Advanced Block-Chain Architecture for e-Health Systems

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***Abstract*—This paper describes our blockchain architecture as a new system solution to supply a reliable mechanism for secure and efficient medical record exchanges. The Advanced Block-Chain (ABC) approach was designed to meet the demands in healthcare growth as well as in the new form of social interactive norms. It is going to revolutionize the e-Health industry with greater efficiency by eliminating many of the intermediates as we know them today.**

Keywords- e-Health system; reliability; security; blockchain; architecture; smart and connected; conformance; audit and tracking

I. INTRODUCTION

The purpose of our e-Health research program is to develop next generation healthcare digital service solutions to improve patient outcomes, decrease costs, and address the complexity of challenging e-Health problems in security, reliability, efficiency and flexibility. As demands of healthcare spending outgrow many countries' GDPs, there are urgent needs to adapt the e-Health technological services to meet the demands not only in numbers but also in improvement of social interactive norms.

Recent advancements in e-Health research [1] have enabled interoperable and scalable networking, applications, and services for effective sharing of electronic health records, flexible data representation including semantic metadata, and more efficient services that access such health data.

However, the integrated view of overall global care outcomes, over-prescriptions and billing integrity cannot be easily addressed by the traditional e-Health architecture solutions as they are more focused on the needs of clinical/hospital/lab usages. To optimize the accountability of the e-Health usage data, a new solution direction is necessary to enhance audit access of e-Health data while balancing it with government mandates in privacy and security.

The new approach in this paper is to explore the Advanced Block-Chain paradigm [2] for e-Health record keeping and while addressing the special needs of patient privacy. As society is moving towards peer networking and on-line practices, we are going to combine the best parts of two worlds in both the healthcare regulation and the technology revolution while formulating advanced solutions.

This paper is organized as follows. In section II, we describe our overall e-Health architecture evolutions. In section III we explained the Block-Chain approach in the context of e-Health requirements and mandates. In section IV, we layout our ABC (Advanced Block Chain) design of the overall architecture that supplements the context management capabilities, regulatory compliance, and collecting e-Health meaningful usages. The final section concludes with a summary of our contributions.

II. E-HEALTH ARCHITECTURE DEVELOPMENTS

We have experienced the rapid changes in e-Health technological solution for interconnection services. While the fundamental DHC (Digital Health Care) architecture [3] was originated from the Service Layer solution over networked e-Health systems, the detail design have evolved from network interoperability solutions and e-Health security framework, to cloud-computing as well as fast development platforms [4,5,6].

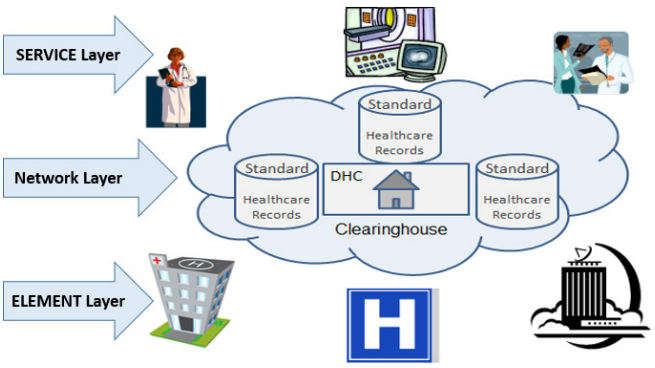

Figure 1. e-Health interconnections

Among the many functions of a continuously scalable universal exchange for current and future e-Health with data originating from diverse sources in multiple formats, key advance processing methods are required for 1) controlling and maintaining data integrity, provenance, security, privacy and reliability; 2) providing trustworthy patient identification and authentication and access control protocols; and 3) maintaining sensitivity to cultural, legal and ethical issues associated with universally accessible e-Health data.

One example of advanced architecture development is in Smart and Connected e-Health Service [7]. It was designed

with context-aware networking capability allowing that any application-oriented services will push the security policies down to the network layer. The access devices and their adaptor gateways are regulated with the e-Health security scheme to facilitate dynamic fork/join of the e-Health network flows. Cross-layer management further provisions with centralized security service management to guarantee the cross-layer performance as well as security assurance.

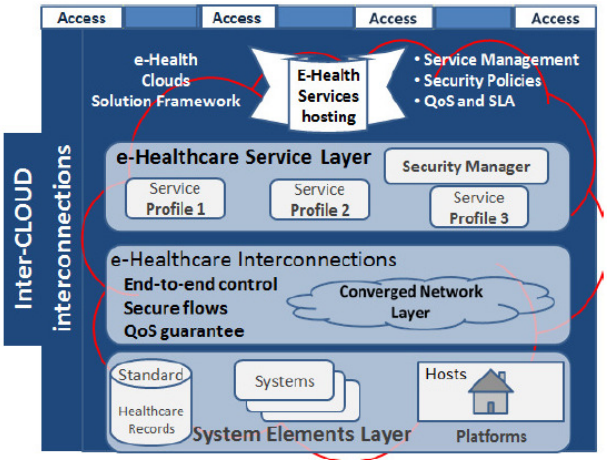

Figure 2. Smart and Connected Secured e-Health Clouds

Another major architecture advancement is the BDeHS [8,9] approach for big data e-Health model that provided trustworthy patient identification and authentication and access control protocols, maintaining the sensitivity to the legal, cultural and ethical issues associated with universally accessible e-Health data of variety of types (structured, semi-structured and unstructured) from variable data sources, including

- HL7 (Health Level 7) well-structured messaging [10,11];
- NCPDP (National Council for Prescription Drug Program) prescription insurance claims and NCPDP SCRIPT for electronic prescription messaging [12];
- DICOM (Digital Imaging and Communications in Medicine) semi-structured data for radiology image exchanges over IP networks [13];
- ISO/IEEE suite of protocols and messaging standards for digital health monitoring and diagnostics devices [14];
- HIPAA transactions for insurance claims and other privacy and security regulation standards [15,16];
- Internal e-Health system logging and security audit records with semi-structured data as far as end-to-end system flows are concerned; and
- Operational data including security events and usage accounting/charging functions.

While most of these system architectures could be preserved for a blockchain environment, the external data links and communication format will be totally revamped into blockchains. We called our new solution Advanced Block-Chain (or A.B.C.) e-Health architecture solution.

III. E-HEALTH BLOCK-CHAIN FUNDAMENTALS

In the context of e-Health, a blockchain maintains a sequence of care records, lab activities, prescription dispense, insurance billings and other supporting activities involving patients, healthcare service providers and supporting organizations. Inside a continuously growing linked list of medical records, each block contains a timestamp and a link to a previous block.

The first blockchain was invented by Satoshi Nakamoto in 2008 [2]. Functionally, a blockchain can serve as an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way. The ledger itself can also be programmed to trigger transactions automatically.

After a successful implementation in the Bitcoin transactions, the design of a public ledger for all transactions has been the inspiration for other applications such as automatic legal services, insurance processing and even supply chain tracking of merchandize. All require to solve the security integrity problem, while without the use of a trusted authority or central server.

Before we describe our architecture design, let us review some technical features [17, 18] in the contexts of blockchain e-Health flows.

A. *e-Health Block Chain*

The key concept is an e-Health transaction which is re-defined as any occurrence of healthcare record generation, submission and exchange. This broad concept can cover EMR, EHR, e-Prescribe, a Lab request and report including simple blood test and complex DICOM files, as well as insurance billing and payment.

The e-Health Block Chain constitutes all published care related transactions in the block format, each linking to the previous block and linked to by the next e-Health block.

B. *Distributed Database*

Each party on a blockchain has access to the entire database and its complete history. After the e-Health data is posted and validated, no single party controls the data. Because the open access to the e-Health blockchains, correlations between records will pave new ways for medical research and pandemic or epidemic reporting. The whole society can benefit from this architecture arrangement.

C. *Peer-to-Peer Transmission*

Communication occurs directly between peers instead of through a central node. Each node stores and forwards information to all other nodes. In healthcare activities, the patients and service providers' records no longer have to be shuffled around via a huge admin center or insurance. Instead each party posts the activities involved to the e-Health blockchain. Once they are validated and agreed upon via the blockchain protocol, the admin center and insurance companies become a pure consumer of the original e-Health

activity blocks. Of course, the insurance payments could form their own blocks outside the healthcare one which are the center of the next generation e-Health solution.

D. Transparency and auto tracking

Every transaction and its associated value are visible to anyone with access to the system. Each node, or user, on a blockchain has a unique 30-plus-character ID that identifies it. Users can choose to remain anonymous or provide proof of their identity to others.

Every party can verify the records of its transaction partners directly, without an intermediary. Audit of care services become feasible by all interested parties. Excessive cure procedures or abusive consumption of healthcare resources can be detected by constantly mining the public e-Health blockchains.

E. Irreversibility of Records

Blockchains are secure by design and are an example of a distributed computing system with high security fault tolerance. Blockchains are inherently resistant to modification of the data, because the data in any given block cannot be altered retroactively without the alteration of all subsequent blocks and the collusion of the network.

Once a transaction is entered in the database and the accounts are updated, the records cannot be altered, because they're linked to every transaction record that came before them (hence the term "chain"). Various computational algorithms and approaches are deployed to ensure that the recording on the database is permanent, chronologically ordered, and available to all others on the network.

F. Computational Logic

The digital nature of the ledger means that blockchain transactions can be tied to computational logic and in essence programmed. So users can set up algorithms and rules that automatically trigger transactions between nodes.

The embedded procedures cover security audits, regulation compliance reporting, billing updates, medication allergy alerts, over-prescription thresholds and personalized medicine tied-in to a specific patient cure blockchain.

IV. E-HEALTH BLOCK-CHAIN ARCHITECTURE

Decentralized consensus is achieved with a blockchain, which makes blockchains potentially suitable for the recording of medical records, treatment events, patient identity management and documenting provenance. However, there are additional hurdles to overcome when an e-Health application is riding directly on a classical blockchain implementation of care record distributions.

A. e-Health Blockchain Protocol

These blocks can contain **any subset and combinations** of the existing HL7 messages, Lab LOINC codes, ICD codes, e-Prescribe as well as the block ID and corresponding signatures from the e-Health service providers and/or the patients acknowledging to the acceptance of care. Figure 3 below is an illustration of the e-Health block that can be further woven into multiple dimensional blockchains as illustrated in Figure 4.

Healthcare service providers (SP) applies digitization of fast e-Health resources and publish available records during transfer of ownership in handling patient cares, so cares can be conducted at a speed more in line with the pace of doing e-business.

Through the use of IDs and permissions, patients can specify which e-Health record details they want others to be permitted to view. Permissions can be expanded for government agencies and auditors, who may need access to more healthcare detail. Having a shared blockchain that serves as a single source of truth improves the ability to monitor security and audit the cares.

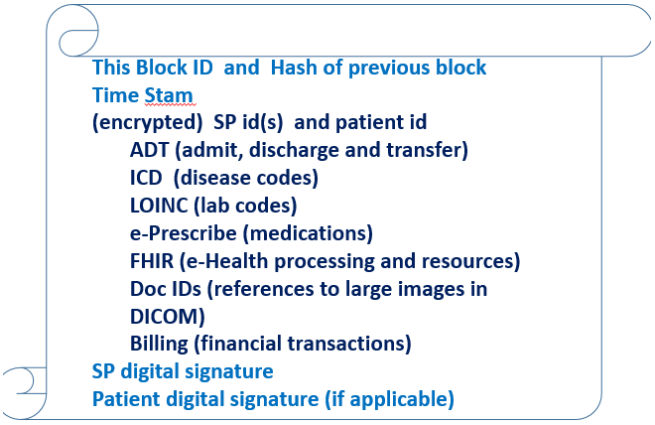

Figure 3 e-Health block solution

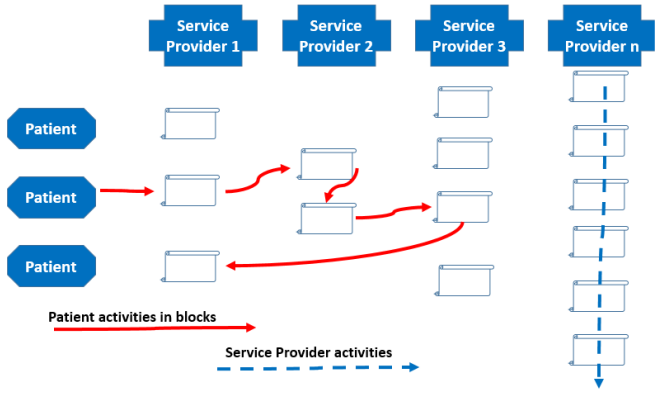

Figure 4. Advanced Block-Chains

In the figure 4 above, there are two dimensional processing threads for the e-Health blockchains. The patient initiated chains forms the information equivalent to the currently know EHR (Electronic Health Records) yet in a total different format (i.e., in the e-Health block format with additional block ID and initiating parties' digital signatures). On the vertical processing threads are the e-Health blocks as processed by the service providers for their rendered treatment services. Each blocks have to be signed by all involving parties before posting. And they are validated by the e-Health blockchain protocol.

While the above figure only shows a two-dimensional blockchain structure, a multiple dimensional blockchain are conceivable when we adds regulatory processing flows and other conformance requirements. Additional system level components will be shown on next page, after the key e-Health blockchain functions are described.

B. Inter-Domain Adatations

Before each party issues an e-Health record to document the activity, adaptations into a common block syntax is required for healthcare service providers and patients alike to post those blocks.

While traditional e-Health element platforms may be used by the blockchain to augment processing. They now have to be augmented via adaptation gateways such that requests and responses can become part of the blockchain. Existing data systems may provide data to influence the behavior of smart contracts and help to define how communications and data transfer will occur between traditional applications/data and the blockchain via gateway API calls through an e-Health cloud.

C. Certificate Authority and Security Operations

Before any party can participate in the blockchain, it has to be certified and be issued with an authenticated certificate. A security manager in the e-Health blockchain cloud will constantly monitoring the security with a predesignated domain.

While the e-Health blockchain usually operate without intermediary intervention, a regulated operational authority can still be instituted. When there are any occasionally non-convergence in blockchain reconciliation as demonstrated in the 2014 Bitcoin (i.e., occurrences of inconsistent and non-convergence transaction records), the e-Health services industry cannot simply rely on the faith of the underlying blockchain protocol to resolve. Since timing is the essence in most of e-Health services, especially in accurate care scenarios.

D. Regulatory Conformance

The e-Health blockchain enhances the privacy as required since HIPAA [15, 16] and facilitates regulatory conformance. Through the use of IDs and permissions, patients can specify which e-Health record details they want others to be permitted to view. Permissions can be expanded for government agencies and auditors, who may need access to more healthcare detail. Having a shared blockchain that serves as a single source of truth improves the ability to monitor security and audit the cares.

E. Advanced Blocck-Chain (ABC) e-Health Engines

Unlike the passive adaptation gateways that mechanically translate with the e-Health blockchain protocols, the ABC e-Health engines provide health-specific logic to trigger smart transactions defined as a proven treatment procedure flows with maximize automation in mind.

This is where the AI (artificial intelligence) and machine learnings are integrated with the blockchain technology for decision making and collaboration. The engine provides the essential supports to other functional blocks in:

- adaptation rules,
- orchestration of service logics,
- API abstraction virtual machine,
- decision rules and processing supports,
- regulatory compliance rules to drive other additional services such as reporting, discovery and research.

F. e-Health Value Added Systems

Additional value-added service systems are derived from accessing to the SP-and-patient identities with voluntarily disclosure. For example, a supporting entity such as insurance may obtain identification information and extract and process the e-Health blocks as referenced by a billing block chain without the physicians to submit billing requests as in existing flows. These activities are in turn automatic because of the computational logic in e-Health blocks automatically trigger billing processing and payment transactions between nodes in insurance and in a doctor's office.

As another example, various reporting services can be supplied when working with the ABC e-Health service engine after appropriate compliance rules are provisioned and constantly updated. Additional value added applications can be extended to health care research and discoveries.

The following figure 5 summarizes the key components as a system solution.

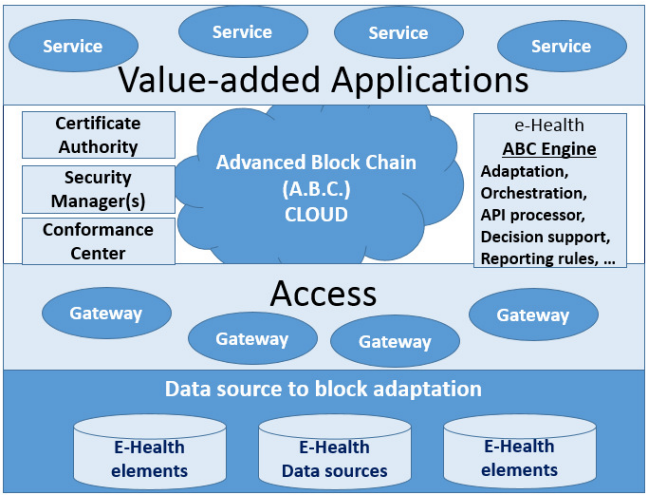

Figure 5. Advanced Block-Chain Systems

Besides the patients and service providers described earlier, additional participants on an e-Health blockchain network play a role in its operation. An e-Health blockchain regulator attends special permissions to oversee the records happening within the network. Blockchain developers create the e-Health application services and smart e-Health contracts that follow the healthcare flows. The e-Health blockchain operators have special monitor the blockchain network. Last but not least, the Certificate authority issues and manages the different types of certificates required to

run a permissioned blockchain either for blockchain users or to individual transactions.

V. BENEFITS AND LIMITATIONS

The key benefits of adopting an Advanced Blocked-Chain e-Health architecture approach are in many folds.

The opening of accountable treatment records and insurance billing records sets new cost-effective analysis and place them directly into the hands of the public. Our solution provides auditable e-Health records while preserving patient privacy and security. Medical researchers are open to access the vast e-Health blocks, while government and regulatory agencies are given additional identifiers for audit and conformance purposes.

The large number of developers as well as the high interest levels in the industry will eventually push the blockchain technology into a well-accepted mode of operation into the e-Health territory. Our solution is a good attempt to further improve efficiency and reliability as inherently derived from the nature of blockchains.

With computational logics to be embedded to the e-Health blockchains, additional personalized medicine is enabled by the complete and consistent data blocks available for all service providers involved. The e-Health Advanced Block Chain engine stands ready for the embedded security audits, regulation compliance reporting, billing updates, alerts from lab results and medication events. Innovative healthcare flows with e-Health devices will eventually emerge from the new e-Health blockchain practices.

Enabled by the readily available blockchains of e-health records to advise, monitor and intervene, a number of healthcare service professionals can adapt their career paths into e-Health "Quality Assurance" workers while AI (Artificial Intelligence) technologies are automating more and more treatments and lab works. The automation using ABC (Advanced Block-Chain) architecture in turn creates more new types of e-Health professional jobs that are not there today.

Yet a number of unknowns can still potentially limit the fact and wide spread of this solution approach. The first one is in the regulation of the public blockchain concerning uniform rollouts and leveling the fields. We recommend that the regulators should keep up with the technological development advances and begin to address any conformance concerns without further delay.

Another potential limitation is the cost of implementation in a wide rollout of this disruptive technology. This concern is alleviated with the understanding that the industry has pooled resources in creating reusable blockchain implementations. A number of developed nations and wealthy multi-national corporations can lead in the realization of the Advance Block-Chain e-Health architecture solution. And the ABC e-Health offerings can be extended to anywhere around the globe with internet coverage.

Finally, how to migrate existing e-Health records into the new ABC block structure is still an open problem that requires additional research and development. The capture of interactions (among healthcare service providers) must serve as the primary sequence of events for the reason of placing the Patient-SP interactions. Future flows have to be migrated to the new Advanced Block-Chain paradigm and derive the inter-SP events using the Patients as focal points.

Even with these challenging limitations, we are still very confident with this direction of e-Health advanced blockchain solution as our design and analysis have shown the feasibility and great potential in access, reliability and growth of new services. The most significance of this efforts is in the ultimate purpose of fulfilling the calls for digital health care priorities [19, 20, 21] around the global world.

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