DOI: https://doi.org/10.31410/ITEMA.S.P.2023.1

Blockchain for Business: An Overview and Benchmarking Analysis of Key Technologies

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Received: December 22, 2023
Accepted: March 29, 2024
Published: May 28, 2024

Keywords:
Blockchain;
Blockchain for business;
Hyperledger Fabric;
Hyperledger Sawtooth;
Corda;
Consensys Quorum;
Benchmarking analysis

Abstract: *The adoption of blockchain technology in business applications has seen rapid growth in recent years. As enterprises explore the potential benefits of blockchain, it becomes imperative to evaluate various blockchain technologies to make informed decisions about their implementation. This paper presents an overview of blockchain technologies tailored for business use cases and analyzes prominent platforms such as Hyperledger Fabric, Hyperledger Sawtooth, Corda, and Consensys Quorum. This study provides valuable insights for enterprises seeking to deploy blockchain solutions by evaluating key metrics such as performance, scalability, security, and consensus and conducting a cross-industry benchmarking analysis. The evaluation process will be based on a comparative and in-depth analysis of the current state of research. The findings shed light on the potential benefits of each blockchain technology, facilitating informed decision-making and promoting the responsible adoption of blockchain in the business environment.*

1. INTRODUCTION

Blockchain recently has gained popularity and an increased interest in the scope of transforming and improving business operations and processes. The design initially presented by Nakamoto has evolved into more elaborate models that have the capabilities to fulfill the business needs to tackle challenging and complex issues. The emergence of smart contracts in the digitalization and automation of business workflows has made blockchain technology more suitable for application in most industries such as healthcare, supply chain, finance, insurance, automotive, cyber security, etc., making blockchain an attractive technology and increasing interest among the research community, businesses, and governments.

For blockchain to be viable for businesses certain premises require adjustments. A crucial requirement is the implied shift toward permissioned networks where user participation is contingent and identity authentication of the users enables them to remain identifiable at all times within the network. A paramount for blockchain for business is performance. Therefore, high transaction throughput and low latency of transaction confirmation should characterize the network. Business transactions and the pertaining data must be private and confidential, highlighting the unnegotiable need for a blockchain for business to be secure. Thus, new blockchain platforms, such as Hyperledger Fabric, Consensys Quorum, Corda, etc, to address these requirements emerged. These platforms enabled the exploration of the blockchain potential to transform business across industries.

In this paper, the authors aim to explore the applications and latest advancements of the blockchain for business technologies in cross-industries and make a relevant benchmarking analysis. The paper focuses on the potential benefits of blockchain technology for business use cases intending to

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facilitate informed decision-making for the adoption of these technologies. The remainder of this paper is organized as a literature review of the top blockchain for business technologies and their latest advancements and projects. Followed by methodology, analysis of the benchmarking, and future research directions for blockchain. The conclusion section concludes the paper.

2. LITERATURE REVIEW

Hyperledger Fabric, as defined by Androulaki et al. (2018) and also known as the blockchain for business, is part of the Hyperledger umbrella project. Its modular architecture and plug-and-play capability characterize it, enabling network designers to plug their preferred components, such as consensus and membership services. The ledger can be split to match different participants with different roles thus giving them different access to data. Smart contracts on Hyperledger Fabric are called Chain Code and can be written in one of the many supported programming languages. The chain codes define the system's business rules and can address different levels of real-world business complexities due to their configurable capacities. The peers on a Hyperledger Fabric network have a clear separation of duties or functions – endorsing peers, orders, and committing peers. This allows a Fabric network to achieve low latency and high throughput for transactions. There is no cryptocurrency associated with the mining of transactions in Fabric. This makes Fabric transactions more deterministic and more suited to an enterprise context. When transactions are committed to the ledger the committing peers update the world database representing the latest state of each asset, as well as record the changes in the transaction's ledger.

Fabric is considered a cross-industry blockchain, with use cases that encompass its versatility for business. Based on Hyperledger Fabric, Wutthikarn and Hui (2018) developed a prototype of an application for dental clinic service with the scope of fostering interoperability between clinics and reducing costs by sharing medical equipment and transactions. Their solution, which uses in addition another Hyperledger project, Composer, is shown to have improved cost-effectiveness and the quality of service offered to the population. Diaz and Kaschel (2023) implemented and tested an Electronic Health Records management system with support for user roles based on Hyperledger Fabric with RAFT consensus implementation and quantitatively measured the scalability with Caliper, concluding that a dual-channel architecture is by a low magnitude more performant and scalable. Shaikh et al. (2022) proposed a Hyperledger Fabric-based architecture for e-healthcare information and privacy management, resulting in a solution that provides more efficient information integrity, provenance, and storage procedures. Xiao et al. (2019) proposed a data identity authentication scheme based on Fabric. Their proposed scheme is deployable for the insurance industry and it aims to improve data security and practicability among the parties. The results they obtained support their proposal. Bodemer (2023) explored a Hyperledger Fabric-based blockchain solution with AI-enhanced smart contracts to address the prevailing challenges in the insurance industry and based on preliminary tests indicated a positive impact on transparency, reduction of fraudulent claims, and optimization of risk assessment processes. Haque et al. (2023) proposed a solution based on this permissioned blockchain for the insurance industry, especially the branch that covers farm insurance, in the Bangladesh case, providing a secure and efficient system against fraudulent cases. The results of the authors' experimental results indicate that the solution is also scalable. Z. Shi, Zhou, Hu et al. (2019) evaluated the benefits of a Hyperledger Fabric-based solution to address the most relevant issues in the pharmaceutical drugs supply chain. Their solution is integrated with IoT devices, like RFIDs, sensors, locators, and QR codes to enable real-time tracking. Functional results show that the application of the blockchain in this case improves transparency and safety while reducing manual operations, leading to a decrease of

human errors. Kumar (2023) explored the employment of the Fabric-based solution aimed at preventing drug counterfeiting, emphasizing the cost and safety aspects of the solution. Banik et al. (2023) proposed employing a platform based on Fabric with the scope of managing vehicle data and ensuring the confidentiality and integrity of such data. The solution empowers authorities to be able to track vehicles even beyond the borders of the state. It addresses issues like the counterfeiting of registration documents or other data manipulations. The measured performance indicates that the solution is usable. Chen et al. (2023) proposed a scheme for the traceability of data in the tea supply chain based on Fabric using IPFS as storage and the ECDSA algorithm for identity confirmation. The solution aims to support anti-counterfeiting efforts in the tea production industry. The performance parameters measured with Caliper show low latency both in the read and write of the transactions. Foschini et al. (2020), have conducted quantitative research on the performance of Hyperledger Fabric. The results of their experiments show that Go is the best-performing language for smart contracts development in Hyperledger Fabric. Shalaby et al. (2020) evaluated the performance of Hyperledger Fabric focusing specifically on how the end-to-end latency and throughput are affected by the batch timeout, batch size, and endorsers while varying the number of parallel transactions. Their results indicate that the latency increases as the number of transactions and batch timeout increase and that throughput increases as the batch size increases.

Hyperledger Sawtooth as defined by Olson et al. (2018) is an enterprise-level permissioned modular blockchain platform launched by the Linux Foundation and contributed by IBM, Digital Asset, and SAP. It is implemented in the form of Blockchain-as-a-Service and can execute smart contracts developed in general programming languages without the constraint of knowing the inner workings of the core of the platform. Sawtooth recognizes two distinct environments: the core ledger system environment and the application-specific environment and segregates these environments thus facilitating the application development and keeping the system safe and secure. From an architectural point of view, as explored by K. T. Sharma (2019), Sawtooth follows a pragmatic approach, by providing a REST API for clients to interact with a validator using the JSON/HTTP standards. This API treats the validator as a black box for submitting transactions and fetching results. The validator receives the requests that come through the API, validates the transaction signature, and forwards them to the responsible transaction processor. The network's validators work together over the network layer to keep the global state of the blockchain consistent. Transaction processors encapsulate the business logic validate the transaction, and decide whether a transaction is added to the next block. Sawtooth's consensus mechanism is a Nakamoto-style consensus algorithm that is designed to be a production-grade protocol capable of supporting large network populations. Its PoET (Proof of Elapsed Time) consensus mechanism enables it to integrate with hardware security solutions, referred to as "trusted execution environments". It also supports other consensus mechanisms, including PBFT.

Sawtooth is considered a cross-industry enterprise blockchain and it has found use in several cases. Owens et al. (2019) proposed a Hyperledger Sawtooth blockchain-based design pattern for a general crypto-asset framework where secondary smart contracts can control assets. Moriggl et al. (2020) concluded that Hyperledger Sawtooth performs well in the field of cybersecurity of Electronic Health Records, with one particular difference in the case of record deletion. Pilares et al. (2022) proposed an Electronic Health Records - specific framework based on dual-channel Sawtooth and IPFS for distributed data storage to address the complexities encountered in the field. Khan et al. (2021) proposed a Hyperledger Sawtooth blockchain focused on the cuber-physical control of power grid control and monitoring system of renewable energy. The results of their work show the benefits of blockchain deployment in such a distributed system, highlighting

integrity, transparency, confidentiality, control access, and security. The performance of Hyperledger Sawtooth was benchmarked by Ampel et al. (2019) using Hyperledger Caliper. Through their experiment, they concluded that the performance of Sawtooth is impacted by several factors. They observed a direct impact of the input transaction rate and batch size on the throughput. Specifically, they observed a linear dependency between these parameters. The relation between the input transaction rate and memory usage is exponential and could lead to a potential bottleneck in transaction speed. J. Shi, Yi and Kuang (2019) empirically studied the performance of Sawtooth and provided insights on the adjustment of the Scheduler and Maximum Batches parameters for optimal performance in a cloud environment. Moschou et al. (2020) concluded that the most performant language smart contracts in Hyperledger Sawtooth are the ones written in Go.

Corda, a unique permissioned private enterprise blockchain, as defined by Brown et al. (2016) is open source, open design, development, governance, and standards. Corda allows businesses and individuals to transact privately, between legal-identifiable counterparties, on a single network that is meant to be highly scalable, and where applications developed by independent developers are interoperable due to network-wide standards. Its end-state principles are privacy, legal footing, and assured identity. The only parties who have access to the details of a transaction are those who participate in the transaction and those who need to assure themselves of transaction provenance. Deals recorded by the ledger are, by contract, accepted as admissible evidence and legally binding by all parties in any dispute. Parties will have assurance over the identity of participants in the network. This is made possible due to Know Your Customer (KYC) requirements of all participants of the network, and the core identity framework which enables Corda to assign a single user profile to any legal entity, whether it be an organization or an individual. Corda architecture offers scalability, longevity, and interoperability. The network is scalable to support billions of transactions daily across industries. Different versions of Corda and multiple applications can coexist and interoperate on the same network regardless of the version.

Fiorenza et al. (2020) propose an R3 Corda-based solution integrated with a mobile application aimed at enabling patients to control the entities that may have access to their Electronic Health Records. Minango et al. (2023) explore the employment of R3 Corda in a proof of concept for the supply chain, obtaining benchmarking results in four parameters that indicate good performance. Kumari et al. (2023) explore a supply chain management system that preserves privacy among the parties involved in the process. Pradhan et al. (2023) designed and deployed a Corda-based multiple peer and notaries network to address relevant cybersecurity issues of a peer-to-peer energy trading network, integrated with the latest transaction broadcasting and validation services. The measured performance of the network indicates optimum parameters and performance.

ConsenSys Quorum as defined by Consensys Quorum (2018) is a soft fork of public Ethereum Blockchain meaning that the Quorum solution is unchanged Ethereum base code. Quorum's solution addresses the issues observed with using Ethereum for business by providing a primary feature that includes privacy – transactions. Peer/node permissions using smart contracts ensure that only known parties can join the network. Allowing fine-grained access only to participants who are involved in a specific transaction or access to entities such as regulatory bodies. The basic architecture consists of two main components. Quorum node, a soft fork of Go Ethereum client (geth), modified by adding a thin layer on top which enables Quorum to use a voting-based consensus mechanism instead of proof-of-work and allowing transactions and smart contracts to be privately executed. The second main component is Constellation, a two-part system responsible for implementing the privacy feature of Quorum. The first part of the Constellation consists of

Transaction Managers that store and allow access to encrypted transaction data, and exchange encrypted payloads with other participants' transaction managers, but they do not have access to any sensitive private keys. Enclave, the second part, works with the transaction manager to strengthen privacy by managing encryption and decryption in an isolated way. The Enclave stores private keys and is essentially a virtual HSM (Hardware Security Module), a known encryption method in the business tech.

A. Sharma et al. (2022) proposed the employment of Quorum for financial accounting and through statistical analysis proved that this technology is one of the best fits in terms of consistency and trust for accounting implementation. They also observed improved transparency, efficiency, and lower costs. Zeydan et al. (2023) proposed a Quorum-based solution for the telecommunication industry aimed at creating a trusted environment among different stakeholders to transparently and securely manage the lifecycle of automated vertical network services in a multi-cloud and multi-domain environment. Shaik and Reddy (2023) focused on Quorum as the basis of a new framework aimed at ensuring the legitimacy and uprightness of the client certifications that eventually comprise e-portfolios. Ktari et al. (2022) utilize this blockchain in the context of the Tunisian olive oil supply chain in a multi-blockchain and multi-sensor architecture to trace the end-to-end process of olive oil production. Li et al. (2023) propose a framework for Trusted Computing as a Service based on the Quorum blockchain, the ESP32 microcontroller with the ATECC508A security chip adding layers of encryptions to the information processed by smart contracts to control the visibility of that information among the peers. Sethuraman and Angamuthu Rajasekaran (2021) propose a solution based on the Quorum blockchain integrated with IPFS to address the single point of failure in IoT networks. Carare et al. (2021) implemented a model based on the Corda blockchain to automate the process of Bilateral Derivatives Over-The-Counter Post Trade transactions by designing a mechanism of the workflow states of the transaction, based on the asynchronous communication among the parties, improving the accuracy and efficiency of this special process performed in the banking industry.

3. METHODOLOGY

The methodology is based on a literature review of recent scientific papers, publications of industry reports, and real-world projects on the blockchain for business key technologies and their application in different industries. This review serves as a compass for identifying and understanding the current landscape of blockchain for business technologies and their application, potential, and benefits. Through the review, the aim is to identify and capture the latest trends, innovations, advancements, and challenges in the adoption of blockchain technologies within the business context. KPIs of the selection process of the publications reviewed are the year of publication, the relevance of the publication, the industry, and the use of blockchain technology. The publication search is conducted in top academic research databases such as Scopus, Web of Science, ScienceDirect, IEEE Xplore, Springer, etc with keywords defined based on KPIs and within the last five years of publication. Considering the relevant real-world projects the search is based also on the publication on each blockchain technology website. After the selection process, a cross-industry benchmarking analysis is conducted. Publications are classified and analyzed based on the blockchain for business technologies, based on the industry, and based on performance and architecture KPIs such as consensus mechanism, activity, performance, scalability, and security. The analysis offers insights into which blockchain for business technologies dominates specific industries and concludes the strengths and weaknesses of each technology to guide the practical adoption of blockchain technologies in diverse industries.

4. ANALYSIS & FUTURE RESEARCH DIRECTIONS

Based on the corpus of publications that regard business use cases of general-purpose blockchains, it is evident there is a high interest in blockchain branches like Hyperledger Fabric and Hyperledger Sawtooth under the Hyperledger umbrella project. The interest has been constant in recent years specifically in the healthcare and insurance industry. Even though blockchain for business is designed to be of general purpose and to adapt to business needs and requirements across various industries, the reviewed papers indicate that specific blockchain projects are more popular in specific industries. The bar chart in Figure 1 summarizes the spread of blockchain technologies per industry.

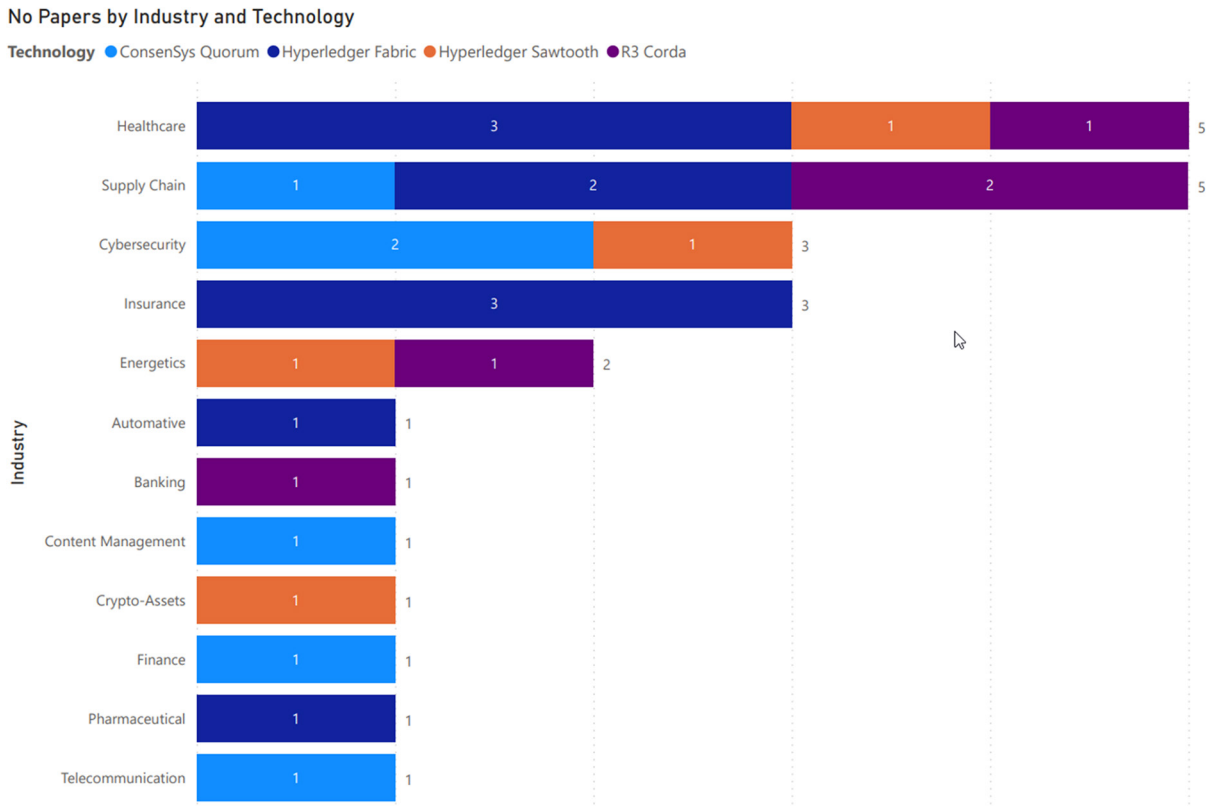

Figure 1. Benchmarking of Blockchain Technologies for Industry
Source: Own research

The sample analyzed in this paper indicates a preference for ConsenSys Quorom in cybersecurity-related applications and other fields related to the ICT industry and a preference for R3 Corda in highly distributed solutions. The reasons for this composition lie in the specific features of the technologies and their integrability in field-relevant ecosystems. Performance parameters also play an important role, presumably skewing the business case implementations based on the most relevant performance parameters for the industry. However, the data that was studied does not suggest enough insights to distinguish the best-performing technology in terms of latency and throughput but rather indicates that optimization per case is achievable. Future research to explore performance benchmarking is suggested. An important emphasis is placed on security, whichever overall is covered by all the technologies taken into consideration in this paper. It should be noted that a degree of freedom is provided to the implementer, specifically by the Hyperledger projects in terms of consensus mechanisms that can be deployed on a specific-case basis. The corpus of the articles and papers that were objects to this study indicate a

preferred technology stack to complement blockchain technologies. The trendiest emerging one resulting from the analysis is the combination of Hyperledger projects with IPFS. Therefore, further research aimed to identify and benchmark the best-fit stacks is to be considered in the future. The analyses show that blockchain in most cases serves as the backbone for more complex architectures and infrastructures that tackle complex industry issues.

5. CONCLUSION

Through this paper, the authors provided an overview of the employability of blockchain for business. The focus was on general-purpose blockchains for business and the scope of the field implementations highlighting relevant performance benchmarking. The selected dataset suggests a strong interest in blockchain for business applications in fields like healthcare, supply chain, cybersecurity, and insurance. In these industries, blockchain tackles complex issues while offering optimal performance and increasing efficiency, transparency, and security. A trend towards integrated solutions is present, with blockchain serving as the backbone of the proposed architectures. With regards to the performance, it is concluded that it can be fine-tuned based on the given business case through a combination of a set of parameters. A high degree of flexibility is identified about the programming languages that can be used to develop and deploy smart contracts per blockchain solution. Experimental results provide insights into the best-performing languages, among which are generic programming languages. Flexibility is also observed in the consensus mechanisms that are applied, especially on Hyperledger projects. This enables a better-fit solution for the business by prioritizing the requirements for a valid solution in a given industry. Overall, blockchain for business is scalable, flexible, and interoperable and thus it empowers businesses across industries to gain advantages through its employment. The study is limited in terms of the use cases it has reviewed and recognizes that a more in-depth review of a wider corpus of data is required to deduct more representative results across industries.

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