Transforming Child Health Records: Integrating Blockchain, NFTs, and IPFS for Enhanced Medical Data Management

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Abstract. In the rapidly evolving landscape of medical record management, the traditional methods often grapple with issues related to data security, integrity, and accessibility. This paper introduces a groundbreaking approach to pediatric medical data management by leveraging the robust capabilities of blockchain, Non-Fungible Tokens (NFTs), InterPlanetary File System (IPFS), and distributed ledgers. Our proposed model meticulously addresses the limitations of the conventional systems by ensuring data immutability, transparency, and decentralized control. Starting with the creation of a unique Global ID for children, we outline a detailed 10-step approach to data storage, query, and update, emphasizing the pivotal roles of smart contracts and NFTs in guaranteeing data authenticity and uniqueness. The implementation section delves deeper into the intricacies of transaction creation, data query, and update mechanisms, underscoring the importance of secure interfaces, rigorous verification processes, and seamless synchronization with decentralized storage solutions. With the confluence of these advanced technologies, our approach promises a transformative shift in pediatric healthcare, simplifying processes for healthcare professionals and ensuring data security and privacy for patients.

Keywords: Pediatric Healthcare · Blockchain · Data Management · Electronic Health Records (EHRs) · Non-Fungible Tokens (NFTs) · InterPlanetary File System (IPFS) · Decentralized Storage · Smart Contracts

1 Introduction

The landscape of healthcare is undergoing a digital transformation, further emphasized by the nuanced requirements of pediatric care. Conventional medical data management approaches, although functional, present gaps in data security,

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interoperability, and accessibility, which are critical in pediatric settings [4,25]. The emergence of innovative technologies like the Internet of Healthcare Things (IoHT), or decentralized architectures promises a sea change in the realm of healthcare data management [14,23].

IoHT has been a pivotal addition to the healthcare ecosystem, offering microservice and brokerless architectures to streamline healthcare processes (e.g., [13]). Yet, despite the influx of technologies, challenges persist in pediatric healthcare, where data sensitivity is even more pronounced. For example, the application of Electronic Health Records (EHRs) has resulted in some improvements, like better screening for children with diabetes [2], but also demonstrated limitations, such as ineffective body mass index assessments [17].

While Electronic Health Records (EHRs) offer myriad benefits for pediatric care, existing systems confront a series of challenges [22,24]. A centralized EHR infrastructure is susceptible to data security issues, unauthorized access, and potential alterations [19]. Moreover, inconsistent interoperability across EHR platforms complicates the fluid exchange of medical data, raising concerns about data accuracy and consistency [20]. To mitigate these shortcomings, emerging technologies like blockchain are being explored as transformative tools in healthcare data management [9]. Blockchain's decentralized nature eliminates single points of vulnerability and ensures data integrity through cryptographic mechanisms [5,21]. Smart contracts enable standardized protocols for data exchange, enhancing the system's interoperability [7].

Beyond blockchain's foundational benefits, additional mechanisms like off-chain storage strategies can improve efficiency, allowing the bulk of child health records to be stored separately from the verification data [12]. Furthermore, the utilization of Non-Fungible Tokens (NFTs) allows for the unique representation of each child's medical history, empowering parents or guardians with greater control over data access and usage. Besides, the InterPlanetary File System (IPFS) augments this setup by providing a decentralized data storage system, enhancing both data availability and resilience [11]. In conjunction, NFTs and IPFS offer an unprecedented strategy for child medical data management, combining data authenticity with robust availability.

Among the significant contributions of our paper, the most prominent is the introduction of a comprehensive blockchain-based framework tailored to pediatric healthcare. This framework securely captures, stores, and facilitates the effortless retrieval of children's medical records, adding a new dimension to data management in pediatric care [10]. We also employ Non-Fungible Tokens (NFTs) to individualize each child's medical records, thereby enhancing transparency and allowing stakeholders to validate the origin and integrity of the data [15]. Our paper furthers the discourse by integrating the InterPlanetary File System (IPFS) to ensure consistent availability of these critical child health records, even in cases of network fragmentation. This innovation augments collaborative healthcare efforts by ensuring data availability across various stakeholders [6].

Importantly, our contributions are not merely theoretical constructs. We have implemented and rigorously tested the proposed framework across diverse blockchain platforms, establishing the system's flexibility and applicability across different infrastructures [18]. Lastly, we extend the functionality of our system by incorporating Pinata, an IPFS-based platform, for persistent decentralized data storage. This serves to fortify the data against risks associated with centralized points of failure, further substantiating the resilience of our approach [11].

2 Related Work

2.1 Electronic Health Records in Pediatric Healthcare

Advancements in digital health technology have had a transformative impact on pediatric care. Telehealth solutions, for instance, have become instrumental in overcoming geographical barriers to healthcare. Van Cleave et al. [25] emphasized the importance of telehealth, especially for children with special healthcare needs residing in isolated locations, which traditionally suffer from limited healthcare access.

Electronic Medical Records (EMRs) have also shown promise in enhancing the efficacy of pediatric healthcare systems. Choudhary et al. [2] demonstrated the role of EMRs in facilitating better adherence to diabetes screening guidelines, which is particularly crucial for childhood diabetes management. However, the use of EMRs is not devoid of challenges, particularly when it comes to vulnerable pediatric populations such as children in foster care. Deans et al. [4] cautioned against relying solely on EHRs, advocating instead for an integrated system that combines electronic health records with child welfare systems to capture a more holistic view of the child's health and well-being.

Strategic interventions using EMRs can lead to immediate and significant healthcare improvements. For example, Crosby et al. [3] employed EMRs to implement home pain management plans for children with sickle cell disease. Their approach led to a noticeable decrease in emergency department visits, underscoring the potential for EHR systems to bring about positive change in patient outcomes.

In the realm of data access and stakeholder experiences, Hagström et al. [8] delved into the nuanced dynamics of allowing adolescent and parental access to Pediatric Electronic Health Records (PAEHRs). They found a complex array of divergent opinions, emphasizing the need to balance transparency with the preservation of adolescent confidentiality.

2.2 Advancements and Challenges of EHRs in Pediatric Care

Electronic Health Records (EHRs) are gradually becoming the backbone of modern pediatric care, offering numerous advantages such as increased efficiency and enhanced patient care. Al-Shammari et al. [1] studied the implementation of an EHR system in a Pediatric Intensive Care Unit (PICU), revealing not only an increase in efficiency but also a positive attitude among healthcare providers towards adopting this technology.

However, it's not enough to simply integrate technology; it must also translate to effective clinical practices. For instance, Shaikh et al. [17] reported that merely incorporating automatic Body Mass Index (BMI) calculations into EHRs did not significantly improve weight assessments or nutritional counseling for children and adolescents. This observation points to the need for thoughtful design and implementation strategies that extend beyond simple technology adoption.

Promisingly, targeted modifications in EHR systems can have powerful effects. Saylam et al. [16] implemented an EHR alert for pediatric migraine patients to assess sleep quality using the Child and Adolescent Sleep Checklist (CASC). This change led to a marked improvement in identifying children with suboptimal sleep habits, showcasing the potential of intelligent EHR design to positively impact patient care.

3 Methodology

3.1 Traditional Model for Pediatric Healthcare

Traditional Model's Components. The classic model for the healthcare of children involves an intricate interplay of several key elements: physicians, comprehensive medical records, the children themselves, their parents or guardians, and auxiliary services like pharmacies and diagnostic centers. For an exhaustive visual representation, refer to Fig. 1.

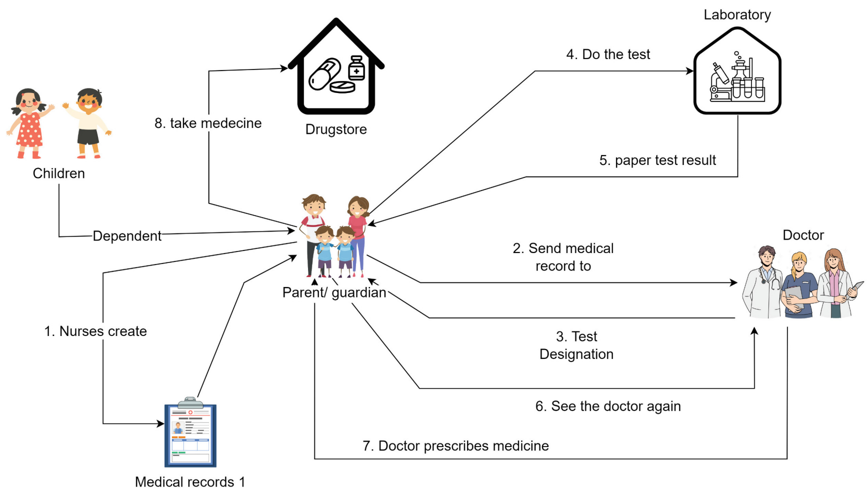


Fig. 1. Classic model for pediatric healthcare

1) Doctor: The doctor stands as an indispensable figure in the healthcare ecosystem, responsible for the initial examination, ongoing care, and medical record creation for children. **2) Medical Records:** Acting as a vital repository, medical records collate comprehensive information regarding a child's health history, diagnosis, test results, and prescribed treatments. These records are managed and updated by doctors to sustain the quality of child healthcare. **3) Children:** Within this framework, children are the primary care recipients, largely reliant on adults for navigation through medical procedures, from diagnosis to treatment. **4) Parents or Guardians:** These individuals are not merely custodians but active participants in the healthcare decisions concerning the child, often providing essential background medical history for more informed care. **5) Drugstore:** Pharmacies serve as the transaction point for medicinal needs, facilitating the dispensing of medications as per doctors' prescriptions to parents or guardians. **6) Laboratory:** Diagnostic centers or laboratories perform various tests as needed by the doctor, contributing crucial data that aids in comprehensive health evaluations for children.

Subsequently, we will delve into an in-depth discussion outlining the eight primary activities that define the traditional model of pediatric healthcare.

Traditional Model's Steps **Step 1: Creating a Basic Medical Record.** In this initial step, a nurse sets the stage for the child's medical evaluation by creating a basic paper-based medical record. This contains crucial data such as the child's name, birth date, and contact details. This completed record is then given to the parents or guardians of the child.

Step 2 and Step 3: Doctor's Visit and Examination. Upon receiving the basic medical record, parents or guardians take the child for a medical consultation. During this session, not only is the record presented, but any additional health information like symptoms or behavioral changes are shared. Subsequently, the doctor undertakes a detailed medical examination. This examination may include questioning to understand the child's health better, performing physical checks like measuring temperature and blood pressure, and potentially recommending further diagnostic tests. These recommendations are documented and handed to the parents or guardians.

Step 4 and Step 5: Laboratory Tests and Results. Following the doctor's suggestions, parents or guardians proceed to a medical laboratory. Specialized lab technicians carry out the prescribed tests. Once concluded, the laboratory assembles a complete report of the test findings, usually in a paper-based format, which is provided to the parents or guardians for the next steps in care.

Step 6 and Step 7: Follow-up and Prescriptions. Armed with lab results, the parents or guardians return to the doctor's office. After examining the findings, the doctor might issue prescriptions or recommend further care steps as needed. These prescriptions become a vital element in the child's healthcare and are handed to the parents or guardians.

Step 8: Medication Collection. Lastly, parents or guardians, prescription in hand, head to the pharmacy where the prescribed medications are dispensed by the pharmacy staff. This step completes the current healthcare process for the child, ensuring appropriate treatment is received.

Traditional Model's Limitation. The traditional model of child care has its roots deeply embedded in centralized systems and methodologies. One of its primary limitations is centralized data storage, which presents a single point of failure. If such a system encounters issues, crucial medical records risk being compromised or lost. Additionally, this centralization raises significant data privacy concerns. Unauthorized access or potential data breaches could lay bare sensitive medical records of children. Even if security isn't breached, the data within these systems might be spread across various healthcare providers, leading to potential inconsistencies and fragmentation. Such dispersion often leads to delays, especially when immediate access to medical histories is paramount in emergencies. Furthermore, the traditional model often requires the physical presence of parents or guardians for consultations, medicine collection, or accessing reports, contributing to operational inefficiencies. Lastly, a subtle yet significant concern is the limited ownership parents or guardians have over their child's medical records.

3.2 Innovative Blockchain Model for Child Care

In a bid to surpass the boundaries of conventional child care systems, our strategy employs an amalgamation of state-of-the-art blockchain technologies. As illustrated in Fig. 2, this comprehensive framework encompasses multiple trailblazing components such as the User Interface, Personal Identification Code, Smart Contract, NFT, IPFS, and the Distributed Ledger. These components collectively enhance the security, efficiency, and trustworthiness of child care practices.

Global ID. This unique identifier is assigned to each child's medical record and is closely linked with their parents or guardians, ensuring unparalleled security and privacy. It acts as a failsafe against data duplication or mishandling and facilitates streamlined data access.

System Interface. Designed to cater to medical professionals, this interactive platform serves as a conduit between the user and the blockchain architecture. It's designed for simplicity, allowing doctors to conveniently navigate, update, and engage with a child's medical data.

Smart Contract. Integrating Smart Contracts into our system revolutionizes the way data manipulation and automation are managed. These are automated contracts that govern the maintenance and alteration of medical records. These contracts activate specific actions when pre-defined conditions are met, thereby minimizing manual errors.

NFT (Non-Fungible Token). We utilize NFTs to establish the uniqueness and authentication of each child's medical data. Each record is tied to a specific NFT, ensuring data singularity and inviolability.

IPFS (InterPlanetary File System). To achieve robust data security and availability, our framework leverages IPFS for decentralized storage. It distributes encrypted data blocks across multiple nodes, offering resilience against node failures and unauthorized access.

Distributed Ledger. This serves as the mainstay for data recovery in our system, linking with decentralized platforms like IPFS to guarantee rapid and accurate data access. This ledger acts as a navigator, guiding users to the precise location of a child's medical records within the complex decentralized network.

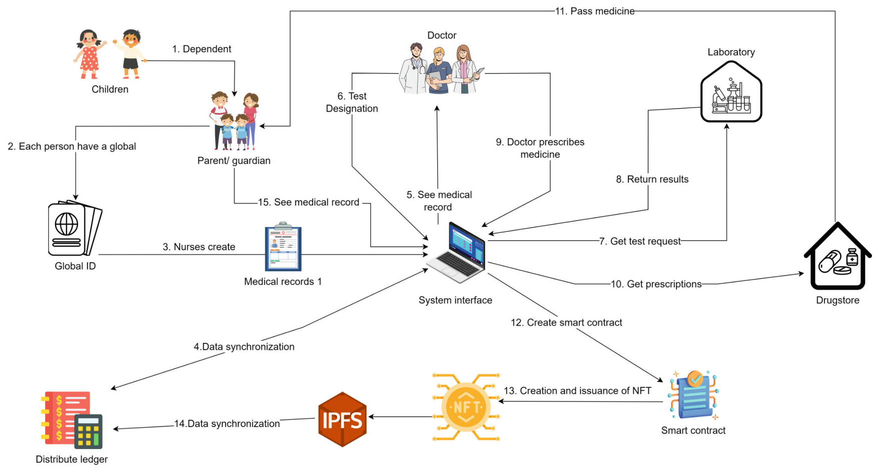


Fig. 2. Innovative Blockchain Model for Child Care

Our groundbreaking methodology for child healthcare is based on a meticulously designed ten-step sequence. This journey starts with the creation of a unique Global ID by the parents or guardians and concludes with them reviewing their child's medical history. It effectively weaves in the roles of nurses, physicians, labs, and pharmacies, all under the aegis of blockchain technology, smart contracts, and IPFS. Our framework's cornerstone is the transparency, integrity, and security of data.

Initialization of Access step: Parents or guardians initialize the process by creating a unique Global ID for their child, serving as the cornerstone for all subsequent system interactions. Upon establishing the Global ID, nurses employ the System Interface to draft the preliminary medical record, documenting key details like the child's name, birth date, and essential contact information (i.e., **Medical Record Initiation**). Once the initial medical record is compiled, smart contracts autonomously incorporate this data into the distributed ledger, which acts as a bulwark against unauthorized access and data alteration - **Integration with Distributed Ledger**.

Doctor's Interface Interaction. Doctors, utilizing the System Interface, not only consult the initial data but also supplement the medical records with diagnostic information, enriching the healthcare narrative for each child.

Diagnostic Recommendations. Where further medical scrutiny is required, doctors can recommend additional tests, which are documented within the dynamic medical record.

Laboratory Involvement. Laboratories interpret the diagnostic requests and, post-examination, update the findings in the system, possibly utilizing IPFS for secure data storage.

Review and Prescription. After evaluating the lab outcomes, doctors prescribe necessary medications or treatment, and this information is securely embedded within the child's healthcare dossier.

Drugstore Engagement. Pharmacies decipher the digital prescriptions, ensuring the exact medications are provided, thereby meeting the child's therapeutic requirements effectively.

Parental Access and Monitoring. Parents or guardians maintain an active role by using a specialized user interface to monitor and manage their child's healthcare journey, thereby ensuring compliance with medical guidelines.

4 Realization of the Framework

The practical deployment of our state-of-the-art child healthcare system rests on the robust execution of three pivotal operations—*transaction origination*, *data retrieval*, and *data modification*. The ensuing discussion provides an in-depth examination of each function's technical architecture, practical implications, and their collective role in enhancing the system's overall efficacy. Through this discussion, we aim to bridge the gap between theoretical excellence and actual benefits realized in a real-world setting.

4.1 Initial Data Entry

The journey commences with a medical doctor, whose expertise sets the groundwork for the child's digital medical portfolio. After conducting a comprehensive evaluation, which includes not only clinical findings but also health history reported by the parents, the doctor decides on the parameters and scope of the medical record to be established.

Next, the System Interface comes into play, serving as an intuitive, user-friendly digital environment engineered specifically for healthcare practitioners. This is where physicians interact with the blockchain, entering, reviewing, and handling medical data in a manner that minimizes the scope for errors and ensures smooth operations.

At this juncture, parents or guardians step in as the key contributors of their child's initial health metrics. This information spans a wide array—from prior

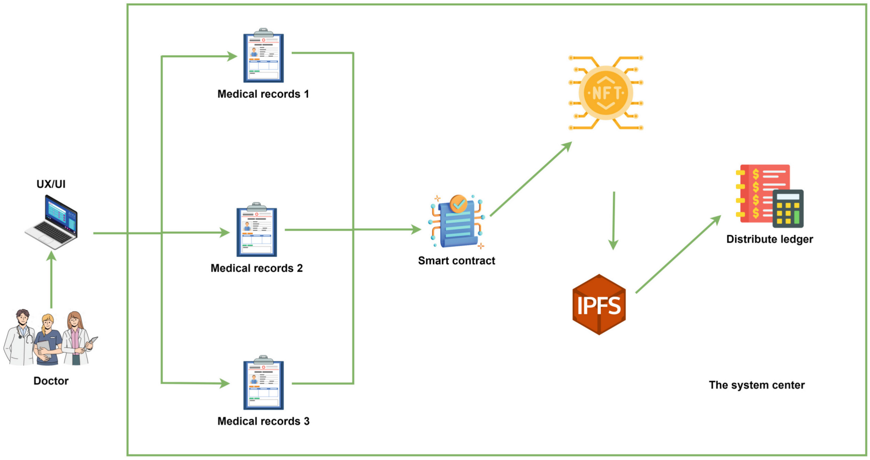


Fig. 3. Initializing Transactions and Data

medical conditions to allergies and genetic factors. After doctor verification, this crucial information is integrated into the blockchain-based system, laying the groundwork for advanced data handling mechanisms (Fig. 3).

This is where Smart Contracts make their entrance. Triggered by the new data entries, they govern the handling, access, and potential modifications of the child's medical data. Programmed to follow explicit rules and guidelines, these contracts add an extra layer of security and operational precision.

Simultaneously, a unique NFT is generated, serving as the cryptographic avatar of the child's health data. Its uniqueness precludes any chance of data collision or unauthorized duplication, thereby elevating the system's data integrity standards.

Moreover, this NFT contains an embedded link that points to the data hosted on the IPFS. Known for its robustness and decentralization, IPFS ensures that the child's medical data remains secure and perpetually accessible, regardless of network conditions or localized technical glitches.

Completing the data management circle is the Distributed Ledger. This blockchain-based ledger works in tandem with IPFS to offer an exhaustive, tamper-proof log of all transactions related to the child's healthcare. Accessible only to verified users, it offers transparency and accountability, enriching the decision-making process at every step of the child's healthcare journey.

4.2 Procedure for Data Retrieval

Data retrieval is a cornerstone activity in our healthcare model, ensuring that healthcare providers can securely and efficiently access a child's medical records. The orchestrated coordination among the user interfaces, smart contracts, and the decentralized IPFS storage forms the backbone of this crucial operation. We

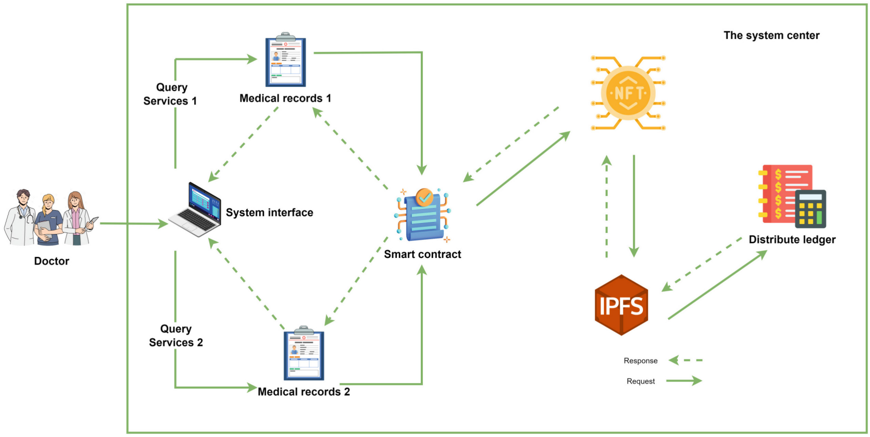


Fig. 4. Process for Data Retrieval

will explore the functioning of the key components involved in this process in the following discussion (Fig. 4).

The initial step for data retrieval takes place through a specialized system interface for medical professionals. This user-friendly platform serves as the nexus where physicians can initiate requests for specific medical records, communicating these requests to the embedded smart contracts. Physicians engage with this interface, equipped with a toolkit designed to facilitate interaction with smart contracts. The pivotal element in this interaction is the child-specific NFT. Physicians utilize this unique cryptographic identifier as the access key for requesting the child's medical details.

The crux of data retrieval lies in the system's processing of the query. Here, smart contracts play an essential role in validating the provided NFT to confirm a physician's authorization to access the specified records. Upon successful verification, the smart contract interfaces with the IPFS storage system. Exploiting IPFS's decentralized architecture, the contract identifies and retrieves the medical data relevant to the physician's request.

The query process reaches its conclusion as the system directs the obtained information back to the requesting physician and updates the distributed ledger. The physician receives the sought-after medical data via the system interface. Simultaneously, to maintain transparency and ensure system robustness, each data retrieval action is meticulously recorded on the distributed ledger. This creates an immutable history, thereby fortifying the system's overall integrity and the security of the child's medical data.

4.3 Data Modification Mechanism

The ongoing management of children's healthcare information necessitates routine updates to the stored records. Whether due to shifts in the child's health status, new medical findings, or supplemental diagnostic tests, ensuring that medical records remain current is critical. This discussion elaborates on the integral components and operations that drive a secure and efficient data modification procedure (Fig. 5).

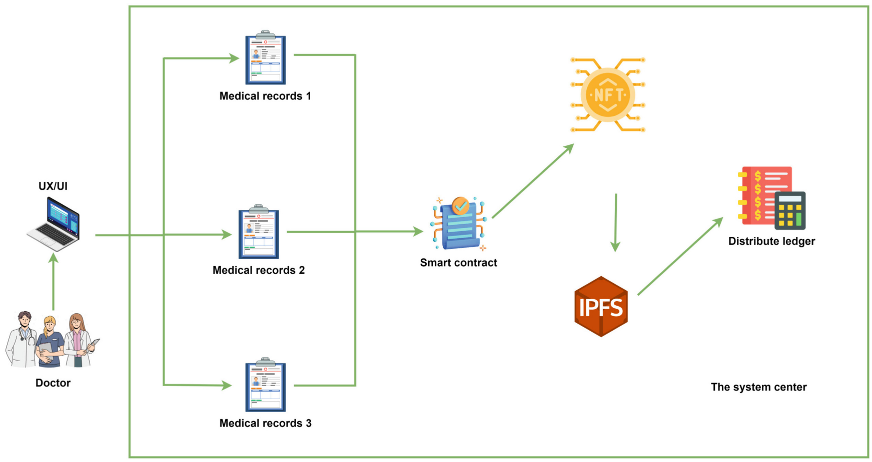


Fig. 5. Procedure for Data Modification

Initiating changes to a child's medical record begins with the physician's engagement with the system interface. The specialized interface, designed for healthcare providers, includes features that facilitate the doctor's ability to adjust or supplement the information within the child's record. Upon confirming the necessary amendments, physicians activate the update instruction, targeting the embedded smart contract and triggering the next steps in the data modification workflow.

Following the issuance of the update command, the system engages in a phase of verification, principally guided by the interactions between the smart contract, NFT, and the IPFS storage. The smart contract, at this juncture, rigorously validates the provided NFT to ascertain the physician's right to modify the data. Once the NFT receives clearance, the smart contract collaborates with the IPFS to fetch the existing version of the medical record set for amendment.

To ensure that the process is both transparent and immutable, a complete log of every update to a child's medical record is maintained. These transaction logs are permanently stored within the distributed ledger, providing an unalterable historical account that upholds both the integrity and the transparency of the modification process.

Beyond simply amending data, the system is ardently designed to safeguard the integrity of the stored medical information. The cornerstone of this protective strategy is a stringent access control, powered by the smart contract, that restricts medical record interactions to only authorized individuals, such as physicians and relevant stakeholders. This multi-layered security architecture serves as an impregnable barrier against unauthorized access or unintended alterations to the records.

This scrupulous data modification scheme is underpinned by the key pillars of blockchain technology, NFTs, IPFS, and the distributed ledger. With blockchain ensuring transaction tracking and authentication, NFTs validating the uniqueness of each record, IPFS supporting decentralized data storage, and the distributed ledger documenting every transaction event, the system guarantees an unmatched level of security, integrity, and efficiency in updating children's medical records.

5 Comprehensive Assessment Methodology

In the rapidly evolving domain of blockchain solutions, multiple platforms with unique attributes and capabilities have come to the forefront. For an exhaustive appraisal of our envisioned model, we elected to implement our smart contracts across four EVM-compatible platforms. Specifically, our selected platforms encompass Binance Smart Chain, Polygon, Fantom, and Celo[1]. These platforms were chosen due to their established reputation, robust underpinnings, and EVM compatibility, which facilitate effortless smart contract deployment. Additionally, given the significance of NFTs in our framework, we also scrutinize their performance on IPFS using the Pinata platform[2], renowned for its efficient and secure NFT storage solutions.

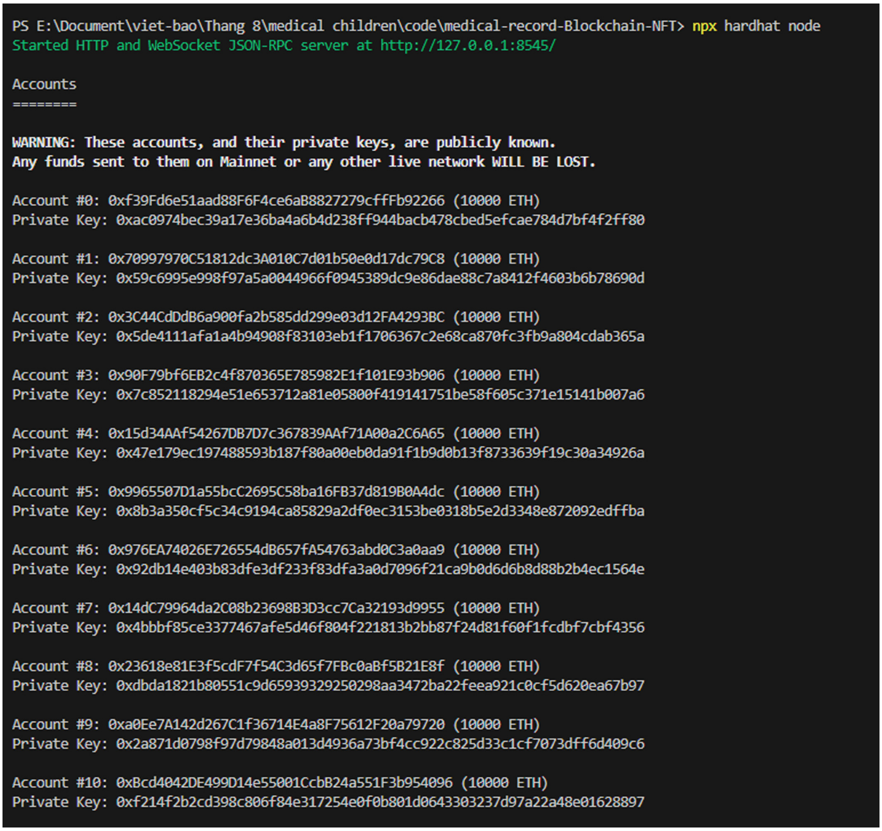
5.1 Scenario-Based Evaluation

To conduct a rigorous analysis of our system's efficacy, we engineered a simulation reflective of likely real-world applications and hurdles.

Fundamental to any distributed system are its nodes. As depicted in Fig. 6, we generated a 20-node sample for our evaluation. Each node was carefully set up with a dual-key system, consisting of a public key for network identification and a private key for encrypted communications, thereby ensuring data privacy and integrity. The arrangement of nodes was designed to mimic a realistic decentralized network, thus providing an environment that accounts for potential challenges like latency, data loss, and node breakdowns. Upon establishing the network, fabricated yet realistic children's medical data was introduced into the nodes. This dataset was diverse, simulating various health indicators, past medical events, and possible health conditions, providing a comprehensive backdrop for evaluating our system's capabilities. The next step involved simulating diverse transaction types, such as the initiation of new medical records, amending existing data, NFT transactions between nodes, and data queries. These simulations offered us insights into system performance parameters like speed, resilience, and security.

[1] References for the platforms can be added here.

[2] Pinata is a noted IPFS developer API https://www.pinata.cloud/.



```
PS E:\Document\viet-bao\Thang 8\medical children\code\medical-record-Blockchain-NFT> npx hardhat node
Started HTTP and WebSocket JSON-RPC server at http://127.0.0.1:8545/

Accounts
========

WARNING: These accounts, and their private keys, are publicly known.
Any funds sent to them on Mainnet or any other live network WILL BE LOST.

Account #0: 0xf39Fd6e51aad88F6F4ce6aB8827279cffFb92266 (10000 ETH)
Private Key: 0xac0974bec39a17e36ba4a6b4d238ff944bacb478cbed5efcae784d7bf4f2ff80

Account #1: 0x70997970C51812dc3A010C7d01b50e0d17dc79C8 (10000 ETH)
Private Key: 0x59c6995e998f97a5a0044966f0945389dc9e86dae88c7a8412f4603b6b78690d

Account #2: 0x3C44CdDdB6a900fa2b585dd299e03d12FA4293BC (10000 ETH)
Private Key: 0x5de4111afa1a4b94908f83103eb1f1706367c2e68ca870fc3fb9a804cdab365a

Account #3: 0x90F79bf6EB2c4f870365E785982E1f101E93b906 (10000 ETH)
Private Key: 0x7c852118294e51e653712a81e05800f419141751be58f605c371e15141b007a6

Account #4: 0x15d34AAf54267DB7D7c367839AAf71A00a2C6A65 (10000 ETH)
Private Key: 0x47e179ec197488593b187f80a00eb0da91f1b9d0b13f8733639f19c30a34926a

Account #5: 0x9965507D1a55bcC2695C58ba16FB37d819B0A4dc (10000 ETH)
Private Key: 0x8b3a350cf5c34c9194ca85829a2df0ec3153be0318b5e2d3348e872092edffba

Account #6: 0x976EA74026E726554dB657fA54763abd0C3a0aa9 (10000 ETH)
Private Key: 0x92db14e403b83dfe3df233f83dfa3a0d7096f21ca9b0d6d6b8d88b2b4ec1564e

Account #7: 0x14dC79964da2C08b23698B3D3cc7Ca32193d9955 (10000 ETH)
Private Key: 0x4bbbf85ce3377467afe5d46f804f221813b2bb87f24d81f60f1fcdbf7cbf4356

Account #8: 0x23618e81E3f5cdF7f54C3d65f7FBc0aBf5B21E8f (10000 ETH)
Private Key: 0xdbda1821b80551c9d65939329250298aa3472ba22feea921c0cf5d620ea67b97

Account #9: 0xa0Ee7A142d267C1f36714E4a8F75612F20a79720 (10000 ETH)
Private Key: 0x2a871d0798f97d79848a013d4936a73bf4cc922c825d33c1cf7073dff6d409c6

Account #10: 0xBcd4042DE499D14e55001CcbB24a551F3b954096 (10000 ETH)
Private Key: 0xf214f2b2cd398c806f84e317254e0f0b801d0643303237d97a22a48e01628897
```

Fig. 6. Example of 20 nodes with respective public and private keys

Vital performance metrics were culled from these simulations to gauge both efficiency and dependability. Metrics examined included transaction validation times, speed of data access, computational overhead, and resistance to security threats.

5.2 Utilizing IPFS for Secure Storage of Pediatric Health Records

In the contemporary digital age, the safekeeping, accessibility, and swift recovery of health data are crucial. With its decentralized architecture, the InterPlanetary File System (IPFS) offers an innovative solution that is resilient against data failure and enhances data security. When it comes to sensitive pediatric health information, storing these records via IPFS becomes particularly relevant.

As illustrated in Fig. 7, a typical pediatric health record is highlighted, containing essential health metrics and past medical data. These records are transformed into a distinct digital hash to maintain data genuineness and integrity.

```
    const body = {
      testType: "testType 1",
      testingResults: "testingResults 1",
      testingTime: "testingTime 1",
      testingPlace: "testingPlace 1",
      doctorName: "doctorName 1",
      nurseID: "nurseID 1",
      childrenName: "children name 1",
      parentsName: "parents name",
      treatmentHistory: "Children treatment History 1",
      result: "result 1",
    };
    const options = {
      pinataMetadata: {
        name: "Children medical records.json",
      },
```

Fig. 7. Example Pediatric Health Record

```
PS E:\Document\viet-bao\Thang 8\medical children\code\medical-record-Blockchain-NFT> npx hardhat test


  Lock
    Deployment
CID QmZbzkyAoMvPa1J8txgspyifUMqdGKFuKitHZErwYTNrAa
      ✓ Should set the right unlockTime (3919ms)


  1 passing (4s)
```

Fig. 8. Generation of Unique Hash Link for Pediatric Records on IPFS

Figure 8 presents the unique hash link generation process for a pediatric record on IPFS. This hash functions as a unique pointer for the stored record. Leveraging the capabilities of the Pinata platform, a known IPFS developer API, these records find their secure home on IPFS. Pinata's advantages include user-friendly features and strong encryption protocols, ensuring data privacy and controlled accessibility.

IPFS's decentralized nature provides insulation from system failures that affect a single point in the network, adding a layer of redundancy vital for maintaining the perpetual availability of health records. Figure 9 displays a pediatric health record identifier as it appears on the Pinata platform, highlighting the harmonious collaboration between IPFS and Pinata.

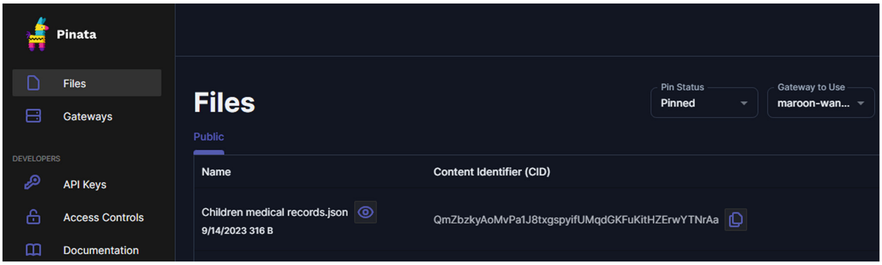


Fig. 9. Pediatric Record Identifier on Pinata Interface

As demonstrated in Fig. 10, upon querying the specific identifier linked to a child's health record, the comprehensive medical information can be recovered. The integration of IPFS and Pinata in our approach assures all involved parties—from parents to healthcare providers—that pediatric medical information remains secure, transparent, and promptly retrievable.

5.3 Assessment Across Platforms Compatible with the Ethereum Virtual Machine

To comprehensively gauge the reliability, scalability, and flexibility of our proposed system, we conducted tests for our smart contracts across four leading platforms compatible with the Ethereum Virtual Machine (EVM): Binance Smart Chain, Polygon, Fantom, and Celo. These platforms offer unique characteristics in terms of infrastructure, transaction fees, and performance, serving as excellent benchmarks to evaluate the adaptability of our framework.

Initial Data and Transaction Setup. The first step in our multi-platform evaluation was to look into the creation of data and transactions. We deployed our smart contracts across the chosen platforms to assess the ease of initiating transactions, the duration required for transaction confirmations, and the fees involved. Metrics like these are essential for assessing the real-world applicability of our system, especially when quick and cost-efficient data setup is crucial.

Creating Non-Fungible Tokens (NFTs). The subsequent phase of our evaluation was devoted to NFT creation. Within our framework, NFTs act as individualized digital signatures for each child's medical data. Employing the token standards provided by the EVM, we were able to create NFTs across the platforms, measuring the efficiency, related expenses, and required time for the procedure (see Fig. 11). The ability to produce NFTs quickly and at a low cost is vital for securely and promptly converting medical records into unique digital assets.

Secure Transfer of NFTs. The final component of our evaluation involved the process of transferring NFTs. Given the sensitive nature of healthcare data, it's essential that NFTs can be safely transferred between different parties, such as

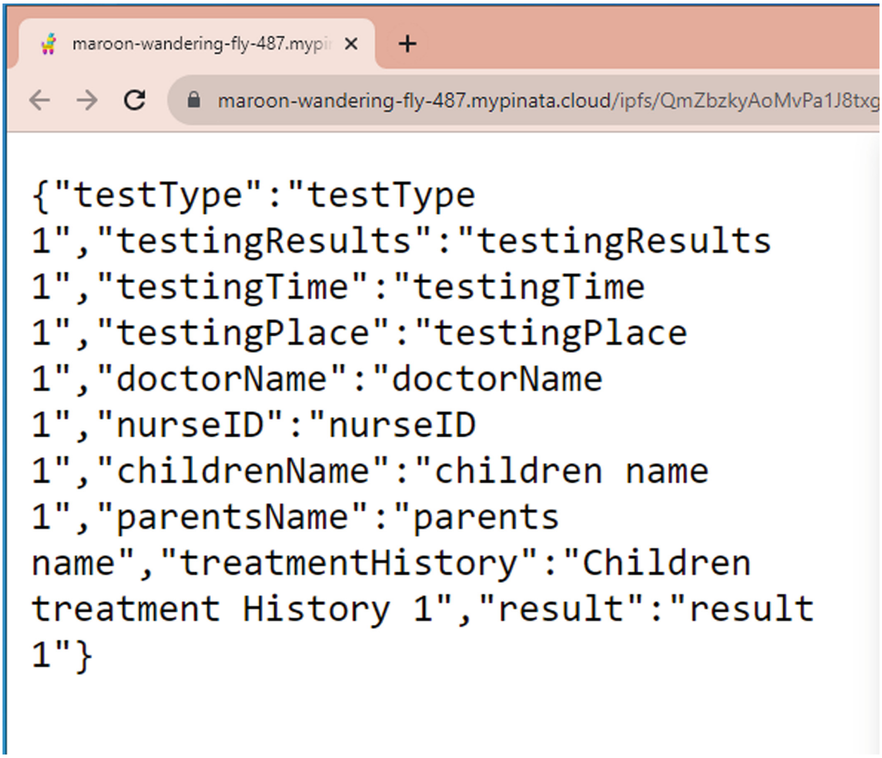


Fig. 10. Retrieval of Pediatric Medical Data Using Identifier

between healthcare providers and specialized medical facilities. We analyzed the transfer rates, security measures, and associated fees on each platform.

5.4 Transaction Fee Across EVM-Supported Platforms

Table 1. Transaction fees across EVM-supported platforms

Platform	Transaction Creation	Create NFT	Transfer NFT
BNB Smart Chain	0.0273134 BNB ($5.74)	0.00109162 BNB ($0.23)	0.00057003 BNB ($0.12)
Fantom	0.00957754 FTM ($0.001823)	0.000405167 FTM ($0.000077)	0.0002380105 FTM ($0.000045)
Polygon	0.006840710032835408 MATIC($0.00)	0.000289405001852192 MATIC($0.00)	0.000170007501088048 MATIC($0.00)
Celo	0.007097844 CELO ($0.003)	0.0002840812 CELO ($0.000)	0.0001554878 CELO ($0.000)

As illustrated in Table 1, the costs associated with three key operations—Initiating Transactions, NFT Generation, and NFT Transmission—are compared across the platforms discussed earlier[3]. The expenses are expressed in the native currency of each respective platform. Noteworthy points include:

[3] We deploy the smart contract and collect the price in Sept 24th 2023.

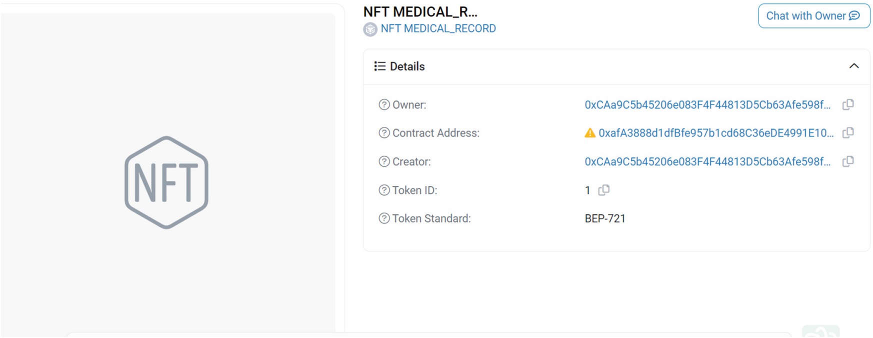


Fig. 11. Details of NFT Creation

- BNB Smart Chain commands the steepest price for initiating a transaction, tallying up to 0.0273134 BNB or about $5.74.
- Fantom displays a far more cost-efficient structure, particularly evidenced by its NFT Transmission fee which stands at a meager 0.0002380105 FTM, roughly equal to $0.000045.
- Costs for executing transactions on Polygon are so negligible that they effectively round to zero when converted to U.S. dollars.
- Celo offers competitive pricing, with an NFT Generation fee of 0.0002840812 CELO, which is practically negligible in dollar terms.

These varying fee structures highlight the crucial role of selecting a suitable platform based on economic aspects for a given application. It becomes essential for both developers and enterprises to take these operational costs into account, especially for applications that are expected to experience heavy transactional activity.

6 Conclusion

In this paper, we've taken significant strides in this direction by introducing a comprehensive framework based on blockchain technology, tailored specifically for the nuanced realm of pediatric care. Our approach not only addresses gaps in conventional systems but also adds new layers of security, accessibility, and transparency through the use of Non-Fungible Tokens (NFTs) and the Inter-Planetary File System (IPFS).

We've demonstrated how our framework eliminates the vulnerability inherent in centralized data storage and management systems, reinforcing data integrity and security. Through the integration of NFTs, each child's medical record becomes a unique, immutable asset on the blockchain, granting parents and guardians more control over their child's data. Coupling this with the decentralized data storage capabilities of IPFS ensures that these critical medical records are consistently available, enhancing the resilience of the entire system.

Our work isn't confined to theoretical propositions; we've validated our framework by implementing it across multiple blockchain platforms. The diverse tests reaffirm the system's adaptability and readiness for real-world application. Moreover, by leveraging the Pinata platform, an IPFS-based data storage solution, we have further fortified the system against single points of failure.

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