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Blockchain technology in the chemical industry: Machine-to-machine electricity market

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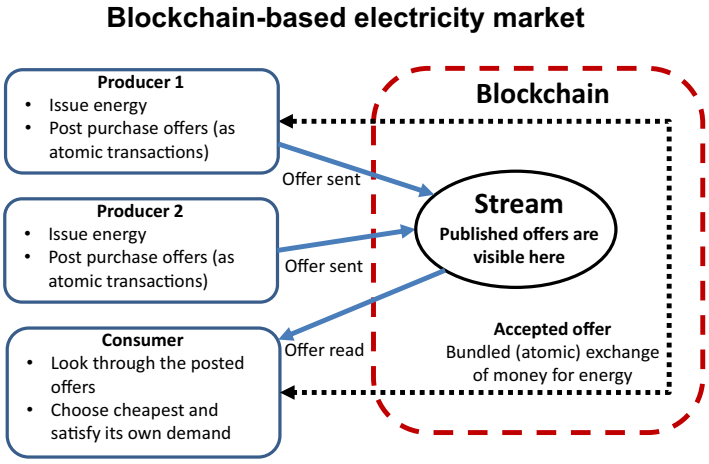
HIGHLIGHTS

- An implementation of blockchain technology facilitating a M2M electricity market.
- Industrial plants are trading electricity with each other over a blockchain.
- Data produced by process flow sheet models of industrial equipment are utilized.
- Technical details and background of blockchain technology are presented.
- This paper explores blockchain technology in relation to Industry 4.0.

GRAPHICAL ABSTRACT



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ABSTRACT

The purpose of this paper is to explore applications of blockchain technology related to the 4th Industrial Revolution (Industry 4.0) and to present an example where blockchain is employed to facilitate machine-to-machine (M2M) interactions and establish a M2M electricity market in the context of the chemical industry. The presented scenario includes two electricity producers and one electricity consumer trading with each other over a blockchain. All participants are supplied with realistic data produced by process flow sheet models. This work contributes a proof-of-concept implementation of the scenario. Additionally, this paper describes and discusses the research and application landscape of blockchain technology in relation to the Industry 4.0. It concludes that this technology has significant under-researched potential to support and enhance the efficiency gains of the revolution and identifies areas for future research.

1. Introduction

Industry 4.0 (or the 4th Industrial Revolution) introduces into industry the concepts of machine-to-machine (M2M) communication, cyber-physical systems (CPSs) and the Internet of Things (IoT) [1,2]. M2M communication refers to the ability of industrial

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components to communicate with each other. CPSs can monitor physical processes, create virtual copies of the physical world and make decentralised decisions. IoT is a dynamic network where physical and virtual entities have identities and attributes and use intelligent interfaces. An eco-industrial plant (EIP) refers to an industrial park where businesses cooperate with each other and, at times, with the local community to reduce waste and pollution, efficiently share resources (such as information, materials, water, energy, infrastructure, and natural resources) and minimise environmental impact while simultaneously increasing business success [3–5]. Implementation of the principles of Industry 4.0 and EIPs in the industry could be aided by blockchain technology. For example, blockchain could be used to facilitate M2M commodity (e.g. electricity) trading. For electricity traded on a wholesale market (as in USA, Australia, New Zealand, many European countries and Singapore [6]) such a system could reduce the overhead costs of the traditional trading practice and increase speed of transaction settlements. Those costs include administration associated with billing, reconciliation, hedging contracts and purchase agreements, which may constitute a significant part of electricity price (e.g. in the UK it is 16% [7] and in Australia approximately an eighth [8] depending on the place e.g. in Tasmania 12.2% [9]). Additionally, two extensive reports on the application of blockchain technology in the energy sector by Burger et al. [10], Hasse et al. [11] describe potential use cases and obstacles, including legislative, that need to be overcome before the technology can be widely introduced. A large number of studies has been published on electricity policies, prices, energy management and the impact of those on industrial competitiveness [12–18].

The purpose of this paper is to explore applications of blockchain technology related to Industry 4.0 and to present an example where blockchain is employed to facilitate M2M interactions and establish a M2M electricity market in the context of the chemical industry. This paper is structured as follows: Section 2 introduces the readers to blockchain technology using the biggest digital currency (Bitcoin) as case study; Section 2.2 describes and discusses the research and application landscape in relation to the engineering industry; Section 3 provides implementation details of the example, including the interactions occurring on the blockchain; Section 4 summarizes the main findings.

2. Background

Blockchain technology is a relatively new research area. Whilst the topic is currently ubiquitous on the news, many readers may not be familiar with the technical terms. For readers' benefit this publication provides a background section with a description of the inner workings and key concepts of blockchain technology and a brief literature review.

2.1. What is blockchain technology?

Blockchain is a type of distributed, electronic database (ledger) which can hold any information (e.g. records, events, transactions) and can set rules on how this information is updated [19]. It continually grows as blocks (files with data e.g. transactions) are appended and linked (chained) to the previous block using a hash (the chaining is visualised in Fig. 1 using Bitcoin as an example). The hash is produced by running contents of the block in question through a cryptographic hash function (e.g. Bitcoin uses Secure Hash Algorithm - 256 bit, SHA-256). An ideal cryptographic hash function can easily produce a hash for any input, but it is difficult to use the hash to derive the input. Additionally, any changes in the original data should result in extensive and seemingly uncorrelated changes to the hash [20,21]. Finally, it should be infeasible for two different inputs to result in the same hash. Using the cryptographic hashes in this manner ensures that in order to alter an entry in a past block all subsequent blocks also need to be altered [20,21]. The ledger is validated and maintained by a network of participants (nodes) according to a predefined consensus mechanism (a set of rules allowing the network to reach a global agreement [22]) so no single centralized authority is needed. Multiple (but not necessarily all) nodes hold a full copy of the entire database.

Blockchain technology is relatively new, continues to evolves and comes in many different shapes and forms. In this paper Bitcoin is used as a case study as it is the most well-known and successful implementation of blockchain technology. Bitcoin is a payment system based on a permissionless (i.e. anyone can read or write to the chain) blockchain maintained by a peer-to-peer network (P2P) [23]. It features its native currency (bitcoin or BTC), a proof-of-work consensus mechanism (note that there exist other types of consensus mechanisms; for more see Appendix A.2), timestamped blocks not larger than 1 MB (number of transactions per block varies depending on their size), anonymity, a financial incentive to publish blocks, optional transaction fees, a cap of the total BTC supply and BTC fungibility. The blocks primarily record BTC transactions, although additional data can also be included. An example of Bitcoin's block and its contents can be viewed in Figs. 2 and 3, respectively. A transaction is a transfer of BTC from a wallet address (or addresses) to another wallet address (or addresses). For creation transactions, only a receiving wallet is required. Wallets are a public representations of the public and private key pairs that are used to store and transfer coins. One or more such key pairs are generated for each participant so business

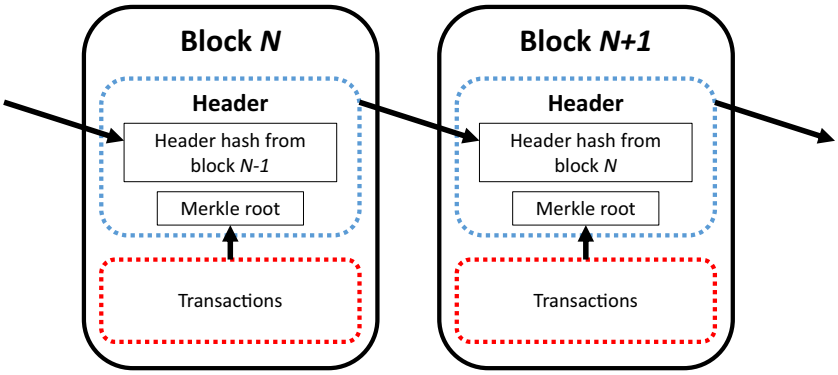

Fig. 1. Chaining of the Bitcoin blocks (adapted from [23]). Note that merkle root is a hash based upon all transactions in a block (for more details see entry "Merkle tree" in Appendix A.1).