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Securing Hospital Data: Blockchain-Enhanced Electronic Health Record Solutions

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Abstract

Managing electronic health records (EHRs) within hospitals presents significant challenges, particularly in ensuring the security, privacy, and accessibility of sensitive patient data. Traditional systems are often vulnerable to breaches and inefficiencies, demanding the need for exploration of innovative technologies. This paper proposes a blockchain-based electronic health records (BbEHR) system utilizing the Ethereum blockchain and Flutter framework to create a decentralized, immutable, and tamper-proof platform for hospital management. The Ethereum blockchain's smart contract functionality provides secure storage and guarantees data integrity, while the Flutter framework enables the development of responsive and visually appealing user interfaces across multiple devices. This decentralized approach enhances data privacy, accessibility, and system resilience against failures, offering a transformative solution for EHR management. The proposed system has the potential to secure healthcare data management by providing a secure, efficient, and user-friendly platform that meets the stringent requirements of modern healthcare institutions, adding the fact that introducing a BbEHR would minimize the danger of manipulating patient data due to its decentralized structure including unique cryptography methods for reaching consensus in each block of the chain.

1 Introduction

More hospitals and health centers are offering healthcare services because medical care is becoming more specialized, and patients can travel more easily for treatment (Andritsos et al., 2014). The doctor may make precise decisions regarding the patient's condition and course of treatment when he or she knows a patient's medical history. The healthcare industry's primary challenge is how clinical data could be shared with other healthcare facilities to ensure patient privacy, data integrity, and confidentiality.

An electronic record of a patient's medical information is known as an EHR (as shown in Figure 1). EHR is currently used to share patients' medical records between different hospitals. Electronic Medical Records (EMRs) comprise EHRs (Dubovitskaya et al., 2020).

The EHR, defined by (Iakovidis, 1998), is "digitally stored healthcare information about an individual's lifetime to support continuity of care, education, and research, and ensuring confidentiality at all times." It consists of different features, as depicted in Figure 1.

A patient's medical diagnoses, allergies, history, current treatments, and lab results are all included in an EHR (Shi et al., 2020). Machine Learning (ML) and data analysis can use the abundance of data in EHR.

Fast Interoperability Resources The health information technology standards that are part of the EHR to transmit medical data from various applications used by different healthcare providers are “Fast Healthcare Interoperability Resources (FHIR) and Health Level 7”, respectively. The other models for exchanging medical data between healthcare professionals are Push, Pull, and View.

Push – The medical data is sent from one healthcare provider to another, and no third party can view the exchange.

Pull – A healthcare provider may request medical data from another healthcare provider.

View – From the patient's record at another healthcare organization, one can view the patient's medical information (Lippman et al., 2022).

The U.S. uses a protected email standard called Direct for the encrypted transfer between sender and receiver. Data integrity is not guaranteed from when the data is created until it is used. It is acknowledged that the sender made an exact payload, and the receiver ingested it precisely. It is completed without using a typical audit trail (Lippman et al., 2022).

Blockchains are decentralized systems used in several sectors, such as the Internet of Things (IoT), supply chain management (SCM), logistics, and finance applications (Beck, 2018). Blockchain is a secure system that stores data in a decentralized way, allowing users to access information without revealing their identity to unauthorized parties (Andritsos et al., 2014). It's incredibly efficient when several users need access to the same database. Because of this, time and money may be saved if you use cryptographically secured access to the same database. The authorized Hyper Ledger Fabric blockchain system provides support to maintain the trust of network participants through the use of Membership Service Provider (MSPs) and Certificate Authority (CAs). There is a need for systems to store and exchange medical data.

With blockchain in health care, increased security measures can be achieved due to possible security risks and data leakage linked to shared and stored healthcare information. Smart contracts are used in the field of blockchain technology to allow for special features to be added between identities within a system. Blockchain can ensure the security of patients' private and health information, which may be accessed and edited through authorized identities if backed by intelligent contracts (Tanwar et al., 2020). This enhanced security feature of blockchain in healthcare helps to protect against unauthorized access, data breaches, and data tampering, mitigating the risks of data leakage and ensuring the confidentiality and integrity of patient information (Tanwar et al., 2020).

In practical terms, users in the Ethereum network are not required to create new code each time they wish to initiate a computation on the Ethereum Virtual Machine (EVM). Instead, developers can upload reusable sections of code called smart contracts to the EVM's state. These smart contracts contain predefined logic that can be executed with different parameters as requested by users. This approach allows for efficient and flexible execution of computations within the Ethereum network without the need for repetitive code creation. [24]

A smart contract can be likened to a script, akin to a vending machine, that carries out actions or computations when triggered with specific parameters and conditions fulfilled. For instance, a basic smart contract for vending could generate and transfer ownership of a digital asset when the caller sends ETH to a designated recipient.

Sepolia, which was established in October 2021 by core developers of Ethereum, serves as a testnet aimed at providing developers with a simulated environment to test their applications and smart contracts before deploying them on the live Ethereum mainnet.

Testnets, including Sepolia, replicate the operating conditions of the mainnet but exist on a separate ledger. They allow developers to experiment and test their code without risking real money or assets. Sepolia was specifically designed to simulate harsh network conditions and offers faster transaction confirmation times, providing developers with quicker feedback on their tests.

Consequently, it becomes clear that the need to build confidence in patients' personal data security and privacy is made even more pressing by a shared way of information sharing and storage. In addition, such a system allows all interested parties to understand each other's transactions and interactions in complete detail, thereby ensuring transparency and accountability. By coupling blockchain technology with its inherent features of distributed and immutable ledger, smart contracts, and transparency, a robust and secure framework can be established for managing EHR in a hospital management setting. This decentralized approach enhances data security, privacy, and trust among stakeholders, including patients, healthcare providers, and other authorized entities, fostering a more efficient and secure healthcare ecosystem (Kumar et al., 2018).

The identity management of health entities is password-based, involving the exchange and storage of shared secrets in an insecure system. Unfortunately, there are no audit trails to track data access, and some hospitals rely on paper-based medical records (Kumar et al., 2018). The current medical data management system leaves the patient's long-term health records fragmented and almost impossible to obtain. Ensure patients can securely access all service providers' health/medical records. It helps them see their complete medical history in one place.

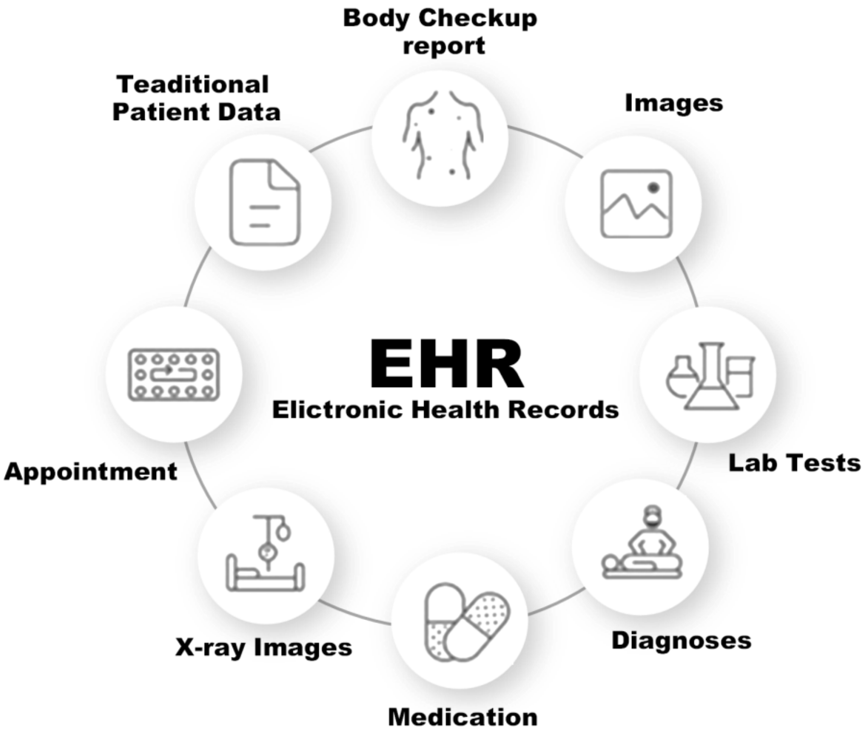

Figure 1: **Electronic Health Record**
Source: own illustration

2 Literature Review

EHRs are digital records of patient’s medical information stored and managed by healthcare providers. The traditional paper-based approach to medical records is time-consuming, error-prone, and often results in fragmented records that are difficult to manage. The adoption of EHRs has significantly improved the quality and efficiency of healthcare delivery by providing a unified and accessible record of a patient's medical history.

However, managing EHRs in hospitals still faces several challenges, including security, privacy, and interoperability. Medical records contain sensitive information that needs to be protected from unauthorized access and tampering. Additionally, the lack of standardization and interoperability between EHR systems makes sharing medical data with healthcare providers challenging.

Blockchain technology provides a potential solution to these challenges by offering a decentralized and secure way of storing and sharing medical records. By utilizing a blockchain-based EHR system, hospitals can ensure that medical records are tamper-proof and can only be accessed by authorized parties. Moreover, blockchain-based EHR systems can enable seamless interoperability between healthcare providers by creating a unified and decentralized platform for medical data (Dubovitskaya et al., 2020).

The hospital's financial, administrative, and clinical areas should be organized using a Hospital Information System (HIS), a comprehensive, homogenized information system. HISs were developed to raise the standard of public healthcare, notably in terms of personal experience, documentation, and records management (Rai, 2022).

Tanwar, Parekha, and Evans (Tanwar et al., 2020) highlight the transformative potential of blockchain technology in healthcare systems, focusing on electronic healthcare record systems for healthcare 4.0 applications. They discuss frameworks like Hyperledger Fabric, Composer, Docker Container, Hyperledger Caliper, and Wireshark capture engine for evaluating blockchain-based healthcare system performance. The authors introduce an Access Control Policy Algorithm to enhance data accessibility among healthcare providers and present a simulation of a chain code-based electronic healthcare record-sharing system. Tanwar, Parekha, and Evans (Tanwar et al., 2020) provide an overview of the evolution of healthcare systems, ranging from Healthcare 1.0 to Healthcare 4.0. Healthcare 4.0 integrates smart technologies, such as cloud computing, big data analytics, Artificial Intelligence (AI), and Machine Learning (ML), to facilitate personalized and real-time healthcare. They highlight the vital role of blockchain technology in enabling real-time access to patient clinical data and fostering collaboration and convergence in the healthcare industry (Tanwar et al., 2020).

Rai (2022) highlights the importance of data sharing in healthcare systems to enhance their intelligence and service quality and puts forth the concept of Patient-Controlled Blockchain-Enabled Electronic Health Records (PcBEHR). This innovative solution offers patients decentralized, immutable, transparent, traceable, and trustworthy control over their medical data. By utilizing blockchain technology, specifically Ethereum, and decentralized Interplanetary File Storage (IPFS), PcBEHR ensures secure data management. Intelligent contracts are employed to establish secure ownership and regulate access control. The author emphasizes the need for patient-controlled mechanisms in healthcare, considering the sensitivity and privacy concerns associated with healthcare data. Rai points out the limitations of existing solutions, such as intelligent cards and web-based healthcare systems, which lack robust privacy preservation and data access control.

The novel contributions of this work include the proposal of a patient-controlled blockchain-enabled architecture suitable for healthcare information systems. The framework addresses critical issues related to privacy, information security, and authentication within EHRs. By storing encrypted healthcare records on the blockchain and utilizing smart contracts, data integrity can be verified, eliminating the need for a central authority. This approach offers enhanced security through an immutable ledger.

Rahul Joharia, Vivek Kumar, Kalpana Gupta, and Deo Prakash Vidyarthi (Johari et al., 2022) present a meticulous exploration of implementing blockchain technology in the healthcare sector to enhance the security of EMRs within Hospital Management System (HMS). Their innovative system, “Medichain”, integrates essential blockchain functionalities to ensure the confidentiality and integrity of patient data. Within Medichain, patient details are stored in blocks within the blockchain, while users can securely upload records as JSON files onto the decentralized network.

The research highlights the potential of blockchain technology in transforming the healthcare industry by providing secure and efficient storage of medical records. By leveraging blockchain, the industry can address the growing data needs and improve record tracking, analysis, and overall healthcare outcomes.

The authors propose a basic blockchain algorithm, simulated using Python, incorporating cryptographic hash, proof of work, and Merkle tree formulation. The simulation results validate the effectiveness and viability of their approach, showcasing positive and encouraging outcomes.

Key features of the proposed system include the use of blockchain as a clinical data repository, immutable patient log creation using a Modified Merkle Tree data structure for secure storage and rapid access to health records, and the ability to update medical records and exchange health information between different providers. The system also ensures high security and integrity through cryptographic hash functions.

Pravin Pawar, Neeraj Parolia, Sameer Shinde, Thierry Oscar Edoh, and Madhusudan Singh, (Pawar et al., 2022) propose the eHealthChain system as a solution that provides complete control to users in terms of acquisition, sharing, and self-management of personal health data. The transition from a traditional hospital-centric model to an individual-centric model in healthcare, where personalized services are provided to the general population. The authors emphasize the importance of Personal Health Information Management Systems (PHIMS) in supporting data acquisition, storage, organization, integration, and privacy-sensitive retrieval. They discuss the design principles necessary for a PHIMS, including privacy-aware health information sharing, individual information control, integration of data from multiple medical IoT devices, health information security, and flexibility.

Blockchain technology is a lucrative option for implementing PHIMS because it includes chronological and time-stamped data records, auditable and cryptographically sealed information blocks, consensus-based transactions, and distributed ledgers. The eHealthChain architecture consists of four layers: a blockchain layer for hosting a blockchain database, an IoT device layer for obtaining health data, an application layer for facilitating data sharing, and an adapter layer that interfaces the blockchain with the application layer. eHealthChain gives users control over their health data and enables secure acquisition, management, and sharing of health information.

Dwivedi, Kumar, Amin, Lazarus, and Pandi (Dwivedi et al., 2022) present a blockchain-based EMR system with smart contracts and a consensus algorithm in a cloud environment. The authors address the limitations of traditional EMR systems, which store patient information in a centralized database, resulting in data security, privacy, and sharing difficulties. With its “write-once-read-only” principle, blockchain technology offers a decentralized solution to these challenges by arranging information in blocks and linking them together using hash values.

The motivation behind their work stems from the need to address the pitfalls of traditional EMR systems, including single-point failure, inadequate security and privacy measures, provider-centric approach, and data-sharing challenges. By integrating blockchain technology, the authors aim to achieve decentralized storage, enhanced security and privacy, patient-centric data sharing, and compatibility with IoT-based smart devices.

The significant contributions include an extensive literature review of blockchain-based EMR systems, a proposed framework for an EMR system using blockchain technology, an intelligent contract algorithm based on a finite state machine, a consensus algorithm for validating new blocks, and the identification of future research challenges related to security.

Table 1: Literature Review and Limitations

Ref	Title	Objective	Drawbacks
(Johari et al., 2022)	BLOSOM: BLOck-chain technology for the Security of Medical records	Proposal of Medichain, a blockchain container-based framework for securing medical records. Simulated blockchain algorithm using Python. Focuses on transforming the healthcare industry by improving record tracking, analysis, and outcomes.	Limited scalability and performance testing

(Tanwar et al., 2020)	Blockchain-based electronic healthcare record system for healthcare 4.0 applications	Explores frameworks and tools for measuring the performance of blockchain-based healthcare systems. Proposes Access Control Policy Algorithm for data accessibility. Highlights the role of blockchain in enabling real-time access to patient clinical data and fostering collaboration in healthcare.	Limited empirical validation and scalability assessment
(Dwivedi et al., 2022)	Blockchain-Based Electronic Medical Records System with Smart Contract and Consensus Algorithm in Cloud Environment	Addresses limitations of traditional EMR systems with centralized storage. Proposes blockchain-based EMR system with smart contracts and consensus algorithm. Focuses on decentralized storage, enhanced security and privacy, patient-centric data sharing, and IoT compatibility.	Lack of real-world implementation and comprehensive performance evaluation
(Habib, 2010) and (Kierkegaard, 2011)	A Novel Blockchain-Based Electronic Health Record Automation System for Healthcare	Introduces a blockchain-based system for EHR automation. Addresses fragmented health records and data accessibility challenges. Utilizes blockchain as a clinical data repository and Modified Merkle Tree for secure storage. Demonstrates improved system throughput and reduced latency.	Limited external validation and long-term scalability assessment
(Pawar et al., 2022)	eHealthChain – a blockchain-based personal health information management system	Proposes an eHealthChain system for managing personal health information from medical institutions. Utilizes Ethereum blockchain, IPFS, and smart contracts. Enables secure sharing and revocation of medical data. Highlights benefits of decentralized control and interoperability.	Limited real-world deployment and validation in diverse healthcare environments, scalability concerns, and performance testing

Source: own table

3 Methology

The conceptual framework for the BbEHR system for hospital management encompasses a comprehensive set of state-of-the-art technologies to ensure robust data protection, confidentiality, and seamless exchange of information. Integrating these advanced technologies into the system is pivotal in safeguarding patient information, establishing trust, and streamlining processes. Continued exploration and progress in these domains can result in ongoing innovations in blockchain-based electronic health record systems, presenting enhanced approaches for secure and streamlined healthcare data management.

3.1 Working Flowchart

Start: The process begins when a patient arrives at the healthcare facility.

Patient Log In: The patient logs into the system, which could involve registering their details or verifying their identity in the EHR system. This information is securely recorded on the blockchain to ensure data integrity.

Record Queue: The patient's details are placed in a queue to be processed. In a blockchain-based system, this could involve adding the patient's visit to the decentralized ledger, ensuring the data is immutable and accessible only to authorized personnel.

Pick-Up: The system checks whether the patient's records or lab results are ready for collection. If they are not ready ("NO" branch), the process loops back to the "Record Queue" step. This could involve waiting for the blockchain to validate and store the required information.

Consultation With Doctor: Once the records are ready, the patient proceeds to consult with a doctor. The doctor accesses the patient's records from the blockchain, ensuring that the information is up-to-date and tamper-proof.

Need Test?: After consultation, the doctor decides if the patient needs further tests. If "Yes", the patient is directed to the laboratory. If "No", the process ends here, and the patient's visit is concluded, with all interactions securely recorded on the blockchain.

Laboratory: The patient undergoes the necessary tests. The test results are added to the blockchain, ensuring they are securely stored and accessible only to authorized users.

Paid and Tested: The patient completes the payment and testing process. The blockchain system can record the payment details and ensure that all transactions are transparent and immutable.

End: The process concludes after the patient has completed all necessary steps, with all data securely recorded in the blockchain-based EHR system, ensuring the integrity and security of the patient's health records.

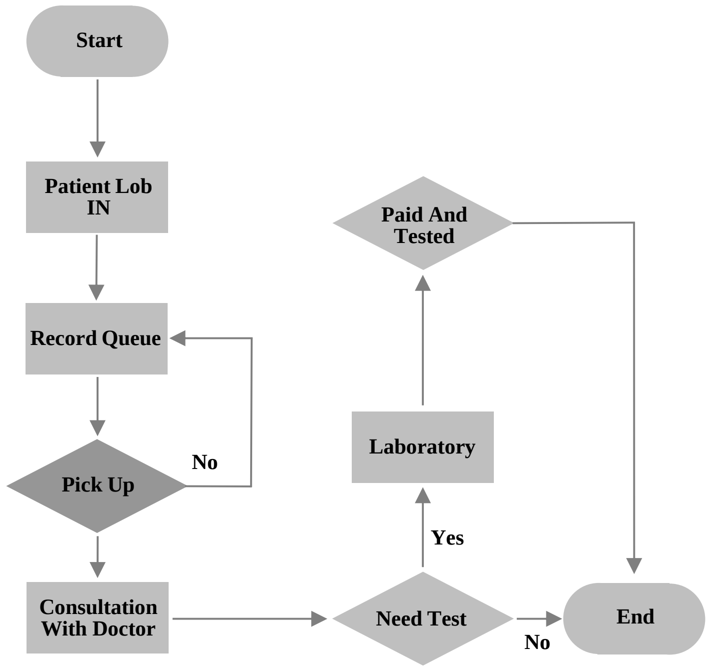

Figure 2: **Working Flowchart of BbEHR**
Source: own illustration

Patient

- The patient is the primary user who interacts with the system through a Mobile Application (APP). This app allows the patient to log in, access their health records, schedule appointments, and view test results.
- **Flow:** The patient uses the APP to interact with the HMS, which in turn interacts with the BbEHR to securely manage the patient's health data.

APP

- The APP serves as the interface for patients to engage with the healthcare system. Through the app, patients can:
  - View their EHR data.
  - Book appointments with doctors.
  - Receive notifications regarding lab results or prescriptions.
- **Flow:** The APP communicates with the HMS, which handles the backend processes and integrates with the EHR on the blockchain for secure data handling.

HMS

- The HMS is the central system that manages hospital operations, including patient records, appointments, billing, and interactions with healthcare professionals.
- **Flow:** The HMS coordinates between the patient's APP, the EHR stored on the blockchain, doctors, labs, and pharmacies. It ensures that all actions taken (e.g., patient record updates, test orders) are reflected in the blockchain to maintain data integrity and security.

EHR

- The EHR represents the patient's health records, stored securely on the blockchain. It contains medical history, lab results, prescriptions, and other critical health data.
- **Flow:** The EHR on the blockchain ensures that all data is immutable, traceable, and securely accessible by authorized entities (like doctors and labs) via the HMS.

Blockchain

- The blockchain is the underlying technology ensuring the security, immutability, and decentralization of the EHR data. Each transaction (e.g., a new entry in a patient’s record) is recorded on the blockchain, making it tamper-proof.
- **Flow:** All updates to the EHR, whether initiated by the HMS, doctor, or lab, are recorded on the blockchain, ensuring that the data remains secure and unalterable.

Doctor

- Doctors access the EHR through the HMS to review patient records, update diagnoses, and prescribe medications. Their actions are logged on the blockchain to maintain an accurate history of patient care.
- **Flow:** The doctor’s interactions with the patient’s health data are routed through the HMS to the blockchain, ensuring that all updates are securely stored and accessible.

Laboratory

- Laboratories conduct tests and upload results to the EHR via the HMS. These results are stored on the blockchain to ensure they are securely maintained and accessible only by authorized users.
- **Flow:** Laboratory results are added to the patient’s EHR on the blockchain, allowing doctors and patients to securely access the information.

Pharmacy

- The pharmacy fills prescriptions issued by doctors. While not directly interacting with the blockchain, the pharmacy relies on the accurate and up-to-date information provided by the EHR to ensure the correct medication is dispensed.
- **Flow:** The doctor’s prescriptions, recorded in the EHR, guide the pharmacy in providing the correct medication to the patient.

The overall process of a user-controlled BbEHR is summarized in the figure. 3, as well as in Figure 4. i.e., Structural embedding of a patient controllable BbEHR within a HMS. (or HIS as defined previously, where is the difference to HMS by the way, HMS is part of the overall HIS but for management purposes).

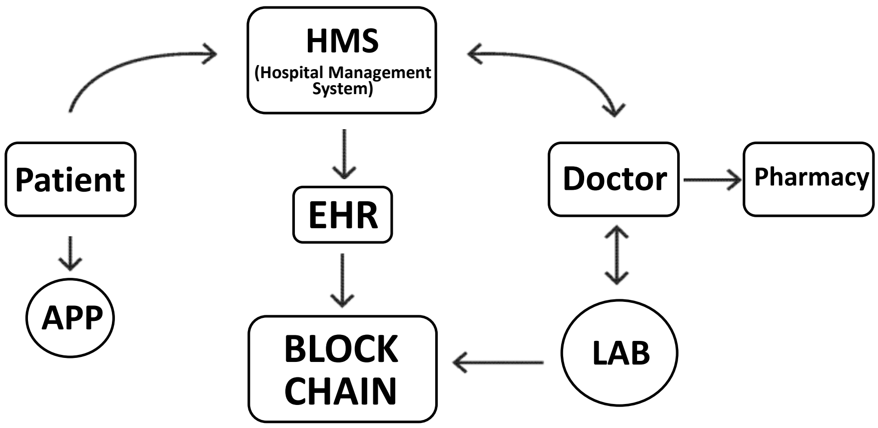

Figure 3: **Hospital Management System**
Source: own illustration

3.2 Key Components and Functionalities of the Smart Contract

Structs

Patients: Stores patient details such as Computerized National Identity Card (CNIC), name, phone, gender, Date of Birth (DOB), height, weight, blood group, allergies, medication, address, and creation date.

Doctors: Stores doctor details such as CNIC, name, phone, gender, DOB, qualification, specialization, address, and creation date.

Labs: Stores lab details, including name, phone, location, address, and creation date.

Appointments: Stores appointment details, including doctor and patient addresses, date, time, prescription, description, diagnosis, status, and creation date.

LabRecords: Stores lab record details, including lab and patient addresses, date, time, report, description, and creation date.

Storage

Various dynamic arrays store the addresses of patients, doctors, labs, appointments, and lab records. Mapping is used to associate addresses with their respective struct instances. Mapping is approved and is used to store permission status between record owners and doctors/labs.

Constructor

Sets the contract deployer (owner) as the initial value.

Patient-related Functions

setPatientDetails: Allows patients to set their demographic and medical details.

editPatientDetails: Allows patients to edit their existing records.

Doctor-related Functions

setDoctor: Allows doctors to set their profile details.

editDoctor: Allows doctors to edit their existing profile.

Lab-related Functions

setLab: Allows labs to set their details.

editLab: Allows labs to edit their existing details.

Appointment-related Functions

setAppointment: Allows doctors to set appointment details for a patient.

updateAppointment: Allows doctors to update existing appointment details.

Lab record-related Functions

setLabRecord: Allows labs to set lab record details for a patient.

updateLabRecord: Allows labs to update existing lab record details.

Permission Management Functions

givePermission: Allows record owners to permit doctors/labs to access and add records.

RevokePermission: Allows record owners to revoke the permission granted to doctors/labs.

Search Functions

searchPatientDemographic: Allows authorized users to search and retrieve patient demographic details.

searchPatientMedical: Allows authorized users to search and retrieve patient medical details.

searchDoctor: Allows authorized users to search and retrieve doctor details.

searchLab: Allows authorized users to search and retrieve lab details.

searchAppointment: Allows authorized users to search and retrieve appointment details.

searchLabRecord: Allows authorized users to search and retrieve lab record details.

Count Functions

getPatientCount: Retrieves the total count of registered patients.

getDoctorCount: Retrieves the total count of registered doctors.

getLabCount: Retrieves the total count of registered labs.

getLabRecordCount: Retrieves the total count of lab records.

getAppointmentCount: Retrieves the total count of appointments.

getPermissionGrantedCount: Retrieves the total count of granted permissions.

Helper Functions

getAppointmentPerPatient: Retrieves the count of appointments for a specific patient.

getLabRecordPerPatient: Retrieves the count of lab records for a specific patient.

The contract provides a secure way to store and manage EHR on the Ethereum blockchain, ensuring privacy and accessibility for authorized individuals.

4 Results

4.1 Data Integrity and Immutability

The system ensures each EHR record is cryptographically hashed and stored on the blockchain, making them immutable.
The decentralized nature of the blockchain guarantees that records cannot be altered or deleted.

4.2 Security and Access Control

The system enforces strict access control, allowing only authorized entities to access or modify patient records.

4.3 System Performance and Scalability

The system efficiently processes transactions and stores data using a combination of Ethereum blockchain and smart contracts.
The architecture supports scalability, though performance under high load may require optimization.

4.4 Privacy and Confidentiality

All patient information on the blockchain is encrypted, ensuring confidentiality.
The system manages patient consent, sharing data only according to patient permissions.

5 Conclusion and Future Scope

5.1 Conclusion

In conclusion, our proposed BbEHR system, leveraging the Ethereum blockchain, Flutter framework, and IPFS, offers a resilient and effective solution for hospitals to manage EHR. The use of the Ethereum blockchain ensures data integrity and immutability through smart contracts, while the Flutter framework provides a user-friendly and visually appealing interface across multiple platforms.

5.2 Future Scopes of the Work

The future scope of our proposed system is promising. As blockchain technology continues to evolve and gain wider adoption in various industries, including healthcare, there are potential opportunities for further advancements in the field of EHR management. Some potential future directions for research and development in this area include:

- **Interoperability:** Further exploration of how blockchain technology can facilitate interoperability among different EHR systems, allowing for seamless exchange of data between healthcare institutions and providers.
- **Data privacy and consent management:** Investigating how blockchain can enhance patient consent management and ensure data privacy gives patients more control over their health data and improves trust in the system.
- **Scalability:** Exploring solutions to address the scalability challenges of blockchain technology, as large-scale adoption of EHR systems in hospitals would require efficient handling of a substantial amount of data.
- **Security:** Continuously strengthening the security protocols of the BbEHR system to safeguard against potential threats and vulnerabilities, ensuring robust protection of sensitive data.
- **User experience and adoption:** Conduct user studies to assess the usability, acceptance, and implementation of the proposed system among healthcare practitioners, patients, and relevant stakeholders, and integrate essential improvements based on valuable feedback.

5.3 Limitations of Blockchain Approaches

1. **Energy Consumption:**
   - Blockchain networks, particularly those using proof-of-work mechanisms, consume significant energy, raising sustainability concerns.
2. **Implementation Issues:**
   - Integrating blockchain technology into existing HIS can be challenging, especially in legacy systems that may not support modern technologies.
   - Training staff on blockchain technology can be time-consuming and resource-intensive.
3. **Cost Considerations:**
   - The initial cost of implementing blockchain solutions can be high, including software development, hardware upgrades, and ongoing maintenance.
4. **Scalability:**
   - Many blockchain networks struggle with scalability, leading to slow transaction times as user demand increases.
5. **External Audits:**
   - Ensuring compliance with regulatory standards and conducting external audits can be complex due to the decentralized nature of blockchain, which may lead to challenges in accountability.

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