A Blockchain-Based Energy Trading Platform for Smart Homes in a Microgrid

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***Abstract*—The MicroGrid, as the need for renewable energy emerges, are becoming essential, renewable energy trading platforms are being developed and established in the microgrid. With the proliferation of technologies such as Smart home based of Internet of Things, interconnected networks, and Blockchain, microgrid has introduced a variety of applications and innovative solutions for efficient system maintenance. This paper, in a blockchain-based smart home, it is impossible to forge data called transaction generated by using blockchain. With this unforgeable transactions, home miner that centrally processes all the transactions generated in smart home know information about energy. Based on this information, we proposes renewable energy trading platform using ethereum's smart contract to ensure secure energy trading run automatically without the third party intervention in a microgrid.**

Keywords-internet of things; microgrid; smart home; blockchain; ethereum; smart contract; network security; energy trade

I. INTRODUCTION

Internet of Things (IoT) is a form in which both the device and the person are connected to the Internet and consists of devices that generate, collect, process, and exchange vast amounts of security and safety-critical data as well as privacy-sensitive information, and hence are appealing targets of various cyber attacks[1].

Smart Home is a technology that can monitor and control many devices and a variety of fields by connecting them through a communication network. And there are many networkable IoT devices such as home appliance, energy consuming devices, security devices in Smart Home and most of them are low energy and lightweight. Thus existing security methods tend to be expensive for IoT in terms of energy consumption and processing overhead because devices that are low energy and lightweight must devote most of their available energy to executing core application functionality [2].

The Smart Grid uses two-way flows of electricity and information in real time between power suppliers and consumers to create a widely distributed automated energy delivery network [3]. A small-scale of the Smart Grid system, microgrid is stand-alone power networks within small communities using renewable energy and energy storage system(ESS) and provide platform to trade locally generated energy within their community.

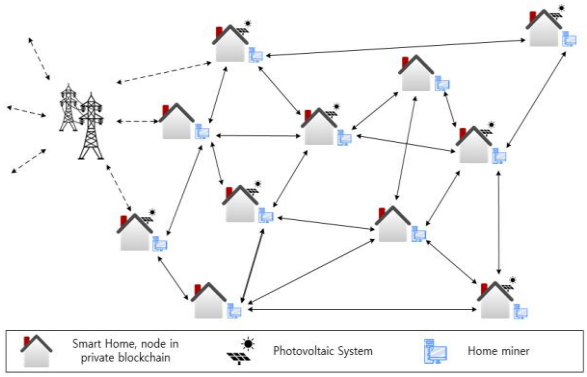

Figure 1. Exemplary microgrid on a private blockchain network.

In this paper, we propose a secure and automated decentralized renewable energy trading platform within the microgrid using smart contract among blockchain technology. As shown in Figure 1, the microgrid is based on a private blockchain network that can only participate in authorized nodes. It can be self-sufficient in power in small areas and is complementary to existing power systems. Each node in the microgrid is divided into two categories: consumer that needs energy to consume it in the home, or prosumer with photovoltaic system capable of producing renewable energy itself. And each node is a smart home where IoT devices are connected to the Internet and has an ESS that can store purchased or produced energy. Home miner in the smart home can manage and control IoT devices and ESS and monitor information about energy use. In addition, it conducts energy trading based on pre-programmed smart contracts within private blockchain.

The rest of the paper is organized as follow: In Section II we describe the properties of blockchain to understand the

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contents of this paper. Energy management and usage measurement in blockchain based smart home is discussed in Section III. Description and implementation of the energy trading platform using smart contract is presented in Section IV. And finally Section V concludes the paper.

II. PROPERTIES OF BLOCKCHAIN

A. Blockchain

A blockchain is a ledger of distributed database that continuously records list of transactions, called blocks. The blockchain network timestamps transactions by hashing them into an ongoing chain of hash-based Proof-of-Work (PoW), forming a record that cannot be changed without redoing the PoW [5]. PoW is the process of finding nonce, a random variable that gives the block's hash the required zero bits [5]. A node that generates transactions to be recorded in the blockchain broadcasts the transactions to all nodes within the blockchain network. Some specific nodes known as *miners* collect the transactions not included in the block and try to solve a cryptographic puzzle named PoW [4]. The node who solves the puzzle first generates new block and broadcasts the block to all nodes. The nodes accept the block only if all transactions in it are valid and not already spent [5]. And the block is connected to the previous block after block verification.

B. Transactions

The transaction is a means for transmitting information for writing to the blockchain to other nodes. Each transaction requires a valid digital signature which can be generated with digital keys to be included in the blockchain. The use of digital signature ensures authentication and non-repudiation of the transaction generator. Each transaction is verified by consensus of a majority of the participant nodes and can never be erased [6]. It is called Data integrity.

C. Private Blockchain

There are two types of blockchains: *public blockchain* and *private blockchain*. Public blockchain, such as bitcoin[5] or ethereum [7], can allow participant nodes to enter the network without any limitaions. On this network, all transactions are verified and shared by all nodes. On the other hand, in the private blockchain, the participant nodes that can participate in reading, writing and consensus processes are designated in advance. In addition, specific nodes can be added or removed as needed. Thus, private blockchain is not possible for malicious nodes to enter the network and provides sufficient security without process such as PoW. In addition, the processing cost and time can be reduced because consensus is achieved between pre-designated participant nodes.

III. ENERGY MANAGEMENT IN BLOCKCHAIN BASED SMART HOME IN THE MICROGRID

A. Blockchain Based Smart Home in the Microgrid.

IoT devices, ESS and home miner in a smart home generate, collect, process, and exchange vast amounts of data that can be used to manage, control and monitor everything that happens in a smart home. As shown in Figure 2, the microgrid, a small-scale grid, is constructed as a private blockchain network. Each node of blockchain is a smart home consisting of IoT devices, energy storage device, home miner and solar panel only for prosumers that produce renewable energy itself. Here, smart home miner is a device that centrally processes incoming and outgoing data to and from smart home and implements energy trading by smart contract. And the miner is placed between devices and home gateway[2]. IoT devices are connected via WiFi, so they exchange data with home miner by wireless communication. The data generated in the smart home is called *transactions.* The transactions are added to the block by adding parameter including device ID, home owner ID, transaction type by the home miner after being authenticated and authorized. The home miner of each smart home collects the transactions not included in the block and works on finding a difficult PoW. When a home miner is successful in PoW, the block consisting of several transactions is appended to the blockchain and miner broadcasts the block to all home miners. They accept the block only if all transactions in it are valid. After this, the transactions included in the block are never forge or falsified.

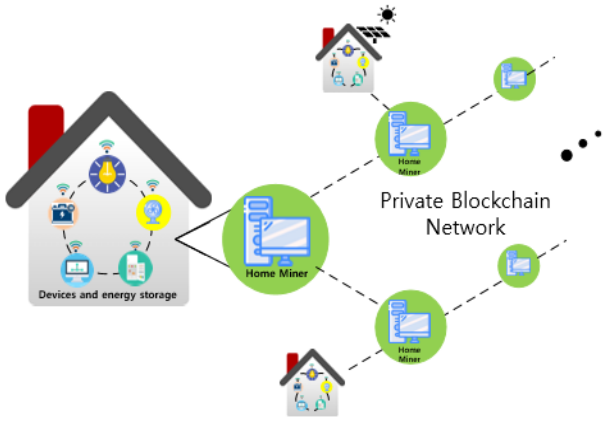

Figure 2. Overview of the smart home in private blockchain network.

Because this consensus process is achieved within the private blockchain, sufficient security is provided and processing cost and time can be reduced.

B. Energy Management

The blockchain based smart home can store energy used in the house through ESS. Consumers that needs energy to consume purchase energy from prosumers. And they charge energy to the energy storage device in the house. Prosumers produce renewable energy itself with photovoltaic system and store it in energy storage device to sell energy to consumers. The aforementioned home miner can centrally process data from all devices and ESS and store data in a connected cloud system or data storage. Using stored data, the home miner can know the current state, the operation history, energy usage of each device, energy output and the amount of energy remaining in the energy storage device.

Other than that, more information is available and can be used for various applications. However, the proposed energy trading platform only requires information on energy usage of each device and the amount of energy remaining in the energy storage device.

IV. Energy Trade Using Smart Contract

A. Energy Trading Process

The consumer's home miner monitors energy usage and energy remaining in real time. If consumer's home miner determines that the stored energy is in sufficient, that is, it detects that the energy remaining is below the specified value, it implements energy trading by smart contract with prosumer's home miner and charges the energy storage device with energy. Energy trading process between consumer and prosumer is in Figure 3.

Consumer's home miner and prosumer's home miners are included in private blockchain network.

1. Prosumer must register the smart contract in which the transaction conditions are written to sell the energy. When the PoW is completed, the smart contract is included in the block.
2. Both the consumer and the prosumer set the price and transaction process. When the PoW is completed, contents of price and transaction process is included in the block.
3. If consumer's home miner determines that the amount of energy remaining is not sufficient, it will convey purchase intention to prosumer. And transaction matching begins.
4. If the transaction matching is successful, the energy transaction is completed. Thus the consumer is supplied with energy and the prosumer receives the price.

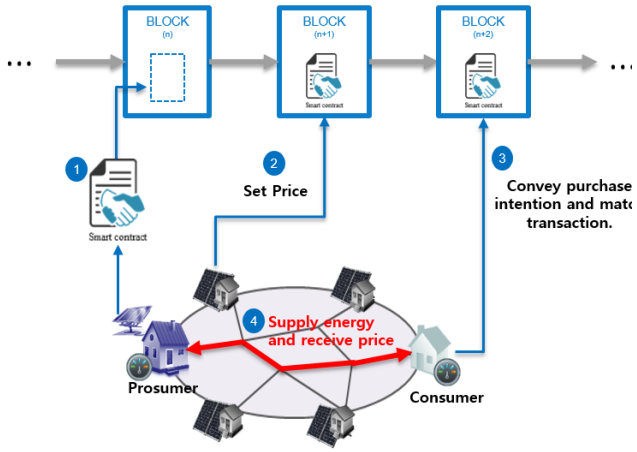

Figure 3. Energy trading process.

The above process uses ethereum's smart contract based on blockchain technology. Because of data integrity characteristics of blockchain, it is not possible to forge or falsify the information about the energy. In addition, using ethereum's smart contract[8], energy transaction is automatically achieved in real time without the third party intervention.

B. Energy Trading Platform Implementation

Utilizing ethereum's smart contract, we implemented an energy trading platform between consumers and prosumers. Private blockchain network is constructed using geth client distributed by ethereum. And smart contract is coded in solidity language. In this paper, there are only two nodes of consumer and prosumer and the transaction is achieved between two nodes.

Figure 4. Information of prosumer and consumer node forming a private blockchain network.

As shown in Figure 4, we can see prosumer's IP address is 163.239.195.12 and port number is 46453 and consumer's IP address is 163.239.195.105 and port number is 36554. And prosumer and consumer are included in private blockchain network.

```
1  contract ES{
2      uint public tradeprice;
3      event trade_event(string message, uint money, uint power);
4
5      function Prosumer_setprice(uint price_of_Prosumer) public{
6          tradeprice = price_of_Prosumer;
7          trade_event("price of power set", tradeprice, 4000);
8
9      }
10
11     function CONSUMER_buy(uint price_of_CONSUMER) public{
12         if (price_of_CONSUMER>=tradeprice){
13             trade_event("trade matched", tradeprice, 4000);
14
15         }
16         else{
17             trade_event("trade not matched", 0, 0);
18         }
19     }
20 }
```

Figure 5. The contents of the smart contract registered by the prosumer.

First, the prosumer runs a contract.js file coded node.js language to register the smart contract. The myContract variable in the contract.js file contains the contents of the smart contract coded in the solidity language and the contents are shown in Figure 5. The contract condition is that when the price set by the consumer is smaller than the price set by the prosumer, the transaction is not matched. If the price is equal to or greater than the price set by the prosumer, the transaction is matched. Here, the tradeprice variable represents the price the prosumer will set and the price_of_CONSUMER variable represents the price the

consumer will set. And the amount of energy traded at one time is 4000W. After run the contract.js file, you can see that the smart contract registration is completed and included in block 356 in Figure 6.

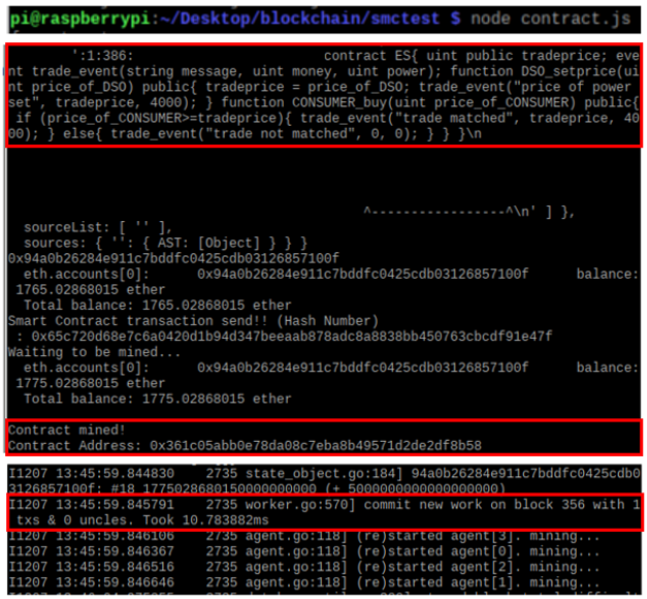

Figure 6. Contract registration process.

Next, to set the price, the consumer runs a consumer.js file, and the prosumer runs a dso.js file. The consumer.js file is coded with the initial price and the transaction process, when consumer's purchase intention is conveyed and transaction matching begins. The dso.js file is coded with the price the prosumer wants to sell, the amount of energy remaining, the current balance and the transaction process. Here, the initial price the consumer wants to purchase is 300$, the price the prosumer wants to sell is 500$, the amounts of energy remaining is 160,000W and the current balance is 32,400$. After run the consumer.js and dso.js file, you can see that the set price is broadcast to the blockchain network and the amounts of energy remaining and balance are displayed. And transaction is included in block 366 in Figure 7.

Next, when a trans.js file is run, the purchase intention is conveyed to prosumer. It codes the trans.js file to run when consumer's home miner determines that the amount of energy remaining is not sufficient. After the purchase intention is conveyed to prosumer, energy trading matching begins. The transaction matching process in this scenario can be seen in Figure 8. Initial transaction matching fails because the initial price the consumer wants to purchase is 300$ and the price the prosumer wants to sell is 500$. The consumer.js file is coded to increase the price by 100$ if the match fails. Thus the purchase price is raised from 300$ to 400$ automatically. Because the 400$ is also less than the selling price of 500$, matching fails and the purchase price is raised from 400$ to 500$. 500$ is equal to the price the prosumer want to sell, so the matching is successful and the energy transaction is completed. After the transaction is completed, the consumer is supplied with energy and the prosumer receives the price. As a result, the prosumer's amount of energy remaining is reduced from 160,000W to 156,000W, and the balance is increased from 32,400$ to 32,900$.

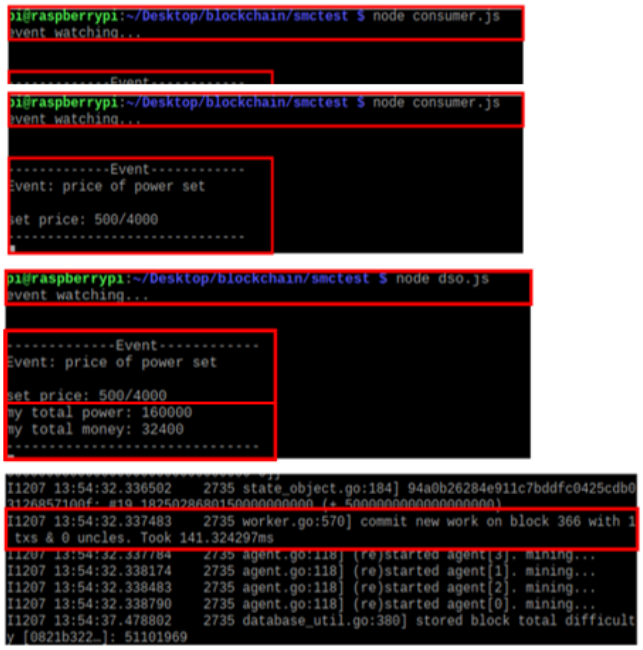

Figure 7. Set price and broadcast it to the blockchain network.

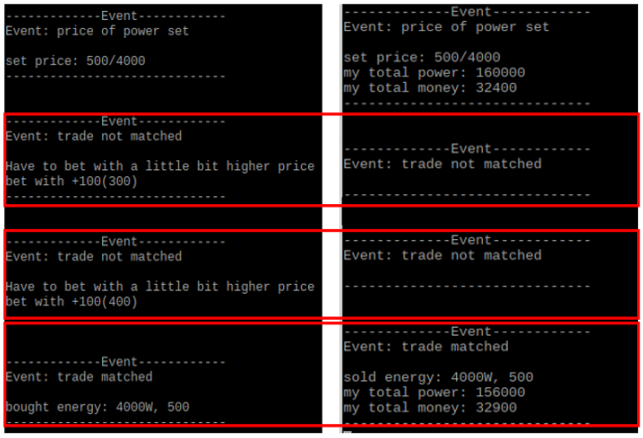

Figure 8. Transaction matching process

V. CONCLUSION

In this paper, we describe transactions, home miner and energy management in blockchain-based smart home and propose secure and automated decentralized renewable energy trading platform within the microgrid using blockchain technology.

In the case of a smart home based on blockchain, home miner could manage, control and monitor all the devices' data that safety-critical and privacy-sensitive. And the data is included in the block in the blockchain. Thus it provides secure access control to the IoT devices and their data in the

smart home. In addition, we have used only the information about energy trading, however more information is available and we can use and utilize it for various applications.

In the case of energy trading platform, we have implemented a simple scenario for two nodes. This scenario shows that the transactions are automatically achieved and are not possible to forge and falsify because of blockchain and smart contract characteristic. We can see that it is scalable and adaptable by coding transaction process and smart contracts contents. Based on this, it is possible to expand the scale to more and more nodes and get closer to the microgrid system. With the start of this platform, we hope to build full-scaled a decentralized renewable energy trading platform suitable for the virtual microgrid.

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