Derivation of Categories for Interoperability of Blockchain- and Distributed Ledger Systems

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Abstract: Due to increasing security requirements e. g. for transaction based smart-x-technologies in distributed systems, blockchain technologies are predestined for secure data exchange and keeping in distributed systems. Although the underlying principle of almost every blockchain is the Byzantine fault tolerance (BFT), its implementation differs significantly between the technologies so that migration or interoperability between systems is nearly impossible. Additionally, this missing interoperability also reduces the chance for scalability between different extents of implementation as there is usually not a one-size-fits-all-blockchain: Different technologies have their advantages for different systems. Therefore scalability and interoperability are tightly coupled. As a basis for further research on and the derivation of generally scalable and interoperable architectures of blockchains, current technologies have to be made comparable and interoperability criteria have to be developed. This paper analyses current literature and introduces technical criteria for the comparison of blockchain- and distributed ledger technologies (BC/DLT).With a list of eleven criteria popular BC/DLTs such as Bitcoin, Ethereum, Hyperledger Fabric, Ripple and Corda are compared regarding general features.

Keywords: blockchain and distributed-ledger technology (BC/DLT); comparison categories; abstraction; scalability; interoperability

1 Introduction

For data integrity and security in distributed systems, blockchain and distributed ledger technologies (BC/DLT) have developed to the state-of-the-art during recent years. Various BC/DLT have been developed and introduced to the public such as Bitcoin, Ethereum or Hyperledger. They provide increased security to and trust into the integrity and authenticity of data in distributed systems by cryptographic linking and consensus mechanisms.

Examples for blockchain applications can be found in many sectors: Benefits are used, e.g. for pharmaceutical tracking and tracing [Ku18; Me16], for healthcare management [DCP18]. Further BC/DLT are proposed to be used in the social sector e. g. the implementation of digital elections as described by [KV18] or [CWB18]. Also for industrial applications considering the Internet-of-Things (IoT) BC/DLT offers new business opportunities. [Hu16] or [FF18] describe scenarios of future IoT, using blockchain for daily applications. Examples for automotive applications of blockchain technology are blockchain-based car insurance systems [La18] or blockchain-based selection of charging stations for electric cars [PKS16].

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Due to the variety of available blockchain solutions, an initial decision for one specific blockchain for a specific application appears to be difficult. Missing concepts for scalability and interoperability prevent data from being transferred or migrated between blockchains. Although some concepts for interoperability have meanwhile been developed with technologies such as Interledger [TS], Overledger [Ve18], Polkadot [Wo] or Cosmos [Te] their acceptance in terms of a distributed system remains critical. They are usually introducing central instances, managing transactions between the blockchain- and distributed ledger systems, bypassing its decentrality. Therefore a universal approach based on *interoperability-by-architecture* in terms of a generic description of blockchain characteristics and properties is needed. Such generic systems, which are still subject to research, can behave like different blockchains basing on its configuration.

For the first step to such an architecture, specific properties of blockchain systems have to be discovered, examined and compared. Such criteria will be derived in this article by literature research. For example, [TT17] created a comprehensive taxonomy on blockchain technology and various comparisons of different blockchains have been executed, e.g. [Hi17; Zh17].

This paper will derive general categories for the comparison of blockchain and distributed ledger technologies. In section 2 technical core principles of BC/DLT and its interoperability will be introduced, before the categories will be developed in section 3.

2 Blockchain-Technology

About ten years after the publication of Bitcoin by Nakamoto [Na09], a wide variety of BC/DLT and related principles can be observed in practical use. Although the underlying technology bases on BFT-mechanisms, practical implementations differ significantly between the different technologies. As there is not yet a generally agreed definition of the terms *blockchain or DLT*, this article refers to the following core principles as essential characteristics for this technology:

block building and chaining by cryptographic lining Unlike general DLT-systems, blockchains are characterized by aggregating verified and valid transactions into a block by miners [Bu19]. As these blocks may also contain false information injected by malicious miners, the miner's role is more sensitive for the complete system security. Although generated blocks are later verified and potentially rejected by other network-participants again, this is a known attack to blockchains - e.g. by selfish mining [Li17].

According to the Byzantine generals problem, this content proposing role is the only which can create information whereas others can only verify. Therefore, special security mechanisms are installed for such sensitive instances, so they cannot be abused by hijacking or infiltrating the with malicious code. In some systems the information creation itself is distributed to multiple peers such as in Hyperledger

Fabric, in other systems the role is randomly switched among qualified (mining) nodes such as in Bitcoin or Ethereum.

Part of this block is the reference to the preceding block, usually represented by the previous block-hash-value. This information forms the chain of blocks by cryptographic links and makes it immutable.

distribution Every peer in a distributed blockchain network potentially - depending on its role - owns a copy of the blockchain [En19]. Therefore all transactions can be seen and verified by every instance of the blockchain. Changing the blockchain thereby means to change all copies at all nodes.

implicit or explicit consensus Generated blocks have to be verified for correctness by using a consensus process. The community-used term usually mixes different aspects of this consensus process:

- It partly includes a *leadership election* for the more influential block-proposer role such as in the *proof-of-work* algorithm,
- it partly requires explicit consent communication such as performed by the endorsement nodes in Hyperledger Fabric proof-of-workör
- the consensus process is executed independently on all nodes by the same algorithm without explicit communication about the consent result such as in Bitcoins or Ethereums proof-of-work and should therefore be rather called *implicit consensus*.

Building up on these principles diverse BC/DLT are created. However, no application could be called *THE blockchain*. By [va] already over forty projects, that support smart contracts, have been listed. Even more could be added if taking those blockchains into account, that do not natively support smart contracts, like for example Bitcoin.

Apart from the capability of executing smart contracts, further differences occur for example in the field of distribution, where the amount of data stored by network peers can differ. Alternatively, in the area of consensus, where many different mechanisms can be used to create a network consensus. Thus each blockchain is different from the others in special features of the implementation or the set of rules and the proposed field of application and use cases.

Differences between BC/DLTs can also occur in terms of interoperability, the „ability of systems to provide services to and accept services from other systems and to use the services so exchanged to enable them to operate effectively together“ [In17], and scalability. [HLP18] state that interoperability between blockchain-systems will be a core requirement if blockchain technology becomes a fundamental future data infrastructure. The increasing acceptance and usage of BC/DLTs make scalability important. But scalability of blockchain-systems is limited by the blockchain size, the transaction processing rate and data transmission latency [Xu17].

3 Derivation of Comparison Criteria

A multitude of BC/DLT variations exists, that are scalable and interoperable in different dimensions. A decision for one BC/DLT-system should base on a comparison of various BC/DLTs. Such a comparison should take aspects of scalability and interoperability into account, because of their importance. Most BC/DLTs are created as standalone systems. Interoperability between BC/DLT-systems will prevent users from being locked to one chosen blockchain [Ve18]. Further, it supports the extensibility of the technologies [Wo18].

The increasing popularity of BC/DLT and the associated increased utilization make scalability important [Cr16]. Today for example in the financial economy BC/DLT-systems are incapable of providing the same performance as traditional payment services [Xu17]. Thus scalability is a challenge to a wide usage of BC/DLT [Zh17].

In table 1 criteria for blockchain comparisons identified or used by several authors [BM17; Di17; Hi17; Ka18; Ra18; TT17; VS17; YW18; Zh17] are listed. The work of [TT17] focused primarily on the development of comparison criteria. It proposes a detailed collection of BC/DLT comparison criteria as well as possible expressions of those criteria, that could be selected.

Unlike that [Zh17], [Ra18], [VS17] and [Hi17] do not only describe comparison criteria, but also use them to explicitly make a comparison between BC/DLTs.

Key characteristics of BC/DLTs have been stated by [Zh17] and BC/DLT properties have been used to compare the BC/DLT types public, private and consortium. Further, comparison of six BC/DLT projects including an extensive description of the comparative criteria used is given by [Ra18].[VS17] made a comparison between three BC/DLTs building upon six comparison criteria. And the comparison of seven BC/DLT implementations based on various criteria is described by [Hi17].

Whereas [BM17], [Di17], [YW18] and [Ka18] are using several criteria implicitly in their papers. By [BM17] a comparison of two projects using Ethereum is made. [Di17] describe a framework to analyze private BC/DLTs. Thereby they use performance metrics to evaluate BC/DLTs, which also serve as comparison criteria. A BC/DLT reference model using a layer structure is proposed by [YW18]. It contains several layers that can be used comparatively. Further, this paper describes some BC/DLT application scenarios. A brief comparison of six BC/DLTs is given by [Ka18], taking several aspects of BC/DLT into account.

In order to gain an overview of the comparison criteria, four categories are proposed:

- Criteria to compare **general characteristica** of BC/DLTs and criteria that do not fit into the more detailed categories, e.g. the purpose of a BC/DLT and its reward system (see Table 1a)
- Criteria to compare **security and privacy issues** of BC/DLTs (see Table 1b)

Tab. 1: Criteria for BC/DLT comparison mentioned in literature

(a) General Criteria

Criterion	Mentioned by
Purpose of the BC/DLT	[Hi17], [BM17], [VS17]
Data stored on-chain	[Hi17]
Native Asset offered?	[TT17], [Hi17], [Ra18], [VS17]
Private/Public/Consortium & Permissioned/Permissionless	[TT17], [Hi17], [VS17], [Ka18], [Zh17]
Consensus Model	[Hi17], [VS17], [Ka18], [Zh17], [TT17]
Smart Contracts enabled?	[YW18], [Ka18], [VS17]
Incentive Layer/Reward System	[TT17], [YW18], [Ra18]
Codebase Creation	[Ra18]
Rule Initiation	[Ra18]
Protocol Governance	[Ra18]
Protocol Change	[Ra18]
Data Broadcast	[Ra18]
Transaction Initiation	[Ra18]
Input	[Ra18]
Programmatically Initiated Transactions	[Ra18]
Locus of Execution	[Ra18]
Reference	[Ra18]
Gossiping	[TT17]
Finality	[TT17]
Header Data Structure	[TT17]
Transaction Model	[TT17]
Server Storage	[TT17]
Block Storage	[TT17]
Tokenisation	[TT17]
Asset Supply Management	[TT17]
Interoperability	[TT17]
Intraoperability	[TT17]
Fee System	[TT17]

(b) Criteria Concerning Security and Privacy

Criterion	Mentioned by
Transparency of Decision Making	[Hi17]
Public Key Infrastructure Used?	[Hi17]
Public Key Infrastructure Managing Authority	[Hi17]
Consensus Mechanism	[Hi17], [Ka18], [TT17], [Zh17], [Ra18], [VS17]
(Limits to) Scalability	[Di17], [TT17]
Fault Tolerance	[Di17]
Immutability	[Zh17]
Data Encryption	[TT17]
Data Privacy	[TT17]
Identity Layer	[TT17]
Registration Authority	[Hi17], [Ka18], [VS17], [TT17]

(c) Criteria Concerning Programming

Criterion	Mentioned by
Scripting Language	[TT17], [Hi17], [VS17]
Coding Language	[TT17]
Code License	[TT17], [Ka18], [Ra18], [Hi17]
Software Architecture	[TT17]

(d) Measurable Criteria

Criterion	Mentioned by
Block Release Time	[Hi17]
Transaction Size	[Hi17]
Transaction Rate/Throughput	[Hi17], [Di17], [Zh17]
Latency	[Di17], [TT17]

- Criteria concerning the **programming** of BC/DLTs, e.g. licenses and programming languages (see Table 1c)
- Criteria that focus on **measurable components** of BC/DLTs (see Table 1d)

Table 1 shows, that already a variety of comparison criteria exists. Taking this extensive list as first basis for a BC/DLT comparison reveals difficulties. Finding data on the listed criteria regarding some BC/DLTs may be difficult. And the number of criteria may become an obstacle for a first evaluation of a system's suitability for an own application.

That is why the list of criteria was shortened. As reducing rule is set that at least one criterion of each category should be represented. Thereby it is ensured that the main aspects of BC/DLT are considered. Further, a reduced set of criteria should include those criteria, that seem to be the most important ones. The number of authors mentioning a criterion might be understood as a parameter for importance. That is why a reference of minimum of three authors should be given for a criterion to be selected.

By this constraints the extensive list of criteria shown in table 1 is reduced to the set of criteria shown in table 2.

Tab. 2: Reduced set of comparison criteria

Criterion
BC/DLT Purpose
Native Asset
Private/Public/Consortium; Permissioned/Permissionless
Consensus Model
Smart Contracts
Reward System/Incentive Layer
Consensus Mechanism
Central Registration Authority
Scripting Language
Code License
Transaction Rate/Throughput

This set of criteria is lacking comparison criteria regarding the interoperability and scalability of BC/DLTs. This is caused by the low number of such criteria in the extensive criteria list in table 1. Only three criteria have this focus. The criteria *Interoperability* and *Intraoperability* are only mentioned by [TT17] and the criterion of *(Limits to) Scalability* is only mentioned by two authors [Di17; TT17].

The criteria of the category *measurable* could be understood as criteria for scalability, but even then only one of these criteria meets the condition of being mentioned by at least three authors. Thus the scalability and interoperability are not sufficiently taken into account by the shortened set of criteria in table 2.

4 Comparison of popular BC/DLTs

Nevertheless, this set of criteria has been used to make an exemplary comparison of some popular BC/DLTs. In the comparison selection, blockchains (Bitcoin, Ethereum, Ripple), as well as DLTs (Hyperledger Fabric, Corda), are included. Thereby it is shown that the results are not only valid for either blockchains or distributed ledger technologies. The results of that comparison are shown in table 3.

By that table 3 it is demonstrated, that data regarding nearly every criterion for those blockchains can be found. Thus the used set is a set of criteria, that is well suited for a basic technical blockchain comparison. It serves as a research starting point and first decision support about the blockchain selection. Based on such a comparison a first selection of blockchains to consider for ones use case can be done. The remaining blockchains should then be analyzed using an extended list of criteria. The analysis should then be focused on a custom set of criteria, that seem to be important for each use case.

Further due to the list of criteria it has been shown that criteria concerning scalability and interoperability have not been considered sufficiently. Taking into account the aspect of interoperability interesting can be the level on which interoperability is enabled. Therefore three criteria could be distinguished. A first criterion is the ability to send transactions between different systems. This could be for example sending data from external systems into a BC/DLT system like described by [Ra18]. A second criterion is the possibility to transfer contracts between different systems while retaining the contracts semantics [HLP18]. A third criterion is the extent of interoperability, that has been considered in the systems design phase. Concerning scalability the measurable criteria (see table 1) as a systems possibility to grow are interesting. As a further criterion, especially regarding future trends, can be seen the ability of BC/DLT-systems at high load to enable an enrichment of own capabilities by enabling the usage of capacities of other BC/DLT-systems.

Tab. 3: Comparison of the BC/DLTs Bitcoin, Ethereum, Hyperledger Fabric, Ripple and Corda regarding the shown set of criteria

Criterion	**Bitcoin**	**Ethereum**	**Hyperledger Fabric**	**Ripple**	**Corda**
Purpose	Cryptocurrency [Hi17]	Run Smart Contracts [Hi17]	(Cross-) Industry Use Cases [Hi17], [Ka18], [SSS17]	Global Cross Border Payments [Rid]	Internet-based Management and Automation of Real-world Agreements [Br]
Native Asset	BTC [Hi17], [Bia]	Ether [Etc]	None [Hi17]	XRP [Rif]	None [VS17]
Public/ Private/ Consortium & Permissioned/Permissionless	Public, Permissionless [Bib]	Public [TT17]	Private or Consortium, permissioned [VS17], [TT17]	Public, Permissioned [TT17]	Private, Permissioned [Kh17]
Consensus Model	Transaction Level (blocks and transactions verified) [Hi17], [Ka18]	Ledger Level (blocks and transactions verified) [Hi17], [Ka18]	Transaction Level (pluggable) [Hi17], [Ka18]	Ledger, Transaction Level [Ka18]	Transaction Level (pluggable) [Br]
Smart Contracts	Yes [BT]	Yes [VS17]	Yes [VS17]	Yes [Rie]	Yes [Kh17], [Co]
Reward System/ Incentive Layer	Block Reward [Bic]	Block Reward [Etc]	None	Extrinsic Incentive [Ra18]	None
Consensus Mechanism	Proof-of-Work [Bic]	Proof-of-Work [Etc]	Practical Byzantine Fault Tolerance [Zh17]	XRP Ledger Consensus Protocol [Rib]	pluggable [Co]
Central Registration Authority	None [Hi17]	None [Hi17]	Individually pluggable for each network [Hi17]	RippleNet [Ric]	Individual CA of each network [Li]
Sripting Language	Script [Hi17]	Solidity, Serpent, LLL [Eta]	Golang, node.js, Java [Hya]	-	Any, that targets Java Virtual Machine [R3a]
Code License	Open-Source [Bia]	Open-Source [Etb]	Open-Source [Hyb]	Open-Source [Ria]	Open-Source [Co]
Transaction Rate	7 tx/sec [Hi17]	theoretically no max [Hi17]	>10.000 tx/-sec [Hi17]	1500/sec [Rif]	up to 1000 tx/-sec [R3b]

5 Conclusion

This paper has given a short overview of the importance of comparison criteria for BC/DLT-systems. Currently used comparison criteria in literature have been listed. Then a shortened list of criteria has been narrowed down, which shall serve as a starting point for BC/DLT comparisons. This set has been used in a comparison of five popular BC/DLTs to show, that the data required for a comparison based on the shortened set of criteria is available for some popular BC/DLTs. The literature surveyed has shown that previous research has created only a low number of criteria regarding scalability and interoperability of BC/DLTs.

This paper proposed approaches for criteria on scalability and interoperability. This should further be addressed by future research. In terms of interoperability interesting questions could be related to a system's scope: Can the BC/DLT system operate with other systems? If so, is it interoperable with all other BC/DLTs or only with BC/DLTs of the same type (private/public or permissioned/permissionless) or only with special other BC/DLTs? Further, the level of interoperability will be interesting concerning whether all elements of the BC/DLTs are inter-operable or for example only transactions or only smart contracts.

Further research is required on the development of criteria concerning economical aspects of BC/DLT-systems to extend the range of comparison. An area of interest will also be the impact of economical aspects on scalability and interoperability.

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