Advantages and opportunities of the IOTA Tangle for Health Data Management: A Systematic Mapping Study

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ABSTRACT

The merging of Distributed Ledger Technology (DLT) and the Internet of Things (IoT) has opened new opportunities for innovation in health data management. Issues such as security breaches, privacy violations and fragmented data are just some of the problems that DLT might solve. This research investigates how the IOTA Tangle can provide reliable and secure health data management.

A systematic mapping study on 10 primary papers from year 2018 to 2021 was conducted with a comparison with findings from previous studies. We discovered that the existing research has been conducted within the knowledge areas of health data management and its relation to the IOTA Tangle, blockchain, and IoT.

The results show that the IOTA Tangle is a good candidate for health data management and that it has been successfully done as proof of concepts. The Tangle is also highlighted in the literature as being well suited for the IoT. This thesis forms the basis for further research into the suitability of the IOTA Tangle in health data management.

KEYWORDS

Health Data Management, Internet of Things, Distributed Ledger Technology, Blockchain, IOTA Tangle, Systematic Mapping Study

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1 INTRODUCTION

The merging of Distributed Ledger Technology (DLT) and Internet of Things (IoT) technology presents a new paradigm in Information Technology and creates new possibilities for innovation. A Systematic Mapping Study (SMS) on the topic of blockchain and sustainability by Lund et al. [1] that focuses on smarts grids and supply chains, found that there where almost no papers describing the experiences gained through real world implementations. The novelty of each technology, and especially the novelty of their combination, is a driving factor behind the desire to explore this emerging field.

This study is also motivated by some of the opportunities outlined in the work by Farahani et al. [2] that examined the opportunities and challenges for the convergence of DLT and IoT. They argue that DLT could solve several of the problems found in traditional Cloud/IoT systems, such as security issues and a lack of interoperability, while also bringing new advantages such as scalability, immutability, and traceability of data.

The aim of this research is to investigate how security and privacy of health data management can be improved with the use of DLT, such as the IOTA Tangle, integrated with IoT. The following research conducts a systematic mapping study that seeks to answer if the available literature supports this goal.

The IOTA Tangle [3] is one of the DLT projects that has been developed with IoT in mind. It attempts to create a lightweight and sustainable network that scales to handle transactions between millions of devices.

An example of a use case for combining DLT, IoT and health data, is the monitoring of a diabetic patient's blood glucose levels. The data would be collected in real-time by a sensor worn by the patient and the collected data is periodically sent to the IOTA network. The data could then be shared with authorized personnel, such as a general physician or a diabetes specialist. Other data associated with the patient such as their medical record, prescriptions and test results could also be privately and securely stored in the same network. Thus, creating an interoperable and accessible platform, for both the patient and caregivers, to manage the patient's health data. This could lead to reduced fragmentation of data across various storage solutions and open new possibilities for real-time monitoring and data analysis. IOTA network may operate as the binding fabric for health data. The use case developed by Hawig et al. [4] is an example of such a system. This systematic mapping study aims to assess the ability of the IOTA Tangle to improve health data management. This led to the definition of the following research question:

RQ: How can the IOTA Tangle provide reliable and secure health data management?

This paper is structured as follows: Section 2 introduces health data management, IoT, DLT, IOTA, and the IOTA Tangle. Section 3 summarizes the method. Section 4 presents the results, which are further discussed in section 5. Section 6 concludes the paper by answering the research question and proposing further work.

2 BACKGROUND

This chapter presents four relevant main topics and how they relate to each other; health data management, distributed ledger technology, internet of things, and IOTA. the relations are visualized in Figure 1.

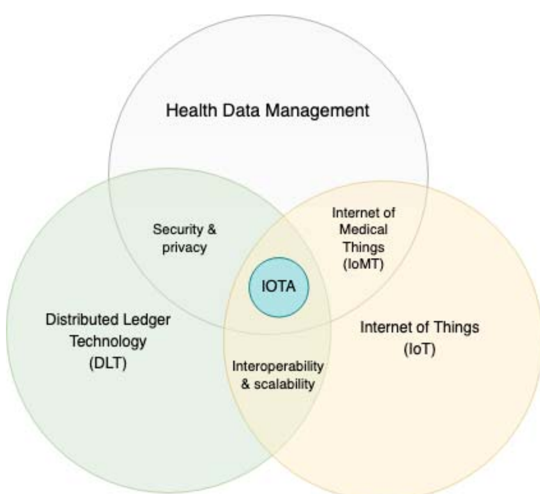

Figure 1: Overview of topics and their relations

2.1 Health Data Management

There are three important data storage options available in today's landscape: EHR (Electronic Health Record), EMR (Electronic Medical Record), and PHR (Personal Health Record) [5]. EHR and EMR are both controlled and used by physicians, in order to provide quality and care for patients. While the EMR focuses on internal use in one institution, EHR provides interoperable information sharing between institutions. PHR, on the other hand, is a personal data storage of health records for patients to access and control themselves.

According to Ozair et al. [6] EHRs are increasingly being implemented in developing countries, replacing paper records of a patient's medical information. The EHRs provide advantages like increased flexibility and access to health data, improved quality of healthcare and decreased costs. Nevertheless, this implementation comes with some disadvantages such as the risk of privacy abuse and security breaches. The priorities to focus on for EHRs are "Privacy and confidentiality, security breaches, system implementation, and data inaccuracies". Privacy and confidentially can be taken care of by access control, and solid privacy and security policies. Security breaches can be avoided by having strict policies and procedures, and including antivirus software, intrusion detection, and firewalls in the system to protect data integrity. The implementation of the system requires an intuitive user interface, involvement, and lectures regarding how the system works for all stakeholders, and standardized best practice workflows. Data inaccuracies can, first and foremost, be handled by providing a user-friendly interface. Another way to prevent data inaccuracies is to make data transfer secure, immutable, and tamper-proof.

Inspired by Hawig et al. [4], Figure 2 illustrates our proposed platform that combines sources of patient data on the IOTA Network. Sensor data from IoT devices like wearables, medical records from your general physician, test results and more could be secure, interoperable, and readily available.

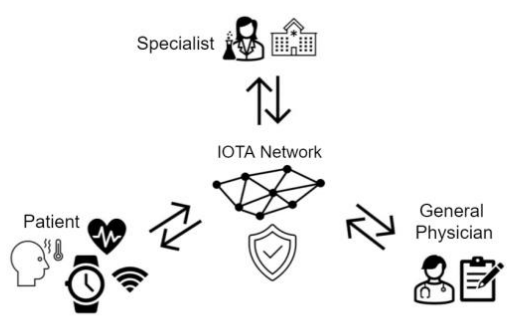

Figure 2: Example for interoperable health data management

2.2 Internet of Things (IoT)

The idea of the IoT has existed for some time [7], but it is not until recently that the technology has seen more widespread implementation across different areas such as industrial production, smart homes, wearable sensors, and weather data collection [8]. The idea itself encompasses the emergence of things with embedded processing ability, sensors, and software, and that they are connected to the internet. This could be anything from your car to your fridge. IoT technology has evolved due to the convergence of several technologies such as powerful embedded computers, smaller sensors and improvements in speed and connectivity over wireless mobile networks [9].

2.2.1 Internet of Medical Things (IoMT). The healthcare sector has also seen an increase in the use of IoT devices, such as wearables that measure health indicators in patients and are connected to the internet, referred to as IoMT [10]. Examples of measurements include heart rate, respiratory rate, blood glucose levels, blood oxygen levels etc. While wearables that measure health indicators have existed for a while, adding smart communication capabilities to these devices opens possibilities such as improved data analysis and remote patient monitoring. It might reduce the fragmentation of personal health data across various paper records, digital devices, and databases [11]. Enabling interoperable exchange of data across different stakeholders may have several benefits but gathering patient health data in a single silo presents security risks. The following sections describes DLT, which some regard as a potential solution to these challenges [11].

2.3 Distributed Ledger Technology (DLT)

DLT is a database architecture that allows a decentralized database network to run securely [12]. This technology allows users to perform secure data transfers, data storage and transactions, by applying cryptography.

2.3.1 Decentralization. DLT networks are managed across multiple nodes and by multiple participants [12]. Each transfer is stored as a record in the distributed ledger and this record is stored in every node in the network. In contrast to typical database system where the data is stored by a central trusted authority, the nodes in the network must come to consensus or agreement on the current state of the distributed ledger. There are some advantages with decentralized networks. A single actor will never be able to shut down the network, as all users have equal rights. Furthermore, there is no single point of failure in a decentralized network, which means that if one component fails, the entire network will not fail. This also makes the network more secure against possible attackers. The consensus algorithm ensures that each transaction is validated by thousands of nodes, guaranteeing its integrity [13].

2.3.2 Immutability. Another important aspect of DLT's is immutability. It means that once a transaction has been finalized and is written to the ledger record, it cannot be modified or reversed. There is only one "source of truth". Every unlawful modification in the network is immediately revealed, ensuring that transactions are completed correctly [13].

2.3.3 Interoperability. Interoperability is the ability of several systems to share resources between one another unrestricted. Some DLTs have this property and can therefore easily and seamlessly interoperate. This allows for their full potential to be realized across multiple use cases [14].

2.3.4 Blockchain. Blockchain is a type of DLT that records transactions. Further, these transactions are grouped into blocks and chained together by immutable cryptographic signatures called hashes. Each block contains a hash of the previous block. Therefore, distributed ledgers often are referred to as blockchains as this is the most common concept in DLT [15]. Typical blockchain architectures separate between users, people that want to send transactions, and miners, people that lend their computing power to solve the cryptographic puzzles that help secure the network. This usually entails a transaction fee paid by the users to the miners. The two most well-known blockchain technologies are Bitcoin and Ethereum.

2.4 IOTA

The IOTA protocol is managed and developed by the IOTA Foundation. On their official website [16], IOTA is described as an open-source scalable communication protocol. The IOTA Tangle is the network architecture used by IOTA and describes their unique directed acyclic graph (DAG) structure. The focus of the IOTA Foundation is to develop a system of payment, transactions, and data transfer for the IoT. The aim is to achieve this by designing a DLT that is fast, scalable and supports zero-fee transactions [17].

2.4.1 The IOTA Tangle. The IOTA Tangle is the data structure for the distributed ledger in the IOTA protocol [18]. It is an example of a transaction based directed acyclic graphs architecture, which means that each transaction in the network references two or more previous transactions. New transactions are validated by some subsequent transactions and this cooperative pay-it-forward system is the reason why the network can operate with no miners and therefore no transaction fees. This is illustrated in Figure 3 where each block represents a transaction and the arrows shows the previous transactions it references, whereas with Blockchain each block only references the previous block. This data structure allows for parallel processing of transactions and makes the IOTA Tangle more efficient and allows it to scale to handle millions of devices.

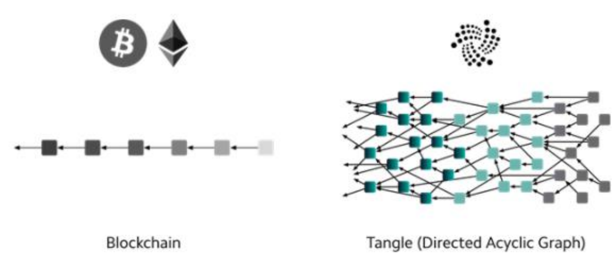

Figure 3: Blockchain compared to *the Tangle*

2.4.2 Masked Authenticated Messaging (MAM). An important tool for realizing authenticated data sharing over the IOTA Tangle is the IOTA MAM organizational tool. It enables the structuring and publishing of encrypted private data on the IOTA Network. Devices connected to the network can use MAM to set up secure communication between authorized partners where the publisher of data can determine which devices can access the data. This tool is central for enabling health data management on the IOTA Tangle. MAM has undergone changes in recent years and the current version has been renamed to IOTA Streams.

3 RESEARCH METHOD

A SMS was conducted to review literature and present an overview of existing research in the field of health data management and DLT's. The SMS of this project follows the guidelines established by Kitchenham [19]. The work of Budgen et al. [20] and Petersen et al. [21] providing research examples of mapping studies in software engineering, have been used as references as well. This section provides a description of the data collection and planning stage for the project. Further, a description of the execution stage of the data collection, and finally the data analysis approach.

3.1 Data Collection (Planning Stage)

A review of the already existing relationship between DLT, such as the IOTA Tangle, and health data management was the specific research topic for this SMS. Collecting, analyzing, and discovering existing gaps of the literature within this field was the motivation behind the formulation of the **RQ: How can the IOTA Tangle provide reliable and secure health data management?**

3.1.1 Search Strategy. Four online databases were selected to search for relevant information, including Scopus, IEEE, Science Direct, and Springer Link. These are all acknowledged academic databases providing broad coverage of interdisciplinary research.

To collect high-quality studies related to the research question the search strings in Figure 4 were applied to the corresponding databases. The search string provided a total number of 386 hits, 16 of which were considered potentially relevant studies, and a total of 10 were selected as primary studies.

Online library	Search string	Hits	Potential studies	Primary Studies
Scopus	TITLE-ABS-KEY ((iota) AND (health*) AND (data OR priva* OR secur*)) AND PUBYEAR > 2016	39	7	4
IEEE	Full text and metadata: iota AND tangle AND health* AND PUBYEAR > 2016	131	3	2
Springer Link	iota, health, tangle (specify years 2016-2021)	149	2	1
Science Direct	iota, health, tangle (specify years 2016-2021)	67	4	3
Total		386	16	10

Figure 4: Search strings and number of hits

3.1.2 Selection Criteria. The exclusion and inclusion criteria are the determining factors for which documents to include for further analysis [21]. Inclusion criteria: (1) The study's main concern is relevant to the research problem. (2) The publish year of the article should be dated after 2016, as the IOTA Tangle was developed in 2016, and up to September 2021, when this SMS was conducted. (3) The study has empirical validation. Exclusion criteria: (1) Exclude papers with less than 4 pages. (2) Remove duplicates: Articles appearing more than once. Include the most complete and recent version.

3.1.3 Quality Assessment Criteria: The selection criteria exclude the irrelevant papers, while quality assessment excludes the poor-quality papers. It is challenging to define precisely what "quality" is, but Kitchenham [19] suggests that "quality" is measured to what extent the study maximizes external and internal validity and minimizes bias. Based on this information, these quality assessment criteria were constructed: (1) The study validates the idea or proposal that it defends. (2) The study contains a proper investigation, using appropriate methods to select and transform data. (3) The study is at least cited four times by others.

3.2 Data Collection (Execution Stage)

The steps listed below were conducted in order to implement the review protocol to the research process. The tools developed in the planning stage, such as the search strategy, selection criteria, and quality assessment criteria, were used to eliminate all the irrelevant papers. The execution stage decreased and narrowed down the number of relevant studies from 386 to a final count of 10 primary studies, recall Figure 4.

3.2.1 First Step. In this first step, the selection criteria were applied to the title, abstract and keywords, of the 386 studies from the initial search.

3.2.2 Second Step. The next step had a similar approach, the only difference was the selection criteria being applied to the entire document of each remaining paper.

3.2.3 Third Step. The final step was committed to a final quality check of the primary studies chosen in the second step. The quality assessment criteria were applied, which resulted in a final total of 10 primary studies remaining. These three steps resulted in a decreased number of research papers with increased relevance.

3.3 Data Analysis

The extraction from the primary studies included the following: author, year of publication, type of paper (journal, conference, etc.), methodology (qualitative, quantitative, or both), data analysis and the main findings. The data analysis and main findings are presented in the results chapter, the rest of the information is summarized in Figure 5.

No.	Type	Authors	Methodology	Title
1	20th IEEE/ACIS International Conference	Saweros, E. & Song, Y.T. (2019)	Qualitative (POC)	Connecting Personal Health Records Together with EHR Using Tangle
2	Medical Internet Research Journal	Hawig, David, et. al. (2020)	Qualitative/ quantitative experiment	Designing a distributed ledger technology system for interoperable and general data protection regulation–compliant health data exchange: a use case in blood glucose data
3	Medical Internet Research Journal	Zheng, Xiaochen, et. al.(2019)	Qualitative/ quantitative experiment	Accelerating health data sharing: A solution based on the internet of things and distributed ledger technologies
4	Computational and Structural Biotechnology Journal	Brogan, James, et. al. (2018)	Qualitative/ quantitative experiment	Authenticating health activity data using distributed ledger technologies
5	IEEE Access Journal	Houtan, B. et. al.(2020)	Qualitative/ quantitative experiment	A survey on blockchain-based self-sovereign patient identity in healthcare
6	Future Generation Computer Systems Journal	Silvano, W.F. & Marcelino, R. (2020)	Qualitative SLR	Iota Tangle: A cryptocurrency to communicate Internet-of-Things data
7	Mediterranean Conference on Embedded Computing	Florea, & Bodgan, C. (2018)	Qualitative (POC)	Blockchain and Internet of Things data provider for smart applications
8	Neural Computing and Applications Journal	Yaqoob, Ibrar, et. al. (2020)	Qualitative SLR	Blockchain for healthcare data management: Opportunities, challenges, and future recommendations
9	Network and Computer Applications Journal	Farahani, B. et. al.(2021)	Qualitative SLR	The convergence of IoT and distributed ledger technologies (DLT): Opportunities, challenges, and solutions
10	Network and Computer Applications Journal	Sengupta, J. et. al.(2020)	Qualitative SLR	A comprehensive survey on attacks, security issues and blockchain solutions for IoT and IIoT

Figure 5: Overview of extracted information from data analysis

4 RESULTS

This section provides the results collected in the SMS regarding health data management. The selection of primary studies consists of papers published between 2018 and 2021. The research methods included five qualitative systematic reviews, [2] [22] [23] [24], three quantitative experiments measuring performance metrics, [4] [25] [26], and two proof of concepts (POC) [11] [27].

4.1 Health Data Management & Blockchain

Yaqoob et al. [23] researched the integration of blockchain in health care systems. Their results show that this integration can improve the healthcare industry in terms of data security, operational efficiency, healthcare staff management, and cost. However, blockchain has some limitations, such as scalability, immaturity, interoperability, complexity, and the difficulty of integration with already existing healthcare systems.

These finding are supported by the work of Houtan et al. [28], who investigate the challenge of integrating blockchain technology into health data management, focusing on patient data and identity management. The solution looks into a blockchain based PHR and EHR, that provides a distributed autonomous healthcare ecosystem. It is mentioned that this solution contains limitations regarding the patient's privacy protection because of the blockchain architecture.

It is concluded by Farahani et al. [2] that IoT and blockchain are complimentary of one another. The paper presents a tamper-proof and secure architecture that is easily integrated into IoT e-health solutions enabling stakeholders to share, monetize, and collect medical IoT data. Their research states that IoT and blockchain together face the major challenges of IoT. These challenges being security, auditability, data integrity, transparency, secure peer-to-peer data sharing, reliability, and data monetization. The findings in this paper are based on various performance tests conducted by the use of HLF (HyperLedger Framework). Even though all the challenges listed above are covered by the test, there were some limitations in the findings. The limitations include scalability and the integration of IoT and blockchain with other technologies.

Sengupta et al. [24] categorizes various IoT attacks, discusses the security issues, vulnerabilities, and suggested solutions, involving blockchain and the IOTA Tangle. In the specific context of healthcare, the paper states that blockchain is revolutionizing the entire healthcare system. The exchange of health data changes with blockchain in such a way that key stakeholders, such as patients, doctors, clinical researchers, pharmacists, gain a more secure, reliable, and simplified access to electronic health data. Blockchain based smart contracts can promote secure management and handling of PHI (Protected Health Information) generated by medical sensors. Generally, regarding the issues and vulnerabilities of IoT, it is mentioned that there are some flaws blockchain technology has which can be solved with the IOTA Tangle, like scalability, synchronization, efficiency, and energy waste.

4.2 Health Data Management & the IOTA Tangle

Another study that also investigates the PHR and EHR aspect of health data management is Saweros and Song's [11]. They propose an IOTA Tangle based system for improved security, interoperability, efficiency, and patient participation in health data management. The system was able to connect PHR with EHR using the IOTA Tangle as a middle layer providing improved security, privacy, and interoperability. It provides a platform for patients to share their data with their caregivers or physicians, and they can then exchange data between one another as well. The platform could also enable personalized tracking and monitoring of biometric data. The biometric data included data such as respiration, blood pressure, asthma, weight, blood glucose, heart rate, cholesterol, food intake and body temperature. This system also resolved the data fragmentation issue, and the patients could monitor their health records because of a continuous time learning progression model. The research investigated the limitations of the already existing PHR system. The major difference from the already existing version of the system is the focus on a decentralized and independent system, without interference from a third-party cloud service. In addition, the patients can now control and access their own data.

Hawig et al. [4] is another example of an IOTA Tangle based prototype for health data management that focuses on privacy, and in this case the new GDPR rules and regulations. The work consists of two different blood glucose data exchange prototypes. The first one implementing the Tangle with MAM alone, and the other implementing the Tangle and MAM in combination with an additional private distributed file system named IPFS (InterPlanetary File System). The difference being the data storage process. The results show that both implementations show good performance and adhere to the latest GDPR regulations and rules. The prototype using IPFS had a complex setup, but allowed for exchange of large files and held a low linkability and reversal risk compared to the other prototype.

4.3 Health Data Management & IoT with the IOTA Tangle

To introduce this combination of technologies Florea et al. [27] conclude in their research that network building on the IOTA Tangle shows great potential in combination with IoT technology and MAM (Masked Authenticated Messaging). It shows the potential to "easily integrate remote sensor data, using a decentralized storage system, eliminating the need for complex databases and query models". The further results in this section explores the same technological area, but in a health data setting.

Zheng et al. [25] and Brogan et al. [26] demonstrate that the IOTA Tangle and MAM is highly compatible with IoT technology, and especially in relation to health data. Zheng et al. [25] verify this with a health-related prototype for data sharing using the IOTA Tangle, MAM and IoT with the goal of a highly scalable, fee-less, tamper-resistant, secure, and granularly controllable data exchange. The results show that this prototype could greatly improve health data sharing and overcome many challenges traditional blockchain based solutions have. In addition, this research showed the possibility of fully decentralized health data sharing by replacing the local server with edge computing devices. The results also showed to the possibilities for this solution being useful in many other areas, such as rehabilitation, sports, and labor health protection in workplaces. This could be implemented using wearables to monitor the workers' workload and health indicators. It could also deploy environmental sensors to monitor the air conditions and other relevant working factors.

The work of Zheng et al. is mentioned in research done by Silvano and Marcelino [22], where they present the study by Zheng et al. in addition to three other papers that include proof of concepts for healthcare using the IOTA Tangle.

A disadvantage of the Tangle highlighted by Silvano, and Marcelino is the temporary reliance on the "Coordinator", which is a node controlled by the IOTA Foundation that assists in securing the network as it matures. The eventual removal of the centralized "Coordinator" is described by the IOTA Foundation in the paper The Coordicide [29]. Silvano and Marcelino conclude that the overall convergence of the IOTA Tangle, MAM and IoT will significantly improve and accelerate health data sharing.

A paper that specifically investigates the combination of the IOTA Tangle, MAM, and the IoT technology of wearables in the health sector, is the work of Brogan et al. [26]. The results correspond to the ones of Zheng et al. [25], demonstrating the possibility of sharing large amounts of authenticated, encrypted, immutable and granularly controllable health data from wearable devices. The results provide interoperability across a diverse digital healthcare ecosystem, involving many stakeholders.

5 DISCUSSION

As discussed in Section 2.1, there is an increased conversion of patient's health records from paper to electronic documents. Two of the primary studies explore this transition through the creation of a proof-of-concept system that merges PHR with EHR: Houtan et al. [28] with the use of blockchain technology, and Saweros and Song [11] with the use of the IOTA Tangle technology. Further, the section lists four important ethical priorities to take into consideration when developing such systems, as this transition comes with risk of privacy abuse and security breaches. The following was listed as the four priorities: Privacy, security breaches, system implementation, and data inaccuracies [6]. the following section is divided into the four mentioned priority topics.

5.1 Privacy

Maintaining privacy within health data management is crucial due to the sensitivity of such information. The health care sector is already familiar with the use of DLTs in their systems, even though IOTA is relatively new. An example of this is the use of blockchain technology which Sengupta et al. [24] claims has revolutionized the health care sector, especially in terms of improved security. The integration of blockchain in health care systems has been an improvement, but there exist some limitations. Yaqoob et al. [23], Farahani et al. [2], and Houtan et al. [28] help define these limitations, all saying that blockchain does not provide scalability and interoperability. Another limitation they mention is that blockchain does not provide sufficient privacy. The limitations are due to its architecture, recall Figure 3.

Based on its DAG architecture, the IOTA Tangle uses an organizational communication tool named MAM, as described in Section 2.4.2. The tool is used in several of the primary studies of this project. These studies all include the use of the IoT and IoMT technology to collect, share, and manage health data, since these technologies are highly compatible.

Both Zheng et al. [25] and Brogan et al. [26] successfully share large amounts of authenticated, encrypted, immutable and granularly controllable health data over the IOTA Tangle using MAM and IoMT devices. This demonstrates that the use of the IOTA Tangle with MAM achieves to manage the two important aspects of privacy in terms of health data management: authorization and authentication.

Another primary study supporting the privacy aspect of using the IOTA Tangle with MAM and IoMT is Hawig et al. [4]. The aim of the study was to find out if these technologies comply with the new GDPR rules and regulations in terms of privacy. The study used a different approach, by comparing two similar IOTA Tangle based system implementations. The first implementation using the IOTA Tangle with MAM, and the second implementation using the same combination but also adding an additional private distributed file system (IPFS). The results revealed that both showed great performance regarding privacy. The only difference was that the latter implementation scored lower on linkability and reversal risk. Thus, IOTA Tangle alone is not optimal for exchanging large files.

5.2 Security

Preventing security breaches in health data management requires a system that can protect the data from attackers. As mentioned in the previous section, blockchain is a secure DLT choice in health data management. There are some limitations due to its architecture, but it can use smart contracts that provide secure management of protected health information generated by IoMT sensors [24].

5.2.1 Availability. The study of Saweros and Song [11], connecting PHR with EHR using the IOTA Tangle as a middle layer, demonstrates a system with improved security. The main advantage of this is the decentralized system the IOTA Tangle provides. The main advantage of decentralized networks is that they provide availability through the architecture, as there is no centralized authority and no single point of failure. If one node fails or gets attacked, the rest of the system will remain.

5.2.2 Integrity. The system of Saweros and Song [11] also ensures integrity using hash algorithms. Another advantage is that every single transaction is validated by thousands of other nodes, which ensures data authenticity. The study demonstrated that there is no need for a third-party cloud service using the IOTA Tangle. Through the new system, data was stored directly, locally, and encrypted, instead of passing through an intermediate connector, making the system secure as well as ensuring data authenticity. Taking this into consideration, the results show that the primary studies by Florea et al. [27], Zheng et al. [25], and Silvano and Marcelino [22] support that using the IOTA Tangle and MAM, in an IoT/IoMT setting increases security.

5.3 System Implementation

System implementation includes technical aspects such as data transfer performance and data storage possibilities. It also includes how people using the system interact with it and if they understand how they access data. This section discusses how implementing the

IOTA Tangle in health data management improves performance and efficiency.

Addressing the term efficiency first, an important aspect of system implementation within health care is communication and sharing of data between institutions and stakeholders, also called interoperability, see Section 2.3.3. Patients do not always stay in the same hospital or have the opportunity to get the same physician or caregiver for each visit. In order to solve this problem, the health data system must be interoperable, meaning that data can be stored and shared securely, privately and efficiently between multiple stakeholders and institutions. Brogan et al. [26] demonstrate in their work a system based on the IOTA Tangle, IoT/IoMT, and MAM that provides interoperability across stakeholders within a large and diverse digital health care ecosystem. Zheng et al. [25] and Silvano et al. [22] reinforce this with similar research results. The background briefly mentions that MAM, Section 2.4.2, can be essential for interoperability in health data management.

Taking this statement into consideration it is likely to assume that even though it is not mentioned specifically in the results, the primary studies of Zheng et al. [25], Florea et al. [27], Brogan et al. [26] and Silvano et al. [22] meet the requirements for interoperability, as they use MAM in their system implementations.

Another aspect of efficiency is increased patient participation in health data management. This can be helpful in use cases including IoT and IoMT, as the result of this project presents. Saweros and Song [11] demonstrate an IOTA Tangle, MAM and IoT based system which includes a platform for patients to share their data with physicians or caregivers. The caregivers can share data securely amongst each other as well. An interesting feature implemented into the system was the patient's complete control over their own data, being able to decide what data to share themselves.

Assuming these kinds of systems are provided to patients capable of handling their own data and all the responsibility connected to it, this is a system implementation with great potential for increased efficiency of health data management. This corresponds with the background, Section 2.2, saying that IoT and IoMT sensors open up possibilities within the health data management, such as remote patient monitoring. Section 2.2 mentions data fragmentation, which corresponds with the performance part of system implementation. The IOTA Tangle, with MAM and IoT/IoMT, can help reduce the fragmentation of personal health data across various paper records, digital devices, and databases. This is supported by Saweros et al. [11] as they were able to solve the data fragmentation issue with a continuous time learning progression model.

The DAG architecture of the IOTA Tangle facilitates parallel transactions, recall Section 2.4.1. This is first and foremost positive in regards of scalability and efficiency. Scalability is one of the properties that almost all the primary studies address as an improvement by implementing the IOTA Tangle in a system. It is specifically presented numerous times as one of the main advantages the IOTA Tangle possesses over blockchain [2] [23] [24]. Several of the primary studies mention that the IOTA Tangle handles scalability well and the phrase "highly-scalable" [25] is used to describe the technology. Although it is scalable, the aforementioned "Coordinator" node temporarily limits the network from achieving its full potential [22].

5.4 Data Inaccuracies

Data inaccuracies can occur due to two factors, recall Section 2.1, (1) mistakes made by people managing data in a system, and (2) malfunctions or other unforeseen problems from the technical part of the system. This section reflects upon whether the IOTA Tangle can minimize data inaccuracies in relation to health data management. Looking at the human aspect of data inaccuracies in health data management, it is possible to prevent mistakes by implementing a user-friendly system that is easy to understand and use. This is beyond the scope of the IOTA Tangle, which is not a user interface framework, but a backend centered technology. Nevertheless, it is not completely wrong to assume that if health data management is improved using IOTA Tangle, this might open the opportunity for the health sector to change their focus and develop user friendly systems.

Based on several of the primary studies it is fitting to describe the IOTA Tangle as both secure and tamper-proof [27] [25] [22]. If data is immutable, it cannot be modified or reversed after being shared. Every transaction will be the correct one and the only source of truth. Primary studies providing an IOTA Tangle based system where immutability is specifically mentioned as a succeeding factor is Zheng et al. [25], Brogan et al. [26], and Silvano et al. [22]. This corresponds with the background, which states that immutability is integrated in the IOTA Tangle with the use of MAM, this ensures immutability in data sharing. To quickly mention data integrity in regards of the IOTA Tangle, this was discussed previously in Section 5.2 where Saweros and Song [11] proved in their study how their IOTA Tangle based system provided data integrity. IOTA makes sure that each transaction and data transfer is validated by several other nodes, which is what ensures the data integrity.

5.5 Limitations

Recall Figure 5, studies 1-6, [4] [11] [22] [25] [26] [28], give a direct answer to our research question. On the other hand, studies 7-10, [2] [23] [24] [27], are only partially related to our research question. The latter studies either discuss the advantages of DLT in health data management or the use of the IOTA Tangle in data management in general. The low number of studies directly answering the RQ made it beneficial to add the partially relevant studies as they contributed to the research.

6 CONCLUSIONS AND FUTURE WORK

The findings of this research support the potential for the IOTA Tangle in terms of health data management. The IOTA Tangle, in combination with MAM and IoT/IoMT technology, provides several advantages and improvements to the issues faced by health care systems today. The results from the primary studies demonstrate the high scalability, tamper-resistance, and security in health data management with the IOTA Tangle. The findings also demonstrate the advantages of using the IOTA Tangle with MAM. MAM allows authenticated, authorized, immutable, and secure health data to be shared over the IOTA Tangle in an interoperable way. The weaknesses of the IOTA Tangle, as stated in the primary studies, include the existence of the "Coordinator" node and the limited file size for transactions. Overall, the IOTA Tangle can provide reliable and secure health data management through its DAG based architecture in combination with MAM and IoT.

This mapping study answers an important research question and establishes the foundation for further work. The next step in this research is for us to develop a prototype that can demonstrate how health data management can be reliable and secure with the use of the IOTA Tangle technology. There exists a gap in the literature in terms of involving users in the development and testing of prototypes. This observation makes the involvement of user an interesting avenue for the further investigation.

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