Vilnius university
Institute of Data Science and Digital Technologies
L I T H U A N I A

INFORMATICS (N009)

CREATION OF BLOCKCHAIN-BASED APPLICATION MODEL FOR DECENTRALISED ELECTRICAL ENERGY EXCHANGE

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October 2019

Technical Report DMSTI-DS-N009-19-17

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Abstract

This report presents an overview of Distributed Ledger technologies (DLT) and main concepts with the aim to explore applicability of DLTs for decentralized energy markets and microgrids. Potential applications of blockchain technologies, factors for efficient design and operation of microgrid energy market and major challenges for blockchain-enabled applications in energy sector are covered.

Keywords: Distributed Ledger, Blockchain, Microgrid, Energy market.

Contents

1 Introduction

Energy market is undergoing transformational changes necessitated by developments brought by Digital Era and requirements of energy policy initiatives for future energy systems – decarbonisation, decentralization and digitalization.

With the aim of EU to shift from centralised conventional generation to decentralised, smart and interconnected markets will also make it easier for consumers to generate their own energy including storing, sharing or selling it back to the market. New smart technologies provide consumers with possibilities to control and actively manage their energy consumption and improve their comfort. These changes will make it easier for households and businesses to become more involved in the energy system and respond to price signals (European Commission 2019).

Challenges posed by emerging decentralization and digitalization of the energy system require exploration and adoption of novel paradigms and distributed technologies. In this regard blockchains could provide solutions for controlling and managing decentralized energy systems and microgrids, and provide trading platforms for prosumers and consumers to trade interchangeably their energy surplus on a peer-to-peer basis (Andoni et al. 2019).

When designing the architecture of any blockchain-based microgrid energy market, the major focus has to be taken for computationaly efficient blockchains which use minimal data, because information technology that uses vast amounts of energy contradicts the sustainability principles (Mengelkamp et al. 2018).

2 Overview of distributed ledgers and their applicability for distributed energy markets

2.1 Distributed ledger technologies

With the introduction of blockchain and financial transactions, distributed ledger technologies (DLT) are attracting increasing amount of attention. As blockchain, being one kind of DLT, has been criticized for its cost and problematic scalability in number of application fields, other types of DLTs get their share of research and investigation.

DLTs share one main goal – to allow users who do not (necessarily) trust each other to interact without the need of a trusted third party. While each DLT is characterized by different data model and technologies, all DLTs are based, in general, on following well-known technologies:

- *Public key cryptography*
- *Distributed peer-to-peer network*
- *Consensus mechanism*

Public key cryptography establishes a secure digital identity for every participant, and enforces control of ownership over the objects managed by the distributed ledger. A peer-to-peer network is used to avoid single point of failure, prevent network takeover by small groups and provides network scalability. A consensus protocol in employed to agree on a single version of the truth by nodes of the distributed ledger, without the need of a trusted third party. The main differences of DLTs in big part lie in the type of used data structure (Fig. 1) and what data they store (El Ioini and Pahl 2018).

In further analysis, we will focus on the blockchain technology.

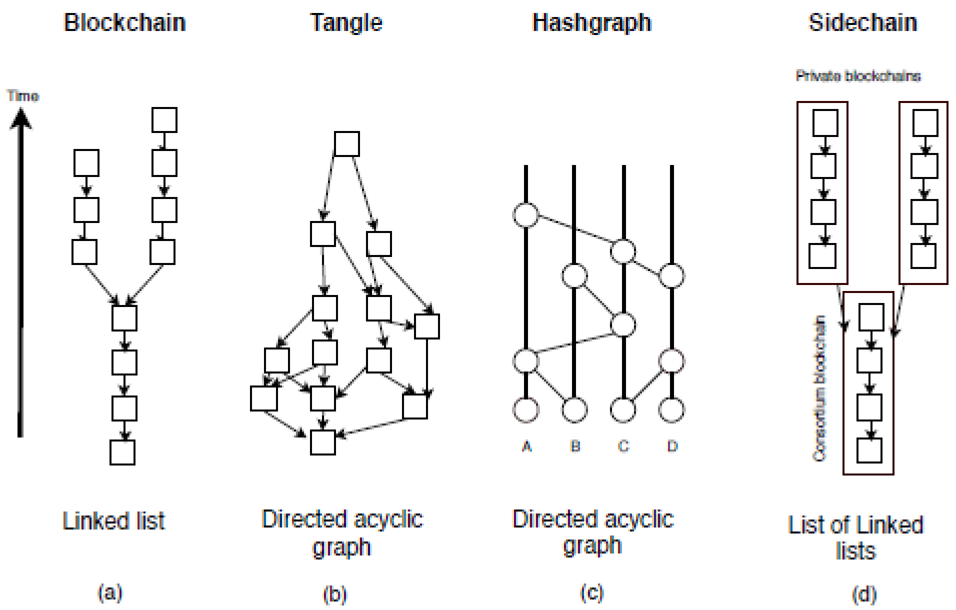

Fig. 1. An overview of the existing DLTs. Source: (El Ioini and Pahl 2018).

2.2 Blockchain

A blockchain can be broadly defined as a digital data structure, a shared and distributed database that contains a continuously expanding log of transactions and their chronological order and runs on a digital network (Andoni et al. 2019).
(Zhang and Jacobsen 2018) propose a layered reference architecture for blockchains (Fig. 2), consisting of six layers:

1. *Application layer* – focuses on developing blockchain solutions for specific applications.
2. *Modeling layer* – expresses workflows that facilitate generation of smart contracts in order to enforce application semantics.
3. *Contract layer* – represent smart contracts themselves.
4. *System layer* – consists of core components like consensus protocol and other subsystems for maintaining the blockchain.
5. *Data layer* – refers to the management of on-chain and off-chain data
6. *Network layer* – represents the network over which communication of peers, and sharing of information is executed.

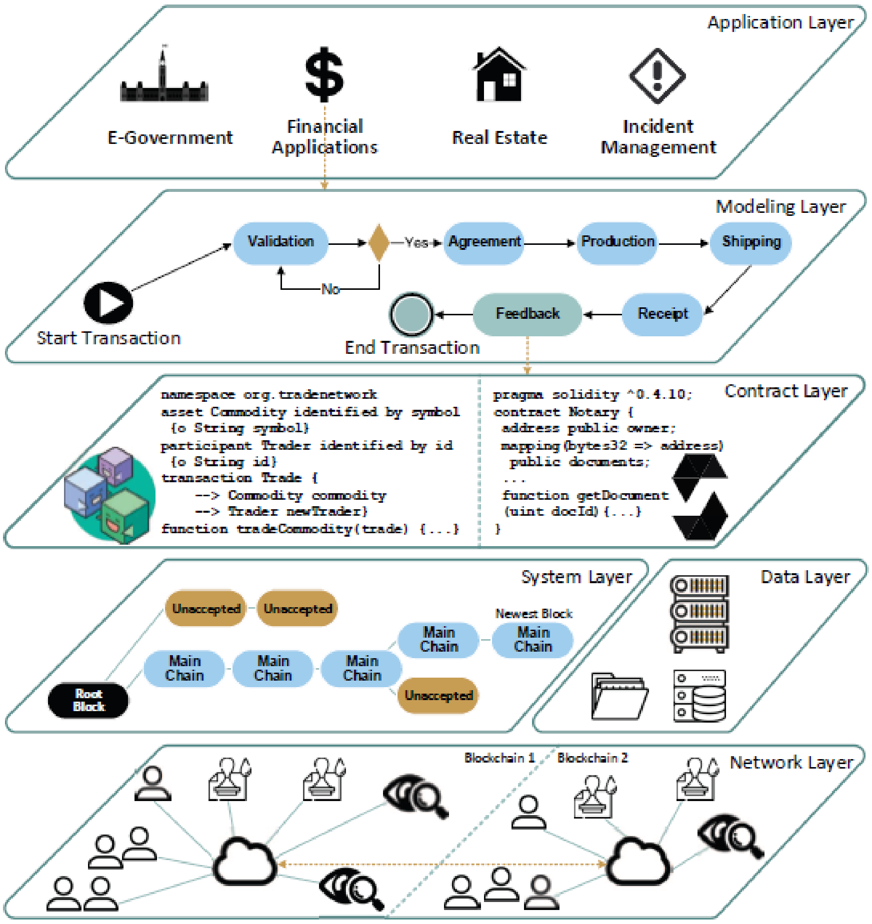

Fig. 2. Blockchain stack. Source: (Zhang and Jacobsen 2018).

2.3 Consensus protocols

Consensus protocol is used by peers to agree on the content of the next block to be added to the blockchain. Consensus protocols can be attributed to one of two main categories: *proof-based* and *leader-based* (Zhang and Jacobsen 2018). For the first category, two components are required: a block proposal algorithm and a branch selection algorithm. A block proposal algorithm allows any peer to propose a block, which can be validated by the rest of peers in the network. A branch selection algorithm is used by peers to decide, which branch to accept, because different branches (different versions of the blockchain) can occur due to network latencies while simultaneous block are added to the network. The second category, leader-based consensus is employed mainly in private ledgers, where a certain level of trust among peers can be maintained. One form of such consensus can be an ordering service, which determines the order of transactions. Peers, which receive blocks from ordering service, for agreement on the outcome of the transactions must execute *Practical Byzantine Fault-Tolerance protocol*.

The most widely used consensus protocols in blockchain systems are *Proof of Work*, *Proof of Stake* along with several modifications and *Practical Byzantine Fault Tolerance*.

2.3.1 Proof of Work (PoW)

The origins of PoW lie in the *Hashcach* proof of work developed to limit denial of service attacks on Internet resources (Back 2002). The idea of PoW is in solving a cryptographical puzzle of finding such a value which hashed produces the output with a number of consecutive zeros at the beginning. The required work to achieve this is in average exponential in the number of those zero bits, while for verification it suffices to execute a single hash (Nakamoto 2008).
Validator nodes (also called miners) compete with each other by trying to find a hash, which is lower than a specified target. When such hash is found, the miner provides his block to the blockchain network, and other nodes accept it if all transactions are valid and unspent.
PoW is hugely criticized for wasting large amounts of energy, because it requires for powerful computational equipment.

2.3.2 Proof of Stake (PoS)

PoS aims to solve the problem of resource wastage by replacing computational work with selection of validator nodes, which depends on the size of their deposits (also called stakes). There are two major types of PoS: chain based and BFT-style. In chain based PoS a validator is selected in pseudo-random way during each time period and has the right to create a single block, which must point to previous block at the end of the previously longest chain. In BFT-style PoS the right to propose blocks is assigned randomly, but agreeing on the right block is achieved through multi-round voting process, at the end of which all validators permanently agree, which block is to be added to the chain (Buterin 2016).

2.3.3 Practical Byzantine Fault Tolerance (PBFT)

PBFT is based on Byzantine Fault Tolerance (BFT) algorithms, and first practical approach is presented by (Castro and Liskov 1999), which proposes the concept of primary and secondary replicas. The secondary replicas check the correctness and capacity to produce a response in a given time of the primary replica. Secondary replicas can switch to a new primary if the original replica is compromised.
PBFT is more suitable for use with trusted (private, permissioned) environments, as transactions are verified and signed by known validator nodes (Andoni et al. 2019).

2.4 Blockchain enabled systems, digital markets and microgrids

(Glaser 2017) presented theoretical foundation and conceptual framework for blockchain enabled systems and implications for digital market models and explored the research question "*How can blockchain (eco)systems and associated roles be described and analysed in the context of digital economies?*".
The presented framework (Fig. 3) divides blockchain systems into two layers: decentralized fabric layer and decentralized application layer. *Fabric layer*, being common concept in the global blockchain development community, contains actual blockchain code base implementing communication and public key infrastructure, also contains the data structures and in general provides execution environment for smart contract languages. *Application layer* contains the application logic of services

provided by smart contracts (or decentralized applications, which, in general, are implemented by one or more smart contracts). Author points out the fact that such system spans across multiple layers of traditional n-tier architecture.

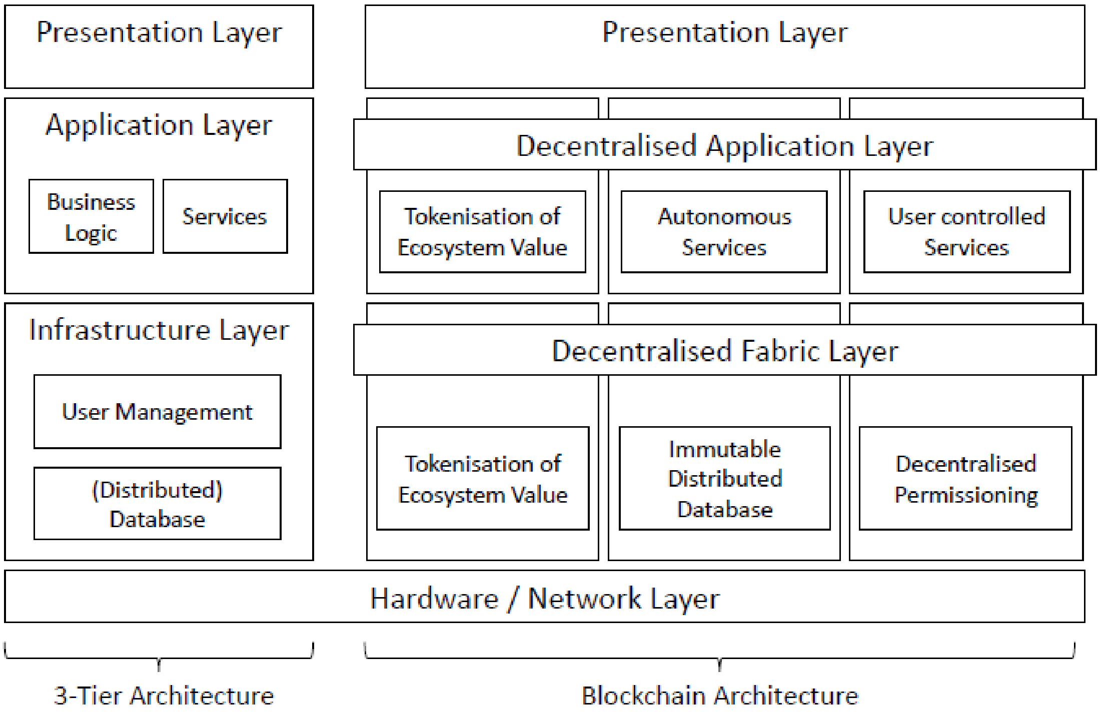

Fig. 3. Layers of Blockchain Systems. Source: (Glaser 2017).

Potential applications of blockchain technologies, related to operations and business processes in energy sector could be summarized as follows (Andoni et al. 2019):

- *Automated billing*
- *Sales and marketing*
- *Trading and markets*
- *Automation*
- *Smart grid applications and data transfer*
- *Grid management*
- *Security and identity management*
- *Sharing of resources*
- *Competition*
- *Transparency*

However, the most natural fit for blockchain enabled systems would be direct energy trading between energy prosumers/consumers in peer-to-peer manner, which realizes the truly decentralized form of an energy market and gives back the control of energy generation and demand to market participants (Andoni et al. 2019).

The decentralized structure of the blockchain is particularly suitable for implementing control and business processes in *microgrids*, using smart contracts and decentralized applications. The most promising use case from the microgrid perspective is peer-to-peer trading, where energy is exchanged and traded locally between consumers and prosumers (Goranovic et al. 2017).

What constitutes a microgrid is described in definition developed by the Microgrid Exchange Group for the U.S. Department of Energy: *"[a microgrid is] a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode."* (Ton and Smith 2012).
(Hirsch, Parag, and Guerrero 2018) elaborates on this description by discerning three requirements:

1. that it is possible to identify the part of the distribution system comprising a microgrid as distinct from the rest of the system;
2. that the resources connected to a microgrid are controlled in concert with each other rather than with distant resources; and
3. that the microgrid can function regardless of whether it is connected to the larger grid or not.

For the efficient design and operation of microgrid energy market, various factors have to be taken into account. In the case of blockchain-based microgrid energy market, (Mengelkamp et al. 2018) propose a framework consisting of seven components:

C1. **Microgrid setup**, including the objective, the definition of market participants and the form of energy traded. The implementation of objectives is reflected in pricing method design (C4). There must be sufficient number of market participants, with subgroup having the ability to produce energy. Access to the market should be given to clearly defined participants. In addition, setup must define if traditional energy grid, or a physical microgrid built for this case will be used.

C2. **Grid connection** defines connection point/points towards the superordinate grid for balancing energy generation and demand within the microgrid. These connection points allow for metering energy flows and measuring the microgrid's performance as well as decoupling from the main grid in case of power outages.

C3. **Information system**, which connects all market participants, provides market platform and monitor the market operations. Requirements for this information system are to be efficient and reliable and work in adequate temporal resolution. These requirements can be met by *blockchain protocol based on smart contracts*, which provides shared infrastructure for decentralized applications.

C4. **Market mechanism**. The main objective of market mechanism is efficient allocation of the traded energy by matching participants' buy and sell orders by employing allocation and payment rules and providing bidding language and clearly defined bidding format. The market mechanism is implemented by the information system (C3).

C5. **Pricing mechanism** accounts taxes and fees, which in microgrid may differ from traditional grid, and reflects energy surplus or lack of it in the microgrid, allowing prosumers to generate profits. Pricing mechanism is implemented via market mechanism (C4).

C6. **Energy management trading system**, based on the real time energy demand and supply data forecasts consumption and generation, adjusts bidding strategy and secures the energy supply for market participants. It facilitates energy transactions by directly accessing market participants' blockchain accounts.

C7. **Regulation** determines allowed microgrid energy market designs, taxes and fees, and market integration into the traditional energy market and energy supply system.

For real life implementation, regulation (C7) is the most important, as it is needed to legalize and fit microgrid energy market into the overall energy system, while operation of the microgrid energy market itself is dependent on the components (C3), (C4) and (C5). These three components are the most important as they can create operational local energy market in its purest form (Mengelkamp et al. 2018).

2.5 Major challenges for blockchain-enabled applications in energy sector

Many ongoing research initiatives and projects in energy sector, adding investor interest, show potential value of blockchain technology, in part for offering disintermediation, transparency and tamper-proof transactions, but the mainstream adoption requires several questions to be answered and problems to be solved (Andoni et al. 2019):

- Blockchain technologies have yet to prove that speed, scalability and security requirements for proposed use cases could be met, as combination of all desired characteristics cannot be achieved without significant trade-offs.
- High hardware and energy costs of verification and validation of data in blockchain systems related to common consensus mechanisms, and cost of storing data in continuously expanding ledgers.
- High development costs of blockchain systems together with lack of experience with large scale applications.
- Security risks caused by bad system design, vulnerabilities from peripheral applications like digital wallets and smart contracts, resulting, in part, from insufficient experience and necessity to create new algorithms, which increases possibility of errors.
- Consumer data protection with simultaneous need to identify blockchain system users to account for their liabilities.
- Regulatory and legal sphere related barriers, the need for more flexible regulatory frameworks, allowing consumer-to-consumer energy trading.
- Need for standards for blockchain system architectures.

3 References

Andoni, Merlinda et al. 2019. "Blockchain Technology in the Energy Sector: A Systematic Review of Challenges and Opportunities." *Renewable and Sustainable Energy Reviews* 100(November 2018): 143–74.

https://doi.org/10.1016/j.rser.2018.10.014.
Back, Adam. 2002. “Hashcash - A Denial of Service Counter-Measure.” *Http://Www.Hashcash.Org/Papers/Hashcash.Pdf*.
Buterin, Vitalik. 2016. “Ethereum Wiki. Proof of Stake FAQ.” *Github.Comt*. http://cryptorials.io/glossary/proof-of-stake/%5Cnhttps://en.bitcoin.it/wiki/Proof_of_Stake.
Castro, Miguel, and Barbara Liskov. 1999. “Practical Byzantine Fault Tolerance.” *Proceedings of the Symposium on Operating System Design and Implementation*.
European Commission. 2019. “Clean Energy for All Europeans.” *Euroheat and Power (English Edition)* 14(2): 3. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2016:0860:FIN.
Glaser, Florian. 2017. “Pervasive Decentralisation of Digital Infrastructures: A Framework for Blockchain Enabled System and Use Case Analysis.” In *Proceedings of the 50th Hawaii International Conference on System Sciences (2017)*,.
Goranovic, Andrija et al. 2017. “Blockchain Applications in Microgrids: An Overview of Current Projects and Concepts.” In *Proceedings IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*,.
Hirsch, Adam, Yael Parag, and Josep Guerrero. 2018. “Microgrids: A Review of Technologies, Key Drivers, and Outstanding Issues.” *Renewable and Sustainable Energy Reviews* 90(September 2017): 402–11. https://doi.org/10.1016/j.rser.2018.03.040.
El Ioini, Nabil, and Claus Pahl. 2018. “A Review of Distributed Ledger Technologies.” In *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*,.
Mengelkamp, Esther et al. 2018. “Designing Microgrid Energy Markets: A Case Study: The Brooklyn Microgrid.” *Applied Energy* 210: 870–80. https://doi.org/10.1016/j.apenergy.2017.06.054.
Nakamoto, Satoshi. 2008. 2008-10-31 *Bitcoin: A Peer-to-Peer Electronic Cash System | Satoshi Nakamoto Institute*.
Ton, Dan T., and Merrill A. Smith. 2012. “The U.S. Department of Energy’s Microgrid Initiative.” *Electricity Journal*.
Zhang, Kaiwen, and Hans Arno Jacobsen. 2018. “Towards Dependable, Scalable, and Pervasive Distributed Ledgers with Blockchains.” In *Proceedings - International Conference on Distributed Computing Systems*,.

Appendix Nr 1.

Used abbreviations:

DLT – distributed ledger technologies
PoW – Proof of Work
PoS – Proof of Stake
BFT – Byzantine Fault-Tolerance
PBFT – Practical Byzantine Fault-Tolerance protocol