Data Management in Appendable-Block Blockchains: A Case Study for IT Life-Cycle Management

Rodrigo W. Silveira[1,2](✉), Roben C. Lunardi[3], and Avelino F. Zorzo[1]

[1] Pontifical Catholic University of Rio Grande do Sul (PUCRS), Porto Alegre, Brazil
r.wetzel@edu.pucrs.br, avelino.zorzo@pucrs.br
[2] Hewlett-Packard Brazil (HP Brazil), Porto Alegre, Brazil
[3] Federal Institute of Education, Science and Techlongy of Rio Grande do Sul (IFRS), Porto Alegre, Brazil
roben@lunardi.inf.br

Abstract. Blockchain has been adopted in multiple areas that require secure and decentralized storage of information. One of them is the management of device lifecycle, which typically employs a centralized storage model. However, the application of traditional blockchains in this context has been growing and presenting challenges, particularly in terms of latency, performance, and scalability. Consequently, new blockchain topologies have been developed to enhance these properties by altering their data structure. An example of this is the appendable-block blockchain model, which removes transaction insertion of block insertion, allowing new data to be added to an auxiliary chain from the main block. The main goal of this work is to expand appendable-block blockchain, addressing contributions and enhancements in storage, persistence, and efficient data access. Besides, this work aims to investigate the process of information retrieval for related lifecycle events from the same device or component, i.e., within the same context. In order to achieve this, we present a real-use case study of a patent that addresses the storage and retrieval of data related to the lifecycle of devices within a company.

Keywords: Blockchain · Appendable-block blockchain · IT management · Lifecycle events

1 Introduction

Information security is a topic that is becoming increasingly important in the realm of technology, mainly because applications and systems are getting

This paper was supported by: the Ministry of Science, Technology, and Innovations, with resources from Law No. 8.248, dated October 23, 1991, within the scope of PPI-SOFTEX, Residência em TIC 02 - 01245.012095/2020-56; IFRS and HP Inc; and call INCT - MCTI/CNPq/CAPES/FAPs nº16/2014; CAPES, Brazil (Finance code 001), CNPq, Brazil (465450/2014-8 and 306250/2021-7) and FAPERGS, Brazil (17/2551-0000520-1).

A. Zaslavsky et al. (Eds.): MobiQuitous 2023, LNICST 593, pp. 476–488, 2024.
https://doi.org/10.1007/978-3-031-63989-0_25

progressively more interconnected. One of the areas in which security plays a fundamental role is in information technology (IT) management [3]. In 1994, Charles B. Wang warned that companies should apply investments and reformulations in order to promote advantages over competitors in this type of application [19]. IT management allows companies to manage their resources, providing the necessary tools for accessing and storing essential information for their management or providing a [4] service.

Management in information technology services [2] is a huge area that encompasses several sections of computing. One of them is the management of device lifecycle events. Lifecycle events are all the telemetry collected from machines, from their assembly to their disposal. This data usually contains information about the device's health and performance. The gathering of this information is essential for companies to check the condition of their products, especially when they are being used by consumers. This is vital to check eventual failures and make improvements. The management has many safety and compliance challenges that must be dealt with in increasing importance, especially in the security area. Consequently, companies usually adopt the Information Technology Infrastructure Library (ITIL) [7] standard, used as a set of best practices for managing information technology-enabled services.

Therefore, there has emerged a need for a model that guarantees availability, security, transparency, and immutable and distributed storage of data. Blockchain was developed with these characteristics, providing such features in a cryptographically secure system, enabling unknown entities to trust the same network without the need for a controlling third party. Trust is ensured through a consensus mechanism [18]. Many proposals use blockchain in different types of systems, making it increasingly common in recent years. One of these areas is IT management [2].

In 2019, Rafael Zotto proposed a patent [20] that suggests storing data and information collected from HP (Hewlett-Packard) machines (computers, printers, and notebooks, for example) in a distributed blockchain. Hence, it is possible to create a system that allows the management lifecycle information of devices on demand by the end user, at any time. The purpose is to analyze the status of their device and prevent failures at any time. However, the proposed model does not have an application in a specific blockchain and also does not indicate a single system for its implementation. Additionally, appendable-block blockchain model [10,12,14] (also known as SpeedyChain) seems to be a promising solution for storing IT lifecycle information. In special, due to its capability to store in different contexts [11,13] and allow retrieval of this information from another device connected to the same blockchain.

The proposed work uses the mentioned patent [20] as a case study for the implementation of improvements in the SpeedyChain storage and recovery mechanisms. This work proposes an improvement in SpeedyChain, allowing to addition of new transaction chains for each component of the device, instead of a single chain in the current SpeedyChain model. Every new lifecycle event collected will be stored in its own chain of transactions, according to the device and component it represents. This new structure aims to improve the performance of data recovery of specific components and improve the registration of component data after an exchange between devices. Additionally, the results of the evaluation show that the proposed structure can be advantageous for data recovery in contexts of different chains.

2 Related Work

In the last few years, some companies have provided a renting device service called Device-as-a-Service (DaaS) [16] or sometimes called Machine-as-a-Service (MaaS). The main concept of this service is to offer a way for smaller companies to rent a specific device instead of buying it, so the company that provides it needs to have a way to manage this device, especially its use and current health through lifecycle events collected. Therefore it is necessary to safely store and manage these events, since the data collected is sensitive and private, some solutions are adopting the use of blockchain for this matter, relying on its properties for better management.

Chen et al. [5] work provides a guide for the research and implementation of blockchain in Product Lifecycle Management (PLM). The research presents a structure organized into five metrics in order to determine whether the target PLM application is suitable to be solved using a blockchain model. Those metrics are related to data security, the requirement of consensus algorithms, data traceability, and the requirement of automated transactions. Also, it discusses possible applications for the lifecycle events management using blockchain. As users are constantly changing, it becomes difficult to determine the corresponding fees based on product usage. This technology can be used to record each user's information, including use duration, power consumption, and device health. Based on the collected information, fees can be automatically calculated and settled by smart contracts. Secondly, users can understand the complete history of the product before deciding whether to share or use the device.

Some researchers [9,17] proposed the usage of blockchain to manage all steps for device lifecycle management in an industry-based PLM, those stages are: beginning of life (BOL), middle of life (MOL), and end of life (EOL). In the MOL stage, it shows an example of using blockchain for the logistics of product and product proactive maintenance. According to lifecycle data collected in real-time, smart contracts can be used to detect occasional failures or faulty devices, alerting maintainers to replace malfunctioning devices.

Steamchain [8] has created a blockchain-based system to manage payments and decentralize information, facilitating interaction between original equipment manufacturers (OEMs) and users. This technology is provided as a service to other companies seeking to store the information of their products, facilitating communication between both parties. Therefore, companies that contract the service can utilize the software to measure a variety of device productivity parameters in real time and use them according to their needs. This solution can be used for Machine-as-a-Service, working as a device fleet management.

Although blockchain is not a new approach to solving PLM, those solutions still lack a deeper discussion on the storage and recovery steps. In the next sections, we present a new approach to managing lifecycle events using the concept of appendable-block blockchain. The main idea is to use SpeedyChain properties to create auxiliary chains for each device component, so the data for a specific context can be recovered easily, with a better performance compared to a traditional chain. Another improvement of this solution would be when trading a component between devices, since the component chain of events is separated, it can follow the component to its new chain in the new device.

3 Background

3.1 Appendable-Block Blockchain

Appendable-block blockchain is a concept used by SpeedyChain framework [12, 14], which was designed for the context of IoT systems. Usually, blockchains for this kind of application have low computing power and limited storage capacity, making it difficult to use a traditional blockchain architecture. To improve those limitations, appendable-block blockchain proposes a model that removes the concept of static blocks, allowing parallel transaction insertion and enabling faster insertion of data into the block [11,13].

The chain structure is composed of three main components: devices, gateways, and service providers. Devices are responsible for producing data and sending them to the gateways, which append these values to the blockchain. Devices do not store blockchain data, they behave like a light node in the chain. Gateways control the access and insertions in the blockchain. Service Providers work as middleware, connecting to the gateways to access the blockchain information.

The SpeedyChain node structure allows the insertion of transactions after a block is inserted in the blockchain. When a block is created and appended to the chain, a first genesis transaction is inserted. The main block header has a special field that stores the hash for this first transaction. After the block is created, new transactions can be inserted into the block, and the transaction generated is appended to the last block transaction, forming a kind of auxiliary chain from the block. Each new transaction has a hash for the previous transactions, just like a traditional blockchain.

To handle block insertions, appendable-block blockchain uses different consensus algorithms, like Proof-of-Work (PoW), Practical Byzantine Fault Tolerance (PBFT), and Delegated Byzantine Fault Tolerance (dBFT) [13]. To solve security issues related to transaction insertion, Lunardi et al. [11] proposed a context-based consensus for appendable-block blockchain. Each device has its own context connected with multiple gateways, consensus will be executed inside each context. After a consensus is performed, a gateway can propagate the new consented set of transactions to the gateways from other contexts.

3.2 Patent - Lifecycle Change Cryptographic ledger

The patent [20] describes a real use case scenario that addresses the use of a model similar to the one proposed by SpeedyChain, but in the context of device lifecycle management. With this new model, it would be possible to improve a company's current IT management by decentralizing the storage of information useful to consumers, such as telemetry data from the lifecycle events of devices such as computers and printers. This data usually includes components' performance and speed telemetry, for all devices. This way, users themselves can retrieve this information and check the "health" of their devices at any time.

In Fig. 1, it is possible to see the structure addressed in the patent, in which each block of the main chain for the devices has pointers to auxiliary chains for each of its components. This way it is possible to retrieve specific components lifecycle at once and efficiently, without needing to go through the entire chain of data. Furthermore, another usability of separating components' telemetry in different chains is the capability of keeping the lifecycle of a component even when trading it to a different device. That's a difficult use case to keep track of in the usual centralized IT management services.

Since the model described in the patent is similar to the SpeedyChain implementation, the idea is to use it to demonstrate the functionality of the new advances explored and implemented in SpeedyChain, especially regarding the storage and retrieval of information, evaluating the viability of the model proposed by the patent in this new context, as well as the behavior of the entire data storage and consistency structure. Therefore, telemetry data for the device will group the information of its components in the same block, as auxiliary chains, to determine improvements in performance when retrieving telemetry data from the same context.

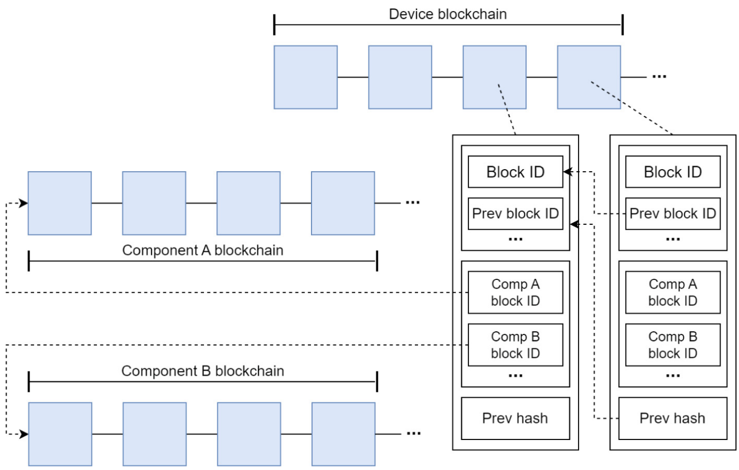

Fig. 1. Patent blockchain structure (adapted from [20]).

4 Appendable-Block Blockchain for IT Management

This work aims to explore the use of blockchain for managing device lifecycle data. To achieve this, advancements are required in the areas of data storage, management, and retrieval within SpeedyChain [14]. In addition to these advancements, the feasibility and functionality of Rafael Zotto's patent [20] are intended to be demonstrated, particularly the implementations involving blockchain and its entire context. SpeedyChain implements an appendable-block blockchain model with the potential for smart contract usage [15]. Various related works developed in the same field will be employed to help the target model [1,10–14]. The development of a decentralized event recovery mechanism will also be evaluated. The goal is to enumerate the challenges of this type of structure, assessing the improvement in managing lifecycle events, from storage to recovery.

The main concept of this proposal is to implement the appendable-block blockchain example depicted in Fig. 2 within the patent's context as a use case. In this model, the blockchain features a main chain, where each block corresponds to a device in the network, and each transaction stored in that block serves as a "pointer" to another blockchain containing lifecycle events for specific components of that device. The proposed example seeks to make modifications to the SpeedyChain model, in order to accommodate the newly acquired data. SpeedyChain includes a mechanism for storing new transactions in blocks already inserted in the blockchain, which facilitates the implementation of the new model proposed in the patent. Studies on the utilization of smart contracts in this chain have been conducted, demonstrating the feasibility of such applications in SpeedyChain.

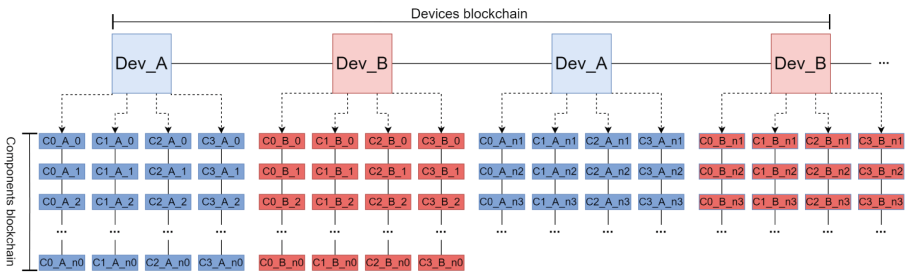

Fig. 2. Implemented Structure

Furthermore, optimizations need to be made in the current version of the appendable-block blockchain to ensure the organization of component data storage in chains of the same context, starting from the main block. As a single device has multiple components, modifications must be made to SpeedyChain to ensure that events for the same device are linked to it, utilizing digital signature information with asymmetric encryption available in SpeedyChain. Currently, this model only displays an auxiliary chain from the main one. Due to multiple components, changes must be implemented to ensure the storage of multiple chains. In the example shown in Fig. 2, each device has four components, meaning four auxiliary chains for each main block.

The work aims to address advancements that have not been fully explored in appendable-block blockchains. One of these advancements is the implementation of data preservation and consistency processes. Currently, this model is oriented towards virtual machines, with data stored in memory only during processing. Therefore, alterations will be made to ensure data persistence for future executions, storing information in structures such as IPFS (InterPlanetary File System) or locally.

To obtain lifecycle events of components, the goal is to develop an application that performs system calls on a computer, thereby obtaining the state of memories, processors, and other device components. Currently, these values are simulated through a data generation created for this purpose. As for the recovery application of lifecycle events, the primary objective is to utilize a different machine for decentralized information retrieval, as outlined in the patent. Since SpeedyChain can be run on virtual machines, this connection can be emulated using such a topology.

Due to this new structuring and changes in data storage and consistency, we present a solution for information retrieval from a predefined entry point. For the context of the addressed use case, the implementation of a mechanism using a unique identifier for a component or device will be used to retrieve all of its telemetry. Consequently, users can access their machine's history at their convenience, collecting the health of their device. Moreover, the concept of smart contracts in SpeedyChain should be reevaluated, allowing for the creation of new contracts to enhance the model's usability. An example within the patent's context involves using collected lifecycle events to identify the need for preventive maintenance in a faulty component, alerting the user to conduct a replacement before the device becomes irreparable.

4.1 Data Generation

SpeedyChain was improved with a new model and code. The original chain was constructed considering the simulation of IoT device information, and storing collected IoT data, such as temperature, GPS, and others. The first implemented modification was in the type of data generated by the simulation, adding the capability to create data simulating four basic components of a computer: processor, graphics card, RAM memory, and SSD. This information was generated with random values based on parameters of real component access speed and performance, e.g., 2000 MHz, 300 Mb/s, and 2.50 GHz, depending on the component.

Based on the parameters generated for the simulation, a structure is created to be stored in the chain with values corresponding to the lifecycle event (Fig. 3). The structure contains the following main data fields: event index, type of stored event (Type), unique identifier of the component (ID), and the value of the simulated data (Data). The generated lifecycle event is stored in its specific transaction and finally inserted into the transaction chain corresponding to the target block component of the device.

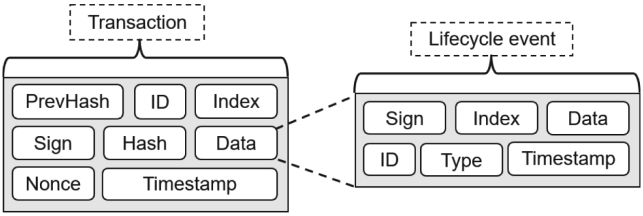

Fig. 3. Structure stored in transactions

4.2 Data Storage

The developed and evaluated blockchain provides data storage through two different methods. The first method utilizes the code previously implemented by its authors to store data from different components in a single transaction chain originating from a block in the main chain. Simulated data is generated for each component and sequentially stored, resulting in the insertion of four transaction block sets into the chain, one after the other, with each new component simulation. Modifications were implemented to store lifecycle event data, instead of the initial use case involving IoT device information, as explained in Sect. 4.1.

The second storage mechanism implemented is the version addressed in Sect. 4 and illustrated in Fig. 1 and Fig. 2. Each block in the main chain features an auxiliary chain for each of the device's components, summing up four transaction chains for the given simulation. Fundamentally, this is the sole distinction between a block in the original chain and the newly implemented version. This alteration enables intelligent context recovery, as it's unnecessary to go through all transactions within a block, it only needs to return the corresponding auxiliary chain for that component.

4.3 Data Retrieval

The implementation of data retrieval was achieved through unique identifiers for both blocks and transactions. In the conducted simulations, each peer in the network behaves as a device containing the four components discussed in Sect. 4.1. Each part of the device has a unique identifier, functioning like a unique serial number. To aid in linking the involved parts, each component's identifier also includes the identifier of its parent device, facilitating the specific recovery of context internally, as the device in question can be recognized solely by the component's identifier.

There are two main methods for information retrieval. The first method utilizes the device identifier to retrieve all blocks from the main chain corresponding to the sought-after device. The second method uses the unique identifier of a component to retrieve, across the entire chain, only the transactions corresponding to that context. It should be noted that, as explained in Sect. 4.2, the transaction retrieval function operates differently for the two types of chains tested, as their internal structures differ due to the number of auxiliary chains for transactions. In both cases, the analysis method for evaluating data retrieval involves measuring the time required to perform search operations within the chains.

4.4 Data Consistence

Regarding the implementation of techniques for the preservation and consistency of stored data in the chain, functions were created to store and retrieve the state of the chain using text files. These functions gather the key pair from each of the peers involved in the blockchain, along with all relevant information related to the blocks and their respective transactions. The stored values are sufficient for preserving the entire state of the chain, making it possible to recreate it from these values and ensure correct order and validation. Therefore, its data is persisted for future executions and tests with greater ease and reliability in the results obtained from the simulations.

Subsequently, the idea is to enhance this work by using a more robust structure for data persistence, potentially utilizing a system like IPFS for consistent storage of Speedychain's context, thus facilitating the storage of a more complex structure with numerous blocks and transactions. However, initially, the current files generated by the simulation are meeting the requirements and facilitating the acquisition of consistent results for each execution and test.

5 Experiment Evaluation

Tests were conducted by simulating four different devices, each of them with the four components discussed earlier in this study. Figure 4 shows the structure used for data recovery tests. For each device, two blocks were created. In each block, 100 transactions were added for each component, totaling 400 transactions per device. Therefore, in the execution of the standard SpeedyChain, each block of the device has a single chain of 400 transactions, with each data from the components interleaved as shown in Fig. 5. A total of eight main blocks and 3200 transactions were created. For the simulations, a computer with an Intel i5-10400 processor, 2.90 GHz, and 6 cores was used, along with 8GB of 2666 MHz RAM and a KINGSTON A400 480 GB SSD with a reading speed of 500MB/s and a writing speed of 450 MB/s.

In Table 1, the results of the data recovery test of two components for different devices, using their unique identifiers, can be seen. The results demonstrate that the information recovery time for the model illustrated in Fig. 4 is significantly faster compared to the original SpeedyChain's implementation. It happens due to the fact that data retrieval in the new model gathers the entire transaction chain directly instead of searching the entire chain for specific component data.

Another preliminary test conducted was measuring the time for the creation of the entire chain compared to its reconstruction from the generated consistency file, discussed in Sect. 4.4. These values can be observed in Table 2, which illustrates a significant decrease in the time required to recreate all chains of

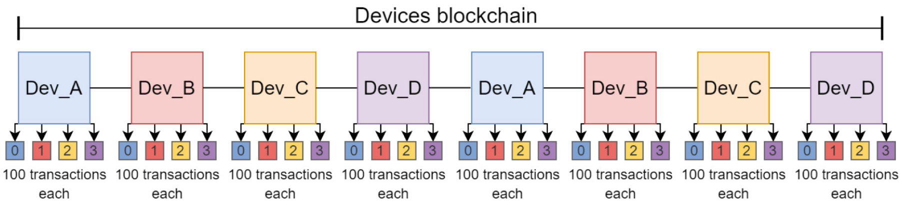

Fig. 4. Modified SpeedyChain structure for the experiment

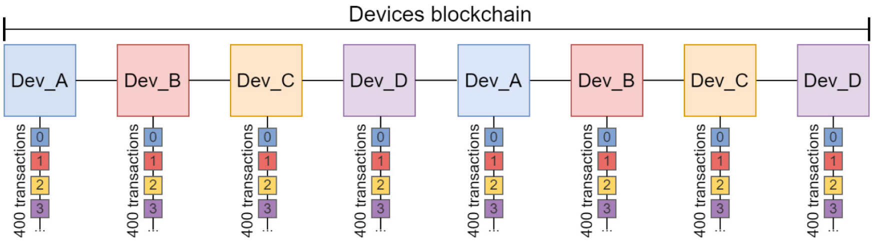

Fig. 5. Original SpeedyChain structure for the experiment

the system. Since the reconstruction of the structure uses pre-validated data from the network, its insertion into the chain is easier compared to the standard creation of authenticated blocks and transactions.

Table 1. Comparison of transaction retrieval times (ms)

	Dev_A - Component 0		Dev_C - Component 2	
ID	New impl	Original impl	New impl	Original impl.
0	0.041007995605	0.519990921021	0.026941299438	0.424861907959
1	0.044822692871	0.463008880615	0.039815902710	0.439882278442
2	0.033140182495	0.416994094849	0.030040740967	0.403165817261
3	0.038862228394	0.405073165894	0.070095062256	0.486135482788
4	0.034093856812	0.531911849976	0.031948089600	0.436067581177
Average	0.0383853912354	0.467595782271	0.0397682189942	0.4378226135254

These are preliminary tests because they consider a small chain with few devices, blocks, and transactions. It is necessary to conduct more elaborate tests, not only to evaluate the recovery performance in this case but also to assess the scalability of the implemented multiple transaction chain approach. Another test that will be addressed in the final study is evaluating the time for block and, mainly, transaction creation. Despite these measurements having already been conducted in the original work of SpeedyChain [14], the changes in the blockchain might have altered these results, especially concerning transactions within multiple chains.

Table 2. Comparison of chain creation times (ms)

ID	Creation	Reconstruction
0	70378.96	23209.98
1	69227.06	22916.13
2	68791.97	22590.59
3	70213.40	23086.82
4	69332.54	22739.11
Average	69588.79	22908.53

6 Final Considerations

The concept of appendable-blockchain presented in SpeedyChain is a recent innovation in the universe of blockchain, and there is no related work to this model in other research in the area of device lifecycle management. Thus, there are still several approaches to be researched and advances in this topology still need to be explored. This work discussed improvements in the storage and retrieval issues of stored data in this structure. The contributions that these advances in the model improved performance, decreasing latency and energy consumption, topics that SpeedyChain itself seeks to improve in relation to traditional blockchains.

As the stored lifecycle data are small, SpeedyChain is expected to be able to meet the data storage performance demand, even if multiple devices are used in the network. Many traditional blockchains use auxiliary structures to perform off-chain data storage. However, SpeedyChain removes the insertion of transactions from the insertion of blocks, thus, transactions can be added in parallel in the chain in the different blocks that correspond to each device. Furthermore, the proposed implementation improved SpeedyChain by using different chains for each component, untying the data from a single chain, allowing not only a smarter retrieval, but also the exchange of context between different machines in a simple way.

A common problem in chained structures such as blockchain is the process of searching for a specific piece of information. Therefore, some existing solutions seek to improve this issue by indexing the stored data. One of the tools widely used in blockchain for this purpose is The Graph [6], a decentralized indexing protocol. This structure guarantees an improvement in information retrieval time because, instead of consulting the entire blockchain, it is able to search for the index of the information to be retrieved in the database. As a future work, this type of protocol can be used to enable efficient data retrieval performance for the implementation by relying on this decentralized indexing structure using a trusted query language.

References

1. de Arruda, E.H.P., Lunardi, R.C., Nunes, H.C., Zorzo, A.F., Michelin, R.A.: Appendable-block blockchain evaluation over geographically-distributed IoT networks. In: 2020 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom), pp. 1–6 (2020)
2. Berdik, D., Otoum, S., Schmidt, N., Porter, D., Jararweh, Y.: A survey on blockchain for information systems management and security. Inf. Process. Manage. **58**(1), 102397 (2021)
3. Brown, C., DeHayes, D., Perkins, W., Martin, W.: Managing Information Technology. Pearson Prentice Hall, Hoboken (2012)
4. Bryan, V.: Chapter 14: Information technology management compendium. M. Moiseichik(ed.), Management of Park and Recreation Agencies, 3rd Edition **14**, 305–347 (2010)
5. Chen, S., Cai, X., Wang, X., Liu, A., Lu, Q., Xu, X., Tao, F.: Blockchain applications in PLM towards smart manufacturing. Int. J. Adv. Manuf. Technol. **118**, 1–15 (2021). https://doi.org/10.1007/.s00170-021-07802-z
6. Foundation, G.: About the graph - what is the graph?, July 2023. https://thegraph.com/docs/en/about/
7. Gërvalla, M., Preniqi, N., Kopacek, P.: It infrastructure library (ITIL) framework approach to it governance. Int. Feder. Autom. Control - PapersOnLine **51**, 181–185 (2018)
8. Hoske, M.T.: New model optimizes machine metrics. Control. Eng. **65**(11), 10–11 (2018)
9. Liu, X., Wang, W., Guo, H., Barenji, A.V., Li, Z., Huang, G.Q.: Industrial blockchain based framework for product lifecycle management in industry 4.0. Robot. Comput.-Integr. Manuf. **63**, 101897 (2020)
10. Lunardi, R.C., Michelin, R.A., Neu, C.V., Zorzo, A.F.: Distributed access control on IoT ledger-based architecture. In: IEEE/IFIP Network Operations and Management Symposium (NOMS), pp. 1–7 (2018)
11. Lunardi, R.C., Alharby, M., Nunes, H.C., Zorzo, A.F., Dong, C., Moorsel, A.V.: Context-based consensus for appendable-block blockchains. In: 2020 IEEE International Conference on Blockchain (Blockchain), pp. 401–408. Rhodes, Greece (2020)
12. Lunardi, R.C., Michelin, R.A., Neu, C.V., Nunes, H.C., Zorzo, A.F., Kanhere, S.S.: Impact of consensus on appendable-block blockchain for IoT. In: Proceedings of the 16th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services, MobiQuitous 2019, pp. 228–237. Association for Computing Machinery, New York, NY, USA (2019)
13. Lunardi, R.C., Michelin, R.A., Nunes, H.C., Neu, C.V., Zorzo, A.F., Kanhere, S.S.: Consensus algorithms on appendable-block blockchains: impact and security analysis. Mob. Netw. Appl. **27**(4), 1408–1420 (2022)
14. Michelin, R.A., et al.: Speedychain: a framework for decoupling data from blockchain for smart cities. In: 15th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services, MobiQuitous 2018, pp. 145–154. ACM, New York, NY, USA (2018)
15. Nunes, H.C., Lunardi, R.C., Zorzo, A.F., Michelin, R.A., Kanhere, S.S.: Context-based smart contracts for appendable-block blockchains. In: 2020 IEEE International Conference on Blockchain and Cryptocurrency (ICBC). pp. 1–9. IEEE, Toronto, ON, Canada (2020)

16. Posey, B.: Device as a service (DAAS) (Abr 2022). https://www.techtarget.com/searchvirtualdesktop/definition/device-as-a-service
17. Tran, V.H., et al.: Machine-as-a-service: blockchain-based management and maintenance of industrial appliances. Eng. Rep. **5**(7), e12567 (2022)
18. Tschorsch, F., Scheuermann, B.: Bitcoin and beyond: a technical survey on decentralized digital currencies. IEEE Commun. Surv. Tutorials **18**(3), 2084–2123 (2016)
19. Wang, C.: Techno Vision: The Executive's Survival Guide to Understanding and Managing Information Technology. Management: MacGraw-Hill, McGraw-Hill, New York, NY (1994)
20. Zotto, R.D.: Lifecycle change cryptographic ledger (Abr 2021). https://patents.google.com/patent/WO2021061146A1/en, publisher: Hewlett-Packard Development Company, L.P. (WO2021061146A1)