Blockchain-based Enterprise Architecture for Comprehensive Healthcare Information Exchange (HIE) Data Management

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ABSTRACT

Timely clinical data exchange has been the primary function of Health Information Exchanges (HIEs). However, there have been growing needs for sharing public health related data among government entities. Because the primary stakeholders for public health data are different from clinical data, data are stored over multiple systems, making the retrieval of related public health data items a hard process. In such situations, blockchain technology may be used to connect and securely exchange those scattered data items. In this paper, we proposed an enterprise architecture (EA) for HIEs to adopt blockchain technology so they could store and exchange both clinical and other health related data for efficient general public healthcare management. With the proposed solution, HIEs can not only exchange relevant data items, but also securely manage, record, and transfer complete health records. In our approach, we have incorporated a Hyperledger Fabric (HLF) Network blockchain technology that utilizes Blockchain as a Service (BaaS) to enterprise architecture so that HIEs can manage comprehensive health data.

KEYWORDS

Health Information Exchange, Hyperledger Fabric Network, Blockchain Technology, Blockchain as a Service, Enterprise Architecture.

I. INTRODUCTION

Health Information Exchanges (HIEs) are geographically bounded institutions that facilitate the electronic transmission and management of patient health records. As patients move between health institutions within a specified geographic boundary, HIEs ensure that records are seamlessly transferred/shared. In the United States, there are several regional HIEs that serve different states. In most cases, these HIEs are sanctioned and funded by the State governments [1].

In most instances, local government health departments and government-sanctioned health institutions work with HIEs to ensure different health records are stored and can be made available when required. Health records can be categorized into one of the following functional groups: electronic medical records, administrative data, claims data, and patient and disease registries. Because of the frequency of health events, variety of data, and constraints related to data transfer, clinical data is stored separately from other health data. For most HIEs, the separation of different health data storages addresses challenges in transferring and managing complete data records securely.

Most health data are derived from and depend on clinical events. As patient clinical data is recorded, administrative data, demographic data, and health status data are extracted and aggregated as public health data [2], [3]. Adequately integrating the aggregated public health data with clinical data increases care coordination, improves patient outcomes, prevents the spread of diseases, reduces redundancies in health related activities, and advance health data management [4].

Blockchain offers a streamlined approach to ensuring that all patient data is adequately handled and transmitted. Because of its distributed peer to peer makeup, blockchain offers a highly fault-tolerant data architecture that can be leveraged to ensure data from different health institutions are well accommodated into systems [5]. By utilizing a Hyperledger Fabric Network (HLFN) blockchain architecture, HIEs can manage the sharing and transference of complete health data on a private blockchain network. Health institutions and affiliated local government health departments can participate in the same network to ensure complete patient health data is stored and managed.

By leveraging cloud computing services with Blockchain as a Service (BaaS), health institutions can easily develop the blockchain infrastructure required to participate in data sharing. BaaS also provides flexibility for small firms to participate in a blockchain network by only managing the patient health data without worrying about the whole blockchain architecture. Smart contract rules developed with the HLF blockchain architecture is a solution to ensuring that the right data is shared with the right organizations, departments, and institutions.

Enterprise architecture (EA) is a tool that allows organizations to identify and document their operations, goals, and technology capabilities to attain a holistic realization of a set future state. In the health industry, EA can be leveraged to attain inter-organizational improvements. EA is generally categorized into four domains: business, application, data, and technology. In this article, EA views are presented to illustrate and support the proposed architecture.

The rest of this article is organized as follows: section two provides a brief overview of HIEs, its importance, and how its leveraged to provide better health results. Section two also highlights blockchain technology and BaaS, focusing on how they can be implemented in healthcare.

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Lastly, section two quickly discusses EA as a tool for technology adoption. Section three provides a detailed literature review of previous work and research in the field. Section four presents an enterprise architecture that supports an HIE's Adoption of Blockchain Technology for the storage and transference of comprehensive health data. A Hyperledger Fabric blockchain network that utilizes blockchain as a service to store health patient health data into a single ledger is proposed. Lastly, section five concludes with a summary of the proposed solution, limitations of the research, possible future work and extensions, and acknowledgments.

II. BACKGROUND

A. Health Information Exchange (HIE)

Health Information Exchange organizations are established to provide a smooth transference of data between health institutions within a specified geographic location. HIEs are collaborative in nature and are designed to provide complete access to patient healthcare data when needed.

Depending on the local government where the HIE is established, healthcare providers (hospitals) and other affiliated health institutions may be mandated to share data with the local government through the HIE. In the United States, the development of HIEs has been greatly aided by federal government initiatives like the Office of the National Coordinator for Health Information Technology (ONC) and policies like the Medicare Access and Children's Health Insurance Program (CHIP) Reauthorization Act (MACRA) of 2015 [6].

Some of the benefits of HIEs include safe and secure sharing of vital patient and general health data including medical history, lab results, etc. Proper sharing of data reduces redundancies in patient testing and increases efficiency in patient care. An improvement in health data sharing is directly correlated to an increase in technology development and a high level of healthcare interoperability.

The development of HIEs is also at the forefront of the development of health technology standards. Because HIEs are established to promote interoperability between health institutions, its technology infrastructure must be designed to accommodate and facilitate the sharing of data. In the USA, the ONC work with HIEs, the health institutions they support, and other Health IT (HIT) institution to recognize a set of IT implementations as standards. Some of these standards are Clinical-Consolidated Document Architecture (CDA), Fast Healthcare Interoperability Resource (FHIR), Health Level 7 (HL7) v2 messaging, and Quality Reporting Document Architecture (QRDA).

B. Blockchain Technology

Over the past decade, blockchain technology has emerged as a viable solution for several use cases relating to privacy, efficiency, security, and interoperability. The development of blockchain has served as a catalyst for technologies like bitcoin and other technologies relating to business transaction recording, communication, and asset management. There has also been a great development around blockchain in IT specifically relating to networking and infrastructure, hardware, storage, and software [7].

At its core, blockchain, literally translated as a chain of blocks, is a distributed ledger of data. In most scenarios, data is presented as a set of transactions and is stored in a decentralized peer-to-peer network where each transaction is verified by all peers in the network. The distributed nature of blockchain technology allows nodes of a network to develop a consensus protocol where additions and changes are validated. Because of its data structure, blockchain records remain immutable as links to historic data and addresses of records before updates are stored [8], [9].

For blockchain data to communicate with conventional applications and databases, software and applications must be developed. Software Development Kits (SDK) and its corresponding Application Programming Interface (API) like Java and Node.js are usually implemented to facilitate the communication between blockchain and conventional systems [10].

Although blockchain by itself has tremendous benefits, there are few implementational challenges. Because blockchain data is immutable, its data storage, processing, and equipment maintenance tend to be expensive. Also, because it uses consensus protocols to validate data, standard blockchain architectures tend to be inefficient, hard to scale [11], [12].

Hyperledger Fabric Network is an implementation of a private blockchain architecture that looks to resolve some of the challenges in implementing blockchain. This scalable and secure permissioned network allows organizations to share blockchain data on a ledger with permitted members of its network [12]. With HLF, only the right organizations can access and process health data. This addresses processing and inefficiency issues standard blockchain architectures present. Although members of a hyperledger fabric network can maintain its own infrastructure to maintain a form of privacy, blockchain data shared with the HLF channel remains visible for all permissioned parties [5]. A channel is a term to describe a specific group which members of an HLFN belongs.

In an HLF, organizations and institutions represented in a channel are referred to as peers, nodes, or members. Members and nodes are added to and removed from HLF networks by a Membership Service Provider (MSP). An MSP serves as the administrator of the HLFN and is responsible for validating membership identities and verifying transactions to ensure that all updates and queries can be trusted.

Blockchain as a Service is a cloud-leveraged service offering where blockchain components can be outsourced to a third-party provider for external management. With BaaS, blockchain data storage and analysis, blockchain SDK or application hosting, blockchain compute infrastructure, or the overall administration of the blockchain network can be outsourced to a cloud provider for management. BaaS provides organizations with the cost and flexibility required for blockchain adoption [13].

By combining the benefits of hyperledger fabric networks and blockchain as a service, health information exchanges and the organizations they service can leverage blockchain technology to solve health data management challenges it currently faces.

C. *Enterprise Architecture (EA)*

Enterprise Architecture is an asset for technology development. It is considered the fundamental concept in the design of a system, its structure and relationships, and principles of evolution. It creates an overview of an enterprise and provides a bird's-eye view of its business processes, applications, data flows, and technical infrastructure. EA frameworks are blueprints and pre-designed architectures that can be institutionalized to fit an organization. Frameworks generally predefine which elements should and should not be part of an architecture. It also describes architectural components, its relationship with other components within an enterprise, and how they affect different architectural layers, domains, and views.

Using EA, organizational processes, applications and data systems, and IT infrastructure can all be diagrammed and mapped to a future desired. EA can also then be used to outline a roadmap to achieving the identified state. According to Shank et al. 2016, organizations spent about $3.49 trillion on information technology. Such investment requires that IT is well-positioned to support business strategies. IT provides a clear path to accomplish such goals.

Architectural Modeling

One of the purposes of architecture is to detail the specifications and components of a system. To adequately communicate the different domains and aspects of architecture, standard communication languages must be used. ArchiMate, Universal Modeling Language (UML), and Business Process Modeling Notation (BPMN) are used to describe the proposed architecture.

Modeling languages are classified into two levels, high-level, and low-level. High-level languages and low-level languages are classified based on their architectural level of detail.

ArchiMate is considered a high-level EA modeling standard because it provides an overarching architectural view of an enterprise or a system. Using ArchiMate, enterprise architects can provide a complete model of an enterprise including its business processes and functions, data components, applications and interfaces, and infrastructural tools and services [14]. The proposed architecture only focuses on the infrastructure (technology) and data (information systems) domains of architecture using ArchiMate. Business and application (information systems) domains are modeled using BPMN and UML.

Low-level modeling standards generally exposes a greater level of detail. Depending on the artifact being depicted, low-level languages like BPMN and UML diagrams can provide domain-specific insight into a system or an enterprise. BPMN is a universally accepted process modeling language. Although BPMN provides a uniform notation for modeling business processes, the standard can be used for application and infrastructure components when modeling business processes and activities [15]. The BPMN diagrams presented in this article represent a combination of application, business, and infrastructure processes.

UML is the most widely accepted modeling standard in the industry. UML's multipurpose use ranges from system design, specification, and construction to general architectural visualization and documentation. UML has 13 sublanguages that can be categorized into three types of diagrams, behavior, structure, and interaction (implementation) [14], [15]. For this article, a sequence diagram is used to illustrate HLF application component interactions.

III. Related Work

There have been major developments in the application of Blockchain technology since its first application with Bitcoin in 2009. Its immutability provides a great level of traceability and security.

In the healthcare domain, there has been a lot of work in the development of Electronic Health Records (EHRs) and healthcare-based storage systems. Whether health systems are designed to manage administrative data, clinical data, or demographic based health data, structural and semantic improvements have been made to ensure that health records can be properly stored and shared.

The introduction of cloud technologies into the healthcare industry has facilitated the development of HIE and blockchain-based tools. These tools have also resulted in the development of integrated tools. Below is a highlight of previous work relating to healthcare-based blockchain technologies.

K. Peterson et al. [8] proposes a blockchain-based health information exchange network where institutions can share patient information. Using FHIR, sensitive patient records are kept out of the blockchain ledger and Uniform Resource Locators (URLs) are used as a reference for every transaction. FHIR is a well-accepted health standard for exchanging and sharing data. This standard has facilitated the development of applications and APIs health institutions can use to share health data. This solution, along with other EHR-based solutions alike lacks the privacy and security robustness a private, permissioned network may present as discussed in N. Tariq et al. [16].

Blockchain-based EHRs facilitate the storage and sharing of health records. It also enforces a high level of security and auditing as needed. A. Ekblaw et al. [17] discuss MedRec, one of the more popular Blockchain-based health systems. The decentralized management system provides a comprehensive means of handling health data using blockchain. Other health organizations and public health authorities were incentivized to participate in the public blockchain network forming a multi-institutional electronic health record. As discussed in R. Angeles et al. [18], researchers do not account for diversities in the technology infrastructure. This proof of work pre-supposes that members of the blockchain network all share similar blockchain infrastructures. Also, since blockchain is implemented on the public ledger, there are major privacy and security concerns even though smart contracts are used for authentication.

R. Angeles et al. [18] also introduce Patientory and the SAP/CryptoWerk Alliance, cloud-based blockchain solutions. AmerisourceBergen and Merck Co. are pharmaceutical companies that have worked together to leverage blockchain technology in their medical supply chain management. This solution connects to private, public, and hybrid networks using an interoperable SAP-based blockchain solution called CrypoWerk. This solution provides a high level of interoperability between pharmaceutical organizations that participate in the blockchain network. For AmerisourceBergen and Merck Co, SAP/CryptoWerk is leveraged as a BaaS. This solution has limitations because it is limited to supply chain management, administrative data, and is industry-specific.

There has also been a great deal of work in the development of Personal Health Records (PHR). With blockchain technology, patients can access and manage their health data and share health records with health institutions as needed. Patientory is a blockchain-based Software as a Service application that focuses on PHR. With Patientory, users can collect health data from traditional and non-traditional sources and store them in a blockchain ledger where patients can view and share data with health institutions as needed. Because Patientory uses a permissioned Ethereum blockchain, patient data is secure and privatized [18]. This work can be furthered to consume and store more data types as well as include more clinical institutions as needed.

IV. Hyperledger Fabric Network Leveraged Blockchain Architecture

Using Hyperledger fabric blockchain technology and leveraging blockchain services over the cloud, we propose an architecture that HIE's can use to address data management issues when serving different health institutions and governmental departments.

In this section, we discuss the architectural makeup of the proposed solution, first from the HIE and health institution viewpoint, and then from a Blockchain as a Service Cloud provider viewpoint. Figures 2 and 3 will be used to illustrate their corresponding views.

A. Proposed Hyperledger Fabric Network Architecture

The diagram below provides a general illustration of the proposed HLF architecture.

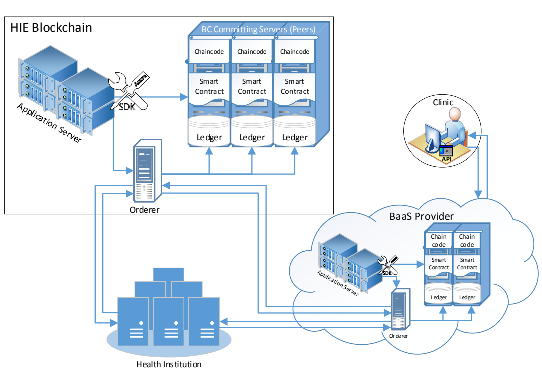

Fig. 1. HIE-based hyperledger fabric architecture

Conventionally, health institutions, hospitals, and government health departments alike have native applications and systems they use to manage their health data. Outside of blockchain, HIEs must work to interact with these different systems to pull and share data when needed. In the proposed health blockchain architecture, a familiar SDK can be used to translate health data from its standard form to blockchain. Figures 4, 5, and 6 provide details on how this performed.

In this architecture, HIEs serve as the MSP. HIEs will validate the addition of different institutions into the HLFN. They will also verify every transaction based on the agreed consensus mechanism to ensure that the right data is stored on the right nodes. S. Hasavari et al. [5] provides great details on the roles of MSPs and how private keys can be used for user membership validation and transaction endorsement in an HLF environment.

Conventionally, HIEs will have the on-premise resources needed to host a blockchain infrastructure locally. Because cloud providers offer a great level of flexibility and cost management, complete blockchain architectures can be hosted in the cloud.

Much like HIEs, large health institutions and hospitals can host the HLF infrastructure on their servers on-premise. Hosting blockchain on-premise provides a high level of control and management, especially with how conventional systems relate to blockchain. An on-premise blockchain infrastructure can also speed up the process of updating and querying blockchain records locally from conventional systems.

For smaller health institutions, government departments, and clinics who cannot afford the cost related to hosting blockchain locally, some cloud service providers offer BaaS. With this service, these users can interface with blockchain systems on the cloud using an API. Using common local applications like a web browser, users in a clinic and subscribe to and pay for blockchain services in the cloud. Figures 2 and 3 provide illustrations and more details on this can be implemented architecturally.

As illustrated in Figure 1, the HIE hosts the blockchain infrastructure on-premises. All local blockchain networks consist of committing nodes, orderers, and an SDK to present data to users. Committing nodes are responsible for storing blockchain data whether data is stored on-premise or in the cloud. Blockchain data is stored on a ledger and different patient records are stored on separate ledgers.

Committing nodes also house chaincode and smart contracts. Chaincode is an executable that sits on committing nodes to determine how conventional applications interact with blockchain data. Chaincode usually contains some business logic through which data update and query triggers occur. Smart contracts are also executables that sit on the blockchain containing business logic to determine which data needs to be added to the blockchain ledger. For each transaction, the smart contract is important for authorization and access provisioning [9].

Orderers sit at the edge of blockchain networks. They are configured to determine which records should be added to the ledger. The orderers interface with other members in an HLFN and the MSP in query and update transactions. Consensus mechanisms occur here.

Smaller organizations like clinics that lack the infrastructure and financial resources to host blockchain on-premise can leverage BaaS. BaaS components like committing nodes and orderers will be configured to connect to the HLFN so that end-users at clinics can view data via web browser APIs.

B. HIE and Health Institution Blockchain Implementation

Using ArchiMate, we illustrate how HIEs and health institutions can be constructed to leverage Blockchain as a Service in a hyperledger fabric blockchain network.

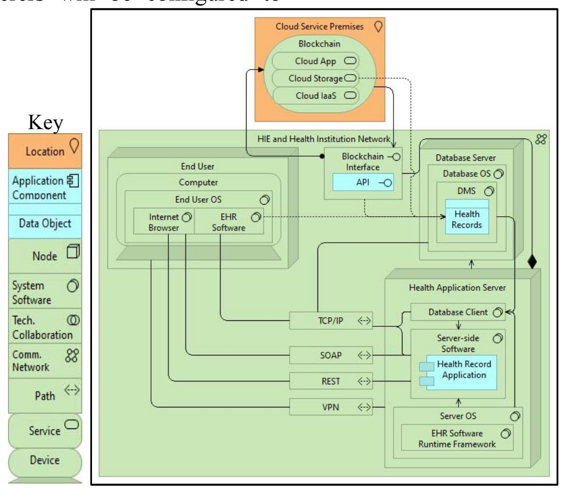

Fig. 2. BaaS-leveraged HIE and health institution architecture

As seen in the image above, HIEs and related health institutions are usually structured in a server-to-client relationship where end-users connect to EHRs or related health info systems via endpoint client software, application, or via a web browser. Using web services like SOAP and REST, or other network communication mechanisms, endpoint applications can access or store records to EHR/health application databases. Health database systems are designed to serve their specific EHR or health application [19].

As an addition to this design, interface systems are inserted into the existing architecture to support the use of blockchain technology. For the proposed design, a blockchain interface carries an API that allows HIEs or participating health institutions to connect to a cloud service provider or a blockchain service provider. The following section further explains service provider roles in the application of the architecture.

C. Blockchain as a Service Hyerledger Implementation

Cloud service providers like IBM, SAP, AWS, and Microsoft Azure provide a suite of services and tools that can facilitate the development of an HLF network. Typically, organizations that implement blockchain using a third-party provider either require the infrastructural services required to build a blockchain-based organization from the ground up. In other scenarios, organizations may only require singular blockchain storage components or blockchain-based application components [20]. Below is an illustration of a BaaS provisioning infrastructure.

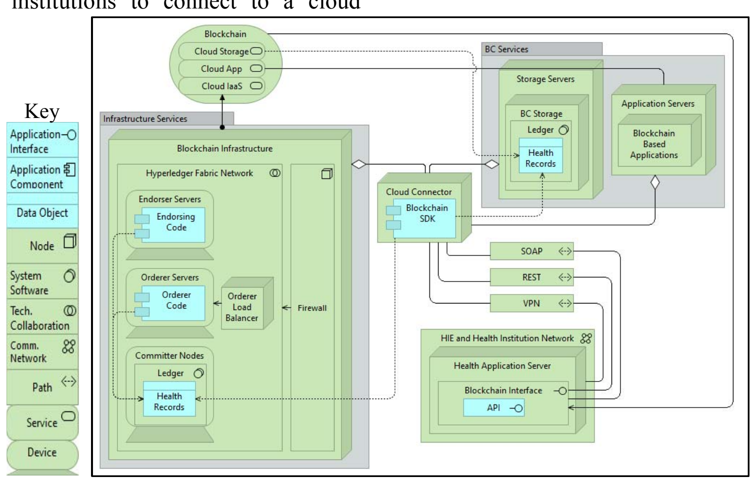

Fig. 3. BaaS Data and Technology Architecture for HLF

Primarily, cloud service providers can provide platform services like storage components or development tools to facilitate the development of blockchain-based applications and systems. In other scenarios, organizations like SAP provides blockchain specific software for data transfer, management, analytics, etc. [18]. These blockchain software services can be leveraged individually whether platform services are leveraged or not. Any cloud-based service provisioning that allows organizations to utilize blockchain technology can be called BaaS.

With a cloud service provider's Infrastructure as a Service provisioning, HIEs and other health institutions that may need computing and network tools can leverage cloud resources to build a blockchain network from the bottom-up. A thorough EA organizational analysis is required for a health institution to determine if its HLF infrastructure should be BaaS based or IaaS based.

In the proposed architecture, we illustrate how HIEs and health institutions can leverage Infrastructure Services or Blockchain Services to participate in an HLF network. From a service provider's viewpoint, connectors must be made available to HIEs and health institution interfaces whether through web services or other means (VPN, etc.).

Blockchain services must be separated and highlighted. In Figure 3, an IaaS-based HLF service provision could include endorser servers, committing servers, orderer servers and its related load balancers, and any other network components that could be needed. We use a Firewall to illustrate potential network components. Organizations that leverage IaaS have greater design and development flexibility.

For BaaS-based services, blockchain applications and storage components are presented. With the proposed architecture, a health organization can leverage specific blockchain services as needed. BaaS provides organizations with great scalability because cloud services can be easily added or removed.

D. HLF Health Record Updating

To update an individual's health record, conventional health records will have to be translated to blockchain data to be transferred to HIE and other health institutions as needed. Figure 4 illustrates the process in detail.

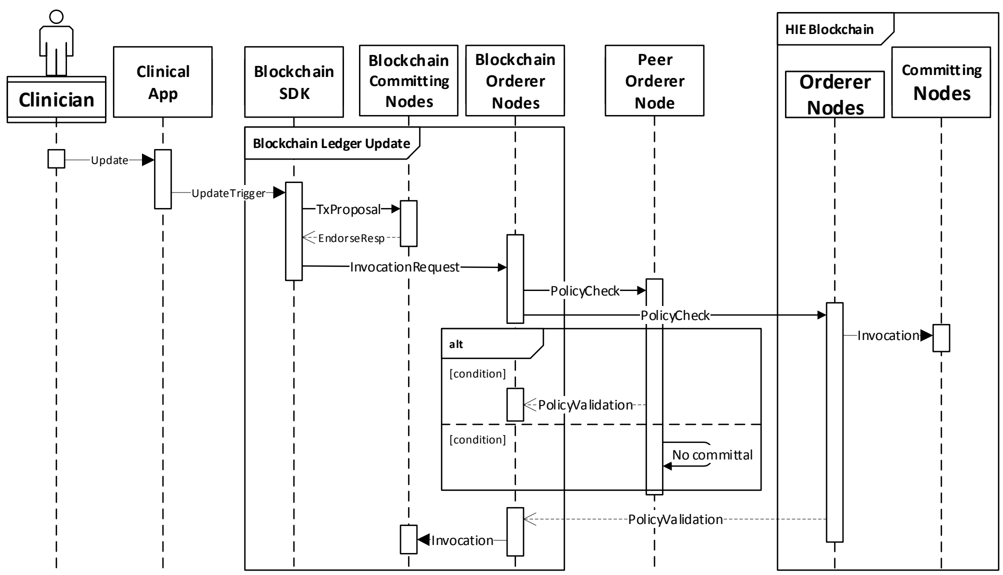

Fig. 4. HLF Record Updating Sequence

Sequence diagrams like the figure above are used to depict system or software interactions in sequential order. For a patient record to be created or updated, a clinician must perform an update operation to a health system. For this illustration, the health system is called clinical app. The update operation commences the HLF Health Record Update process.

After an update is made to a health record, a trigger is initiated to commence blockchain processes. A transaction proposal is created by the blockchain SDK to committing nodes. A response is sent from committing nodes to SDK to confirm the commencement of the blockchain committing process. An invocation request is sent by committing nodes to orderer nodes. Orderer nodes sit at the edge of an HLF local network and are responsible for communicating with the MSP (HIE) and other orderer nodes from different organizations to determine if blockchain data should be stored or transaction entry should be discarded.

The Process of determining whether blockchain data should be edited or discarded is performed with a policy check and a policy validation operation. Depending on the consensus protocol agreed upon in the HLF network, transactions could yield a policy validation, or the transaction could be discarded. Every policy check operation occurs at the MSP (HIE) and orderer nodes from organizations that carry the patient records.

Although endorser nodes may not be necessarily used in an HLF implementation, these nodes can be used as a preliminary reviewer for blockchain transactions. Endorser nodes can sign transactions and convert them to a read/write (r/w) set before data is sent to orderer nodes [5]. Figure 6 in Appendix A further illustrates the record update process.

E. HLF Health Record Querying

Using a BPMN, we highlight the major processes needed to create a request on a conventional health system and trigger a blockchain query process in an HIE-based HLF network.

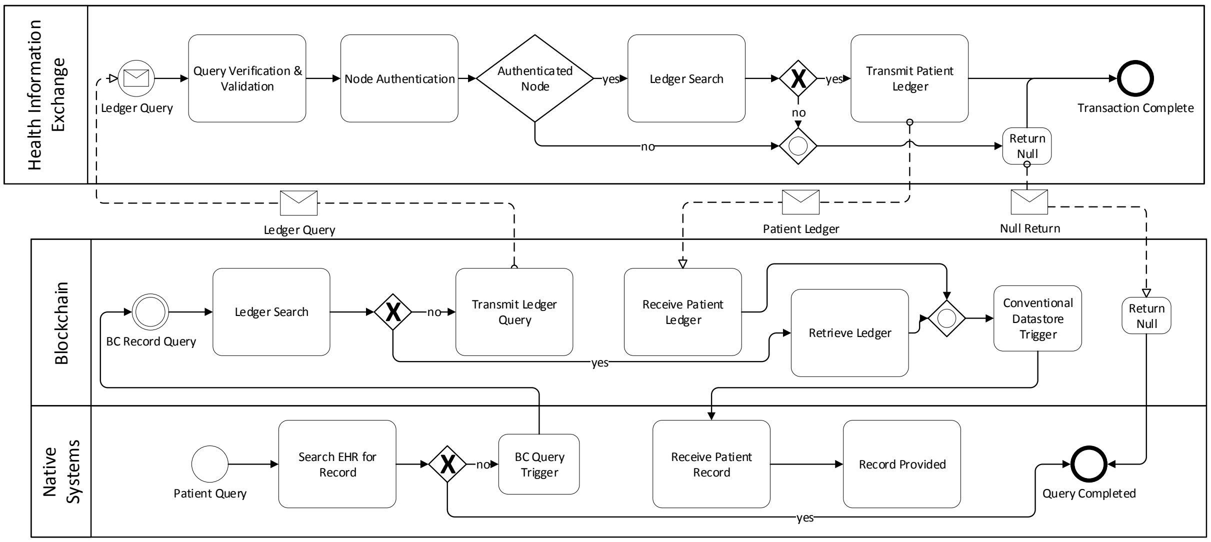

Fig. 5. BPMN for HLF Record Query

To commence the process described above, a clinician or a health admin searches for a health record. The record search process includes a comprehensive search of the native health system database. If the record is found, the query process will be completed. If the record is not found, the blockchain query process takes place.

Once the conventional health systems search fails to return a value, a null value return triggers a blockchain query to the organization's HLF committing nodes. If a user's data is unable to be found in any of the blockchain ledgers, an external query is initiated on the HIE's blockchain network.

Since HIEs in the proposed architecture carry all patient data within its blockchain infrastructure, health institutions within the HLF network can query patient ledgers to find needed health data. Once an HIE receives the blockchain query, a query verification is followed by a node authentication process to ensure that the right data is being requested by an authorized institution. After the node authentication process is successfully completed, the HIE's ledger is searched to find the patient's record. The patient's authorized blockchain data is then transferred to the requesting institution's blockchain infrastructure to be converted into a conventional format readable by the institution's health system. Any errors in this process will be recorded and will prompt a null return to the conventional health systems.

V. Conclusion

We have introduced an enterprise architecture that helps HIEs to adopt blockchain-based technology by utilizing Hyperledger fabric network (HLFN) and Blockchain as a Service (BaaS). With HLFN and BaaS, HIEs can store and manage comprehensive health data efficiently and securely. In this architecture, HIEs serve as the membership service provider and the administrator in HLF delivery. Along with the proposed architecture, artifacts illustrating Update and Query processes are presented. The proposed enterprise architecture allows HIEs to incorporate public health data and related data with existing clinical health data for complete healthcare management.

Future Work

As future work, authors are looking to prototype and implement the proposed architecture. Due to healthcare policies currently in place, a stronger evaluation of the proposed architecture is required to ensure a change to the existing system enhances health results. Once a complete system is developed and implemented, a test of robustness is highly recommended to ensure there is a high level of security and interoperability.

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APPENDIX A

This section contains an extension of section IV D and figure 4. The BPMN is an extended representation of the record update process in an HLF network where HIE serves as the MSP. Processes in this diagram occur between a sample HIE and two different health institutions, sender and recipient

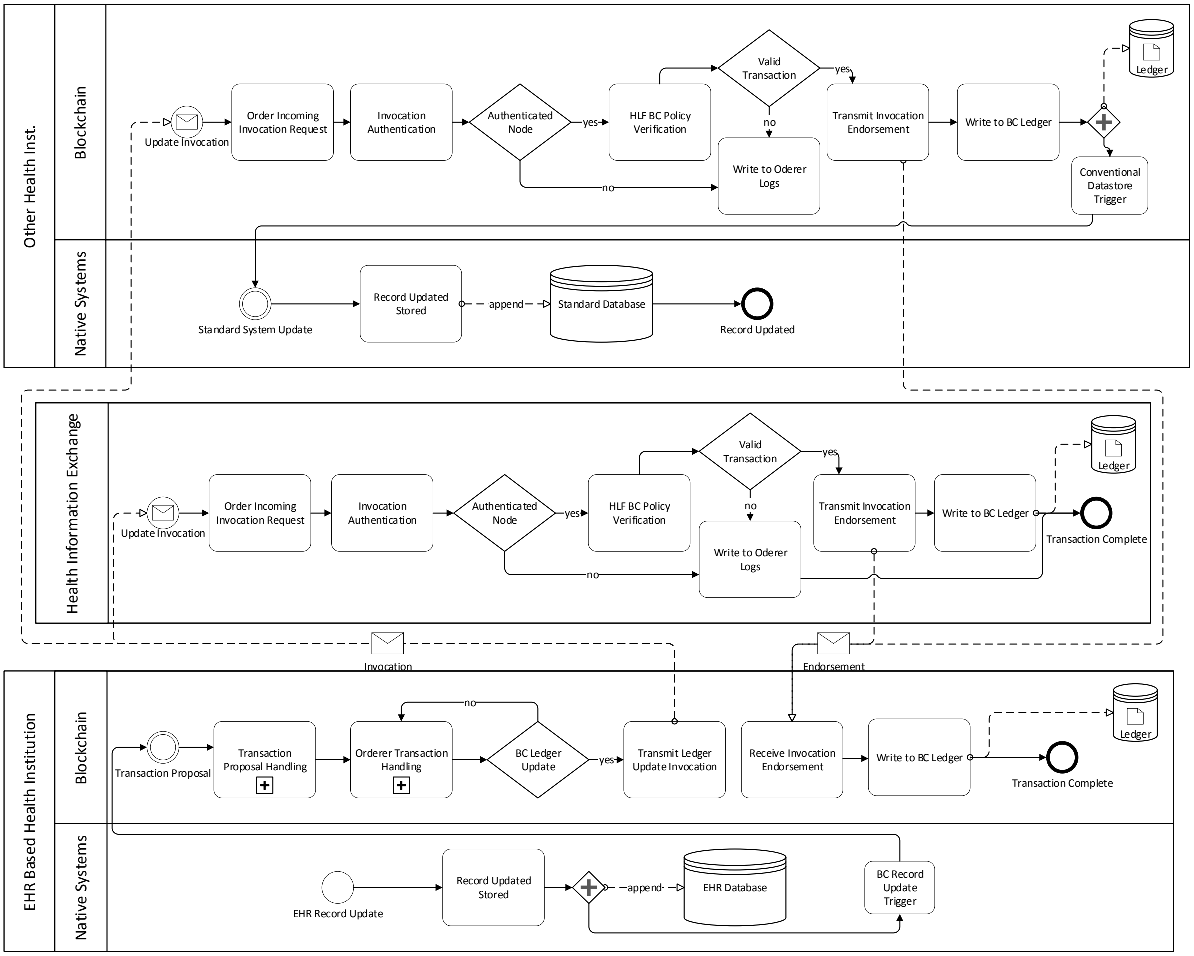

Fig. 6. HLF Record Updating BPMN

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