2019-09

Blockchain Technology in Sub-Saharan Africa: Where does it fit in Healthcare Systems: A case of Tanzania

Kombe, Cleverence

Journal of Health Informatics in Developing Countries

Blockchain Technology in Sub-Saharan Africa: Where does it fit in Healthcare Systems: A case of Tanzania

Journal of Health Informatics in Developing Countries

http://www.jhidc.org/
Vol. 13 No. 2, 2019

Submitted: July 16th, 2019 Accepted: September 11th, 2019

Blockchain Technology in Sub-Saharan Africa: Where does it fit in Healthcare Systems: A case of Tanzania

Cleverence Kombe,[1] Anael Sam,[1] Mussa Ally,[1] and Auvo Finne[2]

[1]School of Computational and Communication Science and Engineering, Nelson Mandela African Institution of Science and Technology, P.O. Box 447 Arusha, Tanzania
[2]eHealth projects in Tanzania 2017-2020, Ministry for Foreign Affairs of Finland, Finland

Abstract

Background: Blockchain technology is a distributed electronic ledger containing digital records, transactions or events that are protected with advanced encryptions, extremely hard to tamper, and updateable through a consensus algorithm agreeable to all connected network nodes. In Sub-Sahara Africa, the technology has started to be adopted in real estate, supply chain, agriculture, and financial sector. Unfortunately, there is a lack of effort in introducing this technology in the healthcare sector. Therefore, this study aims to explore the issues facing electronic healthcare systems in Sub-Sahara Africa taking Tanzania as a case study and introduce blockchain-based solutions for the discovered issues.

Methods: The study used qualitative methods for data collection and analysis. Data were collected through interviews, observation and documentary analysis. Interviews were done with the sample size of 50 participants who were selected from groups of healthcare facility leaders, ICT experts, government representatives, doctors, nurses, laboratory technicians, pharmacists, accountants, and receptionists. Direct observation and participatory observation were used to assess different electronic healthcare records systems' functions. Moreover, researchers used document analysis to collect data from public records (like policy manuals), personal documents (like incident reports), and physical evidence (like training materials and handbooks). NVivo 11 software was applied in managing and organizing data analysis.

Results: Out of 710 healthcare facilities involved in this study, 34.5% fully implemented electronic healthcare records systems and 78% installed Mfumo wa Taarifa za Uendeshaji Huduma za Afya (MTUHA) also known as (District Health Information Software (DHIS) II). The findings showed that the issues facing electronic healthcare records are; difficulties in taking care of the patients' private information, problems in safely sharing medical information between healthcare facilities, bandwidth issues, and improper handling of data integrity.

[1] Cleverence Kombe; School of Computational and Communication Science and Engineering, The Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania. Email: clevernce@gmail.com, kombec@nm-aist.ac.tz P.O Box 447 Arusha, Tanzania

Conclusion: The existing issues facing electronic healthcare records systems can be tackled through blockchain based solutions like self-sovereign identity and sharing and storing patients' medical data securely in blockchain ledgers and interplanetary file system. Therefore, healthcare facilities owners are recommended to use the findings of this study to elucidate the existing issues. In the future, this study will develop the recommended systems for developing countries environment.

Keywords: Blockchain technology; Self-sovereign identity; Interplanetary file system; Sub-Sahara Africa; Electronic healthcare records; Data integrity

1. Introduction

Blockchain technology is an electronic ledger (EL) of digital records, transactions or events that are hashed cryptographically, authenticated, and controlled through a distributed or shared network of nodes using a group consensus algorithm [1,2]. So, this puts additional trust and privacy to the existing Internet [3]. The advantage of this technology is in its capability of protecting the network nodes from being exposed to compromise from a single point of failure. Also, the technology ensures, confidentiality, integrity and availability of stored data, offering improved resilience, encryption, auditing and transparency. This is done through consensus protocols which is a crucial feature of blockchain technology. The protocols improve the integrity and robustness of shared transactions because the consensus among network nodes is required for validating new blocks of data and eliminate the possibility of corrupting or manipulating the transactions by the hacker or one or more malicious network node(s). Also, blockchain technology provides transparency which makes it impossible to make unauthorized alteration to the transactions even through malware or manipulative actions [4–7].

For just a short period of less than ten years, blockchain technology has already added many benefits as well as showing possibilities of improvements in different domains. The domains which benefited the most from this technology are financial, supply chain, real estate, energy supply, healthcare systems, government services just to mention a few. The benefits are; cost reduction since there is no need for third parties, more efficiency and speed in performing transactions, easy verification of assets and fraud prevention, improved security due to the elimination of single point of failure, and greater transparency because of use of shared ledger [8–14].

Despite many advantages and promising future, blockchain technology is still immature facing some challenges. These challenges include executing a lower number of transactions per second compared to existing technologies like VISA and Mastercard transactions. Also, some of the consensus algorithms like proof of work consume a lot of electric energy; slow adoption rate of the technology, and lack of clear regulation on how to use the technology. There are efforts attempted to fight against these challenges; to increase the number of transaction executions per second different protocols such as lightning network and shadowing proposed which promise to perform millions of transactions per second. Also, to facilitate clear regulation, experts in blockchain community have been setting up workshops, conferences, and meetings with decision makers to help them understand more about the technology. Furthermore, new consensus protocols other than proof of work like a deposit-based consensus, federated byzantine agreement, byzantine fault tolerance, delegated proof of stake, proof of importance have been developed which ensures fast transaction processing and most importantly they do not consume electricity [15–19].

Several sub-Saharan Africa countries started to adopt blockchain technology to reap the benefits which this technology deliver. The sectors which this technology has adopted are real estate, supply chain, agriculture, and financial sector. In Ghana, for example, the technology is applied to register more than 80% of landowners who were not able to claim the ownership of their land properties. The Government of Ethiopia on the other hand, applies blockchain technology to track the export of coffee along with implementing genetic sampling to identify origin, species, pesticide and exposure to chemicals for coffee authentication. Meanwhile in Kenya, blockchain technology has been applied to facilitate the micro-lending process to the farmers and enabling trust & cooperation among themselves [20–28].

Nevertheless, the Common Market for Eastern and Southern Africa (COMESA) members are implementing a Digital Free Trade Area (DFTA) aiming to connect sellers and buyers in real time via blockchain technology. Apart from increasing security of e-commerce transactions, DFTA will also generate certification of origin, creating an extra layer of security and assurance for e-vendors and buyers. DFTA will save $450 million, which otherwise would be lost in dealing with the administrative hurdles associated with cross-border trade (via applications, documentation and the processing thereof). Other sub-Sahara Africa nations which are in front line in the adoption of blockchain technology are South Africa, Rwanda, Uganda, Mauritius, Tanzania, Sierra Leone, Democratic Republic of Congo (DRC), Botswana, Nigeria, and Senegal [29–32].

Despite early adoption of blockchain technology in different domains in Sub-Sahara Africa, the healthcare sector lag behind, therefore, this qualitative study explores the issues facing electronic healthcare systems in Sub-Sahara Africa taking Tanzania as a case study. Blockchain technology-based solutions of identified problems are presented. Additionally, the benefits which will be gained through the adoption of the blockchain technology in electronic healthcare systems are identified along with the expected challenges.

2. Methodology

2.1 Study Design and Setting

This research was conducted in Tanzania through qualitative data collection methods like interviews, observation, and documentary analysis from 710 public and private-owned healthcare facilities. Tanzania mainland consists of about 7167 healthcare facilities of which 72.3% are owned by the government, and other 29.7% are owned by the private companies and organizations (Table 1)[33]. Therefore, 710 healthcare facilities were selected to represent the rest of the facilities.

Table 1: Distribution of healthcare facilities in Tanzania

	OWNERSHIP				
	Government	**Parastatal**	**Faith-based**	**Private**	**Total**
Hospitals	98 (39.7%)	8 (3.2%)	105 (42.5%)	36 (14.6%)	247
Health Centers	535 (74.9%)	10 (1.4%)	134 (18.8%)	35 (4.9%)	714
Dispensaries	4554 (73.4%)	168 (2.7%)	697 (11.2%)	787 (12.7%)	6206
Total	5187 (72.3%)	186 (2.6%)	936 (13.1%)	858 (12.0%)	7167

2.2 Sample Size and Sampling Technique

It is difficult to determine the sample size in advance for qualitative studies because they rely on the nature and scope of the research subject, resources available, and study design. Therefore, qualitative research gets sample size mostly when reaching data saturation [34, 35]. Some studies recommend up to 10 homogeneous sample size for case study research [36, 37]. Noting this and limited time in mind, this study interviewed four to six respondents per expertise group, resulting in a minimum of 50 respondents depending on the level of intersection in expertise. The participants were selected purposively in a consecutive manner while maintaining a cross-disciplinary approach to optimize variations to capture various views and experiences [38, 39].

Selected experts for purposive sampling were hospital/ healthcare facility leaders, ICT experts, government representatives, doctors, nurses, laboratory technicians, pharmacists, accountants and receptionists. The researchers ensured that selected experts meet two criteria; first, they cover and represent well the subject matter. Second, diversity is included in each expert group, so that the impact of research questions can be observed. Moreover, opportunistic and convenience sampling techniques were utilized due to unplanned opportunities aroused in the fieldwork. For example, researchers interviewed directors and ICT experts from Ministry of the country - President's Office Regional Administration and Local Government (Wizara ya nchi Ofisi ya Rais Tawala za Mikoa na Serikali za Mitaa (OR – TAMISEMI)) and

Christian Social Services Commission (CSSC) because they oversee the installation and maintenance of all healthcare information systems for government and faith-based healthcare facilities.

Therefore, through purposive, opportunistic, and convenience sampling, researchers interviewed 50 respondents who among them were respondents from some of 710 healthcare facilities involved in this study. Other data collection methods i.e. direct observation, participant observation, and documentary analysis were employed to collect necessary data from 710 healthcare facilities. Furthermore, invitation letters containing information document was sent to the targeted respondents or institutions. The invitation letter was phrased to emphasize that respondents would be qualified to participate despite their background, attitudes and perceptions towards different issues facing healthcare systems. This was done in order to minimize participants' bias because of oversampling of respondents possibly to express positive views.

2.3 Data Collection

This research study recognized value of understanding issues facing healthcare systems from different points of views such as perceptions and experiences of the key stakeholders, observation, and document analysis, in order to aid the decision makers on better ways of solving EHRs problem. Therefore, this study applied qualitative interviews with the stakeholders such as healthcare facility leaders, ICT experts, government representatives, doctors, nurses, laboratory technicians, pharmacists, accountants and receptionists. Qualitative interviews were used in the study because it focuses on answering the research questions directly and allows the researchers to access a wider variety of expertise and conditions [40].

Direct observation and participant observation were used in assessing different system functions and experts' activities. Studies show that direct observation helps the researcher to see, observe physically and direct from a real specific situation which increase validity and reliability of the study [41]. Also, researchers used document analysis from public records (mission statements, annual reports, policy manuals, and strategic plans), personal documents (duty logs, blogs, incident reports, and newspapers), and physical evidence (flyers, posters, handbooks, and training materials). Document analysis is an efficient and effective method of gathering data because documents are more manageable, accessible, reliable, cost efficient and time efficient compared to other methods [42, 43].

Different methods of data collection were designed to help the researcher to collect the data needed to answer the research questions, and to link the collected data to the research propositions. A cross-sectoral approach was undertaken by involving data collection from both public and private sector healthcare facilities in Tanzania.

2.4 Data Analysis Procedure

Data were entered into NVivo11 software [44], which was used to manage and organize the data analysis process. The framework approach was applied to design the analytical process, through the following steps; familiarization and annotation of transcripts, identifying a thematic framework, indexing, charting, mapping, and interpretation [38, 45]. Mapping step used to recognize relationships and clusters around themes, that help in understanding, communication, and interpretation. Moreover, themes used to show the most important issues from the data in understanding views and experiences regarding problems facing EHRs systems. COREQ checklist was used to guide the conduct, analysis, and reporting of this research [46].

3. Results

3.1 Distribution of healthcare facilities and systems

This study involved 710 healthcare facilities; out of this number, 34.5% have fully implemented EHR/EMR systems. The majority of healthcare facilities have installed MTUHA (DHIS II) which is about 78% of involved healthcare facilities. Figure 1 shows the distribution of hospital information systems with EHR systems from involved healthcare facilities.

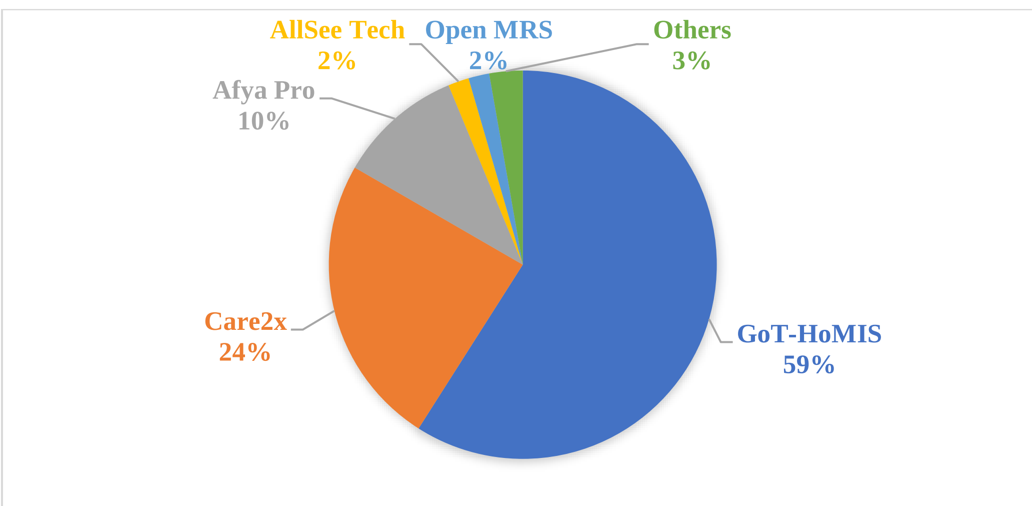

Figure 1: Distribution of hospital information systems with EHR systems fully installed

3.2 Situation in Healthcare Systems in Tanzania

3.2.1 Registration Mechanism/ Privacy

Registration process allows to capture demographic information of the patients, updating their details for follow up, constructing clinical records for them, and capture necessary information for billing process (Figure 2). This process of registering patients provides numerous advantages over the traditional methods which most of the time involve manual processes. The advantages include; allowing fast access to patients records for more efficient services; deliverance of more accurate, up to date, and complete patients' records; and most importantly to improve productivity with reduce running cost. Despite the mentioned merits, registration process and the mechanism of keeping patients' records suffer from the security loopholes. The security issues concern the privacy and safety of patients' details. The existing mechanism allows easy linking up of patients' records with their demographic details even for unauthorized users. This can allow attackers to conduct malicious activities like identity theft and medical financial frauds.

Moreover, when asked about safeguarding medical images, most of the systems' administrators admit the absence of security mechanisms like encryption and watermarking for protecting medical images against breach of confidentiality such as unauthorized access, copying, and modification of medical images which can easily reveal the identity of patients or alter patients' test results. Some interviewees revealed that it hard for them to let researchers gain access to clinical data for fear of exploiting identified and unidentified security loopholes.

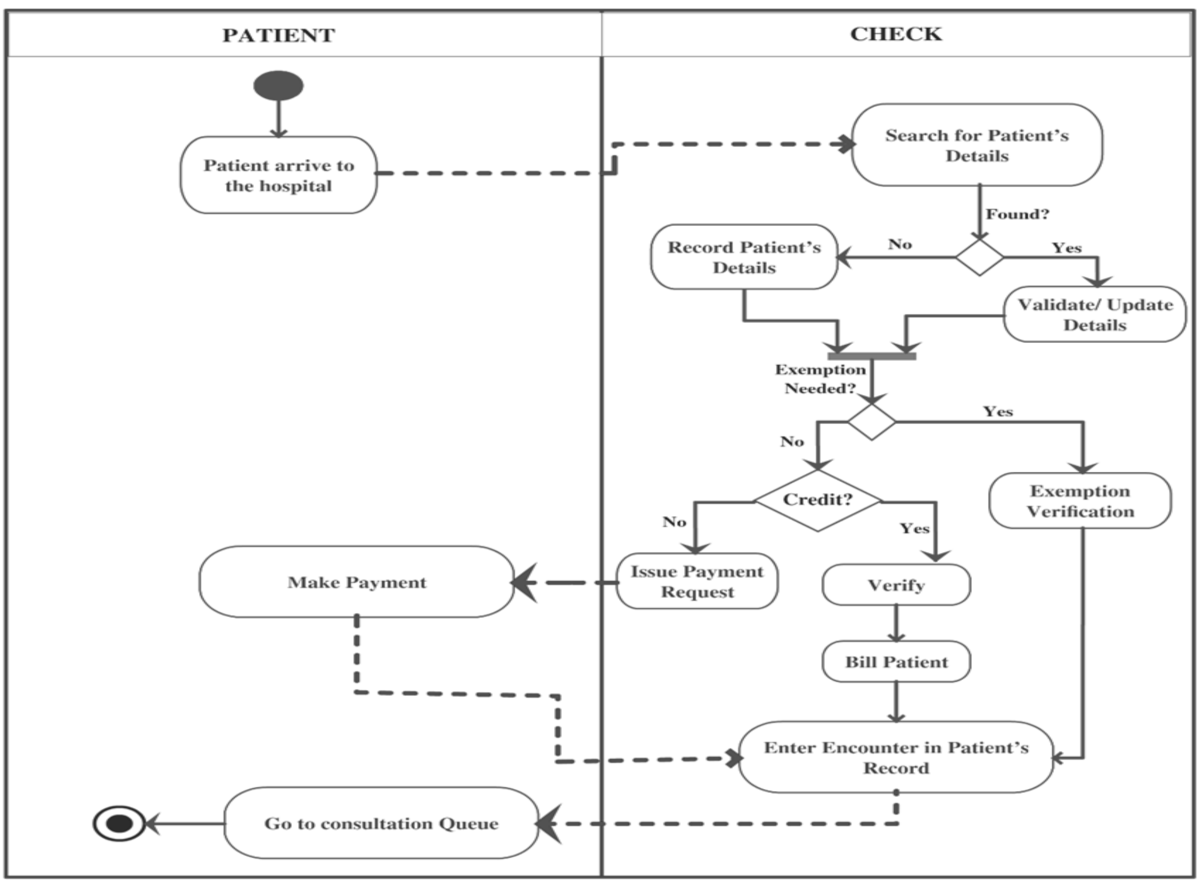

Figure 2: Handling of patients up to consultation queue

3.2.2 Sharing of Information between healthcare facilities

This study reveals that it is very difficult for one healthcare facility to search, receive, or send patients' clinical records form/to other healthcare facility using the EHR system. This difficulty causes the physicians to re-order tests that have already been conducted somewhere else. Also, the problem may lead to treatment decisions without a full understanding of underlying medical conditions or allergies of patients. Currently, it is up to the patients or their relatives to carry the clinical records into printouts from one healthcare facility to the other. A proper sharing of patient records helps healthcare providers to avoid medication errors, decrease readmission, and avoid unnecessary duplicate tests. In addition to the individual benefits, sharing of records eventually helps to create a comprehensive and holistic picture of a patient, history, current state, and prediction of the future. The common barrier for interoperability is the proper security mechanisms of connecting these systems without allowing unauthorized access. For instance, one healthcare facility leader with work experience of 41 years who facilitate the installation and updates of currently available EHR in his facility since 2007 said;

"It is very hard to trust other healthcare delivery institutions with medical records of our patients. Integrating our systems with other systems it is just keeping our systems in jeopardy as you know all these hacking and other malicious activities going on in cyberspace" (Interview with Healthcare Facility Leader)

While one of the ICT coordinators who have 11 years of work experience in working with different EHRs systems of which 7 years he spent in his current work station responded;

"Lack of knowledge about secured methods and mechanisms of sharing information and integrating these systems is main problem for interoperability. Also, we lack cyber security staffs who maybe would help us with these integration issues" (Interview with ICT coordinator)

3.2.3 Bandwidth Usage Issues

Broadband fee in developing countries is high, as it is estimated to be approximately three times higher compared to developed countries. Similarly, broadband prices are two times more in developing countries compared to developed countries. This affordability problem affects the availability and accessibility of EHRs services. About 70% of the EHRs users in Tanzania complained about low bandwidth or lack of internet service at a particular time in a period of 1 month.

3.2.4 Data Integrity

Data integrity in EHRs means a lot to healthcare providers because it is used for patients' decision making. Therefore, the stored information should be consistent, complete, accurate, and updated. Unfortunately, the findings of this study show that some of the systems are susceptible to data integrity related vulnerabilities. Majority of respondents reported integrity-related problems like information consistency which include modification and editing of information problems, challenges in accessing updated information, and tracking changes and medical histories of patients. For example, one medical doctor (surgeon) with overall work experience of 20 years and 10 years of experience with EHR in her facility responded;

> *"I'm blocked from seeing accounting details about the prescription I administer to the patients which would help me make right decisions depending on available options and financial status of the patient. Also, I cannot modify the prescription details once I write it to the system."* (Interview with a Doctor)

On the other hand, one accountant with 4 years of experience in working with finance modules of EHRs and 7 years overall work experience including 2 years of working with finance systems which are not related to healthcare responded with the following integrity-related complaint from the system;

> *"Sometimes the system may collapse which leads to loss of financial information which is very important. This problem occurred last year during the system update. After the update, the system showed weird financial figures as in some records indicated excess of amount of money while in other records indicate the loss of money."* (Interview with an Accountant)

In addition, one medical laboratory technician who has overall work experience of 8 years, 5 years of working with 3 different types of EHRs systems and 3 years of working with currently installed EHR in his workplace reported information integrity related issue with the following statement;

> *"When I make mistake on the system I can't modify. Also, I can't remove wrong test results from the system which affects daily, weekly and monthly analysis reports"* (Interview with Medical Laboratory Technician)

Moreover, this study observed integrity related vulnerabilities like inadequate data encryption, improper data backup, unsecure ways of access control, lack of data validation, and improper tracking of changes. Inadequate data encryption means that some information like demographic data is unnecessary to some system users. This means, information such as clinical records or financial details been visible to unauthorized users, may attract malicious activities like copying, deletion, and modification. Also, this study finds that the majority of the systems were not implemented encryption mechanisms like hash algorithms and Merkle tree which are used to ensure consistency of stored information.

Additionally, it has been found that some EHRs systems do not have proper data backup mechanisms which are supposed to ensure smooth copying and safe archiving of patient data for retrieval in case of failure or loss. In most of the observed systems, data backups are saved in the same location with original/live data. This can cause a complete loss of data in cases of disasters like fire or floods. Furthermore, unsecure access control observed in some systems when two or more users use the same login session to make changes such as updating or adding new information to the system. Access control mechanisms fail to track who make changes or access certain information in a certain period of time. On top of that, this study observed that more than 95% of the systems do not have a mechanism of verifying the correctness of stored data while accessing it. Mechanisms like hash digests and Merkle directed acyclic graph (Merkle DAG) which verify the correctness of accessed data were not implemented on these systems. Also, some systems do not permit its users to delete entered data or document yet fail to show the proper way of tracking or locating the different versions of that data or document or file.

4. Discussion

This study explored the issues facing electronic healthcare systems in Sub-Saharan Africa taking Tanzania as a case study and then discuss blockchain based solutions for the identified problems. The study applied qualitative research methods specifically interviews, observations, and documentary reviews to collect data from healthcare facilities. Out of 710 healthcare facilities involved in this study, only 34.5% fully installed hospital management systems with electronic healthcare records systems. The identified issues which can be solved with blockchain technology are; difficulties in taking care privacy of patients' information, problems in safely sharing medical information between healthcare facilities, bandwidth issues, and improper handling of data integrity. Therefore, this paper proposes solutions to the discovered problems based on blockchain technology's methods, techniques, and tools. The solutions proposed use blockchain-based technologies, tools, and techniques such as self-sovereign identity, hyperledger framework, ethereum, and Interplanetary File System (IPFS).

4.1 Utilizing blockchain Technology

4.1.1 Privacy handling registration mechanism

This study discovered privacy-related issues in EHRs in Tanzania, similar issues also observed in healthcare information systems from South Africa, Kenya, and Mauritius [47]. Therefore, to handle the problem, several ways can be enhanced using blockchain technology. Numerous studies indicate the following; ciphertext-policy attribute-based encryption, integration privacy-preserving online machine learning using a private blockchain network, patient centric healthcare data management system employing blockchain technology as a data store [48–52]. However, the best implementation for preserving the privacy of patient information in EHRs is the use of self-sovereign identity (Figure 3). Self-sovereign identity allows users to own, control, and manage their identity information. Examples of self-sovereign identity systems and frameworks existing today are hyperledger Indy, Sovrin, ShoCard, and uPort [53–56].

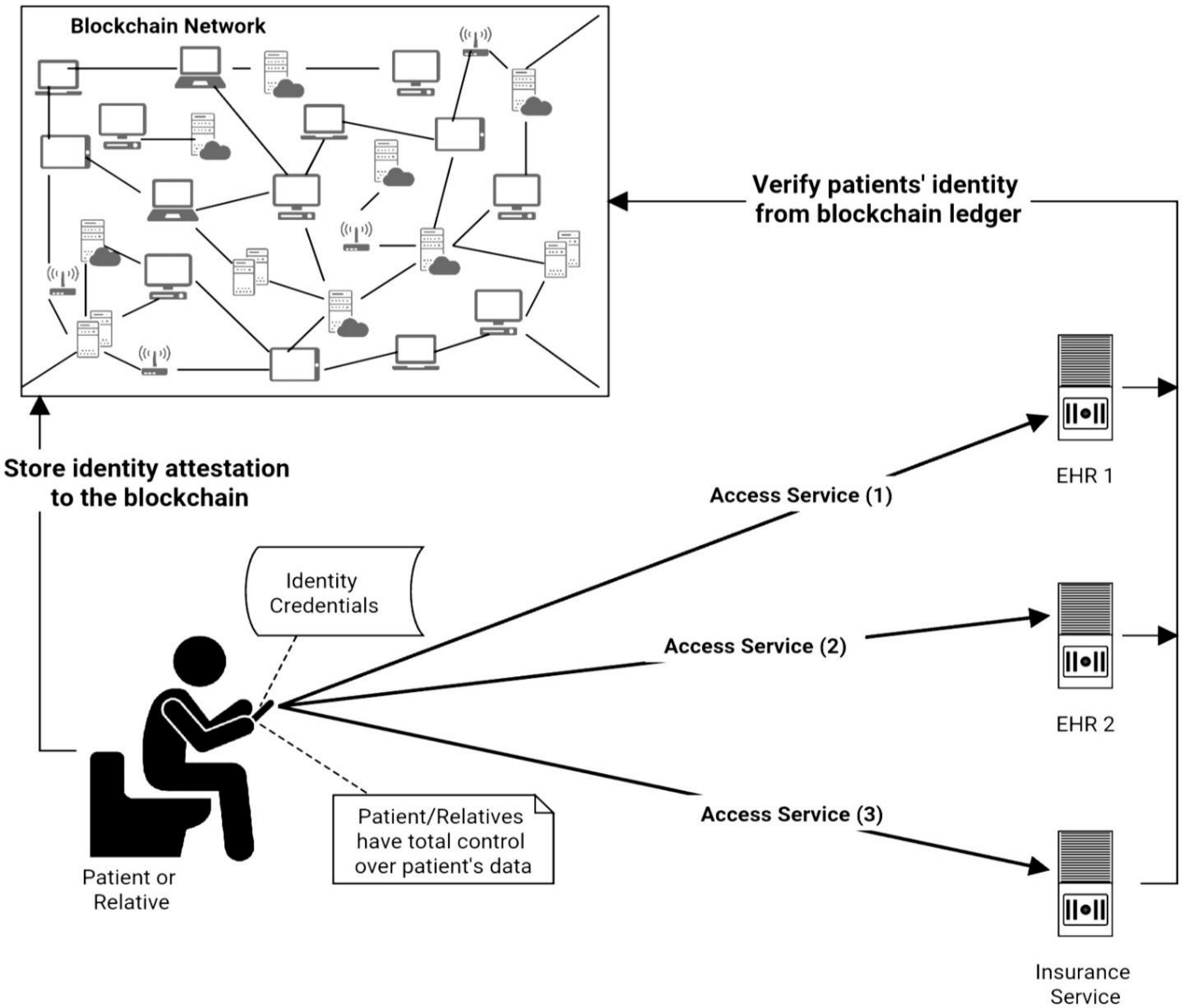

Figure 3: Example of the self-sovereign identity for healthcare systems

4.1.2 Secure Information Sharing Mechanisms

The difficulty of sharing securely patients' records from one electronic healthcare record to another was also the issue revealed in this study. Likewise, several studies discovered related issues in their research; for instance, Mtebe and Nakaka [57] revealed a lack of integration between HarmoniMD and Care2x in one of the healthcare facility in Tanzania. Also, Kamau et al. [58] presented lack of information interoperability between EHRs systems in healthcare facilities in Kenya. Since blockchain technology allows sharing of digital records between different information systems securely and without the need of third parties, it can be used to securely exchange medical information between different EHRs systems. Advantages of using blockchain over existing technologies are; its distributed architecture, immutable ledger, and advanced cryptographic security. Currently, blockchain technologies like hyperledger fabric, hyperledger indy, and ethereum have been used to securely store users' private information securely offchain and publish publicly the fingerprints in blockchain ledgers. This allows different EHRs systems to securely share the patients' information and verify through fingerprints published on blockchain ledgers [59–65].

4.1.3 Ensuring data integrity, proper utilization of bandwidth

This study revealed that bandwidth and poor internet access as a problem facing some healthcare facilities, however, Tanzania government is keeping on fighting by introducing the ICT broadband backbone even though is not properly utilized [66]. Similarly, other studies reported problems on low and expensive internet access in Nigeria, Kenya, Ghana, and other countries of the Sub-Saharan region [67, 68]. Therefore, to ensure data integrity, faster sharing of medical information, and most importantly using low bandwidth this study proposes using Interplanetary File System (IPFS). IPFS is the content-addressed protocol which is peer to peer file sharing system. It comprises of features like block exchange, Merkle DAG, Distributed Hash Table (DHT), Self-Certifying File System, and Version Control System (Figure 4). These features make IPFS immune to; Distributed Denial of Services (DDoS) attacks and single points of failure attacks. For blockchain based networks, to enable large files sharing, IPFS provides a good solution. Using IPFS, users can access their files from IPFS nodes where they are encrypted and stored, while the fingerprints of the files are stored in blockchain ledger for verification [69–74].

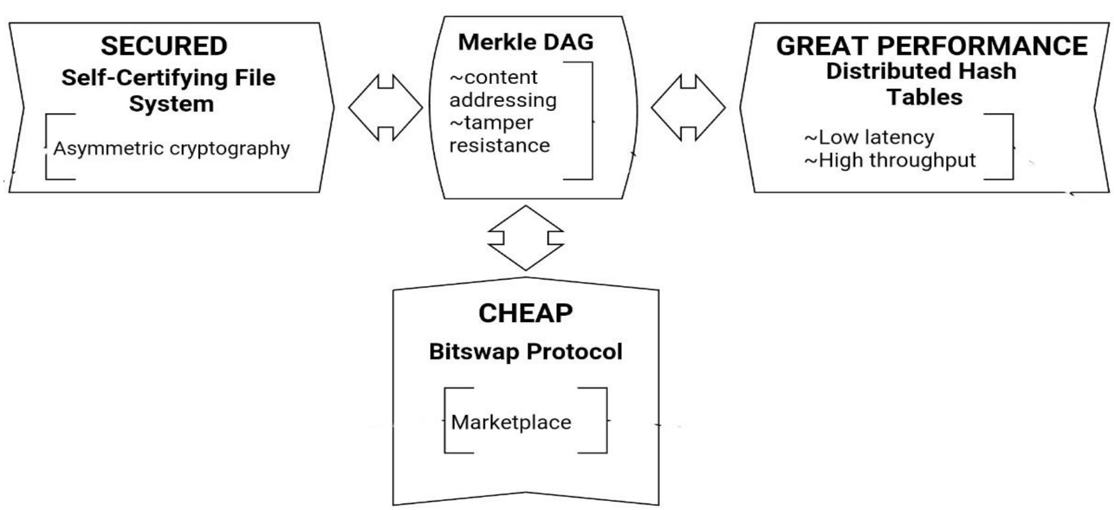

Figure 4: Interplanetary file system features

4.2 Expected challenges

There are numbers of challenges facing blockchain systems today, others are expected to still face the technology for few years to come. Firstly, is to deal with difficulties of some of consensus algorithms such as nothing at stake problem and helping rich to become richer for proof of stake algorithm; 51% attacks, high latency, high power consumption, low transaction rate, and centralization from mining pools for proof of work algorithm. Secondly, is the limited number of blockchain experts in the market. This leads to insufficient tools and supports for blockchain based applications development. Lastly, is dealing with legal issues like proper regulatory framework and institutions since most of blockchain based applications do not have central authority. Some users might take advantage of situation and conduct illegal activities [75–81].

5. Conclusion

This study reviewed the situation of EHRs in Sub-Sahara Africa using Tanzania as a case study. The findings showed that there are difficulties in handling patients' private data, sharing medical information from one healthcare facility to another securely, handling data integrity, and problems relating to bandwidth. Blockchain technology provides solutions to these issues through self-sovereign identity and sharing of medical information securely using platforms and systems such as hyperledger fabric and interplanetary file system. Therefore, it is expected that decision makers, researchers, and healthcare organizations in developing countries will apply the findings of this study to address the shortcoming they face. In the future, this study will develop the recommended systems for developing countries environment.

6. References

1. Antonopoulos AM. *Mastering Bitcoin: Unlocking Digital Cryptocurrencies*. First Edit. Sebastopol: O'Reilly Media, 2015.
2. Nakamoto S. *Bitcoin: A Peer-to-Peer Electronic Cash System*. Epub ahead of print 2008. DOI: 10.1007/s10838-008-9062-0.
3. Swan M. *Blockchain*. First Edit. Sebastopol: O'Reilly Media, http://safaribooksonline.com (2015).
4. Crosby M, Pattanayak P, Verma S, et al. Blockchain technology: Beyond bitcoin. *Appl Innov* 2016; 2: 71.
5. Zheng Z, Xie S, Dai H, et al. An overview of blockchain technology: Architecture, consensus, and future trends. In: *2017 IEEE international congress on big data (BigData congress)*. 2017, pp. 557–564.
6. Cachin C. Architecture of the hyperledger blockchain fabric. In: *Workshop on distributed cryptocurrencies and consensus ledgers*. 2016.
7. Cachin C, Vukolić M. Blockchain consensus protocols in the wild. *arXiv Prepr arXiv170701873*.
8. Xu X, Weber I, Staples M. Example Use Cases. In: *Architecture for Blockchain Applications*. Springer, 2019, pp. 61–79.
9. Xu X, Lu Q, Liu Y, et al. Designing blockchain-based applications a case study for imported product traceability. *Futur Gener Comput Syst* 2019; 92: 399–406.
10. Wüst K, Gervais A. Do you need a Blockchain? In: *2018 Crypto Valley Conference on Blockchain Technology (CVCBT)*. 2018, pp. 45–54.
11. Zhang P, Schmidt DC, White J, et al. Blockchain technology use cases in healthcare. In: *Advances in Computers*. Elsevier, 2018, pp. 1–41.
12. Perera S, Leymann F, Fremantle P. A use case centric survey of Blockchain: status quo and future directions. *PeerJ Prepr* 2019; 7: e27529v1.
13. Sawa T. Blockchain technology outline and its application to field of power and energy system. *Electr Eng Japan* 2019; 206: 11–15.
14. Fridgen G, Lockl J, Radszuwill S, et al. A solution in search of a problem: a method for the development of blockchain use cases.
15. Lin I-C, Liao T-C. A Survey of Blockchain Security Issues and Challenges. *IJ Netw Secur* 2017; 19: 653–659.
16. Zheng Z, Xie S, Dai H-N, et al. Blockchain challenges and opportunities: a survey. *Int J Web Grid Serv* 2018; 14: 352–375.
17. Tasatanattakool P, Techapanupreeda C. Blockchain: Challenges and applications. In: *2018 International Conference on Information Networking (ICOIN)*. 2018, pp. 473–475.

18. McGhin T, Choo K-KR, Liu CZ, et al. Blockchain in healthcare applications: Research challenges and opportunities. *J Netw Comput Appl*.
19. Laurence T. *Blockchain For Dummies*. John Wiley & Sons, 2017.
20. Ven N van de, others. *Explaining the early responses to blockchain technology*. 2018.
21. Kshetri N, Voas J. Blockchain in developing countries. *IT Prof* 2018; 20: 11–14.
22. Chemeltorit P, Saavedra Y, Gema J. Food traceability in the domestic horticulture sector in Kenya: An overview.
23. Ndung'u NS. Harnessing Africa's digital potential: New tools for a new age.
24. World's First Blockchain Coffee Project | 2018 | Moyee Coffee. *Moyee Coffee*, https://moyeecoffee.ie/blogs/moyee/world-s-first-blockchain-coffee-project (2018, accessed 2 April 2019).
25. Win TL. The coffee farmers betting on blockchain to boost business | Reuters. *Reuters*, https://www.reuters.com/article/us-ethiopia-coffee-blockchain/the-coffee-farmers-betting-on-blockchain-to-boost-business-idUSKCN1Q7039 (2019, accessed 2 April 2019).
26. Laurence T. *Blockchain for dummies*. 1st ed. New Jersey: John Wiley & Sons, Inc, 2017.
27. Kinai A. IBM and Twiga Foods Introduce Blockchain-Based MicroFinancing for Food Kiosk Owners in Kenya. *IBM Research Blog*, https://www.ibm.com/blogs/research/2018/04/ibm-twiga-foods/ (2018, accessed 2 April 2019).
28. Gebre S. Blockchain Opens Up Kenya's $20 Billion Informal Economy - Bloomberg. *Bloomberg*, https://www.bloomberg.com/news/articles/2018-06-14/blockchain-is-opening-up-kenya-s-20-billion-informal-economy (2018, accessed 2 April 2019).
29. Barigaba J. Africa's first digital free trade area for rollout in 2018 - The East African. *The East African*, https://www.theeastafrican.co.ke/business/Africa-first-digital-free-trade-area-for-rollout-in-2018/2560-4240522-y4jpnb/index.html (2017, accessed 2 April 2019).
30. Matinde V. 5 blockchain use cases in Africa | IDG Connect. *IDG Connect*, https://www.idgconnect.com/idgconnect/opinion/1000157/blockchain-africa?connect_token=cHJlbWl1bV9hcnRpY2xlMTU1NDIwODkxMA== (2018, accessed 2 April 2019).
31. African countries open for blockchain acceptance. *Finextra*, https://www.finextra.com/blogposting/15656/african-countries-open-for-blockchain-acceptance (2018, accessed 2 April 2019).
32. Kombe C, Manyilizu M, Mvuma A. Design of Land Administration and Title Registration Model Based on Blockchain Technology. *J Inf Eng Appl* 2017; 7: 8–15.
33. CSSC. Experiences of FBOs in provision of health services under PPP framework,

http://www.tzdpg.or.tz/fileadmin/documents/dpg_internal/dpg_working_groups_clusters/cluster_2/health/DPGH_Meeting_Documents_2017/CSSC-_Development_Partners_Presentation_Dec_2017.pdf (2017).

34. Mason M. Sample size and saturation in PhD studies using qualitative interviews. In: *Forum qualitative Sozialforschung/Forum: qualitative social research*. 2010.

35. O'reilly M, Parker N. 'Unsatisfactory Saturation': a critical exploration of the notion of saturated sample sizes in qualitative research. *Qual Res* 2013; 13: 190–197.

36. Creswell JW. Qualitative inquiry and research design: Choosing among five approaches. *Health Promot Pract* 2015; 16: 473–475.

37. Yin RK. *Qualitative Research from Start to Finish*. Second Edi. New york: The Guilford Press, 2015.

38. Ritchie J, Lewis J, Nicholls CM, et al. *Qualitative research practice: A guide for social science students and researchers*. sage, 2013.

39. Palinkas LA, Horwitz SM, Green CA, et al. Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Adm Policy Ment Heal Ment Heal Serv Res* 2015; 42: 533–544.

40. Bryman A. *Social research methods*. Oxford university press, 2016.

41. Rubin A (University of H, Babbie ER (Chapman U. *Research Methods for Social Work*. 8th ed. Andover: Brooks/Cole Empowerment Series, http://www.amazon.com/dp/0495811718 (2014).

42. O'Leary Z. *The Essential Guide to Doing Research*. First. London: SAGE Publications Ltd, 2004.

43. Bowen GA. Document analysis as a qualitative research method. *Qual Res J* 2009; 9: 27–40.

44. NVivo software: for qualitative and mixed-methods research, http://www.qsrinternational.com/nvivo/nvivo-products (accessed 22 February 2018).

45. Gale NK, Heath G, Cameron E, et al. Using the framework method for the analysis of qualitative data in multi-disciplinary health research. *BMC Med Res Methodol* 2013; 13: 117.

46. Booth A, Hannes K, Harden A, et al. COREQ (Consolidated Criteria for Reporting Qualitative Studies). In: *Guidelines for reporting health research: a user's manual*. Wiley-Blackwell Inc.; England, 2014, pp. 1–320.

47. William C. 22 Privacy and Security: Privacy of Personal eHealth Data in Low-and Middle-Income Countries. *Glob Heal Informatics Princ EHealth MHealth to Improv Qual Care* 2017; 269.

48. Zhang A, Lin X. Towards Secure and Privacy-Preserving Data Sharing in e-Health Systems via Consortium Blockchain. *J Med Syst*; 42. Epub ahead of print 2018. DOI: 10.1007/s10916-018-0995-5.

49. Wang H, Song Y. Secure Cloud-Based EHR System Using Attribute-Based Cryptosystem and

Blockchain. *J Med Syst*; 42. Epub ahead of print 2018. DOI: 10.1007/s10916-018-0994-6.

50. Magyar G. Blockchain: Solving the privacy and research availability tradeoff for EHR data: A new disruptive technology in health data management. In: *IEEE 30th Jubilee Neumann Colloquium, NC 2017*. 2018. Epub ahead of print 2018. DOI: 10.1109/NC.2017.8263269.
51. Chen Y, Ding S, Xu Z, et al. Blockchain-Based Medical Records Secure Storage and Medical Service Framework. *J Med Syst*; 43. Epub ahead of print 2018. DOI: 10.1007/s10916-018-1121-4.
52. Al Omar A, Rahman MS, Basu A, et al. MediBchain: A blockchain based privacy preserving platform for healthcare data. In: *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. 2017. Epub ahead of print 2017. DOI: 10.1007/978-3-319-72395-2_49.
53. Dunphy P, Petitcolas FAP. A first look at identity management schemes on the blockchain. *IEEE Secur Priv* 2018; 16: 20–29.
54. Mühle A, Grüner A, Gayvoronskaya T, et al. A Survey on Essential Components of a Self-Sovereign Identity. *Comput Sci Rev* 2018; 30: 80–86.
55. World Economic Forum. *Identity in a Digital World A new chapter in the social contract Insight Report*. Geneva, Switzerland, www.weforum.org (2018).
56. Domingo SAI, Enríquez M. *Digital Identity: the current state of affairs*. 2018.
57. Mtebe JS, Nakaka R. Assessing Electronic Medical Record System Implementation at Kilimanjaro Christian Medical Center, Tanzania. *J Health Inform Dev Ctries*; 12.
58. Kamau G, Boore C, Maina E, et al. Blockchain Technology: Is this the Solution to EMR Interoperability and Security Issues in Developing Countries? In: *2018 IST-Africa Week Conference (IST-Africa)*. 2018, p. Page--1.
59. Gordon WJ, Catalini C. Blockchain Technology for Healthcare: Facilitating the Transition to Patient-Driven Interoperability. *Comput Struct Biotechnol J* 2018; 16: 224–230.
60. Brogan J, Baskaran I, Ramachandran N. Authenticating Health Activity Data Using Distributed Ledger Technologies. *Comput Struct Biotechnol J* 2018; 16: 257–266.
61. Dagher GG, Mohler J, Milojkovic M, et al. Ancile: Privacy-preserving framework for access control and interoperability of electronic health records using blockchain technology. *Sustain Cities Soc* 2018; 39: 283–297.
62. Kombe C, Ally M, Sam A. A review on healthcare information systems and consensus protocols in blockchain technology. *Int J Adv Technol Eng Explor*; 5: 2394–7454.
63. Linn LA, Koo MB. Blockchain for health data and its potential use in health it and health care related research. In: *ONC/NIST Use of Blockchain for Healthcare and Research Workshop. Gaithersburg, Maryland, United States: ONC/NIST*. 2016.

64. Ichikawa D, Kashiyama M, Ueno T. Tamper-resistant mobile health using blockchain technology. *JMIR mHealth uHealth* 2017; 5: e111.

65. Mertz L. (Block) chain reaction: A blockchain revolution sweeps into health care, offering the possibility for a much-needed data solution. *IEEE Pulse* 2018; 9: 4–7.

66. Ludger Kasumuni. Use of ICT broadband backbone low despite huge spending: experts - The Citizen. *The Citizen Tanzania*, 2017, https://www.thecitizen.co.tz/magazine/Use-of-ICT-broadband-backbone-low/1840564-3982710-12789hyz/index.html (2017, accessed 27 July 2019).

67. Odekunle F, Srinivasan S, Odekunle R. Why Sub-Saharan Africa Lags in Electronic Health Record (EHR) Adoption and Possible Strategies to Increase EHR Adoption in this Region. *J Heal Informatics Africa* 2018; 5: 8–15.

68. Adedeji P, Irinoye O, Ikono R, et al. Factors influencing the use of electronic health records among nurses in a teaching hospital in Nigeria. *J Health Inform Dev Ctries*; 12.

69. Hawig D, Zhou C, Fuhrhop S, et al. Designing a Distributed Ledger Technology System for Interoperable and General Data Protection Regulation--Compliant Health Data Exchange: A Use Case in Blood Glucose Data. *J Med Internet Res* 2019; 21: e13665.

70. Heinisuo O-P, Lenarduzzi V, Taibi D. Asterism: Decentralized File Sharing Application for Mobile Devices. In: *The Seventh IEEE International Conference on Mobile Cloud Computing, Services, and Engineering*. 2019.

71. Benet J. *IPFS - Content Addressed, Versioned, P2P File System*, http://gateway.ipfs.io/ipfs/QmR7GSQM93Cx5eAg6a6yRzNde1FQv7uL6X1o4k7zrJa3LX/ipfs.draft3.pdf (accessed 17 July 2019).

72. Cisneros JLB, Aarestrup FM, Lund O. Public health surveillance using decentralized technologies. *Blockchain Healthc Today*.

73. Chen Y, Li H, Li K, et al. An improved P2P file system scheme based on IPFS and Blockchain. In: *2017 IEEE International Conference on Big Data (Big Data)*. 2017, pp. 2652–2657.

74. Nguyen DC, Pathirana PN, Ding M, et al. Blockchain for Secure EHRs Sharing of Mobile Cloud based E-health Systems. *IEEE Access*.

75. Reyna A, Mart\'\in C, Chen J, et al. On blockchain and its integration with IoT. Challenges and opportunities. *Futur Gener Comput Syst*.

76. Epiphaniou G, Daly H, Al-Khateeb H. Blockchain and Healthcare. In: *Blockchain and Clinical Trial*. Springer, 2019, pp. 1–29.

77. Mendling J, Weber I, Aalst W Van Der, et al. Blockchains for business process management-challenges and opportunities. *ACM Trans Manag Inf Syst* 2018; 9: 4.

78. Jahankhani H, Kendzierskyj S. Digital Transformation of Healthcare. In: *Blockchain and Clinical*

Trial. Springer, 2019, pp. 31–52.

79. Yaeger K, Martini M, Rasouli J, et al. Emerging Blockchain Technology Solutions for Modern Healthcare Infrastructure. *J Sci Innov Med*; 2.

80. Boulos MNK, Wilson JT, Clauson KA. Geospatial blockchain: promises, challenges, and scenarios in health and healthcare.

81. Siyal A, Junejo A, Zawish M, et al. Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives. *Cryptography* 2019; 3: 3.