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Experimental bandwidth benchmarking for P2P markets in blockchain managed microgrids

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Abstract

As a basic building block of the smart grid, advanced metering infrastructure (AMI) is substantial for gathering and sending consumption and production data of consumers. The applications facilitated by blockchain technology like local peer to peer (P2P) markets challenge the centrally organized utility industry with its disruptive potential and rely also heavily on AMIs as data source. However, such technologies pose a number of engineering challenges in early stage pilot projects: Unlike centrally managed AMIs, local P2P markets in particular require AMIs to exchange data with their peer devices, which increases the communication requirements due to the decentral nature of blockchain networks. In this paper, we compare the bandwidth requirement of real-time AMI with the requirements for a blockchain managed peer to peer market. By benchmarking both a normal operation and a high throughput scenario we find a ten times higher demand in bandwidth of the blockchain-based solution compared to real-time AMI and select the appropriate communication technology for an upcoming field test.

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Keywords: Blockchain managed microdgrid; communication network requirements;

1. Introduction

In many countries, solar energy is currently amongst the cheapest forms of power generation. While utility scale photovoltaic installations currently achieve the lowest production costs, solar's biggest advantage is that it can be deployed as part of existing infrastructure (e.g., roof tops) in a decentralized way. Solar systems are therefore the leading technology of choice for achieving renewable energy targets in many countries. The trend is further accelerated through decreasing costs of residential scale battery systems [1], which increase both the self-consumption and self-sufficiency rate of prosumer households [2]. While it is technically possible for a prosumer to become fully independent of the grid, this type of autonomous structure is likely not optimal, both from an economic [3] and

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ecological point of view [4]. Alternatively, prosumer and consumer households cooperate in the form of local communities that share energy generation and storage capacity in a local peer-to-peer (P2P) market. Households with power generation and storage capacity thereby sell their surplus capacity in a local market to their neighbors (peers).

1.1. Blockchain managed microgrids and its challenges in real world pilot tests

Traditionally, grid control and coordination are conducted using a centralized management system to control central power-production and large transmission and distribution systems that feed households and industry consumers. The advent of blockchain technology allows now to coordinate and manage distributed production and storage systems in a decentralized way without a central authority managing the distributed assets [5]. Blockchain's ability of making an irreversible transfer of value freely programmable and dependent on events or other data - without requiring an mediator that handles the actual remittances - allows microgrid community members to negotiate the price for the supplied or requested electricity directly between each other. In the lighthouse project "Quartierstrom" (German for district power) [6], we implement such a blockchain based trading system with more than 30 participating households in the village of Walenstadt in Switzerland. The local utility provides the distribution grid as an asset and supplies the community if it cannot supply itself with solar energy. The utility allows trades between peers and acts as a local market participant just like a large prosumer.

Blockchain technology has gained considerable attention from the power industry for its disruptive potential [7]. In the case of P2P markets, blockchains enable not only more cost-effective transactions, but increase resiliency by sharing the ledger across the community members. Such a ledger can be hosted on novel smart-meters with single board computers (e.g. RaspberryPi) that communicate with each other instead of with a centrally managed server. While many new use cases and business models may arise with blockchain technologies, a number of engineering challenges have become apparent when implementing a prototypical P2P market as in the "Quartierstrom" project. This paper focuses on the requirements for the communication infrastructure required for blockchain P2P networks. Many studies exist already that specify requirements regarding bandwidth for smart grid components, which correspond to the centrally managed paradigm. To quantify the required bandwidth for a decentrally managed microgrid, we present a testbed that allows us to benchmark the required bandwidth for a blockchain managed P2P market using blockchain enabled smart-meters. We then compare the obtained bandwidths from the testbed with bandwidth benchmarks published in the literature and derive which type of communication network (3G, LTE, Fiber, etc.) can be implemented based on the observed bandwidths from the testbed.

2. Communication requirements and infrastructure for smart grid

2.1. Smart grid applications

The vision of the smart grid includes the holistic integration of information from the power system infrastructure such as renewable energy systems, consumers and power plants, to seize the full potential of the connected energy resources and to maximize the efficiency of the usage of the grid infrastructure. The integration of applications for the smart grid span from the consumer, over the transmission and distribution operators and to the energy suppliers. They include Advanced Metering Infrastructure (AMI), Demand Response, Fraud and Outage Detection, and Distributed Generation and Storage. The requirements for these applications are numerous and include the communication between end points and the measurement and control infrastructure. AMIs are a core hardware that is required in order to establish P2P markets. Therefore, in the following section we focus on the functionality and communication requirements for AMI applications.

2.2. Communication requirements of AMI

Advanced Metering Infrastructure does not only include the deployment of smart meters into households but also consists of the network and infrastructure enabling it to send and receive data. Smart metering involves communication channels from the metering data management system to the distributed measurement points in consumer and prosumer households. Following the possible minimum requirements listed in the fundamentals for implementation of smart metering systems by the Swiss federal institute for energy, a bidirectional link for data transmission and reading is vital while communication has to be implemented based on open, documented and standardized interfaces. In addition, a smart meter has to provide recorded and momentary data (for example active and reactive power) in periodic intervals as well as on demand. These measurements are ideally available in pseudo-real-time, meaning on second time scale [8]. Smart metering includes different types of information. In the context of AMI, these types include: *Measurement*: As a meter instrument, the core of smart metering is the communication of measured data like power, voltage, and energy. *Clock*: To provide recorded load profiles and act on timing signals (tariff switching), a meter needs to synchronize its clock to a central time. *Updates*: With smart meters being a major step of households into the world of IoT, firmware updates are getting more essential for the security of the underlying networks. Therefore, the ability to provide over-the-air updates to deployed devices in the field is important. *Pricing*: For billing purposes, updates on pricing and tariff information need to be communicated from the issuing utility company

The provision of real-time consumption information and real-time pricing options to customers via home displays or dashboards can result in shifting loads and benefits for both the consumer and utility company. For some AMI applications, like real-time consumption information for customers, low latency and higher bandwidths are essential.

According to [9], the connection for real-time metering should have a latency of around 12 - 20 milliseconds and provide bandwidths of up to 100 kbps per device [10]. This value is used as a benchmark for the testbed setup presented in this paper.

2.3. Communication infrastructure for smart grid

To facilitate these requirements, a variety of communication protocols are available and already used in AMIs in various countries. A number of surveys cover the assessment of communication requirements and suitable protocols, wired and wireless, and their utility for smart grid applications [11].

The most common wired and wireless communication technologies used in a smart grid contexts are listed in Table1. Wired technologies have the clear advantage of being more robust due to a physical connection between the communication endpoints. The different technologies, however, vary in their installation cost due to their specific infrastructural requirements and must be chosen according to existing prerequisites. Wireless technologies bridge the gap between communication endpoints over the air and therefore have the advantage of lower installation costs. However, depending on the chosen technology, service charges apply according to the required bandwidth and volume. Open and freely operable technologies, like (LP-)WPAN, offer good ranges but are very limited in their maximum bandwidth capabilities. In addition to bandwidth limitations, the reach of wireless technologies into buildings where metering infrastructure is often deployed, is limited. To successfully deploy a flexible and robust AMI, the communication technology has to be chosen depending on the already existing infrastructure and the services and applications needed. A real-time advanced metering installation with a required bandwidth of ~100 kbps per device would already saturate a WPAN connection and long-distance power line communication (PLC).

2.4. From centrally to decentrally managed AMIs for P2P markets

The reference application, which is run on our microgrid platform, is a P2P energy market. The market gathers information about buy- and sell-orders within a certain time interval and inputs this data into a blockchain platform. Buy order are essentially a maximum price preference a consumer is willing to pay for local energy. Sell orders, on the other hand, are minimum price bids of prosumers for the supplied energy. The platform then matches the buyers and sellers according to the defined price preferences of the users. Within every matching-interval (e.g. 15 minutes), the participant’s bids are collected. Within every settling-interval (e.g. 24 hours), results from the gathered matchings over the matching intervals since the last settlement are aggregated into transactions containing a payer and a payee. At the end of each settlement, transactions are automatically carried out by the system in accordance with the matching. The resulting data can be parsed into a database to provide real-time feedback on the market situation to every consumer and prosumer.

Table 1. Smart Grid Communication Technologies (summarized after [11])

Technology	Data Rate	Distance	Advantage(s)	Disadvantage(s)
PLC	1 kbps – 10 Mbps	1.5-150 km	Communication infrastructure already installed, low operation cost	High Signal losses and interference
Fiber optic	100 Mbps – 1 Gbps	10-20 km	Long-distance communication, high bandwidth, no electromagnetic interference	High install cost
DSL (ADSL, VDSL)	1-200 Mbps	300 m – 7 km	Often available by telecommunication infrastructure	Charges from communication operators apply
WPAN / LPWAN (ZigBee, LoRa)	10 – 250 kbps	100 m – 50 km	Very low power consumption, open standards available	Low bandwidth
Wi-Fi	11 – 600 Mbps	300 m – 1 km	Low cost installment	ISM band includes high levels of interference
Cellular (GSM, 3G, LTE)	14.4 kbps – 1 Gbps	5 – 30 km	Good scaling solution, open standards	Charges from communication operators apply

3. Decentralized peer to peer market using a blockchain platform

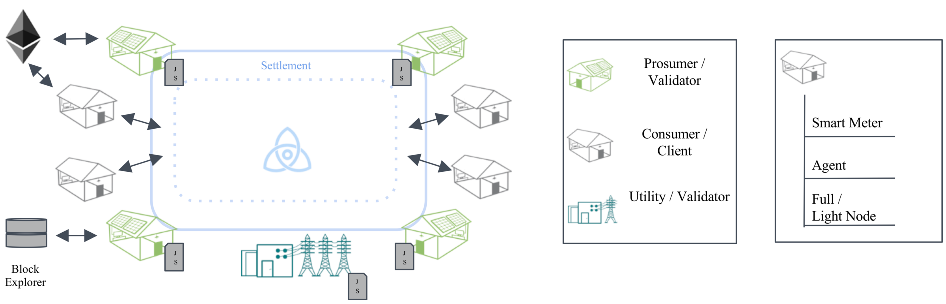

Fig. 1. System overview. The three modules for data acquisition (smart meter), data management (agent), and data processing (full/light node), are part of every participant.

The utilized system is a blockchain based platform for running the P2P trading engine described in the previous section. As seen in Fig. 1, the system consists of three different participant types. The core of the platform is built by its validator nodes, which are represented by the prosumers and the utility company (energy producing entities). Consumer nodes are clients of the prosumers and do not propose new blocks on their own but issue and read transactions using light nodes from the blockchain platform. In the absence of a central coordinator, consensus over the current market prices, net community production and consumption -referred to as state- must be reached. The Tendermint consensus protocol [12] is used in this paper to reach consensus over the current state of the microgrid-system between the validating nodes. Tendermint allows for replicated state machines to be kept in sync between an arbitrary set of validators. Every participant runs either a full or a light node to connect to the underlying blockchain using the smart meter as a data source. The smart meter hosts a software agent that runs the trading application and translates user preference into bids or asks as shown in Fig. 1. In order to offer services to the end-users, such as comprehensible information about consumption, production and market prices via external applications, a block explorer has been implemented to query the system for addresses and transactions, as well as P2P trades. The presented blockchain platform will be implemented as a child chain, which synchronizes its current state over a root chain like the Ethereum or Cosmos blockchain to mark milestones of settlements.

4. Test and results

4.1. Testbed and procedure

The presented testbed mimics the system architecture illustrated in Fig. 1. The testbed set-up runs and is built on top of the Amazon Web Services (AWS) platform. We utilize five virtual machines from the free tier category, running on an Ubuntu operating system and a system configuration comprising of 1GB of RAM and 8GB of hard-drive space and host all validating nodes (i.e. prosumers). In order to benchmark the proposed platform on the targeted hardware, a Raspberry Pi 3 Model B single board computer is used to conduct the following tests.

For testing and benchmarking the platform, we run a full node in two operation modes: A) normal operation with medium transaction throughput and B) stress test with high transaction throughput.

To test the upper bounds of normal transactional operation, we consider a field test size of 300 participants and the aforementioned matching frequency of 15 min. Every 30 seconds, we send bursts of 10 transactions through all six nodes in the system. In order to benchmark the maximum transaction throughput, we generate bursts of 50, 100, and 150 transactions submitted instantaneously. The transactions resemble ones sent out by an agent to commit a buy or sell order with a random value of consumption or production, as well as a randomized unit price.

4.2. Results

The results of the conducted tests are comprised of data recorded by the tcpdump tool, which captures communication traffic on the kernel level. The measurements are taken with second resolution. The diagrams show the transfer speeds of the peer-to-peer communication of the RaspberryPi with the AWS nodes (pidFra-0 - pidFra-4).

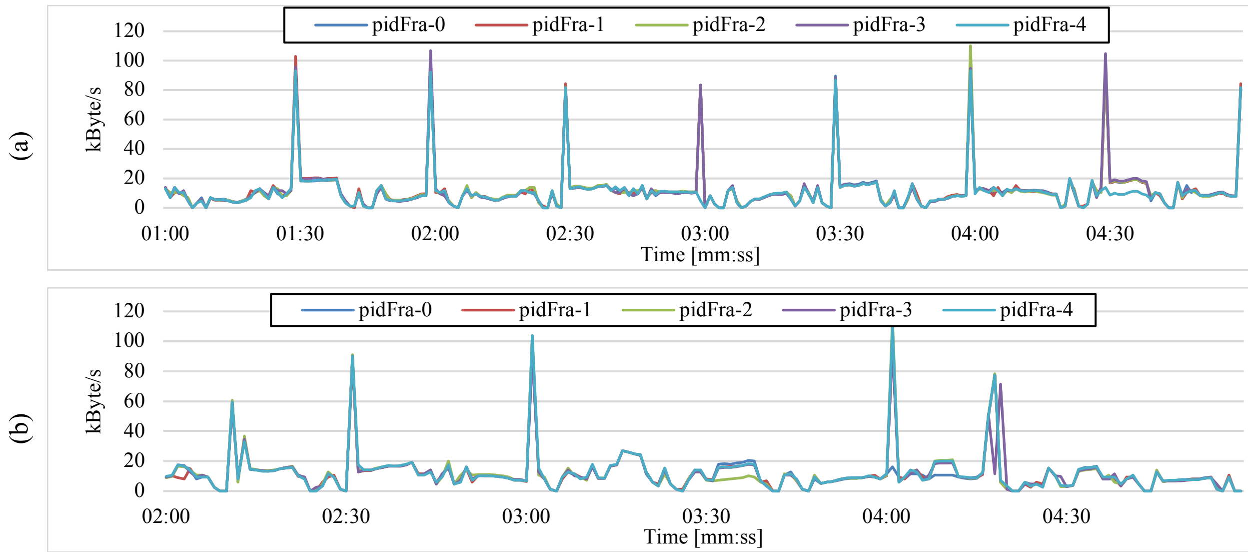

Fig. 2. Network utilization of the normal operation test. The shown graphs show the connection speeds of the RaspberryPi to the AWS nodes pidFra-0-4. (a) While sending 10 transactions every 30 seconds. (b) During bursts of 50, 100 and 150 transactions at 02:30, 03:00 and 04:00.

Fig. 2 (a) shows the diagrams of captured data during normal operation with medium transaction throughput of the platform. As all of the validator nodes take turns submitting transactions to the platform, the communication between the peers rises instantaneously every 30 seconds and reaches peaks up to ~110 kByte/s per device. In between the spikes, peer to peer communication stays below the 20 kByte/s mark. In Fig. 2 (b), we show the captured data of the throughput test. During this test, a validator node sends out a burst of an increasing number of transactions. The bursts are executed at 02:30, 03:00, and 4:00 and include 50, 100, and 150 transactions, respectively, sent to the system at once. The behavior of the system load with respect to the network activity is characterized by rising peaks in the peer communication and spikes reaching maximum packet transmission speeds of up to ~120 kByte/s. The peaks coincide with the growing number of transactions in a burst from 90, to 103 and 115 kByte/s.

5. Discussion, outlook and conclusion

Considering the aforementioned results, we see a higher need of bandwidth for a blockchain-enabled system for an SG application such as a P2P market. Compared to the maximum requirements of a real-time metering infrastructure mentioned in literature, our blockchain-based platform utilizes around ten times the bandwidth at the peaks. However, in between peak operation, peer to peer communication stays within a much lower communication speed of ~20 kByte/s. To choose a suitable communication infrastructure for a system like the proposed platform, some of the mentioned options fall out due to a lack of bandwidth capacity. Short distance PLC technology with a maximum speed of 10 Mbps would reach its capacity limit at around 12 participants and is therefore would be unusable for larger communities. (LP-)WPAN communication does not offer speeds to accommodate these requirements, while wireless technologies like newer generations of Wi-Fi (802.11ac) and cellular networks (LTE) offer sufficient bandwidths. These technologies, however, do not have the necessary range or have the disadvantage of high prices caused by service provider contracts. Individual wired technologies, like fiber-optic and DSL, offer good connection speeds and can accommodate the required bandwidths. While AMI offers services like real-time energy monitoring to customers, the focus of our proposed platform includes extensibility for further services. The conducted throughput test shows potential for implementation of functionality, like demand-response, while keeping within the found bandwidth boundaries.

In this paper we have conducted a benchmark of the bandwidth requirements of a blockchain-based microgrid control platform. We have tested the requirements on an exemplary P2P market as a smart grid application and compared it to the requirements of real-time AMI found in literature. After conducting our tests, we have found a per node bandwidth utilization 10x higher than the bandwidth requirement for real-time AMI and have chosen suitable communication technologies for our platform. In the near future, we will start a field test utilizing the mentioned platform. Due to the given local infrastructural conditions, as well as suitability to our requirements, we have opted for using fiber optic technology for node to node communication.

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