Development of Reliable Wireless Communication System for Secure Blockchain-based Energy Trading

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***Abstract*—Blockchain technology is being developed rapidly in recent years. It has been applied to stock trading, supply chain auditing, crowd-funding, energy trading, and Internet-of-Things. Specifically, in Internet-of-Things applications, how the data is transmitted before reaching a blockchain platform reliably is a challenging issue. In this paper, we focus on an energy trading scenario with Internet-of-Things blockchain applications for energy trading. In this scenario, energy generated from renewable sources can be traded in a peer-to-peer manner among micro-grids. This requires a high level of data communication reliability. Blockchain is adopted as an effective decentralized transaction management solution. In particular, we propose a proof-of-concept for reliable data transmission from smart meters to the blockchain based on Sigfox technology and the Ethereum. To enhance reliability, we configure the base station antenna as a block-based mode and propose a physical data layer for wireless communication. We perform extensive experiments to evaluate the performance of the proposed wireless communication system for the blockchain.**

I. Introduction

Data security and integrity issues in data sharing are always attracting great attention because of a growing number of cyber attack incidents occurred at central servers with serious negative effects. For example, the personal data of 1.5 million patients in Singapore has been hacked, which is the largest cyber-attack in the country [1]. The conventional centralized data management system is difficult to defend against deliberate, targeted and well-planned cyber-attack. Consequently, a reliable decentralized system is crucially important. By storing data across a secured network, the blockchain eliminates the risks that come with data being held centrally. Moreover, with consensus and mining mechanisms, blockchain effectively avoids the stored data to be manipulated maliciously.

With various benefits, one of the potential applications of blockchain is energy trading in power systems. The next generation power system, i.e., smart grid, will support diverse energy consumption and supply nodes such as deferrable loads and renewable energy sources. Each of the nodes can make a decision to buy and sell energy dynamically to minimize the cost or to maximize the revenue. Blockchain can be adopted to facilitate energy trading in terms of data management. However, the data has to be collected from a number of nodes before being put into the blockchain platform, and wireless communications will be a suitable operation for such data transfer. Therefore, it is important to develop a reliable wireless communications infrastructure and test its performance whether it can meet the requirements of energy trading or not.

Therefore, in this paper, we introduce the proof-of-concept (PoC) system of the wireless communications infrastructure that supports the blockchain application for energy trading. The software-based system includes a base station that establishes (a) a visualization of wireless communication and data collection on energy harvesting and (b) a secured channel to transfer data between smart meters and cloud-based blockchain platform. The system is based on the Sigfox technology and the Ethereum [2].

The reminder of paper is organized as follows. Section II reviews the related work. Section III describes a reliable wireless communications system for blockchain networks. Section IV provides the details of experiments for the wireless communications system between Sigfox modules and blockchain miner. Section V presents the experimental results and discussions. Finally, Section VI concludes the paper.

II. Related Work

Recently, blockchain technologies have been applied in many IoT applications [3], [4]. Although blockchain has a high potential to enable secure IoT data transfer, the establishment of a reliable wireless communication system for blockchain-based IoT systems, especially for energy trading, was not well investigated in the literature. There are abundant theoretical research studies and solutions for traditional wireless communication system deployment with different network protocols, e.g., LoRa [5] and NB-IoT. The authors in [5] utilized blockchain to build a trusted, decentralized and open system for verifying transaction data, which integrates blockchain and LoRa wide-area network IoT technology. The authors

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in [6] designed an automated and decentralized pollution monitoring system by using the blockchain and LoRaWAN communication protocol to provide long-range and low-power enabled communications. The authors in [7] designed a decentralized, trustless architecture to enable resource-constrained IoT end-devices accessing a blockchain-based infrastructure through LoRa and gateway in a private blockchain network. A blockchain-based IoT data backend system using LoRa as the networking technology is built in [8] to ensure secure and high-availability data storage and management.

As mentioned in [5], NB-IoT is usually used to built wireless networks managed by mobile network operators. Alternatively, LoRa is mainly operated by private companies or organizations. Compared with these protocols, Sigfox as a narrow-band technology which has been widely used for low-power wide-area networks due to its high network capacity, opening access and longer communications range. Some applications include elderly tracking, pet tracking, or private asset tracking, i.e., short-range sensor object tracking systems. Also, Sigfox offers better transmission performance from the end devices to the base station. In this paper, we therefore employ the Sigfox to establish a reliable wireless communication system for long-range and low-cost data and transaction transfer for energy trading in a microgrid environment.

III. A Reliable Wireless Communication System for Blockchain Networks

For secure and efficient energy trading in a distributed energy market, we utilize the Sigfox to establish a blockchain network with a reliable wireless communication system as shown in Fig. 1. There are three types of entities in the energy trading markets, i.e., sellers, buyers, and sensor nodes. Buildings with energy harvesting devices, e.g., Solar PV, can be the energy sellers to sell the energy stored in energy storage units to the buyers (consumers) through microgrids. The sensor nodes collect data including energy status of energy storage and energy trading transactions and upload to the blockchain network. This wireless communication system is proposed to facilitate data collection, transfer, processing, and storage. The blockchain network in the proposed system consists of three layers, i.e., the sensing layer, the transmission layer, and the blockchain layer. The sensing layer is established on smart meters and Sigfox communications modules. The transmission layer is a Sigfox system including Sigfox base station and Sigfox Cloud. The blockchain layer is a blockchain network with smart contracts, which is a distributed ledger that stores smart meter data and energy transactions. The proposed system is a turnkey solution which includes Sigfox sensing modules and blockchain platform to record, broadcast, download, store and share energy trading-related data during the energy trading. The Sigfox sensing modules will be placed at different locations, such as outdoor and indoor, some extremely different places to analyze the overall performance of the wireless communication system with Sigfox module, base stations and Sigfox Cloud.

The reason for adopting Sigfox is that its network and infrastructure are implemented worldwide by using UNB (ultra-narrow band) based radio technology to connect devices to the global network. It is user-friendly and easy to maintain

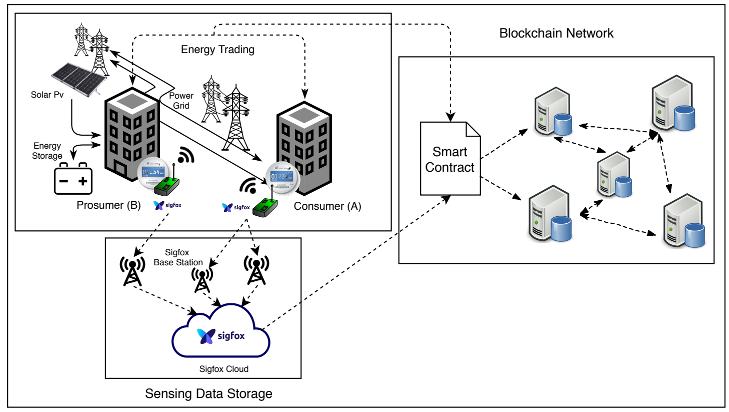

Fig. 1: System Model

anywhere with very low energy consumption, which is particularly suitable and practical for blockchain networks. The Sigfox system is a cloud-based network where data will be forwarded to a Sigfox backend server directly. Then, the users can choose callbacks or application programming interface (API) to route the received data to their own systems [14]. We introduce more details about the modules of the wireless communication system using Sigfox as follows.

A. Data Acquisition Module

A smart meter is an electronic device that records consumption of electric energy and communicates the information to the electricity supplier for monitoring and billing. Smart meters typically record energy hourly or more frequently, and report at least daily. In the proposed system, data collected from the smart meter will be read and transmitted through Arduino/Workstation Server. The collected data include produced energy, consumed energy, and radiance.

B. Data Communication Module

There are two types of communication in the proposed system. The first one is data transmission between the Sigfox Cloud and the blockchain network. The second one is used for energy trading between the users and the blockchain network. The wireless communication system between Sigfox and blockchain storage networks is integrated with UnaShield, an Arduino Shield with a Sigfox transceiver module that is compatible with Arduino Uno R3 and other Arduino-based development board, as a transmitter node. UnaShield pin connected to Arduino Uno R3 transmitted the data at the rate of 9600 baud rate [9]. When sending a set of instructions to the micro-controller on the board, data from a transmitting node will be broadcast to the nearest base station. Every base station by Sigfox Network Operators is directly connected to the Sigfox Cloud where the base stations can detect, demodulate, and report the messages. Due to limited storage in Sigfox devices, the data from Sigfox UnaShield modules is stored in private clouds of Sigfox systems. To create a link between the Sigfox Cloud and platform/server, API is provided to support bi-directional communication. The APIs allow the users to request raw data from Sigfox servers, and the data can be downloaded from Sigfox server to one of the blockchain miners which is a database. The miner will broadcast the data to the blockchain network for mining and consensus.

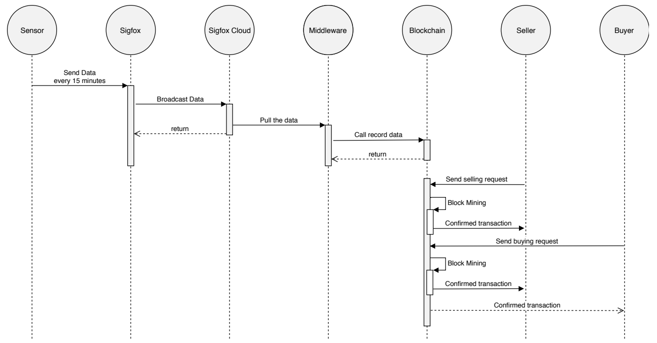

Fig. 2: Flowchart of the data transfer in the proposed system.

C. Data Monitoring Module (Software Application)

Smart contracts associate the user layer and blockchain layer in the proposed system. Firstly, Sigfox Cloud stores all raw data that comes from devices registered on the Sigfox system. The smart contracts will be triggered periodically to retrieve all sensor data from Sigfox Cloud and upload the data to the blockchain networks automatically. Similarly for the energy trading transactions. When a pair of energy buyer and seller in the micro-grids finishes an energy trading action, the transaction records are broadcast to the miner network. Next, all miners compete to solve a mathematical problem based on a cryptography hash algorithm implemented in the Ethereum. Then, the winning miner can add a new block with transactions or sensor data to the blockchain. The new data block is then added to the existing blockchain as a tamper-resistant record, i.e., permanent and unalterable record. The difficulty of the mathematical problem can be adjusted to fit the system requirements in energy trading. The overall system structure is shown in Fig. 1.

IV. Experimentation of Wireless Communication System between Sigfox modules and Blockchain Miner

To test the proposed system with Sigfox modules and blockchain miner, we focus on the performance of wireless communication and the coverage of Sigfox signal. Specifically, we test the combination set of a UnaShield module attached to the Arduino board where they are placed at different locations. With four base stations deployed in the area of Nanyang Technological University, and the nearest base stations are located at the rooftop of Clean-Tech Park One which is a building in a relatively quiet zone. We conduct the performance evaluation for both indoor and outdoor environments. There is one important indicator called link quality. Link quality can be categorized as excellent, good, average and limit based on received signal strength indication (RSSI), number of stations that received a message and Radio Configuration (RC) zone where the device located. [11]. The flowchart is shown in Fig. 2 presents the process of transmitting data to the Sigfox base station from the UnaShield module by commanding Arduino Uno [10]. All the sensing data in the Sigfox will be sent to Sigfox Cloud every 15 minutes. From the Sigfox Cloud, the data can be retrieved by middleware and stored on the Ethereum by using smart contracts. The stored data on the Ethereum can be queried by the energy buyers and sellers. All the buyers and sellers in microgrids can submit request according to their energy demands. Upon receiving the request, miners execute a block mining process to validate new energy transactions and to record them on the Ethereum.

A. Performance Analysis at Indoor Environment

The test location for the indoor environment is a level one canteen which is 800 meters away from the base station at the Clean-Tech Park One as shown in Fig. 3. A Sigfox module is set up at the ground level of this building. According to Arduino script, a message will be sent in every 15 minutes. The message includes produced energy, consumed energy, and radiance. 50 messages have been sent out by Arduino command and recorded at Sigfox back-end. For example the first message, on 2018 Oct 26, 16:29:44, device 2BEF84, the decoded message is 000011940002AF800000002D, which means ”produced Energy (wh)”:4500,”Consumer Energy (wh)”:176000,”Ir-radiance (W/m2)”:45. Looking at the monitoring display, it shows this device has sent 50 messages without fail. Among all 50 messages, 2 of them with good Link quality and 3 of them with limit link quality, the rest of messages is with average link qualitythe overall performance was satisfactory. And the message received on Sigfox back-end is 49 out of 50. That means the receiving rate at this environment is 98%.

B. Performance Analysis at Outdoor Environment

The test location for the outdoor environment is a sport hall which is 1.15 kilometers away from the base station. One Sigfox module is deployed at level 2 of this building. Again, a message will be sent in every 15 minutes, and it includes a counter number, a temperature, and a voltage level. 50 messages have been sent out by Arduino command and recorded at Sigfox back-end. For example, the first message, on 2018 Oct 26, 18:29:44, the same device 2BEF84, the decoded message is 00003458000222e000000086, which means ”produced Energy (wh)”:13400,”Consumer Energy (wh)”:8750,”Ir-radiance (W/m2)”:134.From the monitoring display, this device has sent out 50 messages successfully. Among all 50 messages, 8 of them with average link quality and the rest of them is with good link quality. Message received on Sigfox back-end is 50/50. That means the sending rate is 100% without missing data.

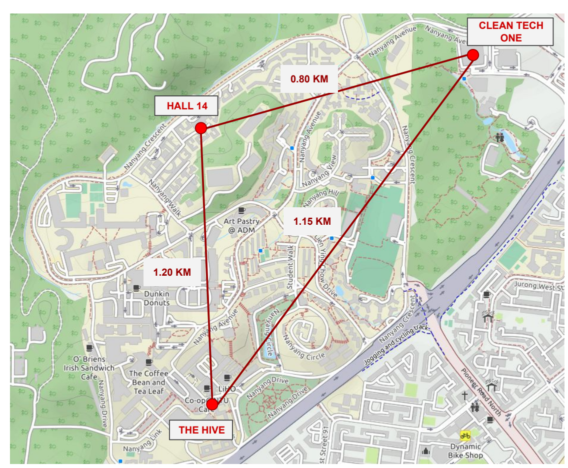

Fig. 3: The map of carrying out experiments

C. Smart Contracts Implementation

We design and deploy secure sensing data storage and energy trading smart contracts on Ethereum. We use the following algorithm presented in the pseudo codes to realize secure energy trading within the microgrids. The pseudo codes of the smart contract include five main functions.

- Adding the Sigfox's information to the smart contract (Line 2 to Line 8),
- Recording the Sigfox sensing data to the smart contract (Line 10 to Line 16),
- Querying the Sigfox sensing data from the smart contract (Line 18 to Line 25),
- Setting the energy to sell (Line 27 to Line 33), and
- Confirming to buy the energy from the seller (Line 35 to Line 41).

Both energy buyers and sellers in the system first obtain personal data storage addresses for storing sensing data and transaction records. Then, the sensing data from different Sigfox systems are transmitted and stored in the corresponding addresses by the data storage smart contracts. The stored data on the Ethereum can be queried by the energy buyers and sellers. The energy buyers send energy demands and prices to the energy sellers. The energy buyers perform energy trading with energy sellers by the energy trading smart contracts [4]. Finally, the energy buyers confirm the energy trading and the energy transaction records are stored on the blockchain through the energy transaction storage smart contract.

Smart Contracts Data Storage and Energy Trading

```
1  contract smartMeter {
2   FUNCTION addSigfox(address sigfoxAddr, string
        sigfoxName) public onlyOwner {
3   Receive message from API.
4   IF noExistAddr(sigfoxAddr) AND noExistName(
        sigfoxName)
5    sigfoxes.push(sigfox(sigfoxAddr, sigfoxName)
6   ELSE
7    ERROR!
8    The inputed sigfoxAddr and sigfoxName were
         wrong or you have no permission
9
10  FUNCTION addSigfoxMsg(address sigfoxAddr, uint
        energy) public onlyOwner {
11  Receive message from API.
12  IF exsistAddr(sigfoxAddr)
13   sigfoxMsgs.push(sigfoxMsg(indexOfSigfox, now,
         energy)
14  ELSE
15   ERROR!
16   The inputted sigfoxAddr does not existed or
         you have no permission
17
18  FUNCTION querySigfoxMsg(address sigfoxAddr,
        uint start_time, uint end_time) {
19  IF msg.sender = onlyOwner
20   Return all timestamps and energy records of
         sigfoxes in chronological order
21  IF msg.sender = sigfoxAddr
22   Return the timestamps and energy records of
         the sigfoxAddr in chronological order
23  ELSE
24   ERROR!
25   Your sigfoxAddr has not been added
26
27  FUNCTION setEnergyOnSaleBySeller(uint
        energyAmount, uint8 price) public
        onlySeller {
28  IF sellerState(msg.sender) = Inactive AND
        energyOfOwner(msg.sender) > energyAmount
29   stateOfOwner[msg.sender] = OnSale
30   send the energy to the contract firstly
31  ELSE
32   ERROR!
33   You have an unfinished trading on sale or your
         energy is not enough
34
35  FUNCTION abort() public onlySeller {
36  IF stateOfOwner[msg.sender] = OnSale
37   stateOfOwner[msg.sender] = Inactive
38   get the energy back from the contract
39  ELSE
40   ERROR!
41   You have nothing on sale in the contract
42
43  FUNCTION confirmByBuyer(address seller, uint
        energyAmount, uint8 price) {
44  IF stateOfOwner[seller] = OnSale AND
        energyAmount = energyInContract[seller] AND
         price = priceOfSeller[seller]
45   stateOfOwner[seller] = Inactive
46   send money to the seller and get the
         corresponding amount of energy from the
         contract
47  ELSE
48   ERROR!
49   The input message has something wrong
50 }
```

V. Results and Discussion

The system is tested in the actual environment to ensure the stability of the system. The wireless communication system of Sigfox is examined to support data transfer in the user layer. We first comparing data communication performance between the indoor environment and outdoor environment. As shown in Fig. 4, the performance of an outdoor environment with a long distance is better than that of an indoor environment even with a shorter distance. We then focus on the test of data communication by multiple Sigfox transceiver modules to evaluate throughput and latency. Specifically, we test three sets of Sigfox modules come with Arduino-based board, and each of them will transmit 12 bytes of data to Sigfox base station every 10 seconds until 140 packages of data are sent out. The performance is based on the variation on the total set of data from the local storage, compared with the data given in the Sigfox Cloud. Based on the testing results, we obtain 100% of data transmitted from the devices to Sigfox Cloud which ensures the reliability of the proposed system.

As mentioned above, there are four base stations set up in the area and the coverage of Sigfox signal is 100%. In this case, a message can be broadcast to different base stations over the whole area at the same time. However, on the same frequency, Signal-to-Noise Ratio (SNR) is varied depending on the location of the base station and environment noise level. As Shown in Fig. 5. Here, we denote SNR as the ratio of the power signal P_{signal} of a signal to the power of background noise P_{noise}. After that, Sigfox Cloud will take in the message from a base station with the strongest signal based on selective algorithms and display in the message interface as shown in Fig. 6.

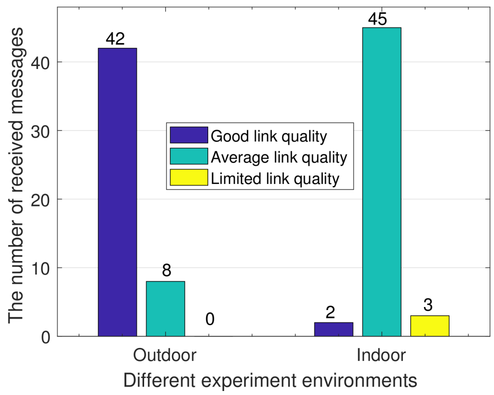

Fig. 4: The performance comparison between data transmission between the outdoor and indoor environments.

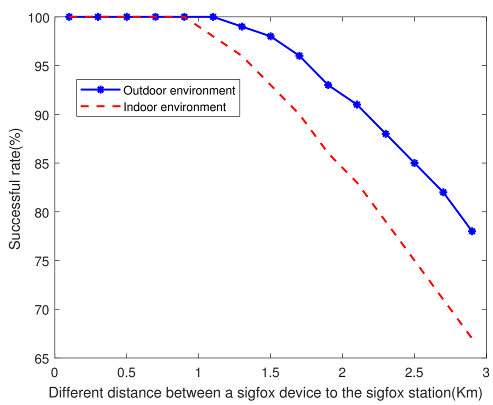

Fig. 5: The successful rate according to the distance.

VI. Conclusion

In this paper, we have introduced a data communication system to support blockchain-based energy trading in a micro-grid environment. In the system, Sigfox has been tested in a campus area which is a remote urban place with 70% of space covered by plantation and mountain. The experiments have shown that Sigfox can be one of a suitable option to the user layer in the blockchain platform as it works reliably regardless of indoor or outdoor environment. For future work, the communication system can be integrated with the blockchain layer. Moreover, we will further perform the analysis on the blockchain system with the block propagation [15] and secure consensus processes [16].

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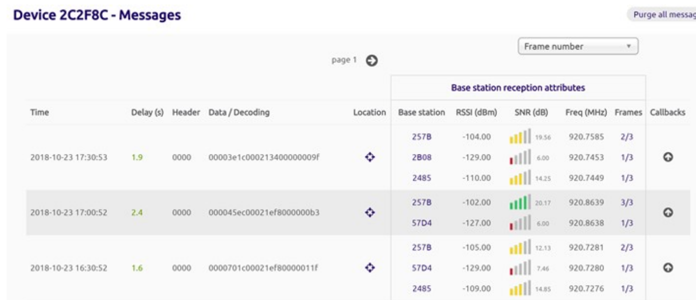

Fig. 6: Message quality

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