A Comprehensive Reference Model for Blockchain-based Distributed Ledger Technology

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Abstract. Blockchain is a distributed, transactional database that is shared across all the nodes participating in the network. This is the main technical innovation of Bitcoin and it acts as a public ledger for the transactions. However, this technology lacks standardisation and uniform understanding. This is due to a few studies, that would provide a comprehensive model of the blockchain and the distributed ledger technology. In this paper we compare four blockchain technology platforms and focus on their business level properties including actors and roles, services, and processes and data model. Our comparison results in a reference model, which could potentially guide the business analysts, system analysts and software developers when developing new blockchain platforms or their supported implementations. Accuracy of the proposed reference model is validated by considering it against selected blockchain technologies.

Keywords: Blockchain technology, Reference model, Distributed ledger, Bitcoin, Etherum

1 Introduction

The first implementation of the blockchain technology, i.e. Bitcoin, was introduced in 2009 [12]. Since its release, the popularity of bitcoins and cryptocurrencies has only kept growing, because customers have started to value the convenience and security of digital currencies, enabled by the blockchain technology. In the traditional banking systems, the ledger is a centralised party (e.g., the bank), which stores all the transactions. Blockchain, which serves as the decentralised public ledger, can also be applied to other fields, such as healthcare, insurance, data verification and others.

Different businesses have developed various implementations using the blockchains. However, only limited analysis [10] exists on the conceptual explanation and understanding of the blockchain technology. In this paper we consider how to unify this understanding and propose a comprehensive reference model to characterise the blockchain technology. Our proposed model is developed and its accuracy is validated by considering actors, services, processes, and data of the existing blockchain platforms. Being presented in ArchiMate, BPMN and UML modelling languages, the proposed reference model could potentially guide business analysts, system analysts and software developers when engineering applications using blockchain technology, developing new blockchain technology platforms, analysing and comparing existing blockchain solutions.

In Section 2 we give an overview of the state of the art of the blockchain technology. Based on it, in Section 3 we present the reference model for the blockchain technology. Section 4 describes how the accuracy of our proposal is validated. Finally, Section 5 concludes the study and presents some future work.

2 State of the Art

In this section, first we will define scope and discuss study background. Next we will survey the blockchain technologies following the scoped properties.

2.1 Scope and Background

Blockchain acts as a distributed public ledger. It is a digital record of transactions and ownership, that is replicated among all of the participants of a peer-to-peer network. A consensus algorithm ensures that each node owns the same copy of the ledger as the other nodes. Technically, it is a back-linked ordered list of blocks, where each block contains transactions [2]. Each time a transaction is made, it is broadcasted to the network. If it is valid, it gets added to a block. When new block is published to the network, all participants (nodes) will run algorithm to validate the block. Majority of the nodes have to agree that the new block is valid and if so, it will be added to the blockchain. Once a block of data is recorded on the blockchain ledger, data becomes *more* secure as the blockchain grows [13].

There are two main types of blockchains: public and private. Bitcoin has a *public ledger* i.e., a *public blockchain*, where anyone is allowed to contribute [14]. There is no need for a third authority to grant permissions. *Private blockchain* is a network where all the participants are known and trusted [6] and the consensus process is managed by a pre-selected set of participants [3]. In our study we consider both public and private blockchains along the following properties:

- **Platforms** - we are considering implementations of the blockchain technology that introduce different approaches to privacy and smart contracts.
- **Actors** - we want to know who the actors are and what roles they play in the given blockchain technology.
- **Services** - what services are provided by the blockchain platform? Who interacts with the services (business level)?
- **Processes** - what are the underlying processes to services? How do network, transaction and mining/consensus processes work?
- **Data models** - what are the entities that hold information? What are the relationships between them?

Blockchain technology platforms can be separated into four groups [1] [11] as illustrated in Table 1. For our study we have selected one blockchain platform of each group. Some others could have been chosen, but we decided to select the most widespread, based on our current knowledge. They can be characterised as follows:

– **Permissionless** - Fully public blockchains, where anyone can read and write.
– **Permissioned blockchain technology** allows to define different permissions on different users on the network. There can be different permissions for reading data, creating transactions, validating blocks, creating new ones and others.
– **Blockchains with Smart Contracts** enable “smart contract” like capabilities and allow building business logic and business process mechanism into the chain.
– **Blockchains with transactions only** are built for transaction capabilities. They support transferring value from one account to another.

Table 1: Overview of chosen blockchain technologies

	Permissionless	**Permissioned**
With Smart Contracts	Ethereum	Chain Core
Transactions only	Bitcoin	MultiChain

2.2 Comparison of Actors

Blockchain technology relies on a decentralised network of individual nodes, but nodes have different purposes and different roles. Table 2 shows an overview of actors who are present in the analysed blockchain platforms.

Table 2: Overview of actors from different platforms

Platform	**Actors**
Bitcoin	Client (Sender / Receiver of Bitcoins), Miner
MultiChain	Client, Miner
Ethereum	Externally Owned Account, Contract Account, Miner
Chain Core	Client (Issuer / Spender of assets), Blockchain operator (Generator / Signer)

For each platform, there exists a notion of a *Client* and a *Miner* or someone who builds and agrees upon which transactions are included in a block [2] [9] [8] [5]. Client interacts with the blockchain (exchanges or adds value by creating and broadcasting transactions). In Ethereum an Externally Owned Account (EOA) is equivalent to the physical actor; and Contract Accounts (CA) can be understood as a system user which acts upon a request by an EOA or by another CA. Since CA is created by an EOA and interacted with by EOA and that they are autonomous agents living inside the execution environments [8], we do not consider CA as a separate actor.

Miners deal with validating transactions and building new blocks. Since Chain Core is a private blockchain, it has *Blockchain operators*, who are either *block generators* or *signers*. Fundamentally, a *Blockchain operator* is a miner, because miner's tasks in a blockchain environment are to create new blocks, sign them, validate them and submit them to the blockchain.

In conclusion, blockchain technology has two primary actors at the business level:

- Human actor who interacts with the blockchain by creating transactions. This actor can be called a "User".
- Human or system actor responsible for verification and validation of transactions, building new blocks, signing new blocks and publishing new blocks to the blockchain. This actor supports trust between the parties involved. In case of public blockchains "proof of work" is provided by the mining software (system), but, for example in Chain Core there exist Blockchain operators (human) who decide on the consensus. This actor can be labelled as "Block generator".

2.3 Comparison of Services

In this section we will compare services used by actors defined in the previous section. The services are summarized in Table 3.

Table 3: Overview of services from different platforms

Platform	**Services**
Bitcoin	Create transactions, Mine bitcoins
MultiChain	Create assets, Create transactions, Grant permissions, Revoke permissions, Mine blocks
Ethereum	Create transactions, Create contracts, (Send messages), Mine blocks
Chain Core	Define and Issue assets, Submit transaction, Validate block, Gather valid transactions, Generate block, Publish block, Sign block, Determine who can participate in the network

Firstly, every platform provides a service to create and broadcast transactions to the network. This is an essential service because transactions dictate the state of the blockchain and add new data to the blockchain.

MultiChain and Chain Core have the notion of assets, which is a type of value, that is issued on the blockchain [9] [5]. Bitcoin and Ethereum both have their native currencies, bitcoin[3] [2] and ether [8] respectively. MultiChain and Chain Core allow creation of different assets.

Bitcoin and MultiChain focus on transactions and exchanging value. Ethereum and Chain Core also rely on state and smart contracts. Ethereum provides a service to create a new contract, that can be submitted to the network; and Chain Core supports the use of smart contract while issuing assets, by defining business

[3] Bitcoin (with upper B) stands for protocol, the software and community, bitcoin (with lower b) stands for a unit of currency

rules for issuing (issuance program [5]) new units of given assets and also rules for spending the assets (control program [5]).

Since MultiChain and Chain Core are both designed to support private blockchains, they support services to manage permissions. MultiChain provides services for granting and revoking permissions to and from specific users [9]. Chain Core allows Blockchain operator to manage connections via network tokens.

All platforms except Chain Core are proof-of-work-based mining solutions. Mining in Bitcoin and Ethereum is publically available for anyone, while in MultiChain user needs to have permission to perform mining (or if everyone on the blockchain are known users, mining can be turned off alltogether [9]). In Chain Core, federated consensus [5] is applied by Block generators and signers. Block generator will use services like gathering valid transactions, generate block and publish a block. Block signers, who validate and sign the block, use block validation services and block signing services.

In conclusion, common services among the technologies are *creating transactions*, *validating blocks* and *mining / creating blocks*. Additionally, permissioned blockchains provide services to manage permissions. Overall, it depends on the features offered by a blockchain, e.g., with Bitcoin being the most generic blockchain, the number of provided services is different compared to Chain or MultiChain. Features like assets, smart contracts and permissions add additional services to the commonly offered ones.

2.4 Comparison of Processes

Table 4 provides our overview of the processes from different platforms. Processes are realisation of services, that the actors of the technology use.

Table 4: Overview of processes from different platforms

Platform	**Processes**
Bitcoin	Network discovery process, Transaction creation process, Mining process, Block verification process
MultiChain	Handshake process, Transactions creation process, Mining process
Ethereum	Network discovery process, Transaction creation process, Mining process, Block validation process
Chain Core	Network discovery process, Transaction process, Chain consensus process

Every platform has a **network discovery process**, which consists of 4 main steps - Peer discovery (finding peers to connect to, either user already knows the IPs or acquires them), Handshake (version check, establishing connection, providing ownership of private key), Network discovery (finding neighbouring peers and letting the network know that a new node has connected) and Synchronization (downloading the latest block data from the network).

In Bitcoin and Ethereum, new node connects to a known peer, they verify that both are running the same version of the software and have the same, latest and longest chain of blocks. In case of differences, new node will download the previous blocks up to the latest one. MultiChain expands the Handshake process

[9] introduced in Bitcoin, by verifying that the connecting node's public address is on the permitted list and by receiving a proof of the ownership of the private key. In Chain Core, the Block Generator will provide Block Generator's URL, a network token and the blockchain ID to the connecting node.

Creating the transaction in Bitcoin requires user to enter value and the receivers address. The transaction is then signed by the user and broadcasted to the network (to neighbouring nodes). The neighbouring nodes check the transaction for validity. If valid, they will propagate it forward to other peers [2]. MultiChain adds additional metadata to the transaction, specifying asset name and transaction type (issuing or spending assets, granting permissions etc.). Similarly the transaction is constructed, signed and broadcasted to the network. In Chain Core, transactions issue new assets or spend existing assets. Issuing new assets or spending assets have to comply with the rules defined in the issuance program or in the control program [5]. Ethereum also supports regular value transactions. The input parameters for the transaction are similar to Bitcoin and MultiChain (i.e. amount and the address of the receiver). Additionally Ethereum supports creating contracts and calling contract functions, which is an additional metadata added to a transaction.

Another common process is the **Mining process (Block generation process)**. Mining is based on the proof-of-work. A miner will build a new block, add collected unverified transactions and metadata, and calculate the computationally exhaustive proof-of-work for the block. If he is the first one to solve the task and mine the block, he can submit the block to the network and receive a reward for that work. In Ethereum, the mining process also requires a state transition process, since it keeps a state of the blockchain. In the state transition process, transactions are validated and in case of contracts, code execution is also performed. When all the state transition functions are valid, miner in Ethereum will provide the proof-of-work for the block. In MultiChain, proof-of-work [9] is optional and mining is permissioned. MultiChain introduces mining diversity to vary the miners creating the blocks.

Chain Core introduces a **Chain consensus process** [5]. When a new transaction is submitted, it will be transferred to the Block generator who will add it to the new block. After certain periods, Block generator will construct the block and send it to block signers, who will validate the block, sign it and send it back to the Block generator. The Block generator can only submit the block if the required block signers have signed the block, according to the consensus program [5].

Bitcoin and Ethereum introduce the block **validation process** which is performed by every node once the miner broadcasts a new block. Since in the public blockchains the miners are anonymous, there has to be a guarantee that the miner has indeed produced a valid block. In Bitcoin, this is called a 'consensus' if all the nodes validate the new blocks against the same rules. In Ethereum, the validation is similar, but additionally it includes the state transition process, which each node has to perform before accepting the block [8].

The four platforms provide similar general processes: *Network discovery*, *Transaction creation*, *Block generation and submission* (Mining and Chain consensus process) and *Block validation*. Conceptually, the processes may be similar, but the inner workflow differs from one technology to another.

2.5 Comparison of Data models

All four blockchain technologies introduce a Block, a Block header and Transactions. Bitcoin, MultiChain and Chain Core also include Transaction Inputs and Transaction Outputs (UTXO). Ethereum relies on the state replication, where each new block's state is the outcome of the transactions that were included in the block. Ethereum has chosen not to use the Input-Output transaction method, because it does not support multi-stage contracts or scripts that could keep an internal state [8].

Ethereum has the notion of Accounts, which are either user accounts or virtual contract accounts, that hold the balance, contract code and internal storage. In Ethereum case, all this data is stored on the blockchain.

With the addition of Assets, Chain Core keeps an Asset entity containing only the asset ID. The assets are tied with certain programs (i.e. Issuance program, for issuing new assets, or Control program, for spending assets). The Consensus program is used by Block generator to verify that a block is ready to be submitted to the network.

To conclude, the main set of entities are the Block, Block Header and Transactions. The Input-Output transactions are *de facto* Bitcoin solution to prevent double-spending, but there are several arguments about the use of unspent transaction outputs and their scalability [4], so in case of Ethereum, to enable the multi-stage smart contracts, UTXO's are not used.

3 A Reference Model for Blockchain Technology

Figure 1 presents the business layer of the reference model represented with ArchiMate[4]. It consists of six major components - Actors and Roles, Services and processes for Network Discovery, Transaction, Consensus and Block generation. We will discuss these components in the following subsections.

3.1 Actors and Roles

In Section 2 we have concluded that there are two main roles (see Figure 1) for each node in the blockchain. We name these as User and Block generator:

- **User -** Actor who interacts with the blockchain by creating transactions.
- **Block generator -** Human or system actor responsible for validation of transactions, building new blocks, signing new blocks and broadcasting new blocks to the blockchain. This actor can also provide consensus to support trust between the parties involved (proof-of-work, proof-of-stake etc).

[4] http://www.opengroup.org/subjectareas/enterprise/archimate-overview

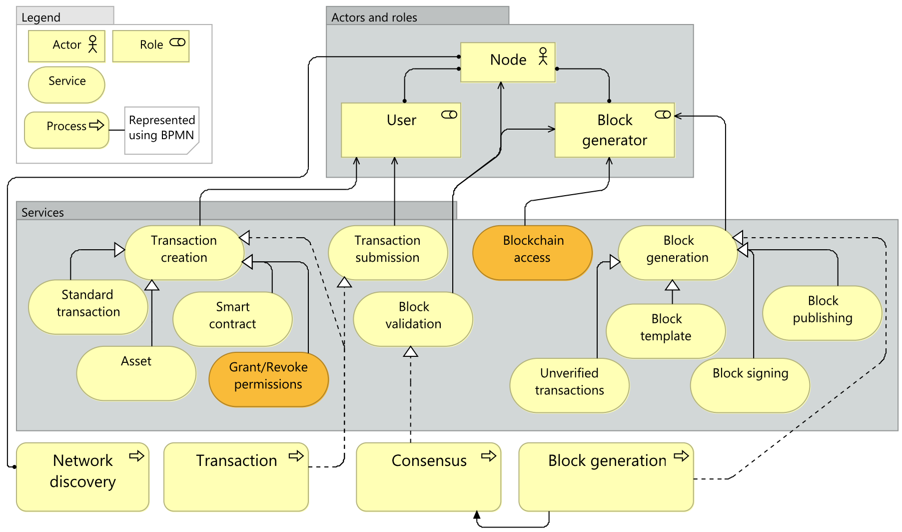

Fig. 1. Reference model for the blockchain technology

3.2 Services

Figure 1 presents **Service** components which display the services used by actors to interact with the technology (services with dark background are specific to permissioned blockchains). Services are:

- **Transaction creation** - Transactions allow Users to add information to the blockchain. Transactions can be used to create assets, spend assets, create smart contracts, call functions on smart contracts, manage permissions etc.
- **Transaction submission** - Transaction submission support signing and broadcasting the transaction to the network.
- **Block validation** - Block validation is a general service used by the nodes to validate the newest blocks that have been added to the blockchain.
- **Block generation** - Block generation is broken down into smaller services that are used differently depending on the type of consensus. A miner in a public blockchain would use the block generation services, but in Chain Core, one party creates the block and other parties sign the block [5].
- ***Blockchain access*** - Blockchain access is specific to private and permissioned blockchains, where administrative nodes grant access to known parties. Can also be used to create network tokens for nodes.

3.3 Processes

The reference model (Figure 1) includes four processes: Network discovery process, Transaction process, Consensus process, and Block generation process. We expand these processes using the BPMN modelling language.[5]

Network discovery process (Figure 2) consists of four subprocesses - *Peer Discovery*, *Handshake*, *Discovering additional peers* and *Synchronization.* Process begins by acquiring an IP of the known peer or blockchain (IP is known from the last session or is acquired from an outside source). Once connected, private blockchains will perform a check if the user is allowed to connect via its public IP or a network token. If permitted, a handshake process is carried out to verify versions and check that both nodes have the same blockchain with the latest blocks. Next, the connected node's IP will be propagated to the network. Once the network is discovered the connecting node will synchronise its blockchain if any differences in terms of the latest block is observed.

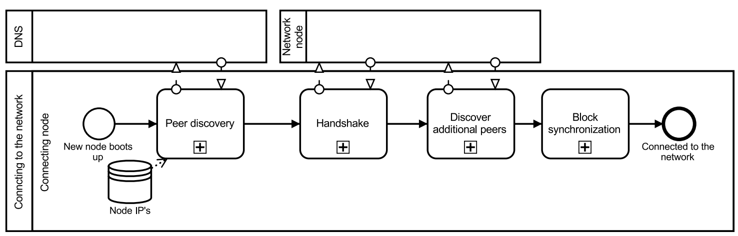

Fig. 2. Network Discovery process

Transaction process (Figure 3) starts creation of a new transaction. Relevant metadata are added depending on the transaction type (e.g., standard transfer of funds, creating assets, deploying smart contract, etc.). In the case of private blockchains, there will be a permission check: (*i*) whether the specific user is permitted to create the transaction, (*ii*) whether the receiver is permitted to receive funds, (*iii*) whether the network permits transfer of funds or creation of specific type of transactions, etc. If the transaction is permitted (or in case of public blockchains, the creator signs the transaction), it will be broadcasted to the network, i.e., to the neighbouring nodes.

Consensus process (Figure 4) is performed by each node when a new block has been broadcasted. Each blockchain defines its own "Consensus rules", according to the type of the validated blocks and transactions. If validated, the nodes will append the new block to the blockchain; otherwise it will be rejected.

During the **Block generation process** (Figure 5), first, a new block is created; next, the previous block's metadata is added. In case of the permissioned blockchains, permission changes have to be applied in order to avoid

[5] http://www.bpmn.org/

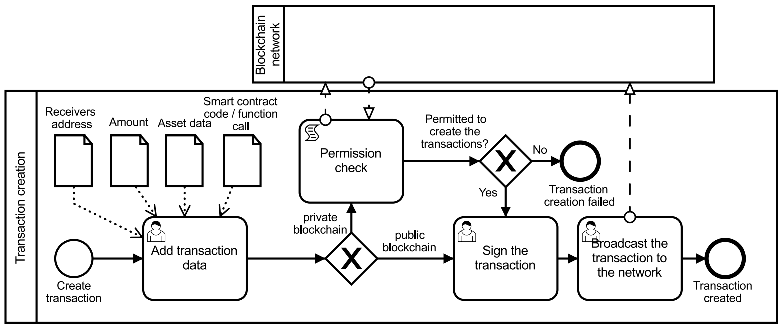

Fig. 3. Transaction process

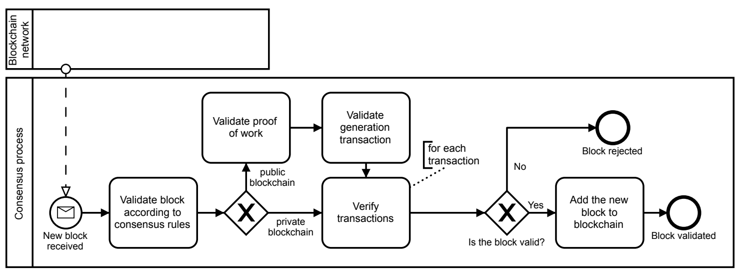

Fig. 4. Consensus process

unwanted actions performed by users, who do not have permission. Next, all transactions will be validated against the consensus rules on the blockchain. In public blockchains, the block generators (i.e., miners) will provide a proof of the work (i.e., proof-of-work or proof-of-stake etc.) and will be rewarded for their work. In private blockchains, the consensus process might be part of the block generation process. Once the block is constructed, it is submitted to the network and propagated to all the nodes.

3.4 Data model

The data model is presented in Figure 6. The model shows that keeping the state of the blockchain is preferred here in comparison to the Input-Output type transaction logic. Since UTXOs are stateless [4], they are preferred for issuing assets or performing standard transfer of value (assets or cryptocurrency). However, since smart contracts are powerful, keeping the state of the blockchain supports complex logic better than UTXOs.

State contains accounts, which have balance and address. In case of contracts (marked with grey box in Figure 6), they also have to keep the executable code and storage specific to the given account. Accounts are linked to transactions and

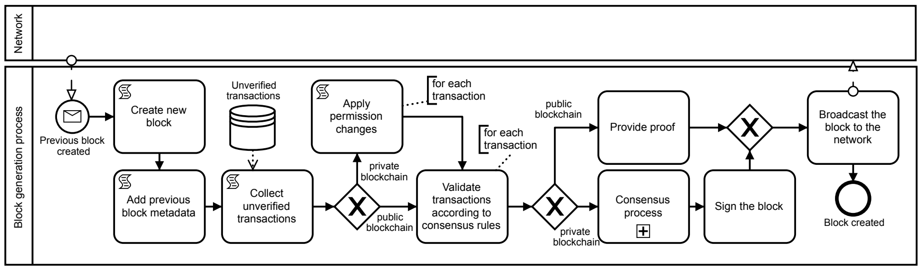

Fig. 5. Block generation process

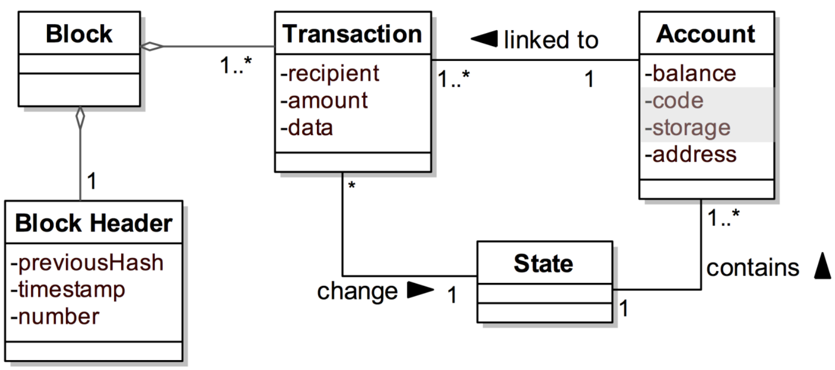

Fig. 6. Data model

each transaction changes the state of the blockchain (balance changes, contracts function calls etc.). Block and Block Header are standard and essential to every blockchain platform. Block contains transactions; the block's metadata is kept in the Block Header.

4 Validation

To validate the reference model we investigate its accuracy by comparing it to the existing blockchain solutions. Firstly, we compare the reference model to the four implementations that were used to build it. We define a Delta (i.e. Δ) metric, which represents the differenc between the reference model and the models of the considered blockchain technologies. Secondly, we select four new blockchain platforms and calculate the Delta value for them. Our goal is to show that using the reference model we are able to capture business perspective of all selected blockchain technologies.

Delta definition. Finding the delta Δ for the four initial Blockchain technologies (Figure 7), we will compare actors, services, processes and data models

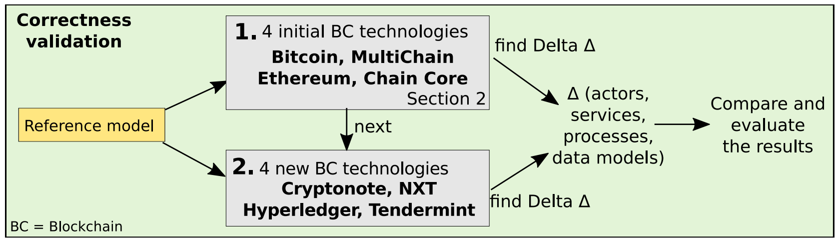

Fig. 7. Accuraccy validation process

separately. The overall Δ will be the sum of all deltas ($\Delta = \Delta_{actors} + \Delta_{services} + \Delta_{processes} + \Delta_{datamodels}$). $\Delta = 0$ means they have the same entities. $\Delta > 0$ means the unified model has more entities. $\Delta < 0$ means that the reference model is missing some entities, that the comparable model has. Finding the delta Δ for the four new Blockchain technologies (Figure 7), we will also compare actors, services, processes and data models separately, but we will only take into evaluation if the given entity exists or is present in the newly presented technology. $\Delta = 0$ means they have the same entities. $\Delta > 0$ means the reference model has more entities.

Table 5: Results of the delta Δ for the selected Blockchain technologies

	Actors	**Services**	**Data model**	**Networking**	**Transactions**	**Consensus**	**Validation**
Blockchain platforms used to construct reference model							
Bitcoin	0	0	2	0	0	0	0
MultiChain	0	0	2	0	0	0	0
Ethereum	0	0	0	0	0	0	0
Chain Core	0	0	0	0	0	0	0
Blockchain platforms *not* used to construct reference model							
Cryptonote	0	0	2	0	0	0	0
NXT	0	0	1	0	0	0	0
Hyperledger	0	0	1	1	0	1	0
Tendermint	0	0	1	0	0	0	0

Results for the Δ values are presented in Table 5. The goal of accuracy validation was to get a Δ value as close to 0 as possible for initial four technologies as well as for four new technologies that were not used as a basis of building the model. From the results we can see that the initial four technologies are covered almost accurately by the reference model, with subtle differences in Data models (e.g., four differences - Bitcoin and MultiChain do not support Accounts and State). We consider this result acceptable, because of the differences that smart contracts introduce to the data model (see Figure 6).

As for the four technologies that were not part of the initial building of the model, we found differences in the data models (e.g., five entity differences - CryptoNote and NXT do not keep the blockchain state, Hyperledger Fabric does not have Block Header, Tendermint misses account representation), Networking process (one entity difference - Block synchronization) and Consensus process (e.g., one entity differences - Transactions in Hyperledger Fabric are verified and endorsed before reaching the miner). This result is also considered acceptable, due to the fact that the new blockchain technologies are different from the initial four technologies, but still perform well under the defined blockchain properties.

Threats to validity. The accuracy validation was done by the first author of this paper with the technologies in hand. Thus, another validation approach might conceive different results, either by defining the Delta differently or by selecting different implementations of the technology. We did not constructed conceptual models for platforms which were not used to create the reference model. These were assessed following their documentations. Potentially we could miss some concepts from the comparison. However this is less likely as the majority of the entities were in fact captured as shown in Table 5.

5 Concluding remarks

This paper gives an overview of the disruptive blockchain platforms: Bitcoin, MultiChain, Ethereum and Chain Core. Each of them presented a different approach to networking, transactions, mining, validation, security and permissions. The comparison resulted in the reference model, that aims to represent the domain of the blockchain technology. The model contributes to the explicit understanding of the technology and its work processes. The paper also presents a brief overview of validation performed on model with the corresponding results. The results reflect that the reference model performed well to cover the known blockchain technologies, such as Cryptonote, NXT, Hyperledger and Tendermint. The results potentially indicate how to develop this fast growing technology further and in a more secure way by expanding its disruptive nature to other application domains.

When it comes to standardisation of the blockchain technology and its presentation it in an unified way, there exist some study that thrive towards this goal. In [10] the technology is defined using three layers - Essential, Infological and Datalogical layer. The information is presented in the UML model and explains the general overview. However it lacks details to define relationships between actors and processes. In our work we have used different notations to present the reference model. We hope that it would guide the business analysts and help them to communicate with the developers. Additionally, we explicitly present the link between the users and processes and expand these processes by showing targeted private and public activities. Finally, the accuracy of our proposal is validated with respect to other blockchain platforms, which were not used to create the reference model.

This type of research on the blockchain technology is a first and hopefully a basis to future research. This being said, we plan to further validate the model via security assessment [7], by aligning the reference model to ISSRM[6]. This alignment (using ArchiMate and BPMN) will help us observe what actors are affected, what services are they using and what processes implement those services. Then, using BPMN representations it will possible get a details of the affected processes. This can be achieved thanks to the reference model.

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