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CHAPTER 5

COUNTERFEITING THE PHARMACEUTICAL INDUSTRY USING THE PERSPECTIVES OF BLOCKCHAIN TECHNOLOGY

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ABSTRACT

The issue of counterfeit medications is a pressing worldwide concern that is becoming worse, especially for underdeveloped countries. Today, the yearly economic costs associated with pharmaceutical counterfeiting reach billions of dollars. A significant contributing factor to drug counterfeiting is the inadequacy of the current pharmaceutical supply chain system. The journey of drugs from manufacturers to wholesalers, distributors, pharmacists, and ultimately to customers lacks sufficient information sharing. This lack of transparency leads to manufacturers having limited visibility into their products' locations, regulatory authorities facing challenges in oversight, and cumbersome, expensive product recalls. Additionally, tracking patients effectively within the existing system is a persistent challenge. In this article, we've looked at how Blockchain technology may be used in the pharmaceutical supply chain to improve visibility, provide traceability, and strengthen security.

The proposed system is tailored for implementation in the pharmaceutical industry, aiming to track pharmaceuticals from production through delivery to the patient. After drug administration, the system will meticulously document its impact on the patient, facilitating future statistical analysis. A restricted-access blockchain will serve as the repository for transactions, exclusively allowing trusted entities to join the network and contribute data securely.

5.1 INTRODUCTION

The realm of Pharmaceutical Research & Development is an intricate journey that spans numerous years, encompassing drug discovery, development, and the rigorous process of regulatory approval. Once this intricate journey concludes and a standardized product takes shape, manufacturers encounter the subsequent challenge: delivering this product to the intended customer in its original, unaltered state. Their main goal is to guarantee that the consumer gets a genuine product made by the authorised producer instead of one obtained from a fake source.

Nevertheless, the current Supply Chain Management (SCM) system within the pharmaceutical industry is outmoded. It falls short in delivering the essential visibility and control required by both manufacturers and regulatory authorities concerning drug distribution. Furthermore, it lacks the resilience necessary to fend off cyber-security threats in the 21st century. The prevailing state of Supply Chain Management (SCM) engenders the manufacturing, distribution, and consumption of counterfeit drugs. This alarming proliferation of counterfeit pharmaceuticals poses a severe and escalating public health hazard, particularly in developing nations, amplifying the gravity of this global issue. Counterfeit drugs have a twofold, highly detrimental impact on health, both through indirect and direct mechanisms.

Indirectly, these deceptive medications often lack the prescribed dosage or essential active agents necessary to combat diseases. This shortfall paves the way for the development of drug-resistant strains, rendering even authentic drugs ineffectual in the long run.

On a more direct note, counterfeit medications may contain active ingredients, but these components can exist in quantities that are either too low or excessively high. Additionally, the production of these ingredients might be marred by impurities, introducing toxic elements into the equation. In such cases, the use of these counterfeit drugs can lead to exceptionally severe health complications.

Counterfeit drug manufacturers sometimes go as far as replicating the branding of legitimate pharmaceutical companies to produce counterfeit products that mimic everyday items, which, while problematic, generally pose lower health risks. However, a far more troubling scenario unfolds when these counterfeit operations extend their reach to essential medications used in the treatment of conditions like cancer, pain management, cardiovascular disorders, antibiotics, contraceptives, and other prescription drugs.

For patients, the fallout from this dishonest conduct can be extraordinarily serious. According to the most current World Malaria Report, there were about 247 million cases of malaria in 2021—a marginal rise over the 245 million cases that were reported in 2020. 619,000 deaths are projected to have been caused by malaria in 2021 compared to 625,000 deaths that were reported in 2020.

Disruptions linked to the COVID-19 pandemic resulted in an extra 13 million instances of malaria and around 63,000 more malaria-related fatalities throughout the course of the two pandemic-affected years, 2020 and 2021. It is interesting that the WHO African Region still has a disproportionately high number of cases of malaria worldwide.

Approximately 95% of all cases of malaria and 96% of fatalities from malaria occurred in this region in 2021. Additionally, a considerable percentage of these deaths—roughly 80%—occurred among children in the Region who were younger than five years old. In less developed countries, every tenth medicine taken by consumers is discovered to be counterfeit and of lower quality, according to a World Health Organisation (WHO) assessment.

- **The Global Count of Counterfeit Occurrences in Pharmaceuticals:** Below image is showing the rise of counterfeit incidents since 2011. An efficient supply chain management system is necessary for the pharmaceutical business to stop the spread of fake medications. The Application of Blockchain technology is the best way to create the ideal SCM system

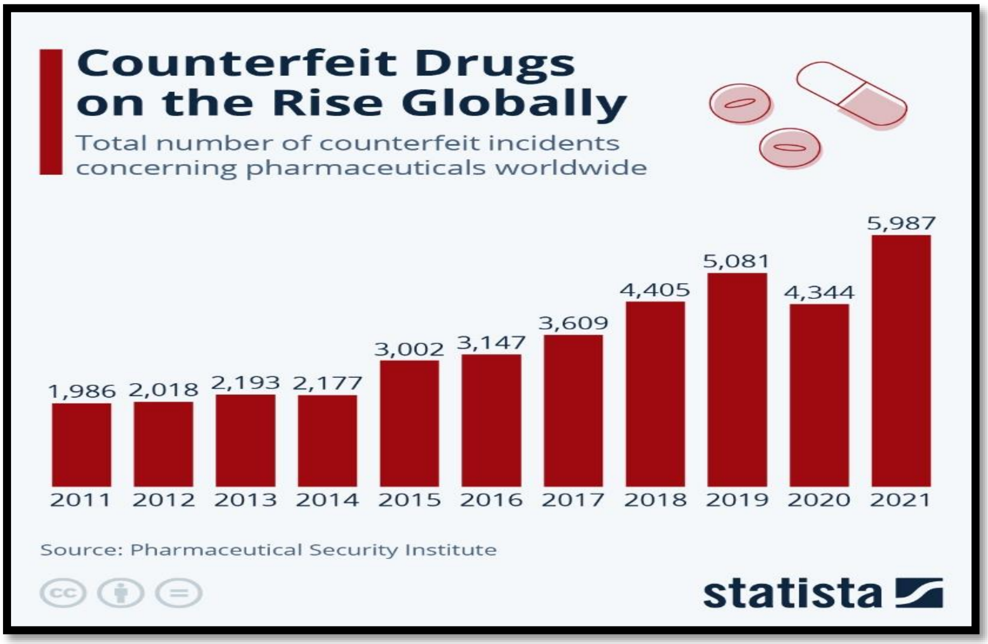

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FIGURE.5.1 ABOVE CHART SHOWING TOTAL NUMBER OF COUNTERFEIT INCIDENTS RELATED TO PHARMACEUTICALS IN THE WHOLE WORLD.

5.2 WHY BLOCKCHAIN

Blockchain operates as a decentralized network of computers, where connected participants collectively uphold a secure ledger of transactions, all without relying on a central server. Each transaction is meticulously recorded in the network, accompanied by a timestamp, effectively eliminating the need for third-party intermediaries. Within this network, each node independently maintains its copy of the ledger, ensuring that even minor modifications to the local ledger are synchronized across the entire network. Consequently, all nodes on the network promptly update their individual ledgers to reflect the most recent transactions. Even in the case of a node failure or disconnection, the network remains unaffected. The primary justification for the incorporation of Blockchain technology into systems such as pharmaceutical supply chain management is its unparalleled security. The most effective way to provide cyber-security for the twenty-first century is through Blockchain, which has an unblemished record of never having experienced a breach. Its basic architecture is focused on preventing any one party from altering transactions or data, which promotes trust and gets rid of biases that are frequently present in conventional supply chain systems. Utilizing blockchain technology, stakeholders can securely exchange digital assets anonymously. There's

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no need for them to be familiar with or have faith in one another, nor must they involve a third party in their transactions. Hence, blockchain emerges as the optimal choice for instilling trust within an inherently distrustful environment. A further strong argument in favour of blockchain technology in pharmaceutical supply chain management systems is its unparalleled ability to precisely record a product's path along the whole supply chain. The blockchain records every transaction that occurs when the product is transferred. Keeping track of a product's whole history makes it simple to identify its true origin and significant turning points. The pharmaceutical supply network's transactions will now be more transparent thanks to this technique. In the realm of the pharmaceutical supply chain, when a manufacturer generates a product and enrols it within the network, it assumes the role of a digital asset, subject to transfer to other stakeholders in a manner akin to cryptocurrencies. Concerning privacy safeguards, blockchain takes the forefront yet again. Within a blockchain network, each participant is allocated a key-pair as their identifier. Private participant data is meticulously safeguarded, with each transaction conducted from one participant's public key to another's within the pharmaceutical supply chain management system. Moreover, in this system, patients' private data remains confidential, while their medical records are accessed publicly but anonymously. Incorporating blockchain technology into quality control and the identification of counterfeit drugs is a significant step toward enhancing safety and ultimately preserving lives.

The ultimate and most compelling rationale for employing blockchain within pharmaceutical supply chain management is the integration of Smart Contracts. A smart contract is a section of code that, when approved by all parties concerned, captures the real rights and obligations as well as the terms and circumstances for delivery of products and services. Smart contracts can be automatically implemented. By adding intelligence and power to blockchain technology, smart contracts allow developers to build cutting-edge, personalized blockchain-based systems that push the boundaries of innovation.

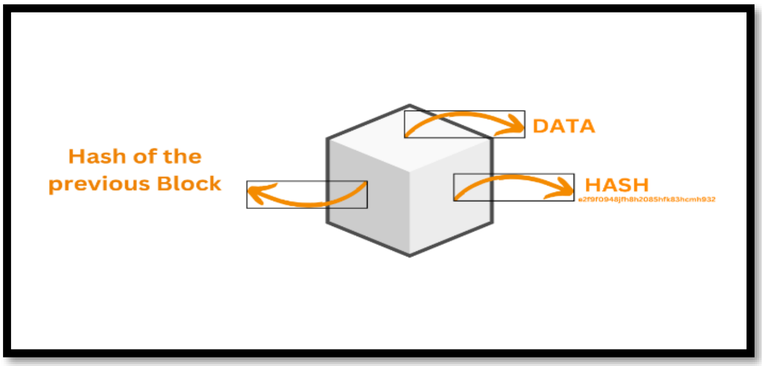

FIGURE 5.2 SHOWING A BLOCK CONTAINING DATA, HASH, AND HASH OF PREVIOUS BLOCK.

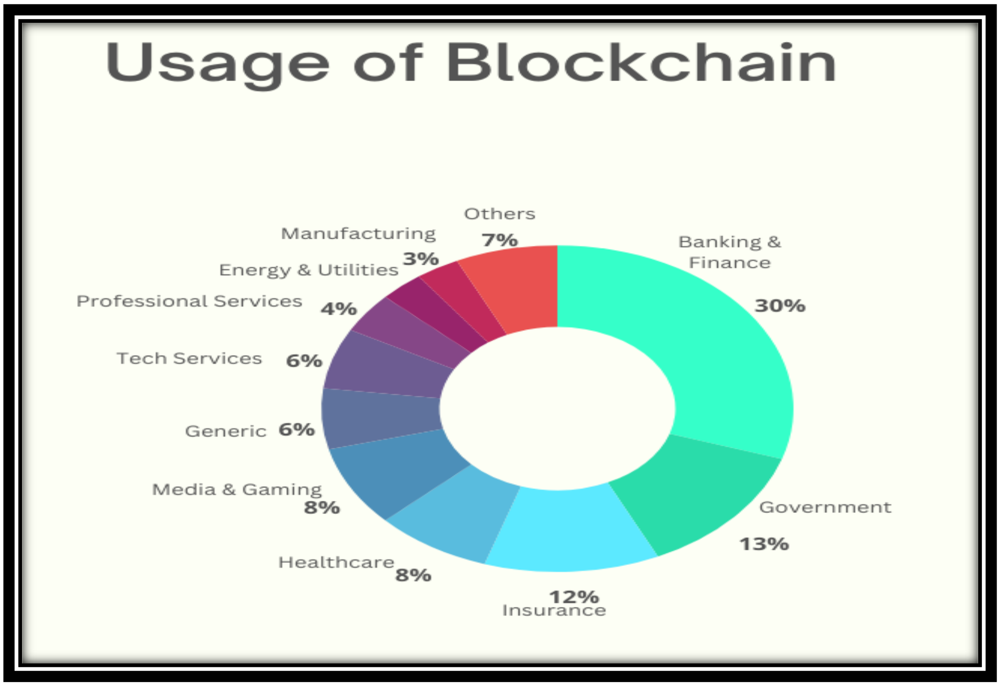

FIG.5.3 SHOWING USAGE OF BLOCKCHAIN IN DIFFERENT AREAS.

5.3 FOUNDATIONAL COMPONENTS OF BLOCKCHAIN

- **Asymmetric key cryptography:** The use of asymmetric key cryptography is essential to the security of blockchain operations within the network. Users require a digital wallet protected by their private key in order to complete any transaction; access is granted by creating appropriate signatures with this private key. To protect user privacy and anonymity, the bitcoin address is the wallet's public key, which is changed with every transaction and is made publicly known. Digital signatures, which guarantee the validity and security of transactions, are performed by the private keys.

- **Transactions:** The exchange of data directly between nodes occurs through the use of files that contain transaction information. These files are initiated by a source node and disseminated across the entire network for verification. Within this network, every node possesses knowledge regarding the real-time status at each address and retains a replica of the current blockchain. This blockchain serves as an extensive record of all past transactions.

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- **Consensus Mechanism:** Given the absence of a central authority to oversee transactions, mediate disputes, or shield against security breaches, a consensus must be reached among all nodes regarding a unified ledger updating protocol that guards against double-counting. When it comes to Bitcoin, miners compete to calculate a cryptographic block hash in order to find the next legitimate block. By providing bitcoin incentives to nodes that find the solution, fresh currency may be created more easily. Nodes come to an agreement to accept this hash value, which is also known as "proof of work," by updating their own copies of the ledger if all transactions and proof-of-work verify as legitimate.

5.4 IMPLEMENTATION

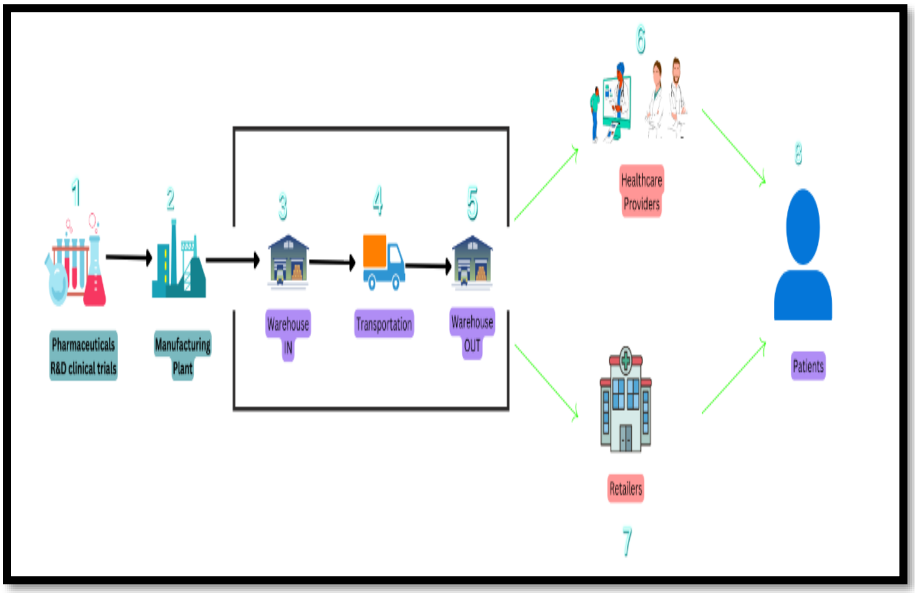

Fig. 5.4 SHOWS THE INTERACTION OF NETWORK PARTICIPANTS

5.4.1 DESIGN AND STRUCTURE OF DSCMR: A BLOCKCHAIN-ENABLED PHARMACEUTICAL SCM AND RECOMMENDATION SYSTEM

5.4.1.1 COMPREHENSIVE FRAMEWORK OF THE PROPOSED DSCMR SYSTEM

The main goal of the blockchain network is to disseminate data in a distributed fashion, with many transactions allowed for each block. For security reasons, these transactions are hashed and encrypted for safekeeping. The proposed system is a service-oriented architecture that provides users with smart contract and distributed

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ledger functions as services. Figure 5 provides a graphic representation of the central system design. The suggested system consists of two separate modules, one devoted to the administration of the medication supply chain and the other to the recommendation system. End users with the capacity to perform transactions inside this system include manufacturers, suppliers, distributors, pharmacies, physicians, and patients. A front-end web application makes this possible. It lets users order medications, provide raw materials, update medication information, manage orders, keep track of records, supervise drug delivery, exchange data, track the path of drugs through the supply chain, manage drugs, and supervise customer relations, among other things.

The foremost objective of this system is twofold. Firstly, it aims to prevent the circulation of counterfeit drugs, ensuring the authenticity and safety of pharmaceuticals. Secondly, it provides a secure supply chain management system that caters to the needs of end-users, thereby enhancing the overall efficiency and reliability of the pharmaceutical supply chain. Our proposed system prioritizes security, leveraging the robust features of blockchain technology to ensure data integrity and protection. Users within the system have the capability to trace the delivery status of pharmaceuticals through the DSCMR system. Moreover, the proposed system offers comprehensive CRUD (Create, Read, Update, Delete) operations among interconnected peer nodes.

We have implemented the notion of channels to improve security between nodes, therefore separating the whole network into discrete private networks. By shielding sensitive information from unrelated nodes, nodes in the same channel can directly communicate data with certain nodes while preserving privacy.
This channel-based approach empowers each participant to establish their individual private networks, thereby bolstering security.

In our system, patients are limited in their direct transaction capabilities, primarily interacting with the system to verify the authenticity of the drugs they purchase from a pharmacy. This verification is accomplished by simply scanning the barcode affixed to the drug packaging, offering an added layer of security and trust for end-users. Patients have access to essential information concerning the drug, such as the manufacturer company, manufacturing date, expiry date, price, and more. This access is made possible through the utilization of blockchain channels. Additionally, we can impose limitations on suppliers, confining their transactions solely to raw material-related activities with the manufacturer. These stakeholders operate within separate channels, effectively using the system as a private network.

Our suggested system's second module presents a machine learning-based recommendation system. This part is meant to provide pharmaceutical companies' clients suggestions for the best medications. We have combined machine learning algorithms, such as Ngram, LightGBM, and sentiment analysis, to accomplish this. These algorithms have been trained on customer-generated comments from websites, encompassing feedback on the quality of medicines, whether positive or negative. With the use of this training set, our model is able to provide well-informed suggestions to a wide range of clients, such as patients, physicians, pharmacies, clinics, and hospitals.

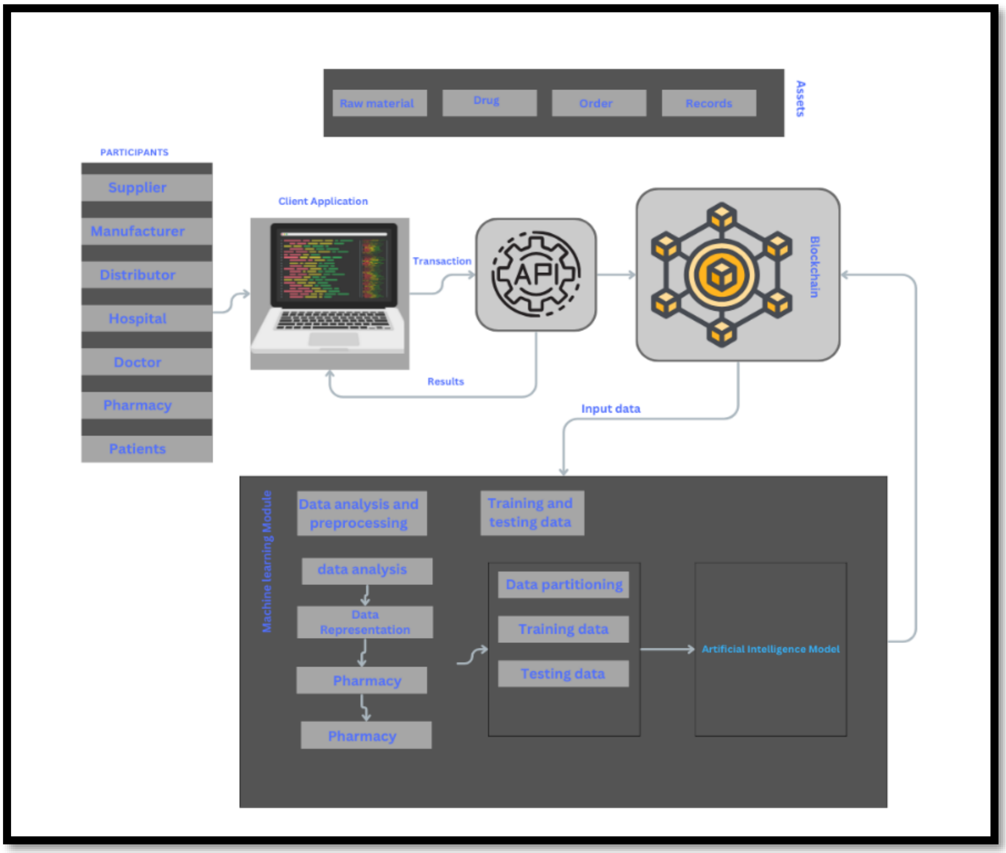

FIG. 5.5 DETAILED ARCHITECTURE OF DSCMR SYSTEM.

5.4.1.2 TRANSACTIONS EXECUTION PROCEDURE OF TRANSACTION EXECUTION IN DSCMR:

This section explains the procedures needed to complete a transaction on the Blockchain network and offers insight into the transactional process inside the pharma supply chain management system. When users are granted access to the front end of a client application, the process begins. This enables users to submit transaction requests and establish a connection to the Blockchain system using their registered login credentials.

The onus of registering all participants within the blockchain network lies squarely with the administrator. Only once participants have been duly registered by the administrator can they proceed with transaction execution. To initiate a transaction within the blockchain network, users log in to the client application and submit their transaction requests using their registered credentials.

The transaction proposal is then distributed to every peer node. The committers and endorsers are two separate categories of these peer nodes. It is the endorsers' duty to carry out and approve transaction proposals. If a proposal satisfies the requirements specified in the smart contract, they accept it; if not, they may reject it. On the other hand, before transaction outcomes are entered into the ledger's transaction block, committer peers are responsible for verifying them.

To comprehend the distinction between these two types of peers, it can be stated that endorser peers are essentially a specialized category of committer peers with the added role of holding predefined smart contracts. These endorser peers execute requested transactions' smart contracts within their own simulated environments prior to updating the ledger upon receiving the transaction proposals. During this process, endorser peers extract read and written data, collectively known as the RW set.

While the read data in the RW set includes information about the world state prior to the transaction, the written data in the RW set relates to modifications made to the world state after the transaction is executed in the simulated environment. The peer endorsers then return the signed transaction and the RW sets to the client application. The client then resubmits the signed transaction with all RW sets to the consensus management. The consensus manager arranges the data into a block and sends the transaction to the committer nodes.

Subsequently, by contrasting the transaction data with the current world state, the committer nodes do transaction validation. The transaction data is entered into the ledger if the validation is successful. As a result, the written data is reflected in the ledger through updates. During the last stage, the client receives a notification from committer peers stating the status of the transaction, which can be "submitted" or "not submitted."

The communication between the client application and the blockchain network is established through the utilization of REST APIs and a software development kit (SDK).

5.4.1.3 RECOMMENDATION MODULE FOR MACHINE LEARNING-BASED DRUG PREDICTION:

In today's scenario, we see a surge in software applications dedicated to healthcare, generating vast amounts of patient health records. Various apps emerge from these datasets, aiming to monitor and manage patient health. Health analysts and data scientists are keen on utilizing this data to build automated systems for the healthcare sector. Selecting and recommending medicines for such a system poses a challenge. To accomplish this, understanding the impact of medications based on patient conditions and symptoms becomes crucial. Despite the numerous reviews, both positive and negative, surrounding each medicine, researchers are grappling with the task of creating a system that can recommend the best medicine considering these diverse opinions.

5.5 DEEP LEARNING MODELS:

In this section, we are going to explain the models used for the recommendation of drugs in our proposed system; natural language processing model (NLP) N-gram for predicting the probability of a word in a sequence, LightGBM for reducing the low gradient features and sentiment analysis dictionary adding for the purpose of emotional analysis.

5.5.1 N-GRAM

Language models, such as the N-gram model, are employed to calculate the probabilities of words within a word sequence. The N-gram model, a specific type of language model, focuses on determining the probability distribution of a word within a sequence. This probability-centric model undergoes training on a text collection referred to as a corpus. During training, the N-gram model estimates probabilities by tallying the occurrences of word sequences within the provided corpus.In practical terms, if an N-1-word sequence is presented to an N-gram model, it predicts words with a high likelihood of appearing in that sequence. The term "N-gram" denotes a sequence of N words. For instance, a bigram constitutes a two-word sequence like "don't disturb," "my car," or "your notebook." Similarly, a trigram represents a three-word sequence, such as "please don't disturb" and "close the door." For example, how the N-gram model predicts the probability of a word in a corpus? Consider we have two sequences “heavy flood” and “heavy rain”; for these kinds of sentences N-gram model will predict the probability of word heavy with rain is more than with flood in the training collection of text. However, the probability of second-word rain will be more and selected by the model.

5.5.2 LIGHT GRADIENT BOOSTING MACHINE (LIGHTGBM):

In the realm of machine learning, the Gradient Boosting Tree algorithm is widely recognized and appreciated. Some notably effective variations of this algorithm include Extreme Gradient Boosting (XGBOOST) and Parallel Gradient Boosting Regression Tree (pGBRT). While these algorithms leverage various engineering optimization techniques, their efficiency and scalability may encounter challenges, particularly in scenarios with high-dimensional features and extensive datasets.

One prominent issue contributing to these challenges is the exhaustive nature of the information gain calculation. Specifically, for each individual feature, the algorithm examines all data instances, resulting in a time-consuming process. This becomes particularly evident and problematic when dealing with datasets characterized by high feature dimensions and extensive data volume. To address this challenge, Microsoft has introduced an innovative solution featuring two novel techniques: Gradient-Based One-Side Sampling (GOSS) and Exclusive Feature Bundle (EFB).

In the GOSS model, the exclusion of small gradient data instances occurs because only instances with high gradients are deemed crucial for estimating information gain. This results in a significant reduction of the data portion used for model training. Consequently, instances with low gradients do not impact the accuracy of model estimation. In our context, only data instances with high gradients are employed for information gain estimation. Despite the reduction in data size, GOSS can still provide accurate estimations.

On the flip side, EFB is employed for feature reduction by grouping mutually exclusive features together. Through the use of a greedy algorithm, EFB effectively reduces features without compromising the accuracy of information gain. Microsoft has coined these implementations based on GOSS and EFB as "lightGBM." Notably, lightGBM stands out as a faster and more accurate model compared to other Gradient Boosting Decision Tree (GBDT) models. Microsoft claims that it is 20 times faster than alternative GBDT models.

5.5.3 DATASET

In the drug recommendation module of our proposed system, we leverage one of the greatest publicly available drug datasets from the UCI Machine Learning Datasets Repository.

Patients' evaluations and ratings of different drugs that they have taken are included in this collection. In particular, we use the datasets from Druglib.com and Drug.com, two well-known pharmaceutical websites. Notably, both consumers and medical experts see Drug.com as one of the biggest and most popular sources of information about pharmaceuticals.
The dataset comprises reviews categorized by specific conditions such as pain, acne, anxiety, blood pressure, etc. Additionally, users have the option to assign star ratings, ranging from 0 to 10, indicating their satisfaction levels with these drugs.

5.6 IMPLEMENTATION OF BLOCKCHAIN-BASED DSCMR SYSTEM:

We developed a client web-based application using HTML, CSS, JAVASCRIPT, JQUERY, and a third-party framework called Bootstrap to give the consumers an eye-catching graphical user interface. The deployment of this system uses the open-source Hyperledger Fabrics blockchain technology, which has the following requirements: docker engine, python, node JS, and VS code. The blockchain network is deployed using Ubuntu 18.04 LTS, a Linux operating system. We have established our participants, assets, access control rules, and smart contracts in the Hyperledger Composer, which is used to design the business logics of the proposed network. Through the composer REST server, which connects the client application to the blockchain business network, users may see and carry out all of the actions at their own web based portals. The user can generate HTTP requests using GET, POST, PUT, DELETE methods through and response will be provided through the Blockchain system accordingly.

5.6.1 DEVELOPMENT OF SMART CONTRACT FOR DSCMR SYSTEM:

When building a blockchain network with Hyperledger Fabric, four essential components need definition:

- **Model File**: Used to define participants.
- **Script File**: Defines smart contract functions.
- **Access Control Rules File:** Specifies rules.
- **Query File:** Performs actions such as select and update.

One of the script file's functions that is especially meant for a transaction is shown by the excerpt that has been supplied. The updating of medication data, such as the production date, price, and expiration date, is handled by this transaction function. Creating, removing, and modifying assets and users in our blockchain-powered Drug Supply Chain Management and Recommendation (DSCMR) system are all handled by the script file.

JavaScript is employed for scripting these transaction functions during the modelling of the smart contract. The diagram illustrates two transaction functions: `sharerecordwithpharmacy` and `sharerecordwithdistributors`.

In the access control rules file, rules are crafted to govern user operations, delineating the actions permitted and restricted for all system users. This is achieved through the utilization of the rules access control language, where permissions for reading, writing, and deleting data are explicitly assigned to users. This approach serves as an effective means to grant users limited access within a blockchain network-based system.

In order to get or update data within the blockchain network's current global state, queries are essential. These inquiries in the Hyperledger Composer-based business network are expressed in a separate file with a specific query language.
These searches are made up of two primary parts: the statement and the description. They resemble SQL database statements and conditions. The statement section uses SQL-like terms to create rules in the query, such as SELECT, ORDER BY, WHERE, OR, AND, etc.
The second part entails the description of that query, encompassing a function string for deploying specific rules.

```
namespace composers.participant
abstract participant Person {
  o String firstname
  o String lastname
  o String username
  o String email
  o String phoneno
}
 participant manufacturer identified by manufacturerID extends Person{
o String manufacturerID
o String company
o String accountno
o String Address
}

participant supplier identified by supplierID extends Person{
o String supplierID
o String company
o String accountno
o String Address
}

participant hospital identified by hospitalID extends Person{
o String hospitalID
o String Address
}
```

FIGURE 5.6 PARTICIPANTS DEFINITION IN HYPERLEDGER COMPOSER.

```
async function shareRecordWithdistributor(records) {
    return getAssetRegistry('composers.Drug.Drug')
        .then(function(assetRegistry){
        records.Drug.distributor = records.distributorID;
        console.log(records.Drug.distributor );
        let factory = getFactory();
        let shareRecordEvent = factory.newEvent('composers.Drug', 'shareRecordWithdistributorNotification');
        shareRecordEvent.Drug = records.Drug;
        emit(shareRecordEvent);
        return assetRegistry.update(records.Drug);
    })
    .catch(function (error) {
    // Add optional error handling here.
    });
}

async function shareRecordWithpharmacy(record) {
    return getAssetRegistry('composers.Drug.Drug')
        .then(function(assetRegistry){
        record.Drug.pharmacy = record.pharmacyID;
        console.log(record.Drug.pharmacy);
        let factory = getFactory();
        let shareRecordEvent = factory.newEvent('composers.Drug', 'shareRecordWithpharmacyNotification');
        shareRecordEvent.Drug = record.Drug;
        emit(shareRecordEvent);
        return assetRegistry.update(record.Drug);
    })
```

FIGURE 5.7. SMART CONTRACT DEFINITION IN SCRIPTS FILE FOR A FUNCTION UPDATE DRUG DETAIL.

5.7 FUTURE SCOPE:

The proposed Drug Supply Chain Management and Recommendation (DSCMR) system, integrating Blockchain technology and machine learning, lays the groundwork for a transformative approach to pharmaceutical supply chain management. As the research advances, several avenues for future exploration and enhancement emerge, providing a rich landscape for ongoing research and development:

- **Blockchain Integration and Interoperability:**
  Future research could focus on further enhancing the integration of Blockchain technology into pharmaceutical supply chains. Exploring interoperability with other blockchain networks or technologies could facilitate seamless collaboration and data exchange between different stakeholders in the broader healthcare ecosystem.
- **Scalability and Performance Optimization:**
  As the DSCMR system evolves, researchers can explore strategies to optimize its scalability and performance. Investigating techniques such as sharding or

advanced consensus mechanisms could enhance the system's ability to handle a growing volume of transactions without compromising efficiency.

- **Privacy and Regulatory Compliance:**
  Addressing privacy concerns and ensuring compliance with regulatory frameworks, such as GDPR in Europe or HIPAA in the United States, is crucial. Future research can delve into developing privacy-preserving techniques within the blockchain network and ensuring that the DSCMR system adheres to global healthcare data protection standards.
- **Machine Learning Refinement:**
  Continuous refinement of the machine learning algorithms used for drug recommendations is essential. Incorporating more sophisticated natural language processing (NLP) techniques, deep learning models, and expanding the dataset to include diverse patient demographics could improve the accuracy and personalization of drug recommendations.
- **Real-Time Monitoring and IoT Integration:**
  Integrating Internet of Things (IoT) devices for real-time monitoring of drug shipments and storage conditions could further enhance the DSCMR system. This could include sensors to monitor temperature, humidity, and other factors, ensuring the quality and safety of pharmaceuticals throughout the supply chain.
- **Global Adoption and Collaboration:**
  Research efforts can be directed towards promoting the global adoption of blockchain-based pharmaceutical supply chain systems. Collaboration with international organizations, regulatory bodies, and pharmaceutical companies can help establish standards and frameworks for the widespread implementation of secure and transparent supply chains.
- **User Education and Training:**
  The success of the DSCMR system relies on the active participation of various stakeholders. Future research can explore strategies for educating and training users, including healthcare professionals, manufacturers, and patients, to ensure effective utilization of the system and its features.
- **Cybersecurity and Threat Analysis:**
  Continuous assessment of cybersecurity threats and proactive measures to mitigate potential risks is essential. Future research can focus on threat modelling, penetration testing, and the development of advanced security protocols to safeguard the DSCMR system against evolving cyber threats.
- **Blockchain Governance Models:**
  Exploring different governance models for the blockchain network can contribute to the long-term sustainability and decentralization of the DSCMR

system. Researching approaches for community-driven governance and consensus on system updates ensures a robust and democratic framework.

- **Regulatory Advocacy:**
  Actively engaging with policymakers and regulatory authorities to advocate for the adoption of blockchain-based systems in pharmaceutical supply chains is crucial. Future research can contribute to the development of regulatory guidelines and frameworks that promote innovation while addressing legal and ethical considerations.

In summary, the future scope of the research involves a holistic approach towards refining and expanding the proposed DSCMR system. Continuous innovation, collaboration, and adaptation to emerging technologies and regulatory landscapes will be pivotal in ensuring the effectiveness and sustainability of blockchain-based pharmaceutical supply chain management.

5.8 CONCLUSION

In conclusion, the widespread issue of counterfeit drugs poses a significant threat to global public health, necessitating a robust solution for pharmaceutical supply chain management. So it advocates for the adoption of Blockchain technology to enhance transparency, traceability, and security within the supply chain. The proposed Drug Supply Chain Management and Recommendation (DSCMR) system leverages Blockchain's decentralized nature, ensuring real-time visibility and preventing the circulation of counterfeit drugs. The integration of machine learning augments the system by providing personalized drug recommendations based on patient reviews. Using Hyperledger Fabrics and Composer, the user-friendly system offers a secure interface for participants. Overall, this chapter presents a concise framework combining Blockchain and machine learning to address pharmaceutical supply chain challenges, promoting a secure and efficient drug distribution network for the evolving pharmaceutical industry.

In an era where counterfeit drugs jeopardize public health, a robust pharmaceutical supply chain is imperative. This study advocates for Blockchain as a transformative solution, introducing transparency, traceability, and security. The Drug Supply Chain Management and Recommendation (DSCMR) system, built on Hyperledger Fabrics and Composer, utilizes Blockchain's decentralized architecture to prevent counterfeit drug circulation and provide real-time visibility. Incorporating machine learning enhances the system, offering personalized drug recommendations based on patient reviews. The user-friendly interface accommodates various stakeholders, ensuring accessibility and participation. This comprehensive framework aligns with the pharmaceutical industry's need for modern, secure, and intelligent supply chain management, laying the foundation for a safer and more efficient drug distribution network.

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