none of these proposals offer a complete roaming and offloading platform for L5GOs. Most of the proposals lack of the real implementations of their proposed systems.

To address mentioned limitations, this paper proposes a novel blockchain based architecture for L5GOs to enable the offload and roaming services. The high level overview of the proposed platform is depicted in Fig. 1. Our solution facilitates unique features explicitly, a universal wallet for each registered subscriber, the secure log of user details, a reputation management system to ensure the quality of service, automatic selection of the best-rated network for a subscriber, the supervision of traffic load across network operators and automatic execution of load balancing techniques and a system to avoid over-utilization. These service offerings are delivered with the establishment of dynamic smart contracts between stakeholders. A prototype of the proposed approach is implemented using Ethereum-based Decentralized Application (DApp). Finally, the performance evaluation is carried on the Rinkeby test network [11].

The rest of the paper is organized as follows: Section II provides a quick survey of existing works. Section III introduces the proposed architecture whereas prototypical implementation is discussed in the Section IV. Section V elaborates the experimental results. Section VI presents a performance analysis. Finally, the Section VII concludes the paper.

II. Related Works

Till date various ideas have been introduced to explain the way blockchain can be utilized for 5G. Among them, few research studies demonstrate on how blockchain can be used to facilitate roaming services. Mainly, they have addressed the potential opportunities and benefits of using blockchain in a roaming platform as one of the many applications [12].

Most of the proposed approaches have aimed to eliminate solely the third party service providers using blockchain [7], [8] and [9]. In the [8] research study, authors have proposed a blockchain based architecture to remove Data Clearing House (DCH) and its business value is validated through a process of analysis. However, in the reference [7], a smart contract is written to settle and notify the roaming charges between HPMN and VPMN. Moreover, a blockchain based user balance transfer through online and offline is proposed. Nevertheless, another literature study [9] has proposed a blockchain based architecture for a roaming platform and has carried out a case study to analyze its performance in both the operator's and user's perspective. A blockchain based roaming fraud prevention framework was proposed in [10], where this approach minimizes the data exchange delay and the excess cost with the replacement of DCH with the blockchain. Also, an economic model based on Stackelberg game was developed to maximize the benefits for users by allowing them to participate in the consensus process and earn extra profits for their involvement. However, theses studies did not focus on addressing almost all the issues that might arise in a roaming management system. Hence, there still remains the need for one new entire roaming and offloading platform to solve most of its key challenges mentioned in section I for future evolution of 5G. Our research study further extends these prior works and delivers the following key contribution.

- Proposes a novel blockchain based architecture that enables both roaming and offload services not only for international but also locally with L5GOs
- Proposes dynamic, real-time and automated roaming and offload decision platform
- Implements the proposed architecture and evaluates the performance of the system

III. Proposed Architecture

A novel architecture for delivering roaming and offloading services to L5GOs is illustrated in Fig. 2. The architecture comprises three major stakeholders, namely subscribers, MNOs and L5GOs. A blockchain based backend is proposed to offer various services to enable offloading and roaming between MNOs and L5GOs. The basic functionalities of the proposed platform are discussed with the help of algorithms. The notations used in the algorithms are listed in the table 1.

A. Registration of Stakeholders

All three stakeholder i.e subscribers/users, MNOs and L5GOs are registered with blockchain.

The user registration process initiated whenever a new subscription is activated. During this procedure, the subscriber's details (i.e.name, the national identity card number, the home address) are uploaded to the blockchain by the MNO. MNO is responsible to store the user's details with their corresponding International Mobile Subscriber Identity (IMSI)

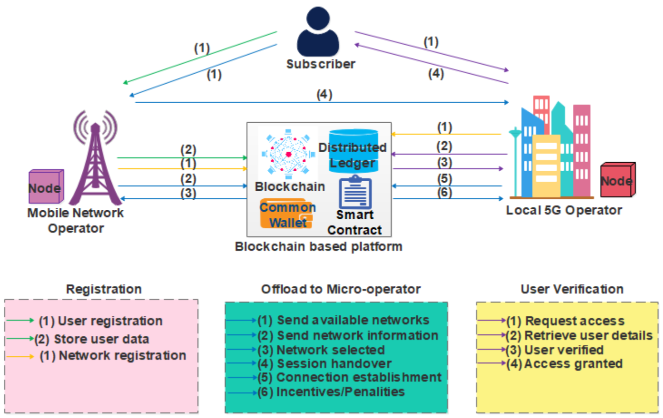

Fig. 2: The proposed architecture

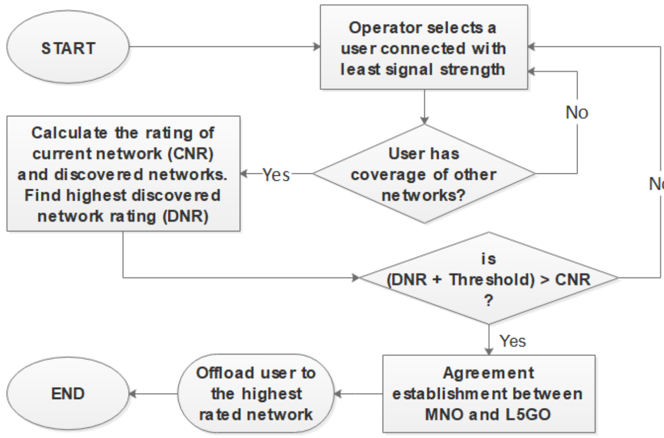

Fig. 3: The flow of offloading procedure

number as the key, in the distributed ledger. Furthermore, a universal wallet will be assigned to each user.

In **the network registration process**, the information of MNOs and L5GOs will be recorded in the chain, including information relating to the network bandwidth, network capacity and their charging scheme. This process allows to create only one account per operator. Any of these details can be retrieved with operator's account address. Moreover, the initial reputation score of the operator is set to the average reputation score of the system to maintain an equality among network providers. The system's average reputation score is calculated by averaging all the reputation scores of the currently registered networks. Further, a cost rating is calculated for each pricing schemes of networks by combining voice, Short Message Service (SMS) and data costs with pre-defined weights for each parameter. The cost score computation is demonstrated in (1).

$$S_{C_i} = W_V * C_{V_i} + W_S * C_{S_i} + W_D * C_{D_i} \quad (1)$$

TABLE 1: Summary of notations

Notation	Description	Notation	Description
AC	Available Capacity	S_C	Cost Score
B	Network Bandwidth	S_O	Offload Score
C_D	Data Cost	S_R	Reputation Score
C_S	SMS Cost	S_{RO}	Roaming Score
C_V	Voice Cost	SS	Signal strength
J_A	Allowed Jitter	W_{AC}	Capacity Weight
J_D	Jitter Deviation	W_B	Bandwidth Weight
J_S	Session Jitter	W_C	Cost Weight
L_A	Allowed Latency	W_D	Data Cost Weight
L_D	Latency Deviation	W_J	Jitter Weight
L_S	Session Latency	W_L	Latency Weight
PB_A	Allowed Blocking Probability	W_{P_B}	Blocking Probability Weight
PB_D	Blocking Probability Deviation	W_{PL}	Packet Loss Weight
PB_S	Session Blocking Probability	W_R	Reputation Score Weight
PL_A	Allowed Packet Loss	W_S	SMS Cost Weight
PL_D	Packet Loss Deviation	W_{SS}	Signal Strength Weight
PL_S	Session Packet Loss	W_V	Voice Cost Weight

B. Universal Wallet

During the registration, a universal wallet is created in the blockchain for each stakeholder. Despite of the network the user is connected to, the usage charges are deducted directly from the created subscriber's wallet based on their consumption and MNOs' pricing policies.

C. Offloading

This functionality applies to the customers who have both the home operator coverage and the coverage of one or more L5GOs. Whenever the Home Mobile Network Operator (HMNO)'s capacity utilization exceeded a pre-defined threshold value of the total capacity, offload process will trigger. Initially, MNO selects a single user or multiple users connected with least signal strength. Then checks whether the selected users have coverage of other nearby networks. Subsequently, the system calculates a offload score for each detected neighbouring network, as depicted in (2) and selects the network with the highest offloading score.

$$S_{O_i} = W_{AC} * AC_i + W_B * B_i + W_C * S_{C_i} + W_R * S_{R_i} \quad (2)$$

Once the network with the highest rating is found, the deviation between the highest rating and the current network's rating is computed. The deviation is then compared against a pre-defined threshold and checked whether it is greater than the pre-defined threshold. Only if that condition is satisfied, a dynamic offloading agreement is established between the MNO and the selected L5GO by using a smart contract. Thereafter, the subscriber will be offloaded to the selected L5GO. The complete offloading strategy is expressed in the Fig. 3.

D. Roaming

This service triggered when a user goes out from the home network coverage area. The user starts the process by sending details, including RSSI levels, of k number of nearby networks to a nearby L5GO. This data will then be processed on the blockchain via smart contracts, to find the best available L5GO for the subscriber. In the network selection algorithm, a roaming score for each network is computed by considering

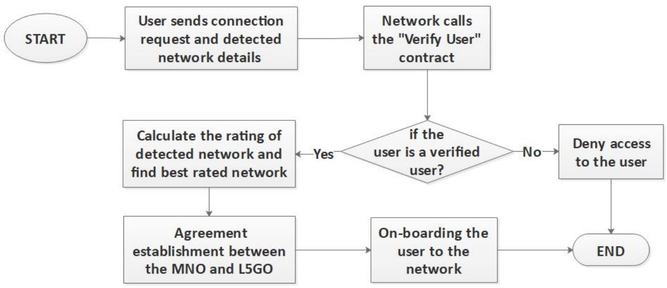

Fig. 4: The flow of roaming procedure

the service cost, reputation score and signal strength as per (3). Cost and reputation data are retrieved from the ledger.

$$S_{\mathrm{RO_i}} = W_{\mathrm{SS}} * SS_{\mathrm{i}} + W_{\mathrm{C}} * S_{\mathrm{C_i}} + W_{\mathrm{R}} * S_{\mathrm{R_i}} \tag{3}$$

Once the roaming scores are calculated for each available L5GOs, the L5GO with the highest rating factor is selected for the user. Then, a dynamic roaming agreement is established between the selected L5GO and the MNO. Thereafter, the L5GO will offer roaming service to the subscriber. The roaming procedure is illustrated in the Fig. 4.

E. Reputation Management System

This system is responsible to maintain reputation score for each L5GO based on their performance. This essentially compels L5GO to offer high quality services and users will ultimately experience a high service quality. At the end of each successful session, the reputation management contract will be called to calculate the reputation score. The reputation score depends on several network performance characteristics. They are latency, packet loss, jitter and blocking probability. Initially, the deviation of these parameters with respect to a pre-defined threshold values, are computed as depicted in the equations (4), (5), (6) and (7).

$$L_{\mathrm{D}} = L_{\mathrm{A}} - L_{\mathrm{S}} \tag{4}$$
$$PL_{\mathrm{D}} = PL_{\mathrm{A}} - PL_{\mathrm{S}} \tag{5}$$
$$J_{\mathrm{D}} = J_{\mathrm{A}} - J_{\mathrm{S}} \tag{6}$$
$$P_{\mathrm{B_D}} = P_{\mathrm{B_A}} - P_{\mathrm{B_S}} \tag{7}$$

Next, to obtain a score value, a weighted sum will be calculated using above parameters as given in (8). Having an unique weight for each parameter allows prioritizing one or more factors over the others.

$$S_{\mathrm{R}} = W_{\mathrm{L}} * L_{\mathrm{D}} + W_{\mathrm{PL}} * PL_{\mathrm{D}} + W_{\mathrm{J}} * J_{\mathrm{D}} + W_{\mathrm{P_B}} * P_{\mathrm{B_D}} \tag{8}$$

Then, the moving average of the reputation score is calculated by considering both the previous average and current session scores.

$$S_{\mathrm{Rmoving}} = \alpha S_{\mathrm{Rcurrent}} + \beta S_{\mathrm{Rprevious}} \tag{9}$$

Where α and β known to be the weight coefficients and addition of these two coefficients should be equal to 1. The network operator is allowed to set values for them depending upon their preference. Finally, the new moving average of the reputation score of the respective L5GO is updated and stored in the distributed ledger.

F. Fraud Prevention

Fraud prevention measures are managed through usage limit smart contract. Whenever a service is requested by a subscriber from a L5GO, usage limit contract will be invoked to retrieve remaining account balance of the subscriber. However, the subscriber's account balance will not be directly shared with the L5GO, instead the contract will calculate the maximum cost for service that the L5GO can charge the customer. With this information, L5GO can determine when to terminate the service given to the user, even before the session is started, essentially avoiding over utilization problems.

IV. Implementation

A. Experimental Environment

A prototype of the proposed platform was implemented using Ethereum based smart contracts. The Fig. 5 represents the interaction between these smart contracts. Codes of smart contracts were written in solidity language by using Remix IDE. Further, the written smart contracts were deployed on a Rinkeby private network with PoS consensus algorithm.

B. Description of Smart Contracts

The Rinkeby network facilitates to operate near realistic smart contracts as Ethereum public blockchain network. The corresponding smart contracts programming in Solidity. The incorporated smart contracts in the implementation setup are as follows :

1) User Registration Contract: The main purpose of this contract is to register new tenants while avoiding duplicates. Only MNOs have the permission to register their subscribers to the blockchain. All the user details will be stored in the distributed ledger and shared among the connected blockchain nodes. Therefore, the user details can be retrieved at any given time by sending the IMSI to the blockchain. Further, a user verification function is implemented here. It checks whether the user has already registered in the blockchain network and avoids unauthorized accesses to the system.

2) Network Registration Contract: The role of this contract is to register MNOs and L5GOs. For each network, their respective capacity, bandwidth, reputation and charging schemes are recorded.

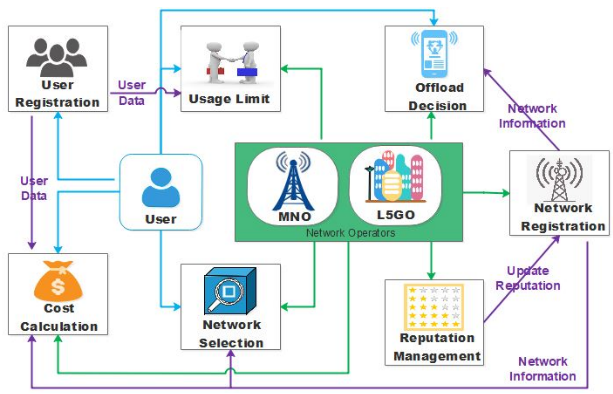

Fig. 5: Interaction between smart contracts

3) Offload Decision Contract: This contract is executed to perform the offload process. It calculates the offload scores as describe in Section III-C and returns the L5GO with the highest score.

4) Network Selection Contract: The main purpose of this contract is to find the best available network for a roaming user. It is initiated when a user starts to send details of all the nearby available networks along with their signal strengths. Further, it calculates roaming scores for all the possible L5GOs as describe in Section III-D, Then, L5GO with the highest score is returned.

5) Reputation Management Contract: The contract is invoked whenever a session is ended. The functionality of this contract is to compute a reputation score for each connected network provider and update the score to the blockchain as describe in Section III-E.

6) Usage Limit Contract: This smart contract acts as the dynamic agreement between MNO and the L5GO. L5GO is strictly responsible to deliver the network services based on the agreement. Additionally, fraud prevention approach which is described in Section III-F, is also coded in this contract.

7) Cost Calculation Contract: The main role of this smart contract is to provide billing information related to user consumption and reputation based incentives or penalties for L5GOs. Failing to maintain the minimum standard will result in penalties, while exceeding the satisfactory level will be rewarded with incentives. Penalties or incentives will be deducted from or added to the operators' accounts.

V. Experimental Results

Rinkeby Testnet [11] is a public Ethereum test network which is designed for carrying out experiments without paying any currencies. We ran several tests in this platform to validate the accuracy and to evaluate the performance of the developed decentralized application (Dapp).

A. Latency Measurements for Various Operations

Connected users can retrieve, store or change data on the blockchain using smart contracts. Any request sent to the blockchain that does not need to change its state, get processed almost instantaneously, since they are not recorded in blocks as transactions. However, when new data is stored on the chain by invoking contracts, such operations will be logged in new blocks as transactions, which involve mining. Therefore, it not only takes more time to process the transaction, but also comes at a gas cost. According to [11], a new block is created every 15 seconds on Rinkeby Test network. However, to put it in a test, every smart contract was run for 100 times and the average latency was recorded with a 95% confidence interval, which are tabulated in table 2.

Based on the tabulated results, it is clearly visible that our tested average is approximately around 24 s. That is the process has experienced 9 s delay than the advertised time which is 15 s. The additional delay is caused due to the latency of the internet service provider and the processing time.

TABLE 2: Latency Measurements for Various Operations

Contract Name	Latency (s)
User Registration	26.11597 ± 2.17257
Network Registration	24.13738 ± 1.54385
Offload Decision	25.48436 ± 2.86953
Network Selection	25.81101 ± 2.95266
Usage Limit	22.65481 ± 1.11385
Reputation Management	24.03633 ± 2.10517
Cost Calculation	22.57387 ± 1.68210

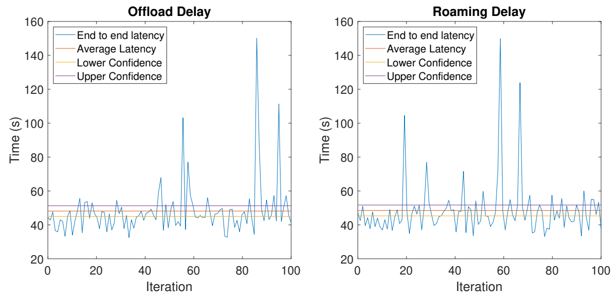

Fig. 6: End to end latency of offloading and roaming processes

Statistics for offloading delay and roaming delay are presented in figure 6 with a 95% confidence interval. These results are obtained by running the experiment for 100 times.

1) Offload Delay: From Fig. 6, the average offload delay is approximately 48.1 s. This offload delay consist of the time taken to execute the offload decision and usage limit contracts and the latency of network level hand-off of 20ms [13].

2) Roaming Delay: Based on Fig. 6, subscriber is connected with the roaming connection after 48 s from the beginning of the process (sending access requests to the network). This roaming delay consists the time taken to execute the network selection and usage limit contracts and to perform the network level hand-off of 50ms [13].

As per [9], the legacy roaming and offloading scenarios have about 1.75-3.5 s latency. In the proposed scenario, latency increased due to the process of selecting the visitor network. This process is happening before the real migration happen. Therefore, impact of this delay is not critical.

B. Cost Calculation for Smart Contracts

Ethereum blockchain defines gas as a unit for the cost of a transaction. When a miner receives multiple transaction requests, it selects the transactions which have the highest gas price to mine in to the next block. Thus, the gas price in our experiment is set to 1 Gwei to mitigate competition. The term gas limit represents the maximum amount of gas that could be expended on a transaction and the remaining gas is refunded. In our system, the gas limit of each contract is set to 2000000.

Two types of costs encountered when deploying a smart contract on Ethereum are transaction cost and execution cost. The transaction cost is the gas consumed when a smart contract is sent for validation along with necessary data whereas the execution cost is the gas consumed for executing a smart contract. Costs for each contract is found from the Remix IDE and they are listed in the table 3.

TABLE 3: Cost Calculation for Smart Contracts

Contract Name	Execution Cost		Transaction Cost	
	Gwei	EUR[a]	Gwei	EUR[a]
User Registration	111415	0.0358	928099	0.298
Network Registration	52050	0.0167	1287451	0.4134
Offload Decision	88373	0.0283	792045	0.2543
Network Selection	68954	0.0221	631856	0.2029
Usage Limit	27782	0.0089	228536	0.0733
Reputation Management	58553	0.0188	466961	0.1499
Cost Calculation	52504	0.0168	474746	0.1524

1 Ether = 10^9 Gwei,[a]1 ether = EUR 321,15 on 27.08.2020

From the experimental results, it is obvious that operational cost of smart contracts is quite low. This cost can be further reduced by moving to a low cost blockchain system.

VI. Discussion

A. Performance Analysis with Legacy Systems

1) Security Analysis: When comparing with the classical roaming facilitation systems, our approach utilizes the blockchain technology to ensure the immutability of the CDR data exchanged eliminating possibility to being tampered.

2) Reliability Analysis: In the classical systems, there is a potential for a single point of failure due to the existence of a single and centralized third-party clearing house. However, proposed solution achieves more resilience than the classical systems due to the decentralization and distributed characteristics of the blockchain. Additionally, the entire proposed roaming/offloading system implemented according to the agreed conditions in the dynamic agreement, that guarantees the transparency and non-repudiation in operations.

B. Comparison with Pertinent Existing Works

Table 4 depicts a comparison between our proposed method with pertinent existing solutions. This table clearly confirms the novelty of our approach.

VII. Conclusion

This paper proposed a novel blockchain-based architecture to facilitate the roaming service in the L5GOs. The proposed solution introduces a universal account to the roaming tenants for seamless connectivity regardless of MNOs associated to each L5GOs. In addition to that, we utilized smart contracts for decision making in the different value added services including MNO connectivity offloading to the L5GOs after an assessment scoring mechanism. The value added features include a smart contract based reputation management system. The proposed architecture is evaluated on Ethereum blockchain platform and analyzed performance factors including gas consumption and latency on different defined operations. The average offload and roaming delay of the proposed system is about 48 s. Besides, we have reflected through the results that our approach is more secure, reliable and cost effective than the classical roaming management system. Our proposal standout among existing blockchain based solutions, since we have proposed a complete roaming and offloading framework to addresses almost all of the potential roaming challenges revealed in previous work related to L5GO network. In future, we will be focusing on utilizing blockchain to provide additional services such as spectrum sharing, security management and IoT data management for L5GOs.

TABLE 4: Comparison with Related Works

Features	Legacy		Blockchain-based				Ours
	[3]	[4]	[7]	[8]	[9]	[10]	
Universal Wallet	No	No	Yes	No	No	No	Yes
Decentralized Operation	No	No	Yes	Yes	Yes	Yes	Yes
MNO Prioritization	No	No	No	No	No	No	Yes
Fraud Prevention	No	Yes	No	No	No	Yes	Yes
Decentralized Traceability	No	No	Yes	Yes	Yes	Yes	Yes
Load Balancing Technique	No	No	No	No	No	No	Yes
No Intermediary Parties	No	No	Yes	Yes	Yes	Yes	Yes
Reputation System	No	No	No	No	No	No	Yes
Openness	No	No	Yes	Yes	Yes	Yes	Yes

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