Communication requirements for enabling real-time energy trading among distributed energy storage systems and aggregators

Antony Mapfumo
School of Electrical Engineering and Computer Science
Queensland University of Technology
GPO Box 2434, Brisbane QLD 4001, Australia
Email: a.mapfumo@connect.qut.edu.au

Abstract—**In this paper I propose a model for implementing a real-time energy bidding and trading system among distributed battery energy storage systems (D-BESS) and aggregators. Energy bidding and trading process flow will be discussed. A message passing mechanism as way to meet the real-time communications requirements of a system based on a suggested model is outlined. The importance of distributed energy resources (DER) and the role aggregators play in the model is also discussed. An overview of possible network architectures and protocols are introduced.**

Index Terms – Distributed Battery Storage Systems, BESS, Smart grid, Real-time energy trading, Energy Bidding, BESS, Distributed Energy Resources (DER)

I. Introduction

A real-time energy bidding and trading system among battery energy storage systems (BESS) and aggregators can result in better financial rewards for energy consumers and producers (*prosumers*) whilst increasing the amount of energy sources in the grid. This is especially important during periods of peak demand like a heatwave or a cold winter night.

To mitigate the intermittent nature of renewable energy sources, battery energy storage systems (BESS) become significant components of the smart grid. As energy storage technology and manufacturing processes mature, BESSs will become more affordable and more efficient. This means in the smart grids of the future a majority of *prosumers* will be able to store excess energy generated from renewable sources like solar and wind and sell it back to the electricity companies any time during the day, not just when the sun is up or wind is available.

When it comes to selling energy back to the grid most prosumers are constrained by two main things. Firstly, due to lack of battery energy storage systems (due to affordability) they can only sell when there is sunlight or wind for example. This is not ideal for them or the power companies. The second issue is that of pricing. They can only sell to the utility company providing them with the electricity that also sets the pricing for them. Ideally they would want a market based energy bidding and trading process involving several aggregators and utility companies to get a competitive price.

To implement a real-time energy bidding and trading system among aggregators and BESSs the following is proposed: -

1) An energy trading model as illustrated in Figure 1.
2) An energy bidding and trading process flow as illustrated in Figure 2 and discussed in III.
3) A message passing system to satisfy the real-time communications requirements as discussed in section IV.

The desired outcome is a framework that simplifies the implementation of real-time energy bidding and trading in smart grids.

The rest of the paper will present related work and the motivation behind the proposed model. An appropriate network architecture and suitable protocols are briefly discussed.

II. Related work and motivation

Distributed Energy Resources (DER): There is going to be a substantial shift from large scale power plants towards a large number of distributed renewable energy sources. Distributed renewable energy systems generate clean electricity at the site where the energy will be used as opposed to remote generation at centralised power plants. There are many benefits of distributed energy systems. There are many benefits of distributed energy systems. According to [1] these include improved efficiency of grid operations, minimisation of operational costs and reduction of greenhouse gas emissions. I think government incentives like the Queensland Government solar bonus scheme also play a major role. The affordability [2] and availability of electrical energy storage units is also helping towards the push for distributed energy systems in the smart grid. From a consumer point of view, I believe there is an opportunity to not only to sell excess energy back to the electric grid but also to get the best price as multiple aggregators and utilities participate in the distributed energy

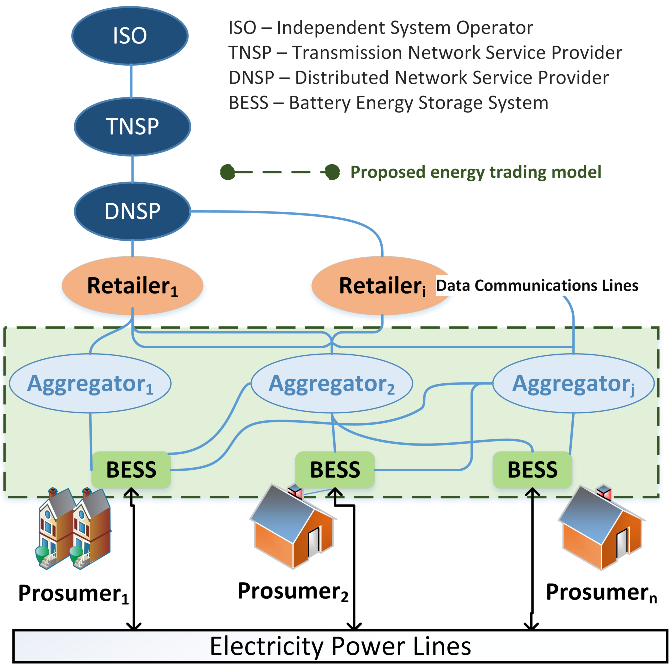

Fig. 1. Current and proposed energy trading model

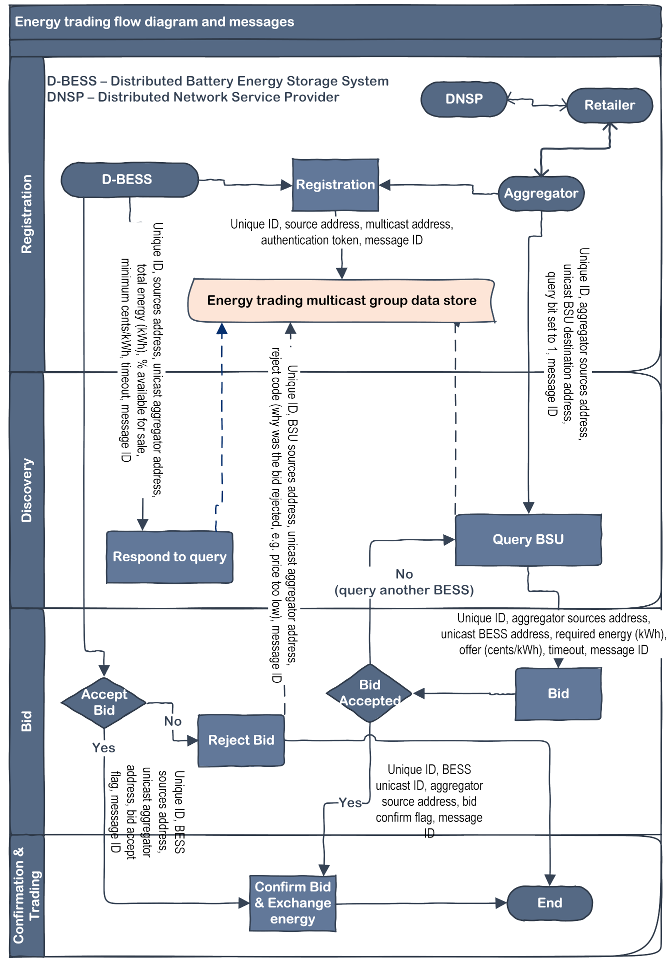

Fig. 2. Proposed energy bidding and trading flow diagram

system thereby recovering investment costs sooner and make a profit.

The role of aggregators: In the smart grid an aggregator is a broker or intermediary between customers and electricity suppliers. "An aggregator is an entity which collects power generated from microgrids and resells it to the utility." [3].

In their paper "A Two-Stage Market Model for Microgrid" [3], they describe a two-stage model that illustrates the role of aggregators in microgrid transactions. They describe how aggregators can mitigate the sudden demand for electricity during peak periods by quickly supplying power to the main grid since they have access to a large of various energy sources like battery storage units and renewable sources like solar and wind.

Day-ahead and machine learning based energy trading: In a day-ahead electricity market sellers and buyers make contracts for the delivery of electricity the next day, they agree on a fixed price the day before the actual electricity is delivered.

Machine learning techniques can be used to determine prices in energy trading. Using a recursive neural network (RNN) technique [4] devised a method for predicting prices in the day-ahead electricity trading market on an hourly basis.

Market-based energy trading: A market-based energy pricing system is a competition based system. For the purposes of this discussion it is competition between aggregators, competing for the energy in *prosumers'* BESSs.

There are several methods for energy trading in the smart grid. For example, Wang and Huang [5] have modelled energy trading between autonomous microgrids for their mutual benefits. They have designed a bargain-based energy trading systems that is based on Nash's model of bargaining.

Energy pricing in the smart grid is very complicated. It is complicated for both the resellers and the consumers. As [6] have pointed out, it is difficult for resellers because of the lack of information from the customer side. Customers face the uncertainty of retail electricity pricing. Implementing a market-based trading system is even more complicated. To overcome these challenges Kim and the team use reinforcement learning.

Electric vehicle (EV) energy trading: Although the initial objectives of deploying electric vehicles (EVs) were environmental it has since been realised that they are also a source of energy. This is especially true during periods of peak electricity demand and emergencies. There are several methods of energy trading between EVs and the smart grid. [7] demonstrated that a smart grid can increase its profits by creatively cordinating renewable energy generation with electric vehicle charging.

Virtual Power Plant (VPP) energy trading: A virtual power plant (VPP) is an aggregation of different power sources

(BESSs, solar, wind, small hydro, etc.) that act as a single power plant [8]. Because of the flexibility of the VPP [9] looked at how the principals of marginal and fixed costs apply to a VPP operation in order to see how much profit can be made in a VPP after trading flexibility. Day-ahead, intra-day and regulating power markets were included in their model to test and confirm the assumption that a VPP can make extra profit by being a participant in multiple markets.

Motivations: Although there are currently several methods of electricity pricing in the smart grid as far as we are aware none currently addresses real-time bidding between consumers with battery energy storage systems and aggregators. There are also several successful network architectures, protocols and services in the smart grid to address substation to substation real-time communication, real-time communication between retailers, aggregators and utility companies, we are not aware of one that has specifically addresses the real-time communication between aggregators and BESSs for real-time market based energy bidding and trading.

III. Proposed Energy Trading Model

Currently the typical scenario is such that a *prosumer* can only trade energy with a single retailer, implying a one-to-one relationship. There are a couple of undesirable characteristics of this model. From the consumer perspective the main drawback is the lack of competition in order to get favourable price for the energy being sold to the grid. The second is the lack of BESSs that lead to a situation where *prosumers* are time constrained as to when they can sell electricity back to the grid.

We propose the model shown in Figure 1. The key aspect of this model is that all *prosumers* have BESSs and they only communicate with aggregators. Each BESS is connected to at least two aggregators, a one-to-many relationship. The more aggregators a BESS is connected to the bigger the chance it has of getting a better price due to increased competition.

IV. Real-time message exchange between BESSs and aggregators

To implement the proposed energy trading system real-time messages need to be exchanged. The aggregators need to know how much energy is available in a BESS and what percentage of the available energy energy can be traded. The registration and bidding processes all involve message passing. Proposed message types are shown in Table I. Different messages have different delay characteristics and priorities as show in Table II. Bandwidth and message sizes are shown in Table III. Messages sizes are calculated as based on following: Minimum TCP segment size is 20 bytes and minimum IP packet size is 20 bytes. As illustrated in Figure 3, Message ID and Device

TABLE I
Message Descriptions

Message	**Description**
Register	A BESS or Aggregator sends a multicast message to join the energy trading group
Query	Aggregator sends a multicast message querying BESSs if they have spare energy for sale
Response	BESS responds to a query message by sending a unicast message to an aggregator indicating total available energy, what percentage is available for sale and the price per kWh
Bid	Aggregator sends a unicast message indicating total required energy and an offer or counter offer
Accept Bid	BESS sends a unicast message to aggregator accepting bid
Bid Confirmation	Aggregator sends BESS acknowledging bid and energy trading commences
Reject Bid	BESS sends a message to aggregator rejecting bid or offer
Terminate	Either BESS or aggregator can terminate trading for a variety of reasons including 1) transaction finished, 2) transmission and distribution errors
Device Failure	Critical message indicating a BESS failure.
BESS Status	Periodic keep-alive and status messages from BESS to aggregator. Payload include battery drainage, voltage, etc

TABLE II
Delay and priority requirements

Message	**Priority (0-high, 100-low)**	**Max delay (ms)**	**Source**	**Destination**
Register	80 (low)	5000	BESS or Aggregator	Multicast group
Query	70 (low)	3000	Aggregator	BESS
Response	15 (high)	500	BESS	Aggregator
Bid	10 (high)	500	Aggregator	BESS
Accept Bid	5 (high)	500	BESS	Aggregator
Bid Confirmation	5 (high)	500	Aggregator	BESS
Reject Bid	50 (medium)	1000	BESS	Aggregator
Terminate	10 (high)	400	BESS or Aggregator	BESS or Aggregator
Device Failure	0 (very high)	200	BESS	Aggregator
BESS Status	60 (medium)	2000	BESS	Aggregator

TABLE III
Message size and Bandwidth requirements

Message	**Message size (bytes)**	**Frequency**	**Bandwidth (bps)**
Register	122	1 message per 60 secoconds	1500
Query	122	1 message per 10 seconds	1500
Response	124	immediate	1500
Bid	122	immediate	1500
Accept Bid	125	immediate	1500
Bid Confirmation	125	immediate	1500
Reject Bid	123	immediate	1500
Terminate	123	immediate	1500
Device Failure	122	immediate	1500
BESS Status	128	1 message per 5 seconds	1500

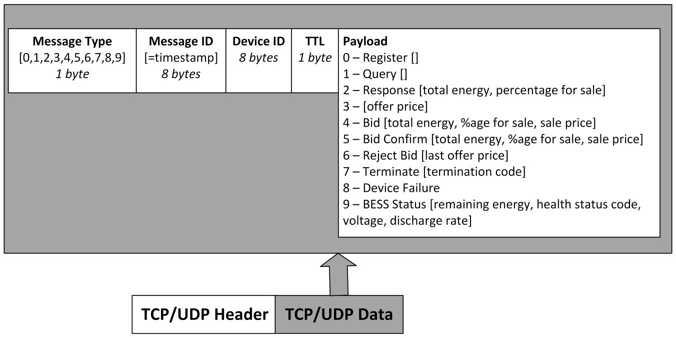

Fig. 3. Energy Trading Protocol (ETP) header and payload

ID are 8 bytes each, the message type and TTL are 1 byte each whilst the minimum Ethernet frame size is 64 bytes for a minimum total of 122 bytes. Depending on message type there maybe extra bytes. For example, in the case of a response message additional information is total energy available and percentage for sale at 1 byte each bringing the total to 124 bytes. This is well below the maximum Ethernet version 2 frame size of 1500 bytes.

Registration: The first step a BESS or aggregator does is to join the energy trading multicast group using the ”Register” message. A register message consists of 1) a unique device ID 2) source address 3) multicast address 4) optional authentication data and 5) a message ID.

Discovery: An aggregator is interested in knowing about the available BESSs and what percentage of the available energy is available for sell. To achieve this it sends a query message consisting of 1) a unique device ID 2) source address 3) multicast address 4) a query flag set on and 5) a message ID. BESSs answer the aggregator’s query message with a response message consisting of 1) unique device ID 2) source address 3) aggregator unicast address 4) total energy in the BESS 5) the percentage available for sell 6) voltage 7) timeout and 8) a message ID.

Bidding: Once an aggregator has received response messages, the next step is to bid for the energy. It sends a bid message consisting of 1) unique device ID 2) source address 3) unicast BESS address 4) required energy (kHw), 5) offer (cents/kWh), 6) timeout (how long we are willing to wait till we get a response) 7) a message ID. How an aggreagator bids depends on a number of factors. The bidding algorithm might select a BESS based on either price or available energy in a BESS. For example it might be desirable to get energy from a few expensive BESSs that meet the total energy required by an aggregator than from several cheap BESS. Another factor that may be considered by the bidding algorithm is ”historical context”, using previous bidding data like last prices and energy traded. A BESS can choose to reject or accept a bid. If the price is favourable an accept bid message is sent to the aggregator. It is a unicast message consisting of 1) a unique device ID 2) source address 3) unicast aggregator address 4) bid accept flag 5) message ID. Similarly a reject bid message can also be sent but with a bid reject code instead of bid accept flag. A bid reject code outlines the reason why the bid was rejected, ”price too low” for example.

Confirmation and Trading: If the aggregator and BESS agree on the energy and pricing details the final step is confirmation and actual energy transfer to the grid. An aggregator sends a BESS a bid confirmation message consisting of

Aggregator, Retailer and DNSP messaging: There are also messages between the aggregators, retailers and DNSP (Distributed Network Service Provider). They are shown in Figure 2 for completeness.

V. Discussions

A. Real-time Communications for the distributed control of energy systems

In a distributed energy storage control system, the storage and control elements are decentralised. At the heart of any distributed system is the communication and coordination of actions by message passing. The control elements are distributed throughout the system and are connected via wired or wireless networks. They have the ability to talk to each other using protocols based on the IEC 61850 standard.

In microgrids a decentralized approach to energy storage control ”allows a very flexible system that can adapt to changing system structures and situations” [10]. Due to the discontinuous nature of renewable energy resources, energy storage is essential in providing a flexible and reliable grid system. Power is usually generated somewhere and consumption is in major population centres that can be hundreds or thousands of kilometres away. The integration of renewable sources of energy in the form of distributed generation (DG) into the grid and microgrids is growing rapidly [11]. All these factors make it essential to have an effective distributed energy storage system. The importance of a distributed energy system is that it appears to the user as a single entity. Energy storage also mitigates renewable energy sources like solar and wind intermittency.

Renewable energy generation systems can form part of a distributed control system in the smart grid by having ”an electrical grid divided into several control areas, distributed renewable energy generation systems, distributed control systems and a real-time communication network” [12]. In [13] they consider Douglas-Rachford splitting as a method for solving real-time control of a large number of units in a distributed energy system.

For distributed renewable energy systems to be effective in the smart grid is the need for real-time communications regardless of the approach or method employed for the control of these systems. The essential factor in having a reliable electricity delivery in the smart grid is by having information that is both reliable and delivered in real-time [14]. As noted by Dehalwar and teammates [15], real-time communications in the smart

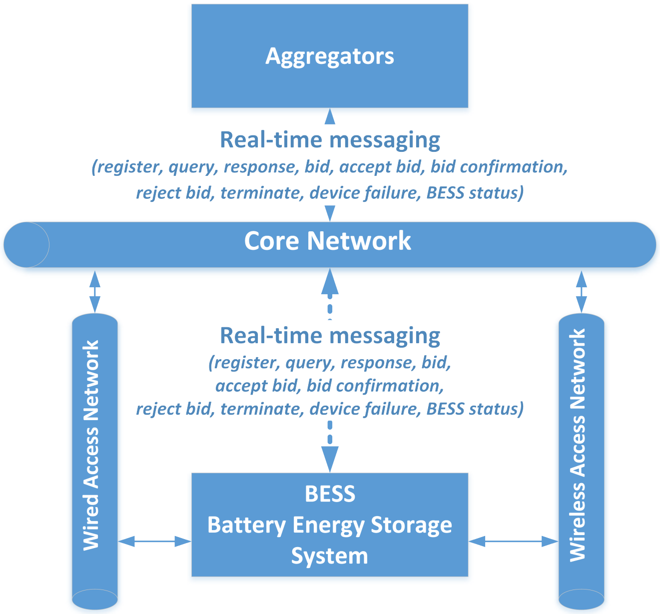

Fig. 4. Network Architecture

```go
type Message struct {
    messageType              int     //register, query, etc
    messageID                int     // is also the the timestamp
    deviceID                 int     // who generated this Message
    ttl                      int     // time to live
    bidPrice                 float64 // offer/bid price, cents/kWh
    salePrice                float64 // final price, cents/kWh
    energyTotal              float64 // battery total energy available
    percentageForSale        float64 // %age of total available for sale
    requiredEnergyAmount     float64 // usually all of it = energy total
    terminationCode          int     //why was the transaction terminated
    remainingBatteryEnergy   float64
    batteryHealthStatusCode  int
    batteryVoltage           float64
    dischargeRate            float64
}
```

Fig. 5. Message data structure

```
> battery -id 25 -reserveprice 12.5
BESS ID: 25 | Total Energy: 13.5 kWh | 50 % is for sale | reserve price: 12.5 cents/kWh)
Highest bid: 0 cents/kWh | by Aggregator ID: 0
2020/06/14 21:15:58 Service started: (tcp) :4000
2020/06/14 21:16:02 Connected to 192.168.1.110:33006
received QUERY message: 1 71132 500 0 0.00 0.00 0.00 0.00 0.00 0 0.00 0 0.00 0.00
received BID message: 3 50822 500 0 5.00 0.00 13.50 50.00 0.00 0 0.00 0 0.00 0.00
Bid too low, REJECTED: 5 cents/kWh
received BID message: 3 50822 500 0 7.00 0.00 13.50 50.00 0.00 0 0.00 0 0.00 0.00
Bid too low, REJECTED: 7 cents/kWh
received BID message: 3 50822 500 0 10.00 0.00 13.50 50.00 0.00 0 0.00 0 0.00 0.00
Bid too low, REJECTED: 10 cents/kWh
received BID message: 3 50822 500 0 15.00 0.00 13.50 50.00 0.00 0 0.00 0 0.00 0.00
Bid ACCEPED: 15 cents/kWh, Highest bider ID: 500
received BID CONFIRMED message: 5 50822 500 0 15.00 0.00 13.50 50.00 0.00 0 0.00 0 0.00 0.00
Percentage for sale left = 0
```

Fig. 6. single BESS and a single aggregator bidding process

grid is very challenging due to its sheer size and associated complexities. Several methods and protocols, including the IEC 61850, have already been drafted to tackle real-time communications challenges in the smart grid.

B. Potential Network Architecture

Based on the real-time requirements of the messages described in section IV and cost, an appropriate network architecture needs to be devised. Cost is important because in order to encourage more home users to invest in BESSs there should be minimal additional data communications expenditure. For example, an optic fibre based architecture would ideally satisfy real-time and bandwidth requirements. However it can be prohibitively expenses. Wireless technologies like 3G, LTE and WiMAX are alternative candidates physical layer architectures.

C. Potential Network Protocols

To facilitate message exchange and network services a suitable real-time protocol suite based on the IEC 61850 standard is required. The IEC 61850 standard outlines a framework for communication between several single devices in the power system. The standard is designed to separate the data model from the method of communication. It addresses the importance of a structured approach to the design of substation automation systems, utilises existing technologies like Ethernet and TCP/IP, simplify system configuration and device measurement sharing and to enable vendor independence. Although the original scope of the IEC 61850 standard is substation-to-substation focussed its abstract model makes it intuitive to develop smart grid applications that extend beyond the substation boundary like a market based energy trading system for example. Real-time parameters will need to be defined. For example, how much delay in milliseconds are we going to tolerate for each type of message and at what layer of the OSI model. It could be based on the existing and widely used TCP/IP protocol suite. QoS could be utilised to prioritize messages. A detailed discussion of a suitable protocol suite and its development will be carried out in future work.

VI. Prototype

A simple prototype to illustrate the protocol implementation and energy trading has been developed in Golang programming language. As per the energy trading protocol diagram in Fig. 3 the messaging data structure code snippet is shown in Fig. 5. In Fig. 6 the BESS had set minimum selling price (reserve price) of 12.5 cents/kWh and managed to eventually sell at 15 cents/kWh to aggregator ID 500. In Fig. 7 the maximum bid of of 7 cents/kWh was eventually rejected for being too low to what the BESS reserve price is. In practise the BESS might want to adjust its reserve price if it's not making any sales. This could be done manually by the *prosumer* or letting algorithm adapt using using historical data from log files. Finally, as can be seen in 8 two aggregators are competing for the stored energy in BESS ID 30 who has set a reserve price of 20 cents/kWh. Because of the competing not only did the BESS manage to sell its energy, after aggregator ID 55 bowed out, but it sold at 23 cents/kWh. That's is 3 cents/kWh above its reserve price.

VII. Conclusion

A possible framework for implementing a real-time energy bidding and trading scheme between D-BESS and aggregators has been presented in this paper. It helps to appropriately reward *prosumers*. The role of multiple aggregators has been discussed to induce competition and ultimately better prices

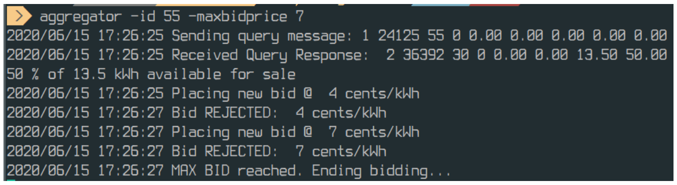

Fig. 7. Rejected bid for being lower than BESS reserve price

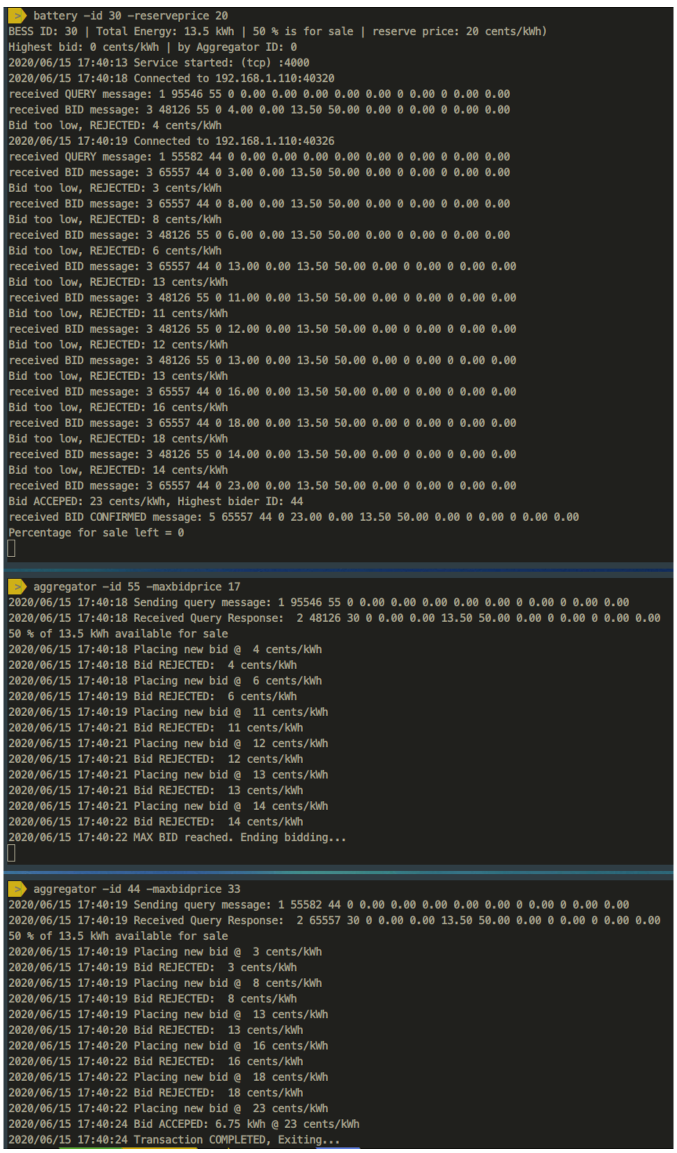

Fig. 8. Two aggregators and a single BESS auction

for BESS investors. A possible messaging system for such a framework has been introduced. An energy trading scheme derived from this framework has the potential to substantially increase the number of renewable energy participants in the smart grid as they will be rewarded competitively for their investment as compared to the current system. An overview of the potential network architectures and protocols has been discussed. Following this paper a detailed protocol design and implementation will be carried out in our future work. Several network services and applications can also be implemented and an accompanying suitable network architecture.

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