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Blockchain-based royalty contract transactions scheme for Industry 4.0 supply-chain management

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ABSTRACT

Industry 4.0-based oil and gas supply-chain (OaG-SC) industry automates and efficiently executes most of the processes by using cloud computing (CC), artificial intelligence (AI), Internet of things (IoT), and industrial Internet of things (IIoT). However, managing various operations in *OaG-SC* industries is a challenging task due to the involvement of various stakeholders. It includes landowners, Oil and Gas (OaG) company operators, surveyors, local and national level government bodies, financial institutions, and insurance institutions. During mining, *OaG* company needs to pay incentives as a royalty to the landowners. In the traditional existing schemes, the process of royalty transaction is performed between the *OaG* company and landowners as per the contract between them before the start of the actual mining process. These contracts can be manipulated by attackers (insiders or outsiders) for their advantages, creating an unreliable and un-trusted royalty transaction. It may increase disputes between both parties. Hence, a reliable, cost-effective, trusted, secure, and tamper-resistant scheme is required to execute royalty contract transactions in the *OaG* industry. Motivated from these research gaps, in this paper, we propose a blockchain-based scheme, which securely executes the royalty transactions among various stakeholders in *OaG* industries. We evaluated the performance of the proposed scheme and the smart contracts' functionalities and compared it with the existing state-of-the-art schemes using various parameters. The results obtained illustrate the superiority of the proposed scheme compared to the existing schemes in the literature.

1. Introduction

In the recent era, *Industry 4.0* has been revolutionized by technologies, AI, CC, Cyber–Physical System (CPS), Cognitive Computing (CoC), and IoT (Zhao, Chen, Liu, Baker, & Zhang, 2020). These technologies have tremendous contribution and shares in *Industry 4.0* according to the requirements of the end-user (Tseng, Yao, Otoum, Aloqaily, & Jararweh, 2020). CPS is an integral component of these technologies, a combination of Sensing, Communication, and Computing. Sensors sense the data from the environment

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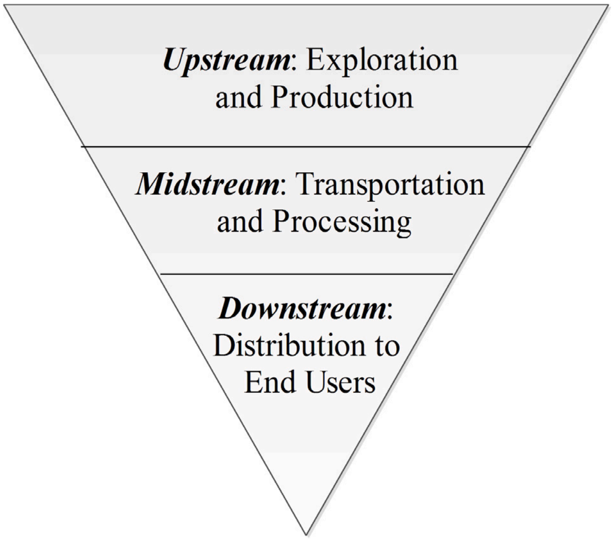


Fig. 1. Streams of *OaG* industry.

in CPS. These entities are connected via various wireless communication protocols to provide scalability, efficiency, autonomy, reliability, safety, adaptability, and functionality of the existing systems. Various industries are widely adopting CPS systems due to their numerous applications such as intelligent transport (IT) (Oham, Michelin, Jurdak, Kanhere, & Jha, 2021), supply chain management (SCM), smart grids (SG), and IoT (Bodkhe, Tanwar, Shah, Chaklasiya, & Vora, 2020; He, Kumar, Chilamkurti, & Lee, 2014; Kumari et al., 2019; Ladha, Bhattacharya, Chaubey, & Bodkhe, 2020).

In this paper, we explore the potential and role of CPS in SCM industries. SCM includes the overall delivery process of materials from scratch to the usage for the end-users. It has many roles to play, such as logistics, supplier, retailer, customer, and end-users (Bodkhe et al., 2020). All these roles must have a general agreement among themselves so that the Quality of Experience (QoE) for the end-users is maintained. Here, consensus mechanisms play an important role to have an agreement between these roles. Mostly, the basic needs include a good supply chain in their transportation from scratch to the end-user such as food, *OaG*, clothes, and raw materials. The business scale has evolved exponentially over the past few years, so goods' necessity has increased many folds. Hence, a reliable and transparent chain of supply is highly required to improve the businesses (Esposito, Ficco, & Gupta, 2021; Li, Wu, Jiang, & Srikanthan, 2020; Tseng, Wong, Otoum, Aloqaily, & Othman, 2020).

In this paper, we focused on the *OaG* domain and its supply chain process. *OaG* supply chain management covers the process from the drilling or digging the *OaG* up-to-the delivery of the final product to the end-users. In *OaG* supply chain management process, landowners, company operators, financial operators, government, wholesalers, retailers, and customers play their vital role by their functionalities and responsibilities. The proper coordination and synchronization among them is one of the key challenges to achieving good performance at every stage (Obeidat, Al Bakri, & Elbanna, 2020).

All supply chains aim to provide goods and services to end-user at the lowest price possible. To achieve maximum profit, companies need to do the whole process at the lowest cost, and efficient supply chain management is one solution. *OaG-SC* consists of various levels such as exploration, production, refining, marketing, and selling. Each of these levels requires a lot of manpower and money, so for an efficient output, all the planning for (each of the level) has been done in advanced, unlike another supply chain. For *OaG-SC*, most of the time at each level, different companies take part; and all these companies want good profits, which results in the high price for the final product. So, automation is necessary at some level to trade off this price. In most supply chains, the products' creativity, innovation, and usefulness are more important than supply chain management. But, for *OaG-SC* there is the same initial and final product for all the competitors, i.e., they have the same exploration product and all the companies have oil and gas as their final product. So, here how they manage their supply chain and how they make it more efficient is the key factors for the success of any business in the market (Chima, 2011). Companies need to make quick decisions, use good management techniques, reduce levels in the chain, and automate their process by adapting new technologies (Aloqaily, Boukerche, Bouachir, Khalid, & Jangsher, 2020).

Fig. 1 shows three stages of *OaG-SC* in the real-time scenario, i.e., upstream, midstream, and downstream. These stages indicate different work following their operations and functionalities (Gong, 2020).

- *Upstream*: It is more inclined towards the exploration and production of the *OaG*. It includes finding a good place from which the companies get a fair amount of *OaG*. Later on, the production stage covers the extraction of hydrocarbons and non-saleable materials from the mixture of liquid hydrocarbons, gas, some solids, and water. At the end of this stage, companies can get the raw materials for selling.

Table 1
Abbreviations.

Abbreviation	Full form
ADNOC	Abu Dhabi National Oil Company
AI	Artificial Intelligence
A_{id}	Admin ID
BC	Blockchain
CC	Cloud Computing
C_{cf}	Cost of Current function
C_i	Total Cost
CoC	Cognitive Computing
CPS	Cyber-Physical System
GPS	Global Positioning System
GUI	Graphical User Interface
H_{key}	Hash Key
ID	Identification Number
IoT	Internet of Things
IIoT	Industrial Internet of Things
IPFS	InterPlanetary File System
IT	Intelligent Transport
L_{ad}	Landowner Address
Min_IB	Minimum value of the initial bonus
Min_Royalty	Minimum value of the royalty
OaG-SC	Oil and Gas - Supply Chain
OCED	Organization for Economic Co-operation and Development
P2P	Peer to Peer
PoB	Proof of Burn
PoET	Proof of Elapsed Time
PoP	Proof of Property
PoS	Proof of Stake
PoW	Proof of Work
Pro_value	Value of the production done per day
QoE	Quality of Experience
R	Royalty amount per day
SCM	Supply Chain Management
SG	Smart Grids
SHA	Secure Hash Algorithm
T_{bonus}	Total initial bonus amount
T_{ear}	Total earning of the landowner

- *Midstream*: It mainly incorporates the transportation of products to the sellers. There are clusters of pipelines and transportation of vehicles through which the transportation is carried out from the wholesalers and sellers.
- *Downstream*: It purifies the raw material received from the upper streams and separates the *OaG*. According to the user's requirement, the process is carried out to sell to the consumers and end-users. The demand for *OaG* in countries like India and Europe has rapidly increased up to 95% in the various organization for economic co-operation and development (OCED). To meet these requirements, the proper execution of the aforementioned streams is required.

1.1. Motivation

As discussed in the introduction, proper synchronization and co-ordination in between streams mentioned above of the *OaG* supply chain is the key factor for the industry to get reasonable profit. In literature, only a few research articles are found in this domain. In this paper, out of these three streams, we primarily focus on the upstream. The upstream is more inclined to explore and produce the raw materials of *OaG*. The process starts with finding the proper soil for the exploration. Various petroleum geological methods are available for finding good soil. It includes heat flow, density variation techniques, magnetic and gravitation anomalies, and electric currents. Later on, drilling is carried out, which consists of the pre-processing of the raw materials. Then, it is transmitted via pipelines to the company store. The existing system works in the same manner.

The existing *OaG* supply chain systems have some issues in their operations. In the first step of the upstream, the prime issue is to find good soil, which the advanced geological techniques can resolve, but issues from the perspective of landowners are also the major concerns and need to be resolved. According to the constitutions of various country's, there are many clauses related to this process. Some countries have the right to property, which shows that the government can use their soil for drilling without providing incentives to the landowners. On the contrary, some governments are in favour to provide incentives to landowners. For example, in 1982, the Federal government has passed a resolution that companies involved in the drilling of land for *OaG* have to give 12.5% of the total production daily as a part of the incentive to the landowners along with the initial bonus based on the per unit area of the land.

The second challenge in the existing system is the landowner's consent, i.e., if he or she agrees to dig into his/her soil, then it is fine. Most of the landowners are not agreed because a lot of work remains incomplete after the digging and drilling process. Hence, it creates a problem to maintain synchronization among themselves. The other concern is to deal with the royalty distribution in certain scenarios, such as when the drilling is carried out on the intersection point of land of several landowners. This is the major concern during the royalty distribution among various landowners; no one can measure the exact amount of raw material received from every individual's land. Another problem is the initial contract signed between the landowners and the *OaG* company. These traditional contracts have some lacunas, which needs to be addressed. In some contracts, they have not mentioned that some percentage of the amount is deducted from the royalty as a part of the cost of transportation for the raw material after completing the drilling process. Lack of clear guidelines about the cost-cutting in royalty during the entire process (from drilling to production house) of the supply chain is also one of the prime concern. Most of the time, landowners feel that the company cheats them due to a lack of veracity. Also, due to the inadequacy of awareness among the landowners, the *OaG* company can cheat them in the royalty distribution and in initial bonus. It creates an imbalance, non-transparency, and lack of trust among the stakeholders. Moreover, the centralized mechanism used in this entire supply chain process, where the third party is an essential requirement to approve this contract. It makes the operation costly, lengthy, manual, and also un-trusted. Further, land and landowners' personal data will be exposed to these firms, which makes this process questionable. Then, existing *OaG* upstream is facing dispute due to the lack of truthfulness, trust, and general agreement between the landowners and companies. There is a need to design an appropriate solution to resolve these issues, especially for the *OaG-SC* industries across the globe. The traditional contracts must be refined so that they should be more efficient, secure, transparent, immutable, cheaper in cost, and less time consuming with high fault tolerance. To mitigate these essential requirements, blockchain is a viable solution due to its numerous properties (Akram, Malik, Singh, Anita, & Tanwar, 0000; Bodkhe & Tanwar, 2020; Kumari, Gupta, Tanwar, & Kumar, 2020; Tanwar, Kaneriya, Kumar, & Zeadally, 0000). A decentralized process' main problem is the lack of trust between the participant nodes in the chain because of a third party's no presence to make any decisions. Through consensus algorithms, BC helps the participated nodes make a mutually agreed decision between them, making BC more suitable to be used in the proposed scheme (Gupta, Kumari, & Tanwar, 0000; Tanwar et al., 2020; Tanwar, Parekh and Evans, 2020).

Industry 4.0 based *OaG-SC* industries are adopting various novel technologies and methodologies such as IoT, AI, CC, big data analytics, and BC to nullify the aforementioned obstacles (Bodkhe, Tanwar, Bhattacharya, & Kumar, 2020; Bodkhe et al., 2020). These technologies have their relevance based on where they have used. We highlight the problems of upstream in *OaG* industry by using the aforementioned technologies and the more suitable and secure technology for the latest scenario for the *OaG-SC* industries is the distributed ledger technology, i.e., BC. According to Satoshi, Nakamoto (2019), BC is the chain of the block, where every block stores the information as per its usage. The data can be personal data of the users in the network, details of the transaction, or any other details as per the applications' requirement, where BC is used. Every block has two-part: (i) one is the header of every block, which involves mainly four entities, i.e., a hash of the previous block, hash of the current block, timestamp, and the transaction details. (ii) the second part consists of details (i.e., metadata) of the block. Every chain starts with the *Merkle root*, which is the first node having all the details except the hash of the previous block (Jindal, Aujla, & Kumar, 2019). In the same manner, all the blocks are connected in a network, which results in a BC (Bodkhe & Tanwar, 0000).

The main thing which makes the BC decentralized is the usage of smart contract in the selected application (Dolgui et al., 2020). In most of the centralized systems, the third party is required to verify the traditional contract designed between the two parties (Berdik, Otoum, Schmidt, Porter, & Jararweh, 2021; Chen, Srivastava, Parizi, Aloqaily, & Ridhawi, 2020). These third parties have kept all required logs and transaction details. Hence, there is a high possibility of tampering or modification of these transactions. But, BC-based smart contracts can reduce the overhead of third-party digitally, in which all the transactions carried out based on the conditions written in them. Moreover, these contracts are immutable and have been kept with high-security (Bouachir, Aloqaily, Tseng, & Boukerche, 2020). Further, consensus protocols are used to make a general agreement between the participants of the chain. They help to decide several decisions during mining of the block, i.e., Who will be the next to mine the node and what should be done? When any new peer joins the network? There are a number of consensus protocols, which have been already defined as per their usage in different applications. It includes Proof of Work (PoW) used in Bitcoin, Proof of Stake (PoS) used in Ethereum, Proof of Burn (PoB), and Proof of Elapsed Time (PoET) (Alfandi, Otoum, & Jararweh, 2020). The consensus protocols also help in establishing the common agreement between all parties participated in the chain. The hash and encryption properties reduce the security problems such as confidentiality, integrity, and availability of the data (Dwivedi, Amin, & Vollala, 2020).

Generally, the company pays two types of payment to the landowner in compensation for using their lands: Initial Bonus and Royalty. The total earning figure is stored with a particular landowner's account, which summarizes both the payments. The proposed decentralized network has distributed ledgers for all the peers in the chain. These ledgers have the relevant data related to the landowners like all the basic details, bank details of the landowners, their land location, the total amount earned by them from the particular day, initial bonus amount, and whether the individual landowner is sharing his royalty with other landowners or not. The proposed smart contracts will notify these ledgers when any transaction is rejected, accepted, or in case of any dispute. The ledger will be updated whenever the initial bonus and royalty will be generated in the transaction. This is how the proposed network will work and for the high throughput of this chain, all the sub-parts of this network have to work with proper harmony and synchronization.

1.2. Research contributions

Following are the research contributions of this paper.

- We propose a BC-based smart contract, which securely executes the royalty transactions among various stakeholders in *OaG* industries.

Table 2
A relative comparison of the proposed scheme with the state-of-the-art schemes.

Author	Year	Objectives	Merits	Demerits
Lakhanpal, Samuel, et al. (2018)	2018	To aware *OaG* industry about BC technology and its benefits.	Highlighted current challenges of integration of BC with *OaG* industry.	Lacks in real-time implementation of their proposed solutions.
Brilliantova and Thurner (2019)	2018	Usage of BC in energy sector.	Exhaustive coverage of concept with examples.	Lacks in practical implementation.
Lu, Huang, Azimi and Guo (2019)	2019	Highlighted theoretical concept of how to integrate BC with the some of the parameters of *OaG* industry.	Explained the process with proper examples and multiple scenarios.	Lacks in giving sufficient practical implementation information of proposed solution.
Pee, Kang, Song, and Jang (2019)	2019	Discussed P2P business model used for energy trading based on BC via ERC20 tokens.	Used energy-efficient smart contract algorithm for energy trading.	Lacks in the meticulous analysis of the proposed approach.
Yang, Malekian, Wang, and Rawat (2020)	2019	Solved issues related to interoperability, privacy and security in BC and industrial Internet when they used in industries like *OaG*.	Good Categorization of issues using various research techniques.	Lacks in practical and numerical data.
Ajao, Agajo, Adedokun, and Karngong (2019)	2019	Explored cryptographic hash based blockchain solution for maintaining the realtime database consists of petroleum distribution records.	Importance of hashing is explained properly.	Selection process of hash function is not explored to its full potential.
Ajao (2019)	2019	Implemented mobile tracking system for trucks, which transports products of *OaG* using GPS and BC.	Strong analysis for their solutions by testing them on GUI.	Lacks in explanation for choosing SHA based hash function for the proposed solution.
Lu, Guo, Azimi and Huang (2019)	2019	Surveyed on the integration of *Industry 4.0* with *OaG* industry.	Incorporated with all the streams of *OaG*, Provides government policies for proper enhancement of this integration.	Lacks in numerical data and practical examples.
Kadry et al. (2020)	2020	Adoption of BC in midstream of *OaG* industry.	Detailed explanation of BC with midstream of *OaG*.	Lacks in practical analysis.
Proposed scheme	2021	Addressed royalty problem of the upstream of *OaG* industry.	Ethereum BC-based secure royalty smart contract for upstream of *OaG* industry with proper evaluation.	–

- We also analyse and compare the performance of the proposed scheme of royalty contract transactions with the existing state-of-the-art proposals.
- We validate the performance of the proposed scheme using various security parameters compared to the existing methods.

1.3. Organization

Table 1 depicts the abbreviations used in the paper, along with their description. The rest of the paper is organized as follows. Section 2 discusses the literature work. Section 3 presents the problem formulation and the system model. Section 4 discusses the smart contract generation. Section 5 discusses the experimental setup, experiment's simulation, and the proposed scheme's performance comparison with existing solutions. Finally, Section 6 concludes the paper.

2. Related work

In this section, we discuss the state-of-the-art by government and industries. For example, *Industry 4.0* based *OaG* uses BC as a part of the security solution to handle privacy and security related issues. Some of the researchers carried out relevant work on the *OaG* industries, which are as follows. Table 2 depicts a comparative analysis of the state-of-the-art with their objectives, pros, and cons with the proposed scheme. It is evident from Table 2 that trading, management, decision making, supervision, and cybersecurity are important parameters for *OaG* industries. Authors in Lu, Huang et al. (2019) discussed the theoretical concepts about how to apply BC technology to the aforementioned aspects of *OaG* industries. They also discussed BC, consensus algorithms such as PoW, PoS, and BC technology advantages in terms of security. They also outlined brief ideas for integrating BC to *OaG* industries using some of the examples of *Vakt* and *Komgo*. They also analysed the risk factors of this integration, along with future opportunities.

Information systems introduce automated and efficient systems for *OaG-SC*. Berdik et al. (2021) described how the BC could be merged with these information systems, discuss how it improves security and describes the futuristic viewpoint of this integration.

Pee et al. (2019) proposed a BC-based solution for energy trading without any third party, which uses the ERC20 token system as a currency for trading. They proposed the smart contract code for the Peer-to-Peer (P2P) network used for the energy trading, which is received from oil, gas, and solar. Moreover, industrial Internet and BC technologies are being used by many industries such as healthcare, aviation, *OaG*, transport, etc. (Bhattacharya, Tanwar, Bodke, Tyagi, & Kumar, 2019; Mistry, Tanwar, Tyagi, & Kumar, 2020; Tanwar, Parekh et al., 2020). But, they are still facing issues such as interoperability, privacy, and security due to flaws in these technologies (He, Kumar, & Lee, 2015). Authors in Yang et al. (2020) performed an in-depth survey and discussed seven major issues and their solutions. But, they have not adequately analysed the systems in terms of practical and numerical efficiency. Lakhanpal et al. (2018) outlined that BC technology can help solve day-to-day problems like supply chain, trading, and cybersecurity and database management with proper background knowledge. They also explored stakeholders' existing challenges while integrating BC and *OaG* industries. But, they did not explore the viability of their proposed approach for real-time implementations.

Ethereum BC is the second biggest in the industry by market value. There are so many contracts that are creating, executing, and terminating in the Ethereum BC daily; some are critical. So, the security of the smart contract is an essential requirement. Hu et al. (2021) analysed the approximately 10,000 smart contracts and found that they are mostly in 4 patterns. It helped them to build a model that secures the smart contract using classification techniques. These techniques are useful in our paper's future work for making our smart royalty contract more secure.

BC achieved security using cryptographic hash functions and asymmetric encryption techniques (Bodkhe et al., 2019). Authors in paper (Ajao et al., 2019) discussed SHA-1 cryptographic hash-based solution to secure the database. It consists of a record for all transactions carried out among the trucks used to transport petroleum products. They concluded that any peer with greater than 75% agreement could access or update other peers' data using the proposed approach. Their approach lacks in providing the relative comparison of the SHA-1 algorithm with state-of-the-art cryptographic hash algorithms. Later on, Ajao (2019) proposed an almost similar system with some advanced features. They used GPS (for reception and transmission) for geo-location sensing, HCR05 ultrasonic sensor, SIM800, ATmega328 microcontroller unit, and BC. They also used SHA based hash cryptographic algorithm and tested it on the same GUI. They concluded that machine learning techniques could be used to mitigate the aforementioned issues. Authors of paper (Brilliantova & Thurner, 2019) performed an in-depth analysis of the opportunities brought by the integration of energy sectors with BC. They mainly focused on the energy markets of South Africa and Russia. They concluded that their approach lacks in to enhance the integration of BC technology in energy sectors. But, their approach lacks practical implementation. Lu, Guo et al. (2019) performed in-depth survey on the integration of the *Industry 4.0* with *OaG*. They considered all the streams upstream, midstream, and downstream of *OaG* industry. They concluded that this integration is in its infancy. So, there is a need to tune its characteristics before its adoption to any application.

Midstream of the *OaG* industry deals with the transportation of the *OaG* to the producers, which extracts required material from the raw products. Authors in Kadry et al. (2020) outlined the integration of BC with mid-stream and discussed their solutions and the existing pilot projects on this field, such as ADNOC and VeChain. But, they failed to propose any practical implementation or prototype. This paper has compared the pros and cons of existing state-of-the-art techniques used in *OaG-SC* industries.

In *OaG-Sc*, all tasks are scheduled in the proper sequence. Most of the time, all of these tasks require data to be stored in the cloud storage. Authors of Baniata, Anaqreh, and Kertesz (2021) proposed a model called *PF-BTS*, which helps to schedule these cloud storage tasks using BC technology. They have included proper calculations and algorithms. They considered working with various advanced algorithms in the future for the same model.

In *OaG-SC*, the material delivery should be efficient, mostly this is done via road transport. Sometimes, there are chances that the vehicles, which are delivering the material, can be compromised and used unethically. Authors in paper (Oham et al., 2021) proposed an application called B-FERL, which secures the vehicles in the network from the outside vehicles using the BC technology.

In conclusion to this section, we analyse state-of-the-art approaches neatly. We compared them in terms of various parameters, such as security and practical implementations. The majority of the papers have a deficiency in giving the proper practical implementations of their solution. Some of the paper have used hash functions to secure the stored data, but they have not provided a proper reason for doing this. Our paper mitigates these types of flaws in the past paper. We provide a practical explanation and evaluation of our solution.

3. Problem formulation and system model

In this section, we discuss the system model and problem formulation.

3.1. System model

Petroleum companies and landowners play two major roles in the royalty distribution process. Proper coordination between them is required to get effective output from the solution. The proposed system model is divided into three sections, including a database of the landowner that stores the registration data of the landowners, a database of the company that stores the companies' required data. The third section is the chain which stores the data of the transactions executed between the landowners and companies. The registration data of both parties are gathered by the website and stored in the databases. Then, this data goes to the smart contract for further processing. Then, after the contract's successful execution, the transaction's information goes to a chain for further analysis.

Landowners database has all the required details of a particular landowner, where L_{id} is the primary key of the landowner database. It represents the unique identification number for the landowner details. The landowner database contains five attributes, which are as follows:

- L_{id} = Identification number of the landowner. (As a primary key in a database)
- *Name*: Name of the landowner.
- *Contact*: Contact number of the landowner.
- *Location*: Location of the land of a particular landowner.
- *Total_Earning*: Amount of money earned by landowner till now.

Companies that offer a fair amount to the landowners in the form of rewards for drilling and exploring oil and gas from the land. A company database contains four attributes, which are as follows:

- C_{id}: Licence number of the company. (As a primary key in a database)
- *Name*: Name of the company.
- *Total_Initial_Bonus*: Amount offered by a particular company as a part of initial bonus.
- *Minimum_Royalty*: Amount of minimum royalty (base value), which the company needs to pay to the landowner.

The *Total_Initial_Bonus* represents the amount of money offered to the landowner who agreed to offer his/her land for drilling and exploration of oil and gas from it. The company calculates this amount by considering the usage of land per unit. Apart from the initial bonus amount, the company has to pay a royalty to the landowner daily. The royalty amount is some portion of the company's total production of the day earned during the drilling process. According to the proposed scheme, the amount of royalty is excluded from the cost of the transportation of the drilled raw materials. According to this clause, only those companies can join the managed chain that is ready to obey the mentioned clause. So, it eliminates the various issues encountered in traditional state-of-the-approaches. Another amount is *Minimum_Royalty*, which the company decides. It indicates the surety of royalty by the company to landowners (Cui, Quddus, & Mashuga, 2020).

In the proposed scheme, there is one admin account for verifying the people who participate either in the role of landowner or company. For the landowner role, the key is L_{id}, and for the company role, it is C_{id}. After a successful agreement/grant by both the roles, the transaction is initiated. First of all, the registered company creates a deal using two parameters: *Total_Initial_Bonus* and *Minimum_Royalty*. If it is being agreed by all the participants (landowners), then the transaction is initiated. Moreover, the initial bonus and royalty will be paid to the landowners as per the proposed algorithms. Then, miners will mine the block in the chain. Fig. 2 depicts the overall structure of the proposed system model.

In the proposed system, if any company or landowner registers on the website, they will receive a unique key, which can be used for accessing their data stored into the Interplanetary File System (IPFS) supported by Ethereum BC. In the proposed scheme, we have used IPFS, which is a distributed file storing protocol for storing the data in a distributed manner (Khalid et al., 2021; Nizamuddin, Salah, Azad, Arshad, & Rehman, 2019). The data can only be fetched by the key generated at the registration time and this key works like a private key for the registrants. For example, if one landowner registers himself, then he receives a key. Then, at the transaction time, the landowner shares the received key to the concerned participating company to prove their validity. So, the person who owns this key can only access the registered data such as Unique Identification Number, Name, Contact, Location, and Total_Earning of a particular landowner who is taking part in the transaction. The final result of the particular transaction gets stored into the Ethereum BC, which already provides *EThHash* for the security of the data (Vujičić, Jagodić, & Ranđić, 2018). It ensures the registrant data's overall security and key ensures that no one can see each other's data without permission.

3.2. Problem formulation

In this subsection, all the landowners receive money from the company in two cases, i.e., Initial Bonus and Royalty. Initial bonus refers to the amount offered only one time to the landowner based on the unit of the land utilized by the company to get raw materials from it. Moreover, the royalty amount is given to the landowner in consonance with the company's production per day. The proposed smart contract executes between the landowners and the company. There are two different scenarios, which can be possible concerning the number of landowners willing to participate in the network.

3.2.1. Scenario-1

In this scenario, we have considered only one landowner who deals with only one company. Therefore, there is no need to share the initial bonus and royalty among the landowners. The participating landowner will get the pre-defined initial bonus as calculated in Eq. (1). Whereas, for the royalty, we need first to take *12.5%* part of the production carried out and it will be added to the *Total_Earning* of the landowner, which is represented in Eq. (2) and (3), respectively.

$$T_{ear} += T_{bonus} \tag{1}$$

$$R = 0.125 * Pro\_value \tag{2}$$

$$T_{ear} += R \tag{3}$$

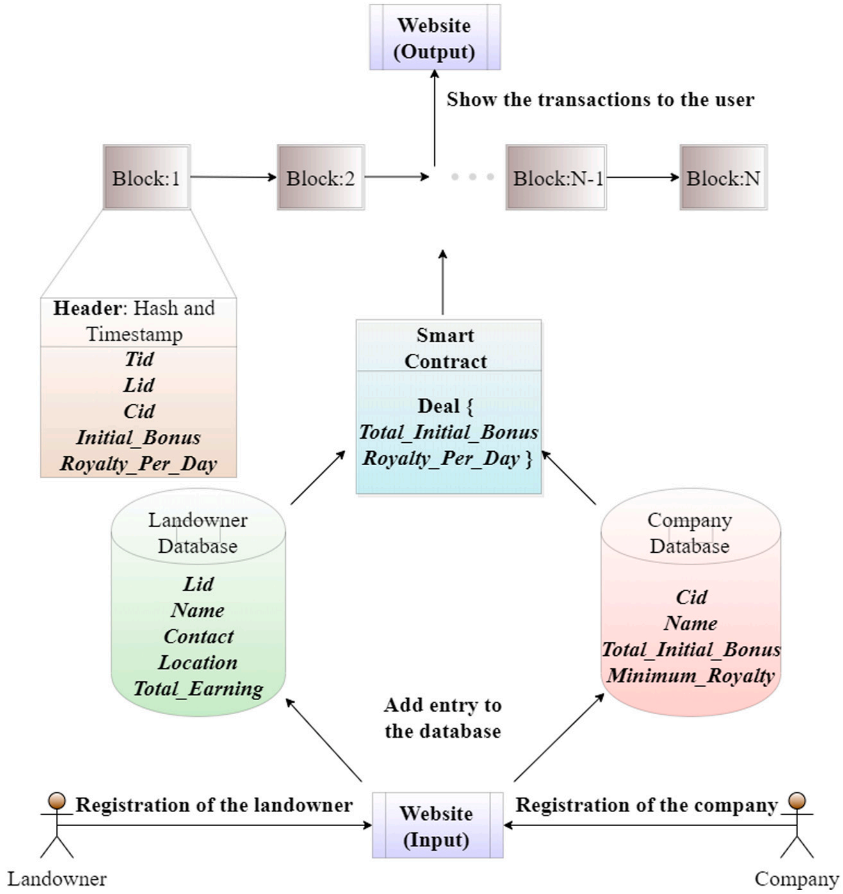


Fig. 2. System model.

3.2.2. Scenario-2

In this scenario, we have considered only one company that deals with the N numbers of landowners for a particular production. So, it contains the record of the participated landowners. Here, the total amount is equally divided among the number of landowners who have participated in the process. The initial bonus is divided by the number of participated landowners calculated in Eq. (4). Total production is counted by summing up all the production completed from the lands of the participated landowners. Then, *12.5%* part is calculated and divided by N as per Eq (5). Then, it is added to the total earning of the landowner given in Eq. (6).

$$T_{ear} += T_{bonus}/N \tag{4}$$

$$R = [0.125 * \sum_{i=1}^{N} Pro\_value]/N \tag{5}$$

$$T_{ear} += R \tag{6}$$

For the scenario in which multiple companies deal with multiple landowners, all the calculations for the landowner side can be performed similarly to Scenario-2. In the end, the participated companies need to distribute the money between them. But, before the execution of any transaction, all the participating companies and landowners have to agree on the same royalty percentage that satisfies both parties' needs. Although, the chances of occurrence of this scenario in *OaG* industry is scarce because no company wants to share their profits among multiple stakeholders, which leads to a complication during their transactions.

4. The proposed scheme

In this section, we describe the transaction algorithms of the proposed smart contract and describe the proposed scheme's detailed flow.

4.1. Royalty smart contract transactions

After the successful registration, the smart contract initiates its royalty execution process. The contract is divided into four phases, which are executed independently from each other. For every particular transaction, participants have to compulsory go through these four steps in the defined order. In algorithms, two explicit procedures are used, which are as follows.

- Grant_role (Role, Address of the sender)
- Notify (Destination address, Message of notification)

4.1.1. Take grant from administrator

The proposed smart contract starts by taking a grant from the admin to define the landowner or company's role. Algorithm 1 shows the procedure of how the legitimate user can take a grant from the admin as per its requirement as the role of landowner or company. It takes the H_{key} (Unique key) as an input, then after the successful transaction, it is being set as the sender's key. Even if the admin gives or denies it, the proposed algorithm notifies the sender through a message in both cases.

Algorithm 1 Take grant from the administrator

Input: H_{key}
Output: Grant or refusal from the admin for the particular role.
Initialization: Admin A_{id} can grant or refuse the request came for become landowner or company. Here, *sender* can be company or landowner.

```
procedure TAKE_PERMISSION
    if sender.request == Become_landowner then
        if sender.request ∉ Landowner then
            grant_role(Landowner, sender.address)
            sender.key ← H_key
        else
            Notify (sender.address, "Requested Landowner address already
            exists");
        end if
    else if sender.request == Become_Company then
        if sender.request ∉ Company then
            grant_role(Company, sender.address)
            sender.key ←H_key
        else
            Notify (sender.address, "Requested Company address already
            exists");
        end if
    end if
end procedure
```

4.1.2. Offer made to landowner from company

After the admin's successful grant, the participated company initiates the offer to the landowner with the minimum initial bonus and royalty. Algorithm 2 represents the procedure that makes an offer to the landowner from the company. If the landowner is satisfied with both the company's amount, then the offer will be accepted by the landowner, and notification will be sent to the company. Otherwise, the company will get notification of request with a demand to increase the amount paid.

Algorithm 2 Offer made to landowner from company

Input: $L_{ad}, Min_{IB}, Min_{Roy}$
Output: Offer made by the company is accepted or rejected by the landowner.
Initialization: Here, the offer or company and offered landowners have the grant from the admin. Here, *sender* is the company.

```
procedure MAKE_OFFER
    if sender.address ∈ Company && L_ad ∈ Landowner then
        if L_ad satisfies with the offer then
            sender.IB ← Min_IB
            sender.Royalty ← Min_Roy
            sender.valid_offer ← true
            Notify (sender.address, "Offer Accepted");
        else
            sender.valid_offer ← false
            Notify (sender.address, "Landowner does not satisfies with the
            offer.");
        end if
    else
        sender.valid_offer ← false
        Notify (sender.address, "Either company or landowner does not exist.");
    end if
end procedure
```

4.1.3. Payment of initial bonus to the landowner

Offer acceptance procedure by the landowners leads to the use of Algorithm 3. It shows how the company pays the initial bonus to the landowners. If both the company and landowner are authorized, and the value given by the company for the initial bonus is greater than or equals to the minimum value set by the company in the offer, then the payment is being accepted by the landowner. Otherwise, the payment will be reverted to the company account with the proper notification.

Algorithm 3 Payment of initial bonus to the landowner

Input: L_{ad}
Output: Initial bonus is successfully given by the company or not.
Initialization: The offer proposed by the company already accepted by the landowner. Here, sender is the company and sender.valid_offer = true.

```
procedure PAY_INITIAL_BONUS
    if sender.address ∈ Company && L_ad ∈ Landowner then
        if sender.value ≥ sender.address.IB then
            L_ad.IB ← sender.value
            L_ad.bonus_paid ← true
        else
            L_ad.bonus_paid ← false
            Notify (sender.address, "The paid initial bonus amount is lower than
            the promised minimum initial bonus.");
        end if
    else
        L_ad.bonus_paid ← false
        Notify (sender.address, "Either company or landowner does not exist.");
    end if
end procedure
```

4.1.4. Payment of royalty to the landowner

An initial bonus has been given only once, whereas the royalty will be paid daily as per the value of the total production in a day. Algorithm 4 takes the total production day value as an input. Until the production is completed, it calculates the royalty value by taking 12.5% of the input value. If the calculated royalty is greater than the minimum value set at the offer, and if the sender's value is greater than the value of calculated royalty, then royalty will be paid successfully. Otherwise, it will be failed and notifies to the company with a proper message. Suppose the calculated royalty value is less than the value of the minimum value. In that case, the company's royalty will be paid to the landowner equals to the minimum value, which has been set at the time of offer.

Algorithm 4 Payment of royalty to landowner

Input: L_{ad}, Pro_value
Output: Royalty is properly given to the landowner or not until the production is done.
Initialization: The initial bonus has been already paid to the landowner L_{ad}. Here, *sender* is the company and *sender.bonus_paid = true*.

```
procedure PAY_ROYALTY
    while Production is not done do
        if sender.address ∈ Company && L_ad ∈ Landowner then
            ro ← 0.125 * Pro_value
            if ro ≥ sender.Royalty then
                if sender.value ≥ ro then
                    L_ad.Royalty ← sender.value
                    L_ad.royalty_paid ← true
                else
                    L_ad.royalty_paid ← false
                    Notify (sender.address, "The paid royalty amount is lower
                    than the promised minimum royalty amount.");
                end if
            else
                L_ad.Royalty ← sender.Royalty
                L_ad.royalty_paid ← true
            end if
        else
            L_ad.royalty_paid ← false
            Notify (sender.address, "Either company or landowner does not
            exist.");
        end if
    end while
end procedure
```

These four algorithms depict the overall usage of the smart contract in the proposed scheme. This contract completes the solution by providing all the pre-requisites for each of these algorithms and the proper inputs, outputs, and conditions. For normal process, landowners and companies must go through these algorithms once as per the mentioned order. These algorithms are independent of each other to be used as per the requirement of the application for more than one time. Suppose, if there are 4 consecutive company registration requests received, then only Algorithm 1 will be used 4 times and there is no requirement for the remaining three Algorithms. So, this independent behaviour of the proposed contract improves their efficiency and reduces the transaction and execution cost of the entire proposed solution. We also calculate the time and space complexity for each Algorithm. Here, no Algorithm stores anything, so the space complexity for each is *O(1)*. All the algorithms contain the if-else conditions, which requires constant time to execute and there are no loops, so the time complexity for all Algorithms is also *O(1)*. Hence, all the Algorithm add constant delay every time in the transaction. We also execute the proposed smart contract in Ethereum BC, which uses *EthHash* for securing the data of the blocks (Yu et al., 2021). It ensures the security of the data, which is to be collected from the transactions. Table 1 depicts various notations used for these algorithms.

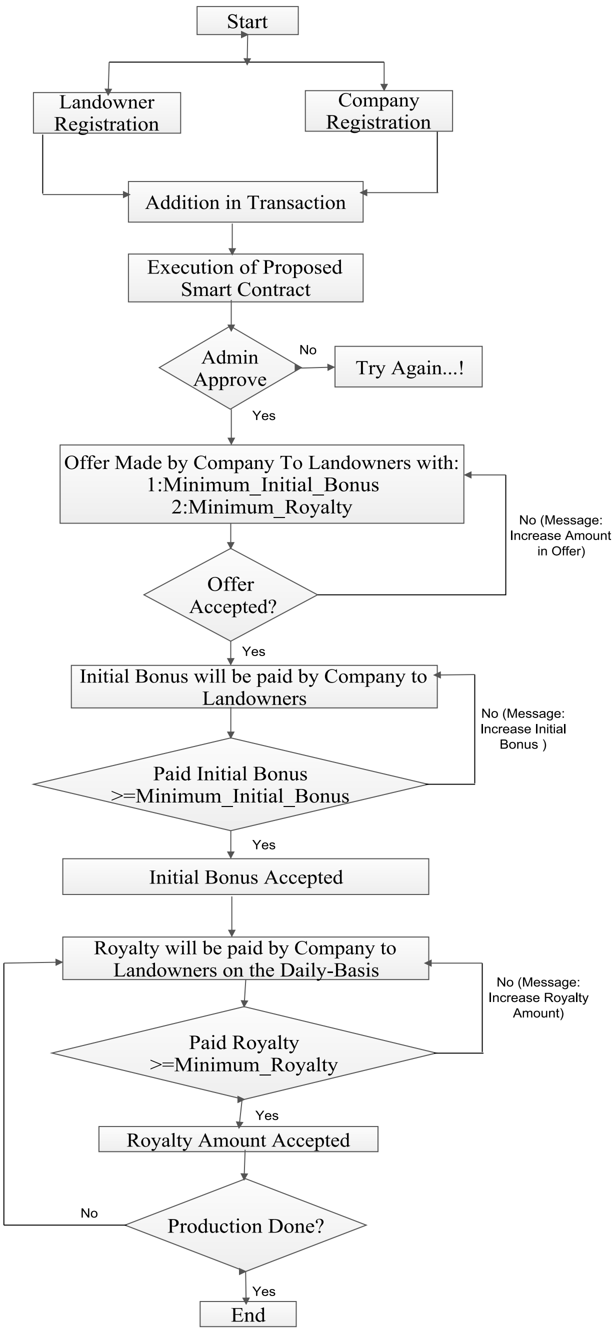
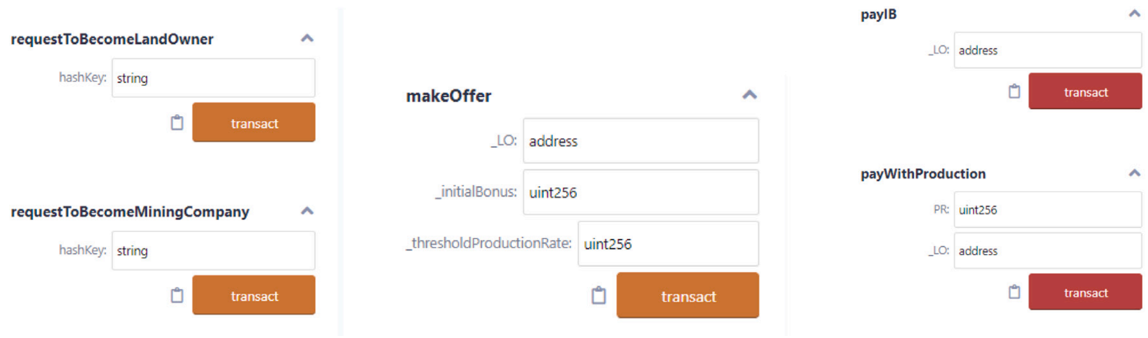


Fig. 3. Flow Diagram.

4.2. Flow of network

Fig. 2 presents the proposed scheme, which consists of one network of the transactions with two databases: Landowner database and Company database. In the first step, the company and the landowners register themselves by filling in all the relevant details, respectively, through their links.

After the successful registration, all the details are available in respective databases. Later on, the proposed smart contract initiates its execution. Registered landowner or company initiates the request to the admin. The admin can give approval or denial to the registered members' requests for granting them to participate in the contract. After the successful participation, a few transactions take place between the company and its respective landowners. The company offers to deal with its landowners, which consists of



(a) Request for Role (b) Make offer (c) Payment to landowners

Fig. 4. Remix implemented functions of the proposed scheme for OaG industry.

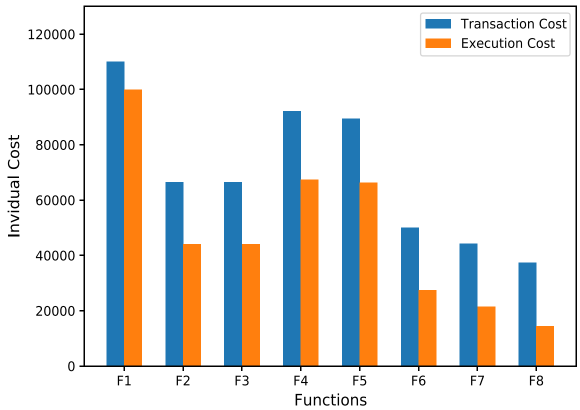


Fig. 5. Individual costs for functions (in gas value).

two main things: The minimum initial bonus (single time) and minimum royalty (per day) the company has to pay as a part of a contract irrespective of the production. If the landowner satisfied with this amount, then the process continued. Otherwise, the transaction will be rejected. After the satisfaction of the landowner, the company has to pay the initial bonus to the landowners. If it passes the threshold value, it will be accepted by the landowner. Otherwise, it will be rejected. Then, until the production's completion, the company has to pay the royalty to the landowners daily. If the production value is higher, then the company has to pay the amount as calculated in Eq. (2). Otherwise, the company has to pay the amount equals to the minimum royalty amount, which has been already decided at the initial offer. Later on, production is completed and the contract is being terminated. Fig. 3 shows the flow of the proposed smart contracts used in the proposed scheme.

5. Performance evaluation

This section presents the potential of the proposed scheme experimentally. The proposed scheme is compared with the traditional scheme in terms of cost, scalability, and network bandwidth utilization. It also includes the implementation interface for debugging and testing the smart contracts between the landowner and mining company.

5.1. Experimental setup

Ethereum is the public blockchain, which has been already implemented since 2015. The cryptocurrency used by this blockchain is Ether (ETH). From a security perspective, the Ether blockchain uses the *Ethash* hash function, which is a slightly modified version of *SHA-3*. The consensus mechanism used by this chain is *PoW* (Tanwar, Tyagi and Kumar, 2020). Remix IDE is used as a scheme tool efficiency to deploy the proposed smart contracts. Firstly, the smart contracts are developed in Solidity language supported by the Ethereum Virtual Machine. Then, they are compiled and deployed using Remix IDE. Finally, testing and debugging is being carried out by deploying these smart contracts in the test environment of Remix (Hu et al., 2021; Remix Solidity, 2020).

Fig. 4a shows the implementation functions interface provided by the Remix Integrated Development Environment. These smart contracts are compiled and then tested for vulnerabilities by deploying them in the remix's testing environment. Firstly, the three stakeholders are defined, such as admin, landowner, and mining company. Fig. 4a represents the functions that have been used for

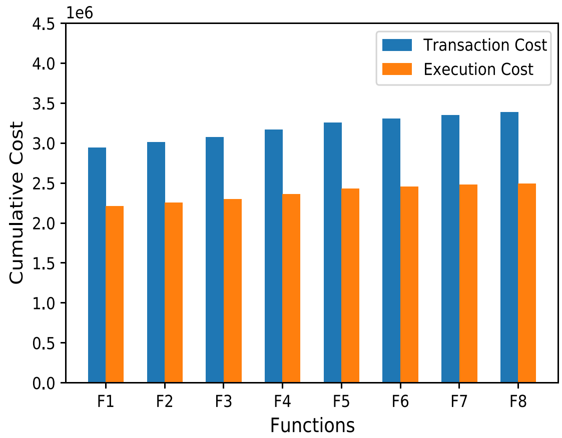


Fig. 6. Cumulative costs for functions (in gas value).

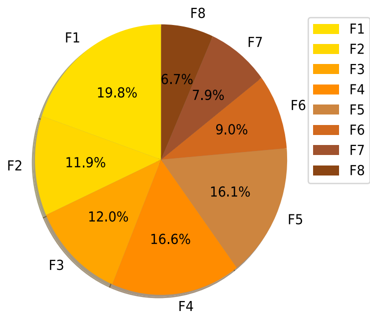


Fig. 7. Individual functional contribution in smart contract.

taking grant from the admin using H_{key}. The identity proofs are used to approve stakeholders by admin. After successfully getting the role, as shown in Fig. 4b, the company offers a deal to the landowner with *address of the landowner, minimum initial bonus and minimum royalty amount*. If the offer is attractive in terms of the initial bonus provided and the royalty percentage decided, the landowner accepts it. As per Fig. 4c, the company pays an initial bonus and royalty to the particular landowner.

The functionality that ensures the payment of initial bonus achieved by the Boolean variable *PaidIB*. If it is true, only the company can pay the royalty; otherwise, the transaction will be reverted. Scenario-2 as mentioned in *Section-III.b*, where N numbers of landowners are there in the transaction. For this, it is assumed that participated company has the details of all N landowners. So, all the company's entries for the payment part of the contract already been divided by N. The proposed smart contracts maintain privacy and have a one-to-one relationship between all the stakeholders. In the proposed scheme, every transaction is time-stamped into the public blockchain of Ethereum, ensuring the immutability of every transaction (Putz, Dietz, Empl, & Pernul, 2021). After it has been added to the blockchain with consensus in their system, any participant can check any particular transaction to ensure trust.

5.2. Results and discussion

5.2.1. Functionality costs of smart contracts

The proposed smart contracts have eight functions, which all have some of the cost in terms of gas value. This gas value of each function spent on executing the proposed smart contracts is traced using the gas profile module provided by Remix IDE. All the functions have two types of cost; execution cost and transaction cost. Execution cost is the cost to execute a particular function virtually. In contrast, the transaction cost is the additional cost to send the contract to the blockchain or the cost required to deploy it on an Ethereum BC, which depends on the contract's size. Here, the cost calculated by Remix IDE is in Ethereum gas, a standard unit that measures the computation required to execute certain functions of the smart contract. The average gas price in Ethereum is about 20 Gwei (or $0.0000065) (Ameer, 2020). In this way, cost calculation can be done in USD from Gwei. So, it can be observed that by embedding BC, a nominal fee is used by the decentralized network to execute these functionalities. This further ensures that the proposed scheme is cost-efficient. So, the transaction cost is the sum of the execution cost and the cost to deploy the BC contract. F_i indicates the ith function and all the functions are represented as follows.

- F1: OilMining (Constructor)

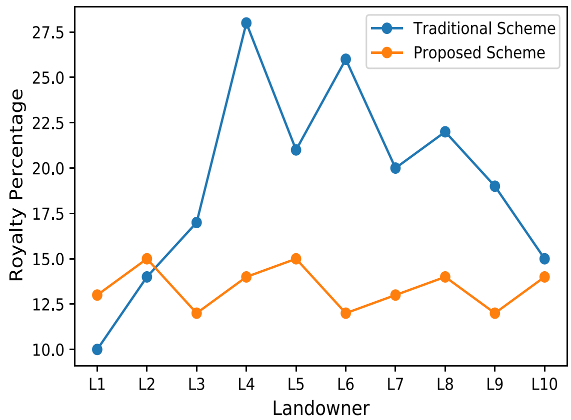


Fig. 8. Royalty percentage range.

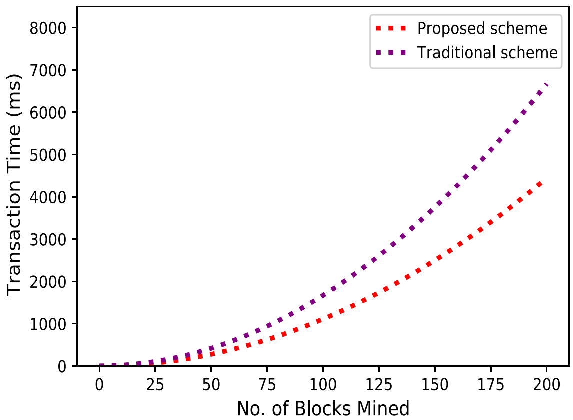


Fig. 9. Scalability comparison of the proposed scheme with the traditional schemes.

- F2: RequestTobecomeLandOwner (Function)
- F3: RequestTobecomeCompany (Function)
- F4: GrantRole (Function)
- F5: MakeOffer (Function)
- F6: AcceptOffer (Function)
- F7: PayIB (Function)
- F8: PaywithProduction (Function)

Fig. 5 shows the transaction and execution costs during simulation when all the functions are executed individually on the smart contract. For the successful completion of one transaction, the flow of the proposed system needs the hierarchy of functions to be executed. So, to execute these eight functions in order from F1 to F8, Fig. 6 shows the cumulative costs for these functions and the calculated as per Eq. (7). The overall system flow's total cost can be obtained by taking the last function's cumulative cost, which is represented as follows.

$$C_i = C_{cf} + \sum_{i=1}^{f-1} C_i \tag{7}$$

Fig. 7 shows the percentage of transaction cost of individual eight functions, which shows the contribution of each function into the total cost of the contract.

5.2.2. Comparison against existing royalty contract transactions model

Company needs to pay some part of their production amount as a part of royalty to the landowner. The traditional system works on the manual task, so the percentage amount is not fixed and varies between 10% to 25% (King, 2020). In the proposed scheme, Fig. 8 shows the royalty contract fixed the range for the royalty percentage between 12% to 15%. Here, L_i indicates the ith number of landowner. It is evident from Fig. 8 shows that the royalty percentage variation in the proposed scheme is low compared to the

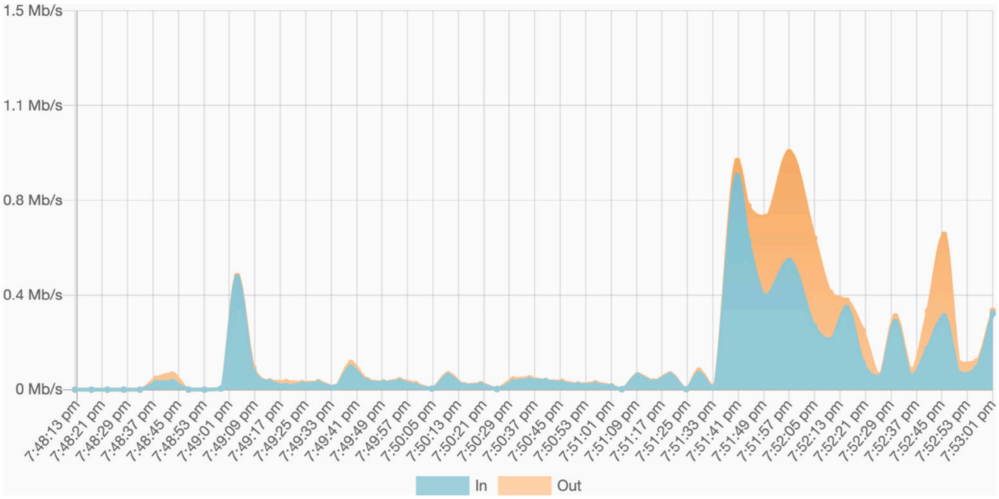


Fig. 10. Bandwidth utilization.

Fig. 11. Hash rate with increasing age of the Ethereum blockchain.

traditional scheme, which results in fair dealing between the company and the landowners. It reduces the production cost and price of *OaG* up to a certain extent.

5.2.3. Scalability comparison

Fig. 9 shows the proposed scheme's scalability comparison and the traditional scheme. It is calculated based on the transaction time and the number of blocks mined during the contracts. The increase in transmission delay increases the block creation time in BC, which would impact the BC assisted security by being vulnerable to block delay attacks such as TendrilStaller (Gupta, Tanwar, Kumar and Tyagi, 2020; Singh, Tanwar, & Sharma, 0000). In Fig. 9, the Y-axis defines the transaction time needed for the process of consensus in BC, whereas a number of blocks mined in the chain are shown on the X-axis. It can be observed from Fig. 9, that the scalability of the proposed scheme outperforms the traditional scheme. Thus, the proposed scheme offers more transactions to be added to the chain at the same quantum of time, which provides services to a more number of users, hence improving the overall scalability (Xu et al., 2021). This is due to Ethereum public blockchain, which is optimized in network parameters compared to others such as bitcoin (Gupta, Shukla and Tanwar, 2020). Moreover, the use of IPFS requires minimum load, which helps to improve the overall scalability.

5.2.4. Hashrate of blockchain

The hash rate of the BC shows the measurement of the processing power computed by the decentralized network. The proposed scheme utilizes the public Ethereum BC for the execution of the proposed smart contracts. Fig. 11 shows the Ethereum Hash rate over time. The X-axis defines the time period and Y-axis shows the hash rate in GH/s. It is generated from the scanning system of *Etherscan.io* (Matthew, 2020). It can be inferred from Fig. 11 that the hashes generated by the miners are relatively optimized to the block difficulty set at that period of time in BC. Hence, it ensures the improvement in network trust and security during the transactions in a system.

5.2.5. Bandwidth usage for IPFS

IPFS is a protocol that helps the user to store their data on the distributed systems in the P2P network. Ethereum BC is also compatible with this protocol. Here, in the contract, we only take the *Hash key* of the particular user instead of his/her complete information as an input. The user is either company or the landowner. Their information stored on the IPFS, which can be retrieved by the *Hash key* provided by the user. To fetch the network bandwidth required for IPFS decentralized data storage protocol, the IPFS node is configured and made active. Then, it is connected via the Internet to the system, where they performed the dashboard analysis of the incoming and outgoing bandwidth. Later on, it was collected and visualized with the graph. Fig. 10 shows the graph, which indicates the input and output bandwidth utilized for a particular IPFS node of a sample time in the system.

6. Conclusion

The stakeholders in the *OaG* industry demands a secure, reliable, and decentralized platform for their numerous royalty transactions. At the same time, maintaining the privacy and security of the end-users are also the key challenges. Moreover, effective decision must be carried out and thoroughly analysed to resolve the aforementioned issues. This paper proposed a blockchain-based scheme, which securely executes the royalty transactions among various stakeholders in *OaG* industries. The secure royalty contract transactions are one of the key contributions of the proposed scheme. We also evaluated and validated the performance of the proposed scheme and functionalities of the proposed smart contract through experimental results.

In future, we will propose a consensus protocol for the secure transaction between *OaG* company and landowners.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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