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Integrating Healthcare Services Using Blockchain-Based Telehealth Framework

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ABSTRACT Blockchain technology (BT) has a wide range of built-in features, such as decentralization, transparency, data provenance, security, immutability, and has moved beyond the hype to practical applications in the healthcare industry. Telehealth turns out to be the most efficient and effective way of dispensing healthcare services even in remote areas. Though telehealth has the proven potential to improve the quality of healthcare, its implementation and adoption remain far from ideal. There is a need for a telehealth system that not only ensures the privacy and security of the users but also provides authentic services that enhance the trust to the highest level. Existing applications are leveraging BT and providing limited telehealth services. These applications are focused on a few services; hence do not cover all aspects of healthcare. To unveil the true potential of telehealth, this paper aims to develop an effective telehealth framework-BlockHeal which integrates all essential healthcare services under one platform and ensures a full-fledged trusted environment. The methodology employed includes survey of existing telehealth system, identifying their weaknesses and critical reasons behind their lack of widespread adoption. The proposed framework addresses the limitations and includes all stakeholders of the healthcare system instigating a consolidated platform to ensure authentic, safe, and timely healthcare facilities. Additionally, as the proposed framework is based on BT, it ensures the provision of secure, fault-tolerant, transparent, and tamper-proof data. Moreover, it offers decentralized storage via hyperledger fabric and a collection of decentralized applications (DApps). Finally, the effectiveness of the BlockHeal framework is validated by demonstrating several use-cases.

INDEX TERMS Blockchain technology, healthcare, hyperledger fabric, telehealth, telemedicine.

I. INTRODUCTION

Healthcare is an essential service that is the primary need of every human being. The quality healthcare is considered to be safe, patient-centered, cost effective, equitable and accessible with continuing efforts for improvements [1]. However, this basic necessity is quite neglected in developing countries [2] such as Pakistan [3], India [4], Kenya [5], Zambia [6]. Around half of the population in developing countries is living on an average \$1.25 earning a day and are located in rural areas [7]. Healthcare facilities are limited even in urban areas of developing countries. The people living in rural areas of developing countries are less likely to get an acceptable level of healthcare services even in normal circumstances. The situation, certainly, gets worse in pandemic. The recent COVID-19 outbreak intensifies the need for remote healthcare not only in under developed countries, but also in most developed nations. Therefore, a technological solution is needed that

address the challenges of healthcare and provides a platform that is capable of providing accessible, affordable and personalized healthcare facilities to both rural and urban population effectively and efficiently.

Telehealth plays a vital role in improving the healthcare services through the use of technology. Telehealth is a collection of means or methods for enhancing healthcare, health education delivery and support using telecommunication technologies [8]. With the widespread use of technology and its adoption in rural areas, telehealth has showed notable advantages [9]. Moreover, it reduces costs to the patient and healthcare system, particularly for the patients living in rural areas [10]. The patients can be diagnosed remotely and their data is shared with clinical experts either via store-and-forward technology or in the online session. Apart from patient diagnosis, telehealth also provides efficient ways for purchasing medicines and medical equipment to pharmacies and patients. However, in online setting, maintaining the sensitivity, security and privacy of data is indispensable [11]. Besides, the safe and secure exchange of data

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between healthcare organizations and researchers also face interoperability issues in order to get the full benefit.

Blockchain is one of the progressing technologies of the current era that has a great potential to address the security and privacy issues [12]–[14]. Blockchain was initially introduced as a distributed ledger system for crypto currency; however it is rapidly adopted in number of application areas including supply chain management, digital voting, real state and healthcare. Blockchain can be simply defined as a decentralized, distributed ledger that records the provenance of a digital asset and it offers authentication, security, immutability and anonymity.

Recently, several studies have been conducted that enlighten the role of blockchain in healthcare sector [10], [15]–[17]. However, majority of these studies are focused on individual aspects of telehealth system. This paper presents the comparative study of existing blockchain based telehealth systems, identifying the need for an integrated approach towards a holistic healthcare system. Citing the limitations in the existing telehealth approaches, this research introduce a comprehensive blockchain based telehealth framework – BlockHeal; that deals with every aspect of healthcare. The BlockHeal framework aims to include essential patient centric services by integrating all stakeholders of healthcare industry. The focus of this research is to develop an effective, secure and trusted telehealth framework that is able to unveil the true potential of telehealth by integrating all essential healthcare services. The major contributions of this research are summarized as follows:

1. We proposed a novel blockchain enabled telehealth system – BlockHeal, that encompasses all the essential healthcare services, including those that are specifically required during COVID-19, by considering the limitations in the existing telehealth approaches
2. We incorporate many unique components of telehealth in the BlockHeal framework such as Language translator, Pharmacovigilance, and Emergency services to facilitate users and improve the effectiveness of the framework.
3. We present the comparative study of recent blockchain based telehealth applications with the BlockHeal framework highlighting its key benefits to all stakeholders.
4. We analyze the BlockHeal framework by considering different practical scenarios

The rest of the paper is organized as follows: Section 2 discusses telehealth and blockchain technology features and gives insight into the related work. Section 3 describes the proposed framework BlockHeal in detail and Section 4 demonstrates various use-cases to validate the proposed framework. Section 5 concludes the paper with future considerations.

II. BACKGROUND AND RELATED WORK

The outbreak of COVID-19 has immensely increased the adaption of telehealth services to facilitate the patients

remotely. During the pandemic, many doctors started online consultation sessions, individually, on their own or through hospitals. Similarly, there was a rapid growth of online medicine delivery services. However, up to the authors' knowledge there is no process that guarantees the legitimacy and validity of either online doctors or medicines. At first, this section briefly discusses the telehealth, its opportunities and the barriers that are ceasing its ways. It is followed by the blockchain technology characteristics and blockchain based telehealth applications.

A. TELEHEALTH

Telehealth is the use of digital information and communication technologies (ICT) to access and manage healthcare services remotely [18]. These technologies help to utilize healthcare services without being physically present in healthcare centers. Telehealth has the potential to improve remote health monitoring and diagnosis, online consultations, making healthcare accessible globally.

Numerous applications have been developed so far for telehealth services providing virtual consultation sessions, digital prescriptions, online buying of medicines, and automated payments [15], [16]. However, the patients are reluctant to rely upon these services and question their authenticity. Besides, there is no complete telehealth solution that covers all aspects of healthcare. Hence, a comprehensive, all-embracing solution with security, confidentiality, privacy, and transparency of data is acutely required.

B. BLOCKCHAIN TECHNOLOGY

Blockchain technology is a distributed ledger that provides verifiable, persistent and tamper proof records. It uses the notion of smart contracts to document the terms and conditions that should be abide by all its participants. It can be implemented in anyone of three categories i.e. public, private and consortium [19]. Adoption of BT in current telehealth system can bring numerous opportunities for secure digitizing of healthcare services such as, managing and sustaining confidentiality of patients' personal records, verifying healthcare practitioners' credentials, tracking drugs to reduce counterfeiting possibilities, tokenizing prescription for authentication etc. The details of BT features can improve the telehealth system are explained below:

1) DECENTRALIZATION

It is the process of breaking up the storage of records from one major server to multiple servers through blockchain's ledger. There is no central authority or single entity dominancy hence does not have a single point of failure and isolated information. This feature will help in increasing reliability, scalability, validity and usefulness of telehealth applications.

2) TRANSPARENCY

Blockchain offers transparency and privacy concurrently. The identity of each participating user is pseudo-anonymous as a result anyone can view the whole trail of transactions at

any point of time. This level of transparency makes system more traceable and searchable. For example, in drug supply chain, from medicine ingredients up to reaching consumers all records can be maintained and monitored.

3) IMMUTABILITY

Smart contracts, asymmetric cryptography and consensus mechanisms collectively offer another striking feature of blockchain, that is, immutability. Transactions made within the blockchain network are digitally signed by the public key and hash is being stored in decentralized storage system. Once data is stored it cannot be modified hence ensures integrity and reliability of data.

4) PROVENANCE OF DATA

BT records each transaction with a time stamp eliminating the chances of deception and mistreatment. Blockchain based systems have developed a certain level of trust by proving detailed information of each transactions made within the network. This inherent feature will also enhance trustworthiness and validation in telehealth system that leads to identify and cross check health practitioners' credentials, medical equipment functionality for home bases diagnosis and drugs abuse.

C. RELATED WORK

Telehealth system covers various aspects of our daily healthcare. Many telehealth systems which are available today do not encompass all critical prospects of a comprehensive telehealth system.

A Telehealth framework presented by Haddad *et al.* [20] was established during COVID-19 pandemic to provide patient care services. These services include Video telemedicine, Remote patient monitoring, and Mobile health. Edmunds *et al.* [21] introduced a policy based framework to integrate regulatory, operational, and clinical factors in Telehealth. Live video conferencing, remote monitoring, support for secure electronic transmission of X-rays, CT scans and digital images are some of the key features discussed along with regulatory bodies, quality standards, privacy protection and payment models. Nevertheless, these frameworks provide very limited functionality and do not consider critical issues inherent in all ICT based systems such as privacy, security, trust, etc. To overcome these issues, Yaqoob *et al.* [15] focuses on the integration of blockchain with healthcare systems. The authors discuss the blockchain based system comprising patient records, clinical trials, health insurance, drug traceability, and payments.

Guardtime, together with its industry partners launched a comprehensive blockchain-supported Personal Care Record Platform (MyPCR) in June 2018 [22]. MyPCR is a blockchain based governance tool for medical data. They claimed that the platform is live with up to 30 million NHS patients enabled for smartphone access. The platform delivers immutable proof of health data provenance and integrity with the General Data Protection Regulation (GDPR) data rights

management. A similar project is initiated by Philips Healthcare in 2018 to mitigate the illegal use and monetization of patient's private data; using blockchain technology [23]. This project is called as "verifiable data exchange" which will enable researchers to request the data they need and track its trail. MedRec supported by MIT Media Lab, is also providing decentralized Electronic Health Records (EHR) record management system [24]. It makes use of smart contracts that links patients and health institutions to the addresses of existing records. It stores the patient's data by encoding it with metadata (information about ownership and permission requests) that makes data to be accessed by patients securely. Zhang *et al.* [25] proposed blockchain based architecture for Fast Healthcare Interoperability Resources (FHIR) named FHIRChain. The proposed architecture is validated by using remote cancer care as the use case. These blockchain based telehealth systems are focused on EHR. However, other telehealth services like prescription management, payments, insurance claims, remote patient monitoring and drug tracking are not addressed in these studies.

Online consultation platforms are one of the top services of telehealth. The MedX Protocol is a global healthcare market of patients and physicians [26] in which patients from anywhere from the world can connect with a global network of physicians and consult online with full control of their data. On the other hand, the physicians' registry on MedX is maintained as token-curated registry i.e. a list judiciously curated by token holders in exchange for economic rewards. The developers interpreted it as a "bulletin board" for health services. Medicalchain [27] is a decentralized platform that enables secure, fast and transparent exchange and usage of medical data. The platform is providing two applications simultaneously; doctor-to-patient telemedicine application and a health data marketplace. With the telemedicine application, a patient can consult to the doctor remotely with control on his/her data. HealPoint.io [28] provides telehealth services for direct communication between a patient and doctors utilizing telecommunication technologies. This platform facilitates patients to consult multiple experts simultaneously to get a second opinion for their diagnosis with any internet-enabled devices. Block chain based AI algorithms calculate the probabilities of the diagnoses and connect the patient to respective doctors of the chosen country. Although, these platforms allow virtual consultation sessions but cannot assure the trustworthiness of the doctors except in MedX. Moreover, payments, insurance claims, prescription management are not offered by these platforms.

Telehealth systems are not only limited to online patient records and doctor consultations but also include drug delivery and related services. Information Hub for life sciences by SAP [29] connects many pharmaceutical organizations with their supply chain partners which enables various trading partners to exchange large amounts of data securely across the network. This hub was mainly designed to reduce drug counterfeiting and follows authoritative instructions issued by governments and ensures delivery of safe medication to

the patient. The MediLedger Project [30] was introduced in 2017 as a fully decentralized peer-to-peer blockchain network that brought together pharmaceutical manufacturers and wholesalers in a working group. This project aims to provide ease to endorse the authenticity of raw materials and drugs and avoid counterfeit and fraudulent by enforcing cross-industry business rules and keeping the private data confidential. Considering the critical parameters of the pharmaceutical supply chain such as quality of medicines, traceability, and regulatory compliance; Ambrosus [31] implements blockchain-based solutions for the supply chain specifically for the food and pharmaceutical industry. Authentag [32] is a Blockchain-based digital ledger technology that allows users to obtain Global Unique Device Identification Database (GUDID) information by scanning the barcode over medical devices. The application uses Food and Drug Administration (FDA) Application Programming Interfaces (APIs) to verify a device's barcode that should have been formatted as per the approval and hold the most up-to-date information. These projects add remarkable benefits to the healthcare industry but are limited to drug counterfeiting and hence do not include other major features of the telehealth framework.

BlockMedx [33] is a secure end-to-end cloud based solution for transceiving and tracking electronic prescriptions. Blockchain technology makes the Patients and pharmacies utilize this solution more securely and free of cost in comparison of legacy solutions. Project Heisenberg [34] is hosted on an Ethereum Consortium Network and is authorized by a custom JSON genesis file. This is a decentralized system serves as identity management and pharmaceutical ERP system ensuring a secure and genuine end to end medication prescribing process. Doctors prescribe medication and validate the prescription by tokenizing it. The doctor gives input such as doctor id, patient name, quantity, dosage, and expiry date to the token which gets formalized as metadata through the PrescriptionNFT.sol file which is a smart contract. The patient fills the valid prescription at an authorized pharmacy. Blockchain technology is responsible to verify the signature between the patient and the respective doctor and after verification, the medication gets disbursed. Scalamed [35] leverages the latest in Blockchain technology to form a secure bridge between providers' clinical software directly to the patients' smartphones. Through ScalaMed doctors can generate an immutable and unique digital prescription that cannot be used even twice. Leveraging AI technology, patients can be advised, assessed their response to the medicines, reminded, and alerted regarding their medications. These application lack counterfeit mechanism therefore the authenticity of medicines and pharmacies cannot be assured. Typically, digital prescriptions will be more authentic and effective if they are supported by a counterfeiting mechanism.

Change Healthcare [36] is a leading independent healthcare Technology Company in which customers and service providers work collectively utilizing Blockchain ledger

technology to exchange financial and clinical data across Healthcare networks. Transactions sort from eligibility checking to claims processing and payment squaring off to pharmacy messaging, lab order and its results, e-Prescribing, and medical record interoperability. HSBlox [37] brings patient-centric solutions to the healthcare ecosystem leveraging Blockchain's distributed ledger technology and machine learning collectively to secure, aggregate, analyze, and report on data in real-time with accuracy and insight.

The above mentioned applications have a lot of potential but are limited to specific aspects of healthcare services as summarized in Table 1. Few are focused on Patient Record Management and Drug deliveries, while other provides online consultation services. Moreover, none of these applications facilitate users in case of language impediment between the patient and healthcare providers. A robust telehealth system should congregate all facilities such as secure storage and protection of patients' medical information, credibility of the physician who interacts remotely, trustfulness of payment system, and prevention of counterfeited drugs. Additionally, the system should also enable patients from any part of the world to communicate and consult safely in order to provide a superior, safe and sound care. Table 2 summarizes the limitations of existing telehealth systems.

Taking into account the above mentioned needs, we propose a novel framework BlockHeal that incorporates all the healthcare services. The novel contribution of the BlockHeal framework includes Pharmacovigilance, Emergency Services and Language Translator services among others. The framework also integrates various third parties under a regulatory body to ensure that all services are provided by authentic parties.

III. BlockHeal – THE PROPOSED FRAMEWORK

This section introduces BlockHeal, a framework for a telehealth system built on top of the blockchain. BlockHeal integrates all stakeholders of the healthcare system and provides a consolidated platform to ensure authentic, safe, and timely healthcare facilities. The framework features eleven major components encompassing all services that could be part of the healthcare industry which includes patient ownership to his data, trusted healthcare practitioners, auditable drugs supply chain from their origin to wholesalers and pharmacy, and pharmacovigilance primarily. The details for each component are given in succeeding sections. The core of the framework is based on blockchain technology which ensures the provision of secure, fault-tolerant, transparent, and tamper-proof data. Moreover, the use of smart contracts enables enforcement of access control, enhance trust and traceability, improve security and execute transactions transparently. Figure 1 illustrates the BlockHeal framework which involves two layers i.e. the data management layer and the decentralized applications (DApps) layer. The framework is administered by the central health regulatory authority to ensure verified and trusted participants of this telehealth system.

TABLE 1. Blockchain-based telehealth applications and frameworks.

| References | Patient Record Management | Prescription Management | Drug Tracking | Clinical trials and medical reports | Automated Payments | Health Insurance claims | Reputation aware doctor recommendation | Remote patient health monitoring | Language Translation | Emergency services | Pharmacovigilance |
|------------|---------------------------|-------------------------|---------------|-------------------------------------|--------------------|-------------------------|--|----------------------------------|----------------------|--------------------|-------------------|
| [15] | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X |
| [20] | ✓ | X | X | X | X | X | X | ✓ | X | X | X |
| [21] | ✓ | X | X | X | X | X | X | ✓ | X | X | X |
| [22] | ✓ | X | X | X | X | X | X | X | X | X | X |
| [23] | ✓ | X | X | X | X | X | X | X | X | X | X |
| [24] | ✓ | X | X | X | X | X | X | X | X | X | X |
| [25] | ✓ | X | X | X | X | X | X | X | X | X | X |
| [26] | ✓ | X | X | X | X | X | ✓ | X | X | X | X |
| [27] | ✓ | X | X | X | X | X | X | X | X | X | X |
| [28] | ✓ | X | X | X | X | X | X | X | X | X | X |
| [29] | X | X | ✓ | X | X | X | X | X | X | X | X |
| [30] | X | X | ✓ | X | X | X | X | X | X | X | X |
| [31] | X | X | ✓ | X | X | X | X | X | X | X | X |
| [38] | X | X | ✓ | X | X | X | X | X | X | X | X |
| [33] | X | ✓ | X | X | X | X | X | X | X | X | X |
| [34] | X | ✓ | X | X | X | X | X | X | X | X | X |
| [35] | X | ✓ | X | X | | X | X | X | X | X | X |
| [36] | ✓ | X | X | ✓ | ✓ | X | X | X | X | X | X |
| [37] | ✓ | X | ✓ | ✓ | X | X | X | X | X | X | X |
| BlockHeal | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

A. METHODOLOGY

This study was carried out using fundamental research approach. Initially, a thorough literature survey is conducted and various existing telehealth frameworks and applications were studied. Next, the selected frameworks and applications were categorized with respect to their features and services. Further, each application is evaluated and their pros and cons are extensively analyzed. Limitations of existing telehealth systems are finally identified, laying out the foundation for proposed framework. Keeping in view, the limitations of telehealth systems, a novel framework is presented which addresses the issues and provides a platform that integrates all healthcare services. Various use cases of the proposed framework are described, validating the efficacy of the BlockHeal framework.

B. DATA MANAGEMENT LAYER

BlockHeal framework manages its data via Hyperledger Fabric; a blockchain architecture which provides permissioned blockchain with modular design [39]. It also provides varying access levels which helps in enabling respective permission

and access control against each DApp within BlockHeal. The data stored in the traditional database will also be used for the verification of related participant however; other interactions among all participants will be recorded as a transaction on a distributed ledger.

C. DECENTRALIZED APPLICATIONS (DApps) LAYER

BlockHeal framework includes distinct DApp for each of its potential users, which includes patient, doctor, health ministry, pharmacy, drug manufacturer, supplier, medical laboratory, translator, or any other contributor to the healthcare industry. Figure 1 outlined the features of each of the following DApps:

- **Health Ministry DApp:** This DApp is intended to be used by the central health regulatory authority in order to have a sound and secure telehealth infrastructure. Further, it is responsible for verifying all the users from their concerned regulatory authority and their registration.
- **Patient's DApp:** Patient's DApp will allow patients to access and control their data from anywhere any-time eradicating the information silos created by the

TABLE 2. Limitations of existing telehealth systems and proposed framework—BlockHeal solutions.

| S. No. | Telehealth Requirement | Existing Telehealth Systems Limitations | BlockHeal Solution |
|--------|---|---|---|
| 1. | Patient Record Management | <ul style="list-style-type: none"> - Patient records are maintained by individual hospitals or laboratories. - Patient has no access to his own digital copy of data - Patient cannot share the digital copy of data with others for consultancy - Patients medical data is shared by hospitals/doctors without the patients' consent | <ul style="list-style-type: none"> - Patient maintains the ownership of all health records - Records are tamper-proof - Traceability of medical history - Patient can share and lease his data as per his consent |
| 2. | Prescription Management | <ul style="list-style-type: none"> - No record of previous prescriptions - Misuse of OTC (over the counter) medicines that leads to drug abuse | <ul style="list-style-type: none"> - Digital Prescriptions - No misinterpretation due to direct transfer to pharmacy - Only prescribed drugs are given to patients |
| 3. | Drug Tracking | <ul style="list-style-type: none"> - Existence of unregistered drug manufacturers and pharmacies - Drugs are being counterfeited - Lack of transparency in drug delivery process | <ul style="list-style-type: none"> - Registered manufacturers, wholesalers and pharmacies - Traceable drugs from their origin - Authentic drugs, No drug counterfeiting |
| 4. | Trusted Clinical Trials and Medical Reports | <ul style="list-style-type: none"> - Personalized recommendation of laboratories by Doctors - Limited book keeping of clinical tests results raising its authenticity issue. - Laboratories become the owner of patient's health records. | <ul style="list-style-type: none"> - Verified Laboratories from their regulatory authority - Immutable records for each transaction - Medical diagnostic test results are updated on Patient's profile, making patient their owner |
| 5. | Automated Payments for Medical Billing and Claims | <ul style="list-style-type: none"> - Lack of payment transparency and security due to third party services - No micropayments support in automated payment - Resource and time consuming process - Likelihood of fake claims | <ul style="list-style-type: none"> - Cryptocurrency for automated payments - Immutable and transparent records |
| 6. | Reputation Aware Doctor Recommendation | <ul style="list-style-type: none"> - Unavailability of updated Doctor's profile - Presence of Quacks - Lack of trust on online reviews | <ul style="list-style-type: none"> - Verified doctors by regulatory body - Tamper proof Doctor's profile - Patients can rate Doctors based on their personal experience |
| 7. | Remote Patient Health Monitoring | <ul style="list-style-type: none"> - Very less support for remote patient monitoring | <ul style="list-style-type: none"> - Supports online consultation from verified Doctors across the world |
| 8. | Health Insurance Claims | <ul style="list-style-type: none"> - Lack of transparency and security - Time consuming process - Manual managements of claim records | <ul style="list-style-type: none"> - Verified Insurance companies - Optimized insurance process due to the elimination of multiple parties - Traceable records minimizing false claims |
| 9. | Language Translators | <ul style="list-style-type: none"> - Patient cannot consult with the Doctors outside their locality as language barrier may leads to miscommunication - Lack of guidance and counselling if there is a language barrier | <ul style="list-style-type: none"> - Verified translators will assist in overcoming the language barrier - Patients and Doctors from anywhere can communicate effectively. |
| 10. | Pharmacovigilance | <ul style="list-style-type: none"> - Patient cannot report directly in case of ADR - No record of ADR available for analysis - Inadequate monitoring and recording of adverse events and ADRs | <ul style="list-style-type: none"> - Patient can report against any ADR via their DApp - ADR data can be analysed and monitored - Direct communication between Patients and Pharmacists via respective DApps |
| 11. | Emergency Service | <ul style="list-style-type: none"> - Multiple service providers are to reached one by one to find the most appropriate and immediate service | <ul style="list-style-type: none"> - Appropriate Service provider will be selected immediately by the system |

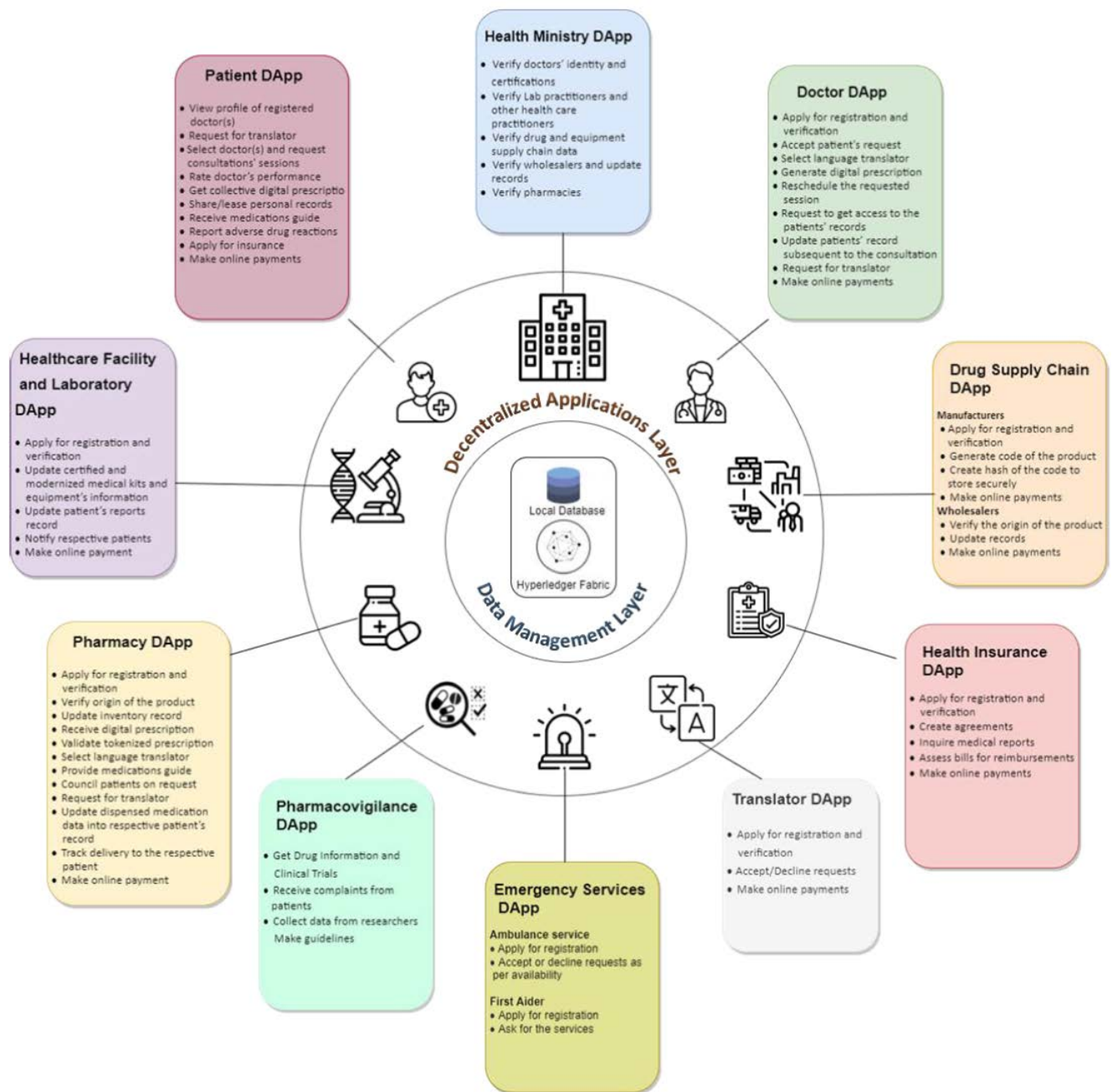


FIGURE 1. The BlockHeal framework.

concerned hospital and laboratories. Patients can rate doctors, laboratories, pharmacies according to their performance and report Adverse Drug Reactions (ADRs) caused by consuming medicines directly to the pharmacists and get recommendations to suppress the side effects.

- **Doctor's DApp:** Doctor's DApp ensures inclusion of only verified doctors in BlockHeal framework as each doctor has to get verified by the related authorities.

The doctors will be rated by the patients and their profile is maintained.

- **Pharmacies' DApp:** This DApp allows pharmacies to get them registered and receives digital prescription from the patients via this DApp. Digital prescriptions will be tokenized and upon further processing through smart contracts get validated by extracting the identity of the registered doctor who has prescribed the medications. This whole process leads to control drug misuse.

- **Drug Supply Chain DApp:** The whole trail of the drug supply chain from manufacturer to retailer can be verified via this DApp. All stakeholders of this ecosystem can track the entire supply chain thus eliminating the counterfeit drug dealers and ensuring the delivery of authentic medicines to patients.
- **Health Insurance DApp:** This DApp allows creating and substantiating finance structures according to the insurance agreement. Legitimate insurance companies can track and verify insurance plans eliminating the case of false claims. Also, as data is available on a single platform the process of insurance claims is expedited.
- **Healthcare Facility and Laboratory's DApp:** Patients can reach out to verified laboratories for diagnostics tests recommended by Doctors. These laboratories will update patient record on the patient's profile. The respective patient will become the owner of his record and can share with any health practitioner.
- **Translators' DApp:** Communication between people living in remote areas and the doctor in any other part of the world will become more comfortable by having a translator. This DApp allows authenticated translators to render this service to patients, doctors, or any other participant of BlockHeal framework.
- **Emergency Services DApp:** This DApp will allow the authorities of emergency services such as ambulance and first aid givers to get verified and deliver their service in a trusted environment. Patient can post emergency service request through the framework and can get the response immediately from available emergency service providers.
- **Pharmacovigilance Services DApp:** This DApp is responsible for receiving, assessing, and managing drug-related issues. Entities associated with this DApp receive pharmacists' and patients' reporting regarding the adverse event and adverse drugs reaction and recommend medication or treatment to suppress the cause. Furthermore, they research over the related issue to ensure safety and maintain records for future work. They keep tracking drugs manufacturing and passes the drugs through thorough clinical trials and examination to prevent dangers. Moreover, an active research team is also associated with this DApp and keeps updating with therapeutic side effects and benefits.

D. COMPONENTS OF BlockHeal FRAMEWORK

The BlockHeal framework offers various services to its users through corresponding DApps. These include patient record management, prescription management, drug counterfeiting, clinical trial and medical reports management, automated payments for medical billing and claims, reputation aware doctor recommendation, remote patient health monitoring, health insurance claims, language translators, emergency services, and pharmacovigilance. Moreover, BlockHeal framework provides enhanced level of availability and fault

tolerance for all DApps. The details of each component of the framework are given below:

1) PATIENT RECORD MANAGEMENT

The Secure Patient Record Management is the core component of the BlockHeal framework. This component manages patient data which includes patient's medical history, medication, diagnosis, treatment plans, and related information. The patient is the owner of the data ensuring the privacy as data cannot be shared without the consent.

In traditional systems, each hospital or laboratory keeps a separate record of patients i.e. the data is not shared among the healthcare institutions. Hence institutions, not patients, are the primary owner of EHR. This institution specific ownership leads to significant hurdles for patient in sharing their own information. With the digital evolution, EHRs are being produced in massive amounts and are found to be significant for epidemiologic review [40]. However, EHR software systems make use of diverse clinical technologies, technical specifications, and functional capabilities which cause hindrance in creating and sharing data in one format. Additionally, the centralized management of data imposes the risk of a single point of failure.

Patient record management component of the framework address the above mentioned issues. The BlockHeal framework has not only the potential to store this enormous amount of data with the guaranteed transparency, but all transactions within the BlockHeal framework are immutable, verifiable, and tamper-resistant.

2) DIGITAL PRESCRIPTION MANAGEMENT

This component of the BlockHeal framework facilitates the patient in acquiring medicines prescribed by the doctor. It allows creating and sharing digital prescriptions as paper-based prescriptions can be easily misunderstood by a pharmacist or deteriorated due to environmental conditions [41]. On the contrary, digital prescriptions are delivered directly to the pharmacy eliminating the chance of misunderstanding.

BlockHeal framework offers digital prescriptions and its management that will help to abolish the aforementioned concerns as it produces traceable and tamper-proof records.

3) PREVENTING DRUG COUNTERFEITING

Drug counterfeiting prevention is one of the critical components of the BlockHeal framework that ensures authentic drugs delivery to patients. It is estimated by World Health Organization (WHO) that about a million people die every year due to counterfeited drugs [42]. The main reason behind drug counterfeiting is the imperfect process of the supply chain. After completion of the manufacturing process, the supply chain cycle of drugs incorporates transportation, handling, storage, redistribution, and retail stages. These stages are vulnerable as they involve many junctures and people.

BlockHeal framework tends to assist in overcoming the drug counterfeiting problem since all transactions are

immutable and time-stamped, which ensures that the information is tamper-proof. Hence, the complete trail of a drug can be managed easily. Once the drug moves from one stage to another, its movement will be stored on the hyperledger fabric that ultimately reduces the risk of medicines' falsification and provides improved drug traceability.

4) TRUSTED CLINICAL TRIALS AND MEDICAL REPORTS

Reporting of clinical trials and medical tests can be protected via this component of the BlockHeal framework. Clinical trials are research studies that embrace new tests and treatments and evaluate their effects on human health [43]. They are the primary way that researchers find out if a new treatment, like a new drug or diet, or medical device is safe and effective in people. Clearly, wrong reporting of results will put human health at stake.

BlockHeal framework generates immutable records that increase the trustworthiness of data and ensures data integrity. Moreover, the most common type of clinical fraud i.e. fabricating consent forms which include falsifying patient consent and editing his/her records can be eliminated by maintaining auditable and traceable records via smart contracts.

5) AUTOMATED PAYMENTS FOR MEDICAL BILLING AND CLAIMS

This is the prominent component of the BlockHeal framework which provides automated payments to each of its stakeholders. Healthcare systems are centralized and incorporate third-party services to provide payment services to patients and caregivers [16]. The inclusion of third-party services makes them non-transparent and vulnerable to hacking. Further, these systems support either no or expensive micropayments.

BlockHeal framework employs cryptocurrency with encryption techniques to control the value and verify payments. The wallet-based transactions directly transfer the amount to the associated party surpassing the need for centralized mediation. Moreover, the systems become transparent and secure as transactions are digitally signed and can be audited and traced at any point in time eradicating the occurrence of fake claims.

6) REPUTATION AWARE DOCTOR RECOMMENDATION

Telehealth provides an ease to consult healthcare specialists all around the world. However, the level of trust is harder to establish in a virtual setting. Moreover, the presence of quack clinics and doctors contribute even more to shattering that trust. Proving the identity of a legal doctor is difficult in the virtual environment. Reputation-aware doctor recommendation is the most promising feature of the BlockHeal framework. It produces immutable records with a proper traceability mechanism. The doctor's profile in the BlockHeal framework will always exhibit valid data as data cannot be altered once it is recorded. Also, the patients can recommend Doctors on the basis of their personal experience with the respective Doctor.

7) REMOTE PATIENT HEALTH MONITORING

Remote patient health monitoring is one of the salient components of the BlockHeal framework. Telehealth services use direct-to-consumer (D2C) and business-to-business (B2B) models to monitor the health of remote patients [16]. In D2C, patients can directly inform specialists about their wellbeing conditions. While in B2B, the caregivers take part in the consultation and medication process through audio and video conferencing. Due to limited data sharing, health institutions are unable to manage the patient's EHR effectively. Through the BlockHeal framework, all institutions will get a single and coherent patient profile which helps in tracking patient's medical history and recommending appropriate medication.

8) HEALTH INSURANCE CLAIMS

Fake insurance claims can be easily fixed by this component of the BlockHeal framework. Insurance companies use centralized systems to store and process their data. Additionally, multiple third parties are involved throughout the cycle of the insurance scheme. Data is shared among different stakeholders who make the insurance procedure insecure and endangered.

BlockHeal framework offers notable transparency as it stores all the transactions with a time-stamp. Agreement records, transactions, and other information are collected in an automated manner via smart contracts; leads to improving administrative processes. Moreover, they can help to detect fake or exaggerated insurance claims.

9) LANGUAGE TRANSLATORS

The language barrier that may hinder the communication process between patients and health practitioners is overcome by the language translator component of the BlockHeal framework. As the telehealth system is expanding its reach around the globe, linguistic interaction becomes an important feature to provide effective care. BlockHeal framework permits the translation service providers to bestow certified telehealth translation services to remote patients' diagnostics and health practitioners.

10) EMERGENCY SERVICES

Emergency services component is the significant component which provides access to reliable emergency facilities timely to the BlockHeal framework participants. These services include first aid, pre-hospital treatment and transport to the hospital.

11) PHARMACOVIGILANCE

Pharmacovigilance is the component which provides vigorous, robust and diligent supervision of drugs' adverse reactions in BlockHeal framework. Pharmacovigilance is connected with entities such as patients, doctors, pharmacists, policy makers, researchers, pharmaceutical industries and medical regulators. Pharmaceutical companies usually conduct pharmacovigilance audit after manufacturing of

drugs [44]. Drugs are sent for clinical trials and tested among heterogeneous population for accurate results, regarding side effects or any adverse reaction to minimize loss.

BlockHeal framework uses smart contracts to automate the execution of an agreement among stakeholders without intermediary's involvement. All participants are certain of the outcome of the processes and information is immediately available to concerned parties without any delay. Data collected through pharmacovigilance activities is timely shared with researchers to ensure safety of patients and minimization of adverse effects.

IV. BlockHeal USE CASES

This section describes the implementation of the BlockHeal framework in six substantive usage scenarios of telehealth services. All the participating entities have to get registered and verified first, therefore, it is demonstrated as a separate case of use. The use cases exhibited include patient's online consultation with doctors, healthcare and laboratory facilities, drug counterfeiting, language translation, pharmacovigilance, and emergency services. The details of each use case for validating BlockHeal are given in the succeeding sections.

A. USE CASE – USERS' REGISTRATION AND VERIFICATION

BlockHeal offers a secure platform for all the stakeholders of the healthcare industry. However, it is intended to be run under a central authority. Doctors, pharmacies, drug suppliers, laboratories, and other healthcare practitioners are required to get registered in order to provide services, as depicted in Figure 2. These entities initially request for the registration through the smart contract to the concerned regulatory authority for verification via their respective DApps. Once these entities are verified, their profiles and other related information are stored in decentralized storage as a certified component of the BlockHeal system.

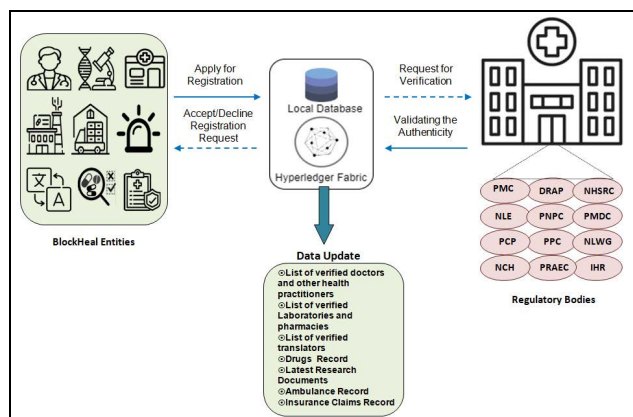


FIGURE 2. User's registration and verification use case in BlockHeal.

B. USE CASE – PATIENT'S ONLINE CONSULTATION SESSION WITH DOCTOR(S)

The patient sends a request to the verified doctor using their corresponding DApp i.e. patient DApp and doctor DApp.

Doctor after receiving the request from a patient can either set a time of consultation or cancel the request. The Doctor can also recommend other specialists if necessary.

For consultation purposes, if the doctor wants to access the patient's previous medical record, a request will be sent to the patient. If the patient grants access then the doctor will be able to access the data. Meanwhile patient has all the rights to cease the given access. Figure 3 represents this scenario. The doctor prescribes the medicines by generating a digital prescription with the process of tokenization in which the doctor has to give information to authenticate the prescription so that drug manipulation can be effectively controlled.

Smart contracts enable the doctor to update the patient's health record and medicine prescription using his DApp which cannot be modified once stored. The patient can also get connected with any verified international doctor around the globe for a second opinion.

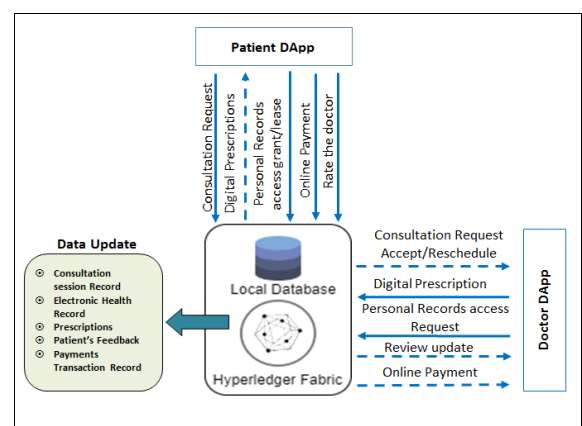


FIGURE 3. Use case—Patient's online consultation with doctor(s) in BlockHeal.

C. USE CASE – HEALTHCARE AND LABORATORY FACILITY

Figure 4 illustrates the process in which patients can access the registered healthcare and laboratories information and request for the medical diagnostics tests, recommended by the doctor, using the patients' DApp. Patient request for medical diagnostic test is forwarded to corresponding healthcare facility, which may send lab staff to the patient's doorstep.. Digital report will be posted to the respective patient's profile and the patient will be notified through healthcare's DApp. Once the record is created it cannot be altered but only viewed by the patient, Doctor or any other authorized user, using corresponding DApp.

D. USE CASE – DRUG COUNTERFEITING

Counterfeit medicine, a deliberately mislabeled drug with respect to identity or source is a critical issue creating health and safety hazards for patients. The BlockHeal framework is able to minimize such counterfeiting issues to a great extent by tracking drugs end to end as demonstrated in Figure 5. This process involves DApps for manufacturers,

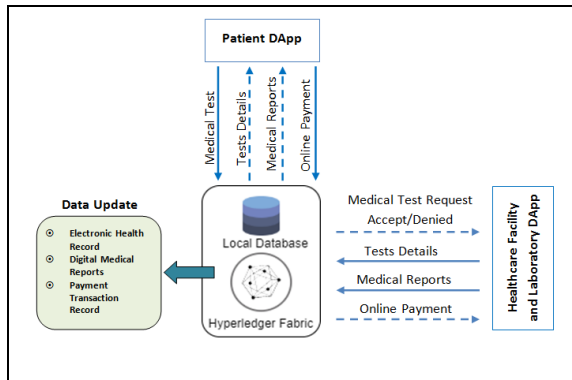


FIGURE 4. Use case—Healthcare and laboratory facility in BlockHeal.

wholesalers, pharmaceutical companies, pharmacies, and regulatory authorities. The pharmaceutical industry and manufacturers have to get registered and verified by concerned regulatory authorities which were illustrated in Figure 2. Once they get registered their drugs information and transactions data will be recorded and continuously monitored. Likewise, registered wholesalers would be able to verify the product origin. The immutable and transparent tracking of complete supply chain guarantees that all medicines reaching the patient through this platform is authentic with complete audit trail.

A patient can send the digital prescription through DApp to the registered pharmacy. The tokenized prescription will be processed that is validated by smart contracts to control drugs mishandling that it must be prescribed by a verified doctor and the patient is not misusing the prescription. Once the prescription is verified, medication will be delivered and the patient is notified with the delivery tracking information.

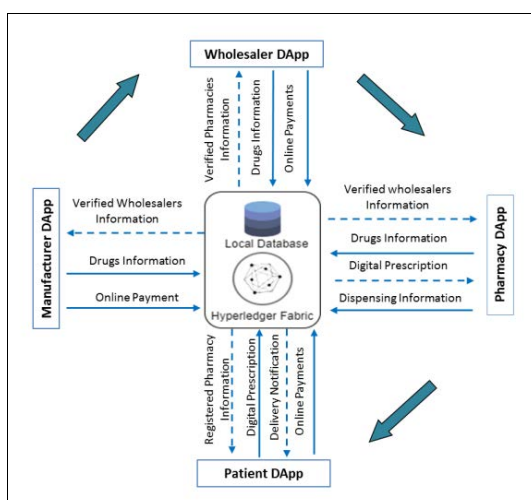


FIGURE 5. Use case—Drug counterfeiting in BlockHeal.

E. USE CASE – PHARMACOVIGILANCE

Patients are given a special feature in their DApps through which they are able to report in case of any adverse

event (AE) or adverse drugs reaction (ADR). Upon consuming a medicine, if the patient feels unusual, say, itching or dizziness, then the patient can connect with pharmacovigilance DApp and submit all the related information regarding drug and its effects as exemplified in Figure 6. The pharmacovigilance team receives and suggests remedy accordingly with their DApps and forwards the case to the researchers and pharmaceutical team for further analysis and action.

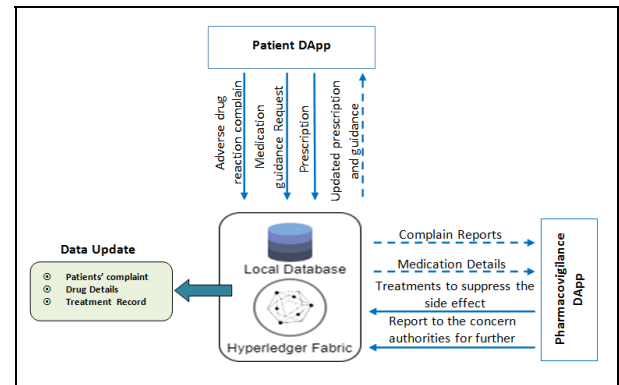


FIGURE 6. Use case—Pharmacovigilance in BlockHeal.

F. USE CASE – LANGUAGE TRANSLATION

The BlockHeal framework facilitates the patients by fixing the language barrier between the patient and the doctors with the collaboration of verified translator agencies. A patient can send a request for a language translator for any language to the registered language translators through this framework. If the desired language translator is readily available, the request will be accepted and communication begins between doctor and patient through the translator. This whole process is presented in Figure 7.

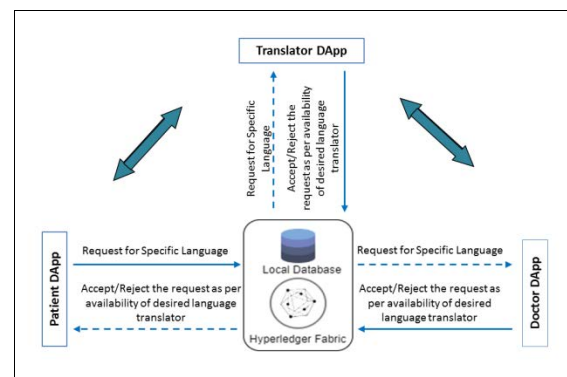


FIGURE 7. Use case—Language translation in BlockHeal.

G. USE CASE – EMERGENCY FACILITY

The BlockHeal framework incorporates emergency services providers within this framework. In case of emergency, appropriate services can be requested using the patient's

DApp as shown in Figure 8. The request is immediately forwarded to all emergency service providers and the connection between the requester and matching service provider is established using smart contract.

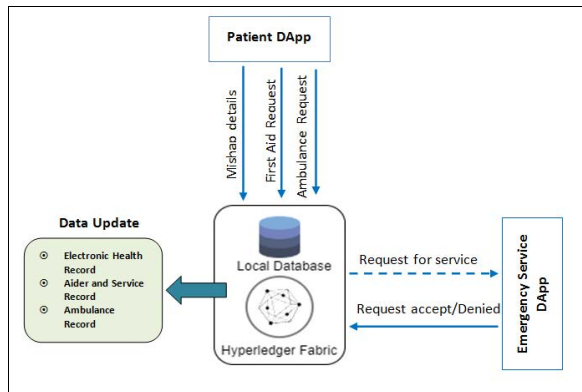


FIGURE 8. Use case—Emergency service in BlockHeal.

V. CONCLUSION

Telehealth services have been available in one form or another since the last decade. However, these services were rapidly and widely adopted across the world since the outbreak of COVID-19. Telehealth played a vital role in reaching out to COVID-19 patients remotely. This research presents a blockchain-based comprehensive telehealth framework, titled BlockHeal that addresses the limitations of existing telehealth solutions. The BlockHeal framework aims to provide a holistic solution that offers all the essential health-centric services. The BlockHeal framework incorporates all stakeholders of the healthcare system and delivers a complete and secure telehealth solution with the use of blockchain technology. Blockchain technology is a new, decentralized architecture that has the potential to transform traditional centralized industries into a secure and trustable system. Therefore, combining blockchain technology in the BlockHeal framework guarantees authentic, safe, and timely healthcare facilities. The framework is divided into two layers i.e. the data management layer and the decentralized applications (DApps) layer which is administered by the central health regulatory authority to ensure verified and trusted participants in this ecosystem. We demonstrated the application of the BlockHeal framework with six healthcare scenarios and highlighted the significance of integrating patient concerns and needs into blockchain-based designs. We believe that the BlockHeal framework bridges the gap between the patient, living in any part of the world, and the quality healthcare services. The BlockHeal framework reinvents the virtual in-person care model and its large-scale implementation and adoption will lead to improved healthcare access with affordability.

To this end, this research presents a framework that provides integrated telehealth services, not only to healthcare

professionals but also includes all stakeholders. At this point we have developed various use cases to validate our work; however the complete study involving healthcare professionals and other stakeholders is the next step of this research. We further intend to extend this framework and deploy a pilot project to demonstrate the true potential of the BlockHeal framework.

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