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SIOTEHR: Secure IoT based EHR Scheme in Blockchain Ecosystem

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Abstract— In the present era, the number of illnesses and traumas is steadily rising. In addition, COVID-19 is still spreading in waves. Therefore EHRs (Electronic Health Records) has become a necessity now which can be used to access a patient's prior medical records through the EHR system. India is still falling behind the rest of the globe in the adoption and use of EHR. The IoT-based EHR aids in patient monitoring and enables the doctor to treat the patient right away if necessary. The goal of the EHR system will fail if the central server, which was the system's defined point of failure, fails or is compromised. In this situation, security is a major concern. In this work, we suggest adopting the blockchain technology to resolve this. We created a SIoTEHR (Secure IoT Based EHR) system that is fully decentralized, secure, traceable, auditable, private, and trustworthy by utilizing a private Ethereum Blockchain.

Keywords- Blockchain, Ethereum, EHR, IoT, IoTEHR, SIoTEHR

I. INTRODUCTION

The pandemic is still not ended and the world is facing many consequences of it as well as newer challenges. China is severely suffering from a new variant of Covid-19 and it may be affecting the neighboring countries as well including India. The COVID-19 epidemic has claimed many lives around the world and poses an unprecedented threat to public health, food systems, and the workplace. The economic and social consequences of the epidemic are devastating: tens of millions of people are at risk of falling into extreme poverty, and the number of undernourished people, which is presently projected to be almost 690 million, might climb by up to 132 million by the end of the year [1]. Regarding health, economic advancement, public trust in governments, and social cohesion, the COVID-19 pandemic has shown how health system flaws can have significant effects [2].

A computerized version of a patient's medical chart is an electronic health record (EHR). EHRs are patient-centered, real-time records that make information instantaneously and securely available to authorized users. Although an EHR does contain a patient's medical and treatment history, it is designed to go beyond the typical clinical data gathered in a provider's office and can include a wider perspective of a patient's care. EHRs are essential components of health IT because they store a patient's medical history, diagnoses, prescriptions, treatment plans, immunization dates, allergies, radiological pictures, and laboratory and test results. [3]

In September 2013 the Ministry of Health & Family Welfare (MoH&FW) notified the Electronic Health Record (EHR) Standards for India. The set of standards given there were chosen from the best available and used standards applicable to Electronic Health Records from around the world keeping in view their suitability to and applicability in India [4], these standards were further defined and enhanced in the year 2016, notification of EHR since then many software were made for EHR system. There are three different types of software-based EHR one that uses the cloud for storage, Cloud-based EHR software, one that is owned by the hospital/doctor itself Physician-hosted Systems, and software made by a third party for use in the hospital is Remote –hosted Systems. [5]

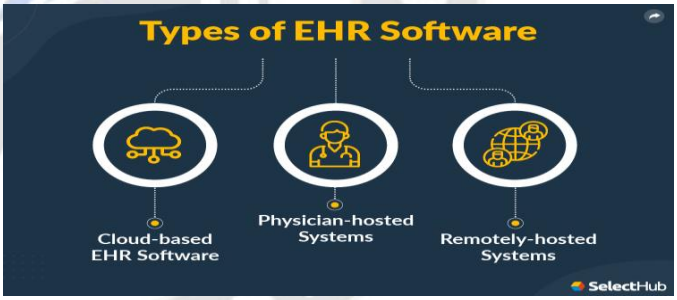

Figure 1: Types of EHR software [5]

Some of the most popular EHR systems are

- Athenahealth
- DrChrono
- EpicCare
- Cerner Ambulatory
- eClinicalWorks

There are different types of challenges and limitations in building an EHR system. [6]

- **Security:** EHR system consists of a centralized server. As the safety of patient data is paramount to both clinics and patients. If this centralized server is compromised the whole idea will fail.
- **Costly:** The maintenance and implementation cost of EHR is high. Small hospitals cannot

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spend that much amount for record-keeping, for them maintaining paper files is enough.

- **Not User-friendly:** Most EHR software does not have a user-friendly interface. This is what an EHR lacks.
- **Downtime:** EHR is based on the use of a computer server if this fails or a problem occurs the EHRs face considerable downtime that may last for weeks or even months.

The introduction to IoT has given a new realm to the EHR system. New IoT devices have opened newer opportunities in the healthcare system [7]. IoT devices like a smartwatch produce a large amount of data that needs to be properly utilized [8]. In an IoT healthcare network, remote patient monitoring (RPM) technology can be effectively used, RPM enables the monitoring and treatment of patients outside of the traditional healthcare context by using data received from various IoT devices and other sources [9] [10]. For instance, wearable IoT devices sense patient data and transmit it to hospitals or other healthcare facilities. The data is subsequently kept at backend databases and storage systems as part of the patient's electronic health records (EHRs). When patient data is transferred across heterogeneous IoT networks, there are security and privacy concerns [11]. Several IoT manufacturing and service providers have served the healthcare sector by providing IoT-enabled healthcare sensors, actuators, System-on-Chips (SoC), cloud services, and data analytics [12]. Security and privacy continue to be two major challenges even though IoT-enabled healthcare systems improve services to patients and medical institutions in terms of time and cost (e.g., how to protect heterogeneous healthcare data sources and securely transfer them). For example, secure transmission, tamper-proof monitoring, data storage, integrity, and privacy-aware authentication should all be included in crucial IoTEHR and healthcare systems [13, 14].

Blockchain technology has the potential to improve the security and privacy of IoT-based healthcare systems [15]. The EHR system comprises of a central server where all the information is stored. Data security is a major concern of such a system. Blockchain provides a decentralized and secure solution for such a system.

In this work, we present a revolutionary Blockchain-based IoTEHR. A simulation is developed that depicts how blockchain can be useful for IoTEHR. The system is built using Ethereum Private Blockchain**.**

II. BACKGROUND

A. Basics of Blockchain

Blockchain Technology can be a perfect solution for the secure implementation of IoTEHR, it consists of a hashed chain of blocks, and the first block in the blockchain is the genesis block. The elements of the blocks are Distributed ledger Technology, Immutable Records & smart contract. Figure 2 shows the working of the Blockchain.

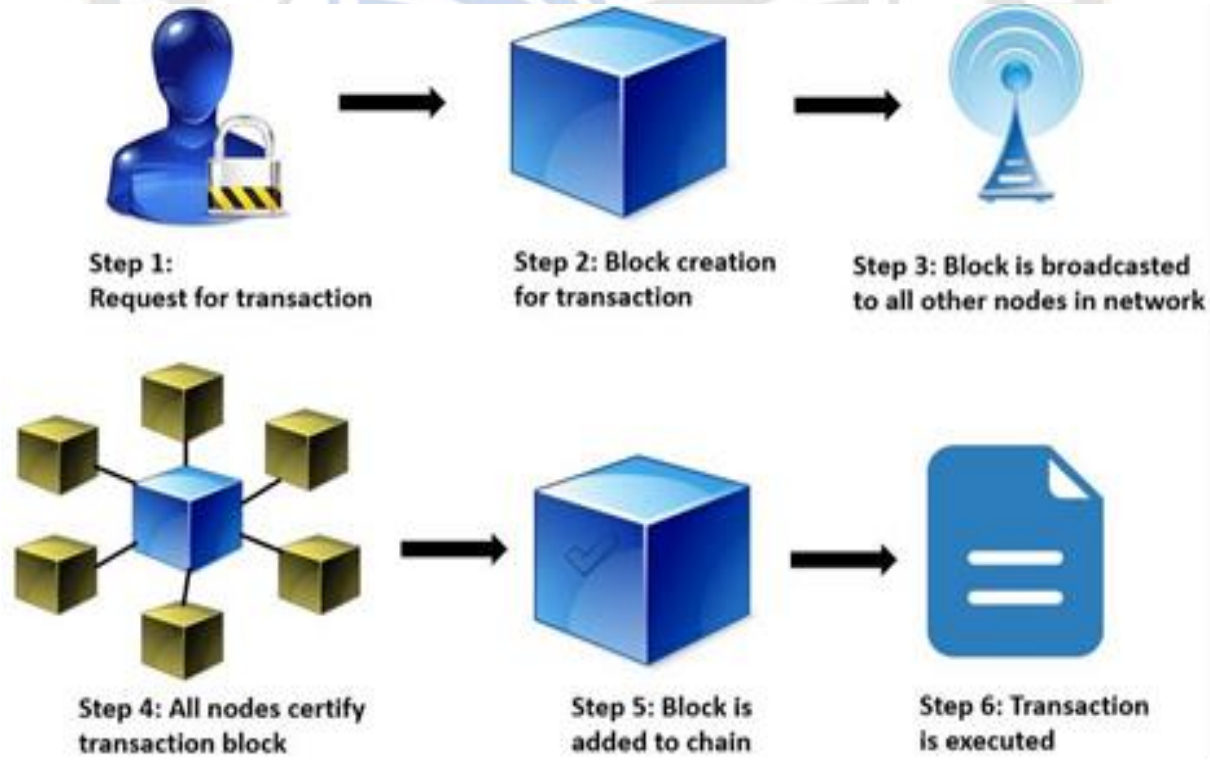

Figure 2: Working of Blockchain [14]

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The components of Blockchain are [14]

- Distributed Ledger Technology
- Consensus Mechanism
- Peer-to-peer network
- Cryptography
- Virtual Machine

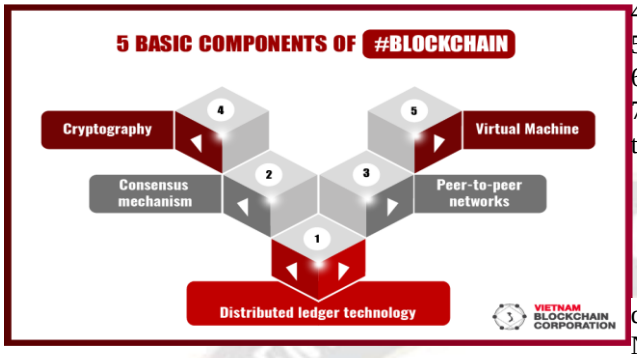

Figure 3: Blockchain components [14]

An Electronic ledger is a database that contains all the transactions, it will be constantly updated. It is composed of multiple blocks (each containing at least one transaction) and these blocks are linked together into a chain using a cryptography algorithm. The traditional system has centralized control whereas in distributed ledger there is no such central control. In distributed ledger technology each node processes and verifies every transaction. A Peer-to-peer network is based on n decentralized concept, which allows all the nodes to conduct transactions without the t need for any centralized control**.** In Blockchain, peers are the nodes that have the computational power**.** Consensus Mechanism is a set of rules that will tell how a node will participate in the transaction. Consensus algorithms come in a variety of flavors, including Proof of Work, Proof of Stake, Proof of Authentication, and many others. Cryptography lets the data secure using an encryption algorithm. A virtual machine is a program that simulates a computer system. The Ethereum virtual machine is used to ensure that transactions processed on completely different environments and computer configurations will always create the same results on the Ethereum platform. Essentially, an EVM is a machine that processes smart contracts running on Ethereum [15].

The block in Blockchain is made up of the following elements: the block header, which is made up of a pointer to the previous block, the timestamp, nonce, Merkle root, and the block content, which contains transactions. Merkle root is a hash of all nodes in a Merkle tree [16,18]. Fig4 shows the function of the Merkle tree.

There are three types of Blockchains; public, private and consortium. A public blockchain allows any stakeholder, such as miners and users, to access the blocks and transactions. In a private blockchain, stakeholders need to be granted prior consent to join the blockchain, thus it is more restricted. Finally, the consortium blockchain is suitable for enterprises or large business applications where a group of people can grant or revoke access to the blockchain [19].

Salient Features of Blockchain are listed below:

1) It is based on distrusted system technology.
2) Block is the basic fundamental unit of blockchain.
3) Node can store partial as well as full ledgers.
4) Hash function is used to link different blocks.
5) Transaction is created by the node.
6) Blockchain is secure and immutable
7) Consensus decides how the nodes will perform the transaction.

B. IoT in Health Care

The Internet of Things refers to wireless digital devices that can gather, transmit, and store data in a network. No Human interaction is required for IoT devices to send data. The IoT provides several advantages for streamlining and improving the delivery of healthcare, including the ability to detect health issues in advance and to diagnose, treat, and keep track of patients both within and outside of hospitals [20]. Every year, thousands of people die as a result of various diseases or health problems. They are paying more attention to health following the Covid-19 outbreak [21]. About 60% of the total death worldwide is because of chronic diseases, where times play a vital role [22]. IoT devices are made up of sensors and actuators that are embedded in physical equipment to monitor and communicate data via various IoT protocols such as Bluetooth, Wi-Fi, Zigbee, and others. The sensors in IoT device collects physiological information about patients like temperature, pressure rate, electrocardiograph (ECG), and electro and encephalography (EEG) [23].

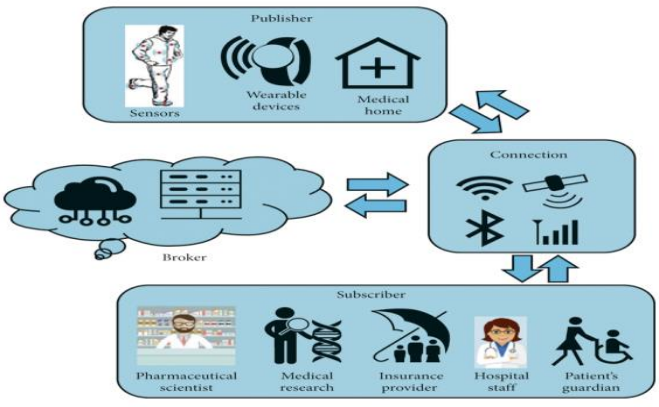

Figure 4: HIOT architecture [23]

HIoT is Health based IoT system. Different components of the IoT healthcare system are connected to provide instant health parameters to the patient. HIoT consists of users such as publishers, brokers, and subscribers [24]. The publisher's responsibility in the network is to connect sensors and other medical devices. The information given by the sensors is blood pressure, heart rate, temperature, oxygen saturation, ECG, EEG, and EMG [25]. The broker receives

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this information continuously as sent by the publisher. The broker is responsible for storing data in the cloud. The subscriber is responsible for monitoring the health data it uses smartphones, computers, and tablets for this.

C. Benefits of using Blockchain in IoTEHR

There are several benefits of using Blockchain technology for IoTEHR. The features of blockchain are listed below [26].

1. Distributed System: Blockchain is a distributed system so no issue of failure of a centralized system.
2. Immutability: This feature assures that once the data is recorded it cannot be changed.
3. Security: Blockchain uses asymmetric cryptographic algorithms and hash functions to provide security.
4. Increased Capacity: Blockchain increases the capacity of the whole network because of its distributed nature.
5. Transparent: In Blockchain every node knows about the transaction in the network.
6. Consensus: Consensus is the decision-making ability of the blockchain which will help to decide how the nodes will work.

III. RELATED WORK

A. REVIEW OF PREVIOUS WORK

Since 2017 many researchers have contributed towards betterment of EHR systems using Blockchain, some relevant works are listed in table 3.1.

P.P.Ray et al. has given the architure for a blockchain based EHR system [6]. V.P et al. describes a light weight protocol for Internet of Things [7]. D.Puthal et al. describes the consensus algorithm that can be used [8]. It emphasizes on the use of Proof of Authentication for IoT Based Blockchain. P.Mishra et al. defines software-based IoT system [9]. G.Magyar has explained the new approach of an integrated health information model, where a complex and highly connected EHR will use the blockchain to operate [15]. The concept is purely theoretical. J.Vora et al. has proposed a differential privacy model for providing data privacy of EHR system based on Blockchain [16]. It has given a framework where whole data is stored in the blockchain which increases the processing time. Then the researchers have suggested that the hash can only be stored to increase the processing time. F.Tang et al.[17]defines the EHR system design in order to realize the authentication scheme. Blockchain was used to create an identity-based signature method with numerous authority. The scheme has efficient signing and verification algorithms. Kelly J. Campbell et al.[18] has stated how Internet of Thing can be used in Health sector. G.Yang et al.[15] has made comparison of three authentication scheme to be used for EHR. The basic of comparison was number of signature versus time.

Most of the existing works are based on simple Blockchain implementation, very less work has been done for IoT Based EHR systems. The practical implementation work and analysis are very less. As a result, it is difficult to argue if these efforts can genuinely demonstrate the usefulness of adopting Blockchain for IoT-based EHR. In the proposed work an IoT-based EHR system is developed. The system is built using a private blockchain where only the trusted parties can participate in transactions. Some more work is compared in Table 1.

Article	Year	Blockchain-IoT	EHR	Contributions
S.D. [14]	2021	Both IoT & Blockchain	No	Blockchain implementation in IoT
G. Magyar [15]	2017	Only Blockchain	No	Theoretical Study
J. Vora et al. [16]	2018	Only Blockchain	Yes	Platform-based Implementation
F. Tang et al.[17]	2019	Only Blockchain	Yes	Mathematical Modeling
Kelly J[18]	2020	Only IoT	Yes	IoT Implication for health care
Zhang [20]	2019	Only IoT	Yes	Systematic review of Healthcare work
R. Guo et al. [21]	2019	Only Blockchain	Yes	Mathematical Modeling & Simulation

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Dang[22]	2019	IoT	Yes	Cloud computing implementation for IoT based healthcare
M.Kuliha et.al[23]	2021	Both IoT & Blockchain	Yes	Only theoretical description
S.B. Baker[24]	2017	IoT	Yes	Technology, challenges and opportunities are defined
Mohd Javaid [25]	2021	IoT	Yes	IoT for Healthcare system
N. Kshetri [26]	2018	Only Blockchain	Yes	Theoretical Discussion
A.R.Rajput et al.[27]	2018	Only Blockchain	Yes	Architecture Modeling
K.R. Ozyilmaz et al.[28]	2019	Partial	No	Preliminary Structure
A. Islam et al.[29]	2019	Partial	No	Mathematical Modeling
I. Kotsiuba et al.[27]	2018	Only Blockchain	Yes	Architecture Modeling
F.Li.K [32]	2022	Both IoT & Blockchain	Yes	Platform-based Implementation
Proposed Work	2023	Both IoT & Blockchain	Yes	Framework Design, Modeling and Implementation

Table 1: Comparison of the related research

IV. PROPOSED SCHEME

We outline the system design and technique for implementing the proposed SIoTEHR system in this section. We are

A. Tools Used

Ganache-Truffle suite: Ganache is a component of truffle suite. It allows the researcher's to work on the Ethereum network. Ganache gives ten accounts with 100 test ether.

Meta Mask: Meta mask is a digital wallet where we store the account. It comes as a browser extension.

VS code: VS code is the IDE that provides the environment for writing code. The Code is written solidity, which is a statically typed code created specifically for smart contracts.

Web3: Web3 is an online ecosystem that is decentralized. It is based on Blockchain**.**

B. Implementation Details

The implementation specifics of our proposed blockchain-based EHR system are presented in this section. The suggested solution is based on a private Ethereum blockchain, to which only authorized users have access. The smart contracts are written in Solidity and tested with the VS code IDE, which allows for the construction and management of smart contracts.
The EHR system consists of three Actors:

1. Admin
2. Doctor
3. Patient (equipped with IoT device)

All the actors access the smart contract using DApps. The smart contract at the Admin will register doctor, patients and IoT devices using the Ethereum account. The blockchain is private as only authorized user can make transactions. All the registered users will commit transactions and the data is stored in the ledger.

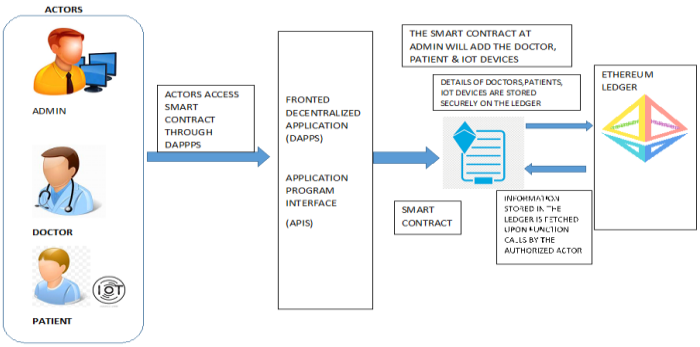

Figure 5: System Architecture of SIOTEHR system

C. UML

UML defines the system effectively. Use cases & Sequence diagram are made to understand the system effectively. The Use cases describe the role of each user.

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1. Admin Use Case

Admin is the main node in the blockchain. The consensus algorithm used is Proof of Authentication. Admin adds the users to the Blockchain. Admin adds Doctor, Patient and IoT devices to the block chain network.

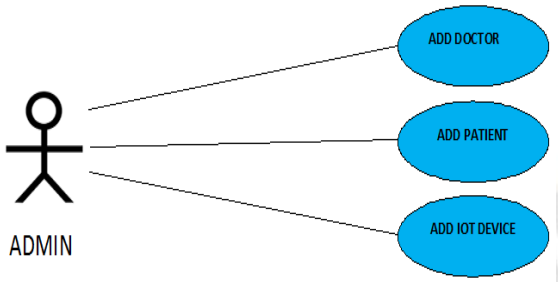

Figure 6: Admin Use Case

2. **Doctor Use Case**
3. Doctor in the SIoTEHR adds the records of the patient in the blockchain. It can edit its own information as well as view history of the patient, for this account ID is required.

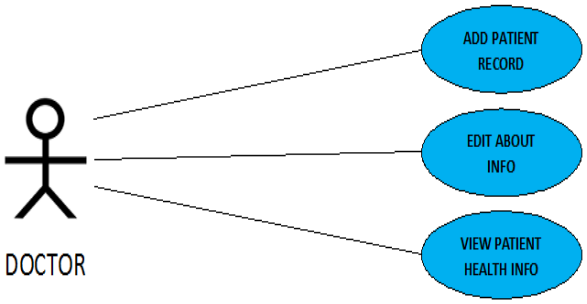

Figure 7 : Doctor Use case

4. Patient Use Case

Patient in SIoTEHR system can view his medical records. He can edit his information. Patient can click on IoT device to start recording data.

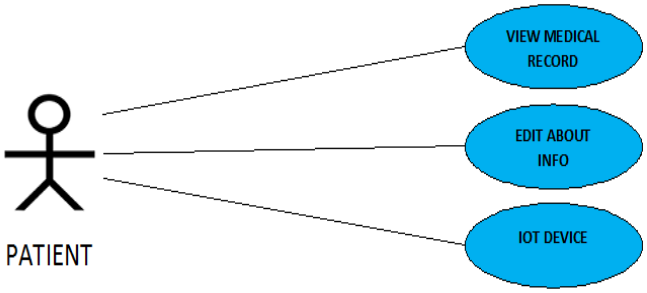

Figure 8: Patient Use Case

5. Sequence Diagram

Sequence diagram given below describes the flow of the system.

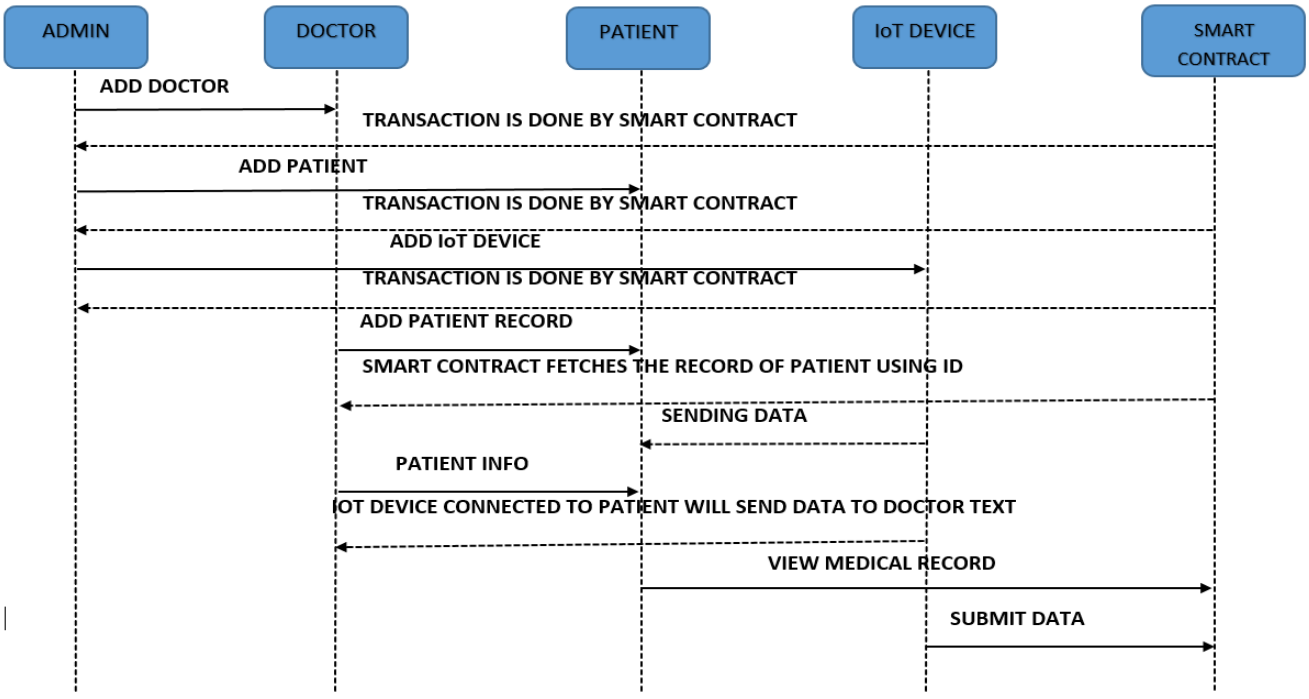

Figure 9. Sequence Diagram of the proposed solution

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D. Algorithms

Algorithm 1 is used to add doctors and its information .The Input for this is taken as ID of doctor.

Algorithm1: Add Doctor

Input:drId,drInfoHash

```
1. function addDoctorInfo(address _drId, string memory _drInfoHash) onlyAdmin
   public {
2. Doctor storage drInfo = doctors[_drId];
3. drInfo.drHash = _drInfoHash;
4. doctorIds.push(_drId);
5. doctor.add(_drId);
6. doctors[_drId] = drInfo;
7. }
```

Output: Doctor details is added

Algorithm 2 is used to update and get information about doctor

Algorithm 2: Update & Get Doctor information

Input:drId,drInfoHash

```
1. function updateDoctorInfo(string memory _drInfoHash) onlyDoctor public {
2. Doctor storage drInfo = doctors[msg.sender];
3. drInfo.drHash = _drInfoHash;
4. doctors[msg.sender] = drInfo;
5. }

6. function getDoctorOwnInfo() public view returns (string memory) {
7. return (doctors[msg.sender].drHash);
8. }
```

Output: doctor Information is updated

Algorithm 3 is used to add the patient for this patient ID is required

Algorithm 3: Add Patient

Input:patId,patInfo Hash

```
1. function addPatientInfo(address _patId, string memory _patInfoHash) onlyAdmin public {
2. Patient storage patInfo = patients[_patId];
3. patInfo.patHash = _patInfoHash;
4. patientIds.push(_patId);
5. patients[_patId] = patInfo;
6. patient.add(_patId);
7. }
8. function getPatientInfo(address _id) public view returns (string memory) {
9. return (patients[_id].patHash);
10. }
11.
}
```

Output: Patient information is added

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Algorithm 4 is used for adding the medical records of Patients. For this patient id and recHash is taken.

Algorithm 4:Adding Medical Records of Patient

Input: recHash,patId

```
function add MedRecord(string memory _recHash, address _patId) onlyDoctor public {
MedRec storage record = records[_patId];
record.recordHash = _recHash;
recordHashes.push(_recHash);
records[_patId] = record;
}
function viewMedRec(address _patId) public view returns (string memory) {
return (records[_patId].recordHash);
}
```

Output: Medical Records of patient is added

Algorithm 5 is used for adding IoT devices and retrieving data from it. The IoT device is linked with patient. The data is send to doctor. The doctor can get the IoT data of the Patient by searching its ID

Algorithm5: Adding IoT devices & Retrieving data

Input: deviceHash,patId

```
function addDeviceRecord(string memory _deviceHash, address _patId) public {
MedRec storage record = records[_patId];
record.deviceHash = _deviceHash;
records[_patId] = record;
}
function viewDevRec(address _patId) public view returns (string memory) {
// require(doctor.has(msg.sender) == true, "Only Doctor Can Do That");
return (records[_patId].deviceHash);
```

Output: IoT device is added to patient and data is sent in blockchain.

V. RESULTS & DISCUSSIONS

We have created an immutable, secure EHR system. The SIOTEHR system administrator adds Doctors and Patients using their blockchain addresses. Once the Patient has been joined to the network, the doctor can add a prescription for the patient. A special ID is used to identify the Patient. By entering the Patient's blockchain ID, Doctors can access the patient's history.

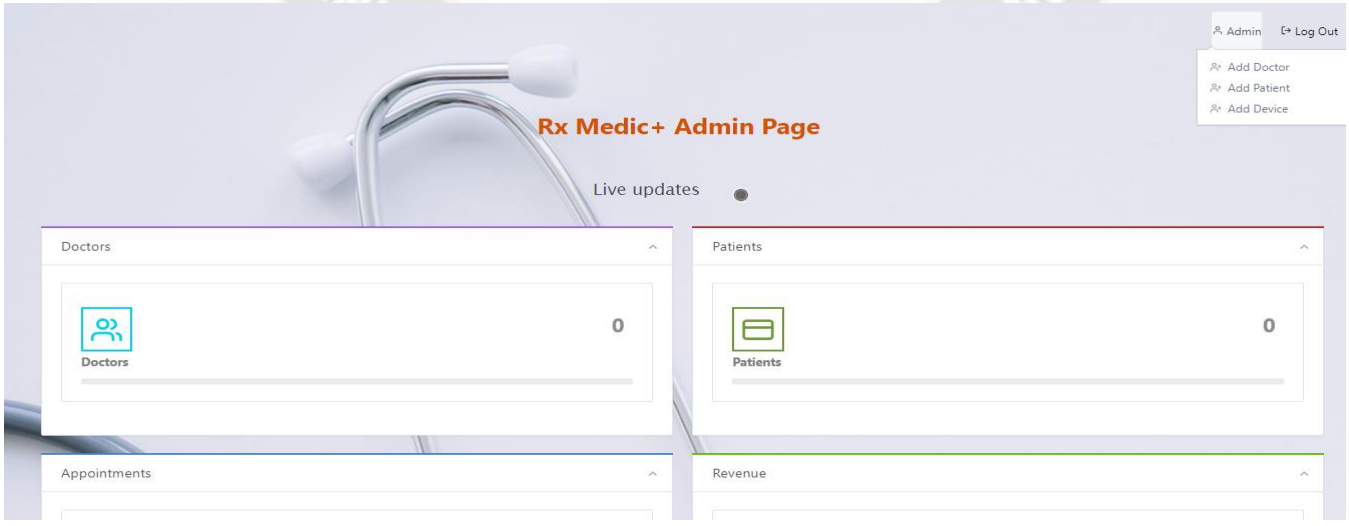

Fig 10: EHR Admin Interface

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The IOT Device is assigned to the patient by the SIOTEHR system administrator. Utilizing Blockchain ID, the IoT gadget is registered in the SIOTEHR network.

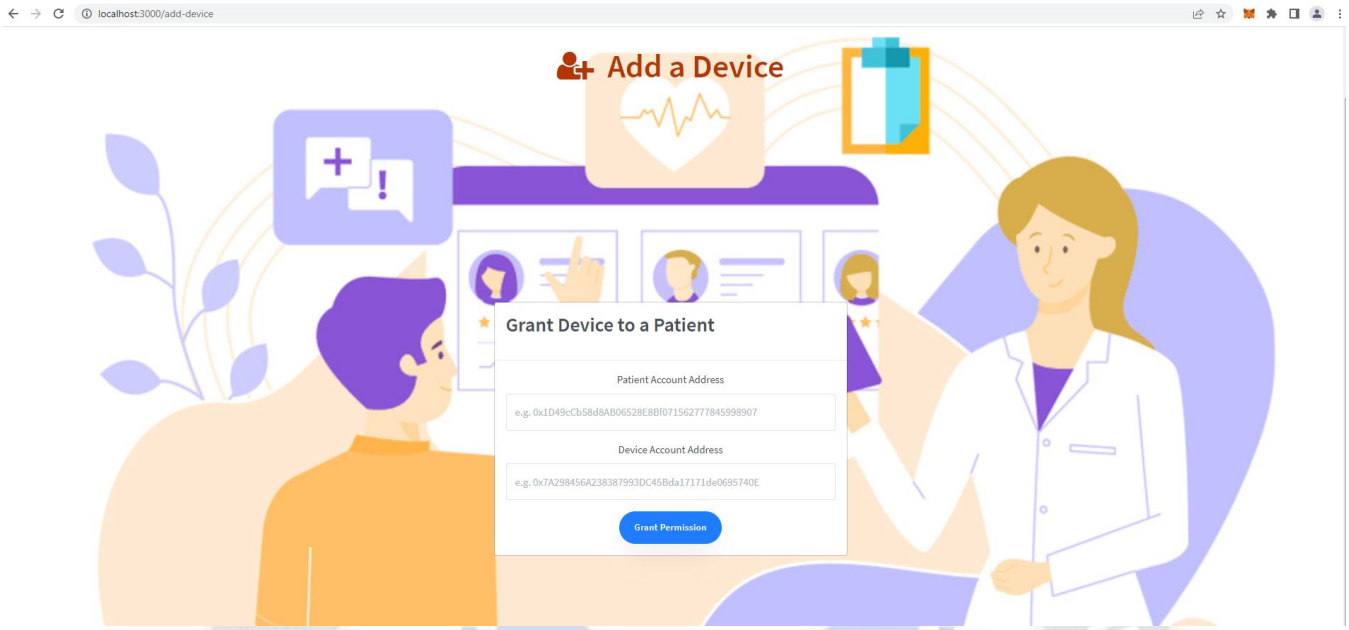

Fig 11: Add Device Interface

The patient's real-time IoT data is gathered by the SIOTEHR system. Heartbeat rate and SPO2 have been used as two vitals in our simulation. The doctor can view this real-time data from IoT devices, which will enable the doctor to take immediate action if the range of vital signs reaches a critical level.

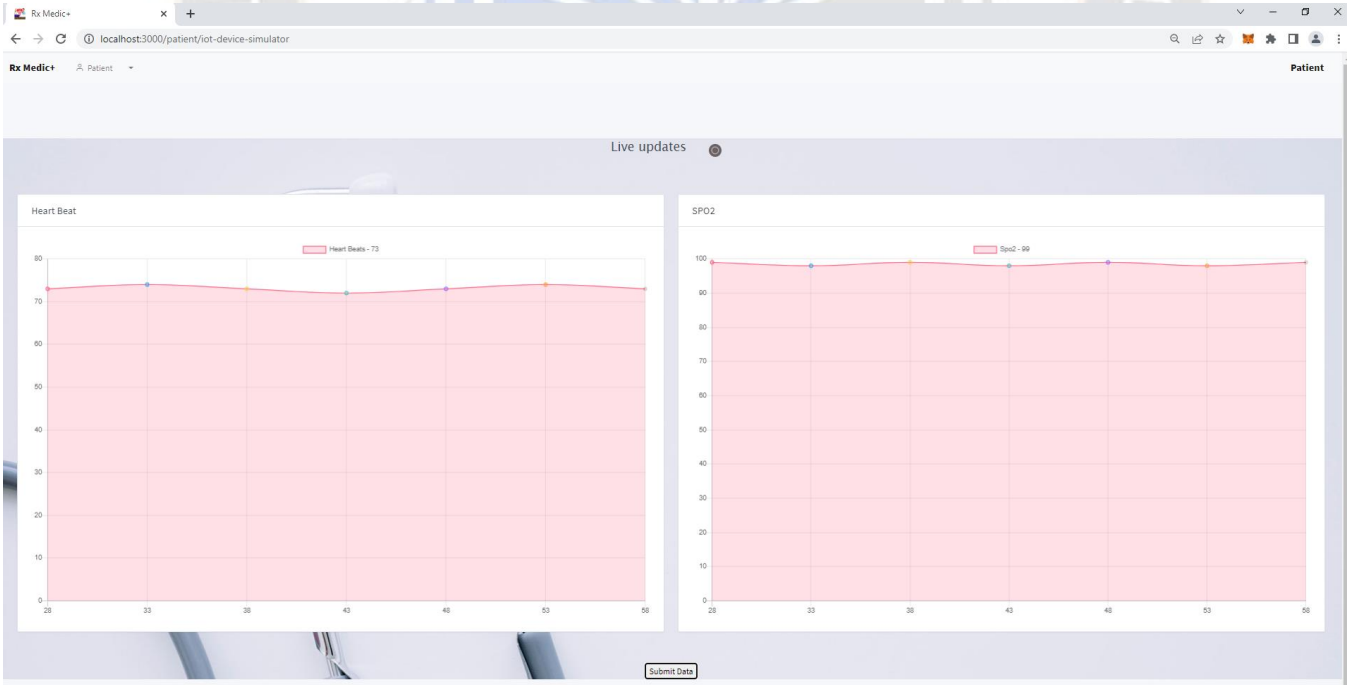

Fig 12: IoT Interface

The SIOTEHR system has the potential to revolutionize healthcare because it can decrease the death rate. It could be beneficial for the emergency medical system since it would enable doctors to treat patients more quickly by giving them access to real-time IoT data.

The comparison between the existing system and SIOTEHR is depicted in table 2.

S.No.	Comparison Basic	Existing System	SIOTEHR
1	Function	Centralized. Controlled by the central server.	Distributed. Not controlled by anyone.
2	Censorship	Not free. Owned by some authority or government.	Free. No single authority or government owns it.
3	Traceability	Not Traceable	Easily Traceable. The transaction history can be easily viewed.
4	Trust	Trust is based on the central party.	Highly trusted because of the chain of blocks.
5	Immutable	Not immutable, as data can be changed centrally.	Immutable. A transaction once committed cannot be deleted in the blockchain
6	Transparent	Not transparent	Transparent, as everyone in the blockchain, can see the transaction.
7	Information storage	Size can vary, depending on the server capability.	Fixed-size block
8	Security	Not secure, as security rely on the centralized system	Highly secure. Uses SHA256, hash algorithm and elliptic curve cryptography.
9	IoT Based	Not IoT based	It is a IoT based EHR system
10	Monitoring of patient	No live monitoring of patient is possible.	It enables live monitoring of patient vitals.

Table 2 : Comparison of Existing EHR system and SIOTEHR

VI. CONCLUSION

Our novel approach is definitely going to majorly assist the IoTEHR world. SIoTEHR gives a secure version of EHR system by using Blockchain technology. The patient's medical record can be accessed instantly .The study reveals that the system will be secure and transparent. Doctor's can see the patient instantaneous IoT data all time and in case if the patient is going in an emergency condition, the treatment can be suggested instant. Implementation of this in the real world will be however challenging. The resources required for the blockchain implementation lead to increase in the cost of the system. Integrating IoT device is also challenging as most of the IoT devices need vendor permission to link with any network. But the study shows if successfully implemented it can revolutionalize the medical record handling system.

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