Multi-Agent Systems Coursework

Two-Sided Pay-As-Bid Multi-Unit Auction
Mechanism for Renewable Energy Trading

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1 Introduction

Renewable energy being produced by individual households is becoming increasingly popular with the use of solar cells on rooftops and small-scale wind turbines, allowing households to be self-sufficient energy-wise.

However, the unreliability of nature means that power needs may not be met on a given day forcing such a household to use ‘dirty’ non-renewable energy from a utility company. Renewable power generation may also exceed the household’s needs and currently, the options are to sell it onwards to a utility company (often at a pittance) or to allow the energy to go to waste.

Multi-agent systems allows for multiple renewable energy households in an area to communicate about their energy needs and transfer energy to each other in an rational fashion.

By using an auction protocol to generate fair pricing, households are given an economic incentive to participate. Those with excess energy can offer it at higher prices than the flat rate typically offered by a utility company. Households with insufficient energy generation can participate and meet their energy needs with renewable sources at lower prices and non-renewables. The independent nature of each agent allows households to set their own rules. For example, they may be willing to pay more than the cost of non-renewable energy for renewable energy or they may wish to stay within a budget and opt to withdraw and reduce their power needs through other action.

This report details the design, implementation and evaluation of a prototype renewable energy sharing system that uses a two-way ’pay-as-bid’ multi-unit auction mechanism to generate pricing and facilitate energy transfers anonymously.

2 Design

The prototype created uses a two-pay 'pay-as-bid' auction mechanism to match buyers and sellers in the energy market.

2.1 Choice of Protocol

'Pay-as-bid' (Wittwer, 2020), also known as 'discriminatory price', is used in multi-unit auctions where winning bidders pay the price they submitted. This prevents any uncertainty over the price that is paid. This of particular note in a household application where staying within a budget may be important and a household may wish to limit their energy use instead of paying an unexpected higher price which may occur in a uniform-pricing auction. Two-way 'Pay-as-Bid' allows the sellers to only sell at the price they submit. Matches are made between sellers and buyers at their specified price.

Our auction protocol is multi-unit. This allows for a more efficient transfer of goods (ELMAGHRABY & OREN, 1999). This is important for two reasons. Firstly, energy transfer is not lossless. Transmission between two households will incur some energy loss and by trading in larger quantities between two agents rather than multiple single units from multiple agents, this energy loss can be mitigated. Secondly, a multi-unit auction allows an agent to satisfy their needs in fewer messages. This makes the market more efficient and therefore allows the market to be more accessible to lower-power agents.

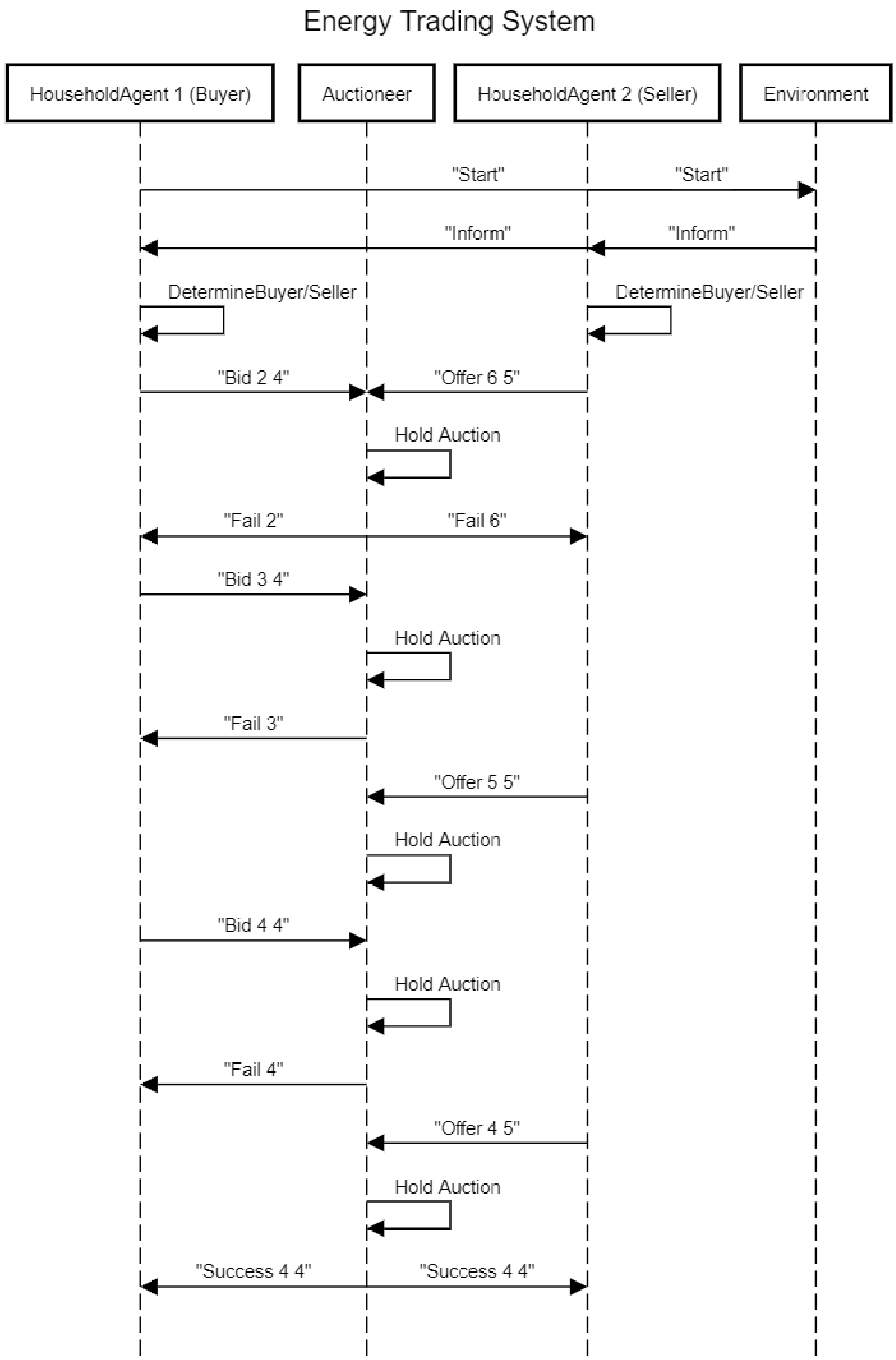
Buyers and sellers send messages to an intermediary auctioneer agent. These messages indicate whether the agent wishes to bid or offer, the price and the quantity needed/offered. Rapid auctions are held where bids/offers with matching prices are matched. The buyer and seller that are matched are sent a success message detailing the transaction. When multiple price equivalent matches are made, the auctioneer prefers matches that transfer the highest amount of energy.

If no match is made, a failure message is sent. Upon receiving this message, a household agent may make a decision as to whether to alter their bid, leave it as is or exit the auction.

The auction is held continuously. New bids and offers can be matched immediately. The auction is also anonymous. Only the auctioneer knows the identity of the agents involved. This helps prevent malicious behaviour between agents such as collusion (Heim & Götz, 2021).

The auction ends after a set number of turns pass without any new bids/offers or if all agents withdraw.

2.2 Sequence Diagram



Note: In the source code implementation, a agent of type 'LoggingAgent' is present. This is used to format the final output messages of each agent to be output to a CSV file. It does not affect the auction mechanism.

2.3 Agent Selection Function

Upon initialisation of the system, every household agent sends the 'environment' agent a 'start' message. The household agent receives an 'inform' message from the environment agent which acts as a stand-in in the prototype for the energy generation forecasts that a real-world implementation would have. This 'inform' message contains the following:

1. Demand - energy needed for the household
2. Generation - renewable energy expected to be generated
3. Utility Purchase Price - the current rate to buy a unit of non-renewable energy from a utility company
4. Utility Selling Price - the current to sell a unit of renewable energy to a utility company

If demand is greater than the expected generation, the household agent will operate as a buyer. If the demand is lower than the expected generation, the household agent will operate as a seller. To determine an initial bid/offer, the agent looks at the prices for selling/belling from the utility company. This serves as the lower and upper bounds for the bidding strategy as all agents would prefer renewable energy but not at the expense of paying more and selling for less than what the utility company offers. These bounds are specific to this implementation and a strategy where renewable energy is valued higher than a less expensive non-renewable would be valid and functional.

An agent's initial bid as a buyer is set to the rate that the utility company provided it as for selling renewables to it. It is assumed that this value would be similar to what other agents receive and therefore selling agents would not be interested in bids lower than this.

Similarly, an agent's initial offer as a seller is set to the rate that the utility company provided it as for buying non-renewables. It is assumed that this value is similar to what other agents receive and therefore buying agents would not be interested in offers higher than this.

After the initial bid/offer has been received by the auctioneer, if no match is found during the auction, a failure message is sent to the sender of the bid/offer.

Upon receiving this failure message, the agent considers whether the current bid/offer being raised or lowered respectively would still be beneficial. If raising or lowering would push the bid outside of the lower/upper bounds that have been established, no adjustment is made. Otherwise, the agent linearly increases/decreases their bid/offer by a set interval. This is set to 1 but could be user-set in a real-world implementation. Additionally, an agent could be set to change their bid based on time passed which may be useful in auctions that take a set time.

Upon receiving a success message, the agent's dearth/excess of energy is updated. The successful transaction indicates to the agent that more offers at this pricing may be successful so the agent sends another bid/offer at the winning price, assuming its needs have not been met.

When an agent has met it's needs, it withdraws from the auction and shuts down. If it has not met its needs and the auction finishes, it will purchase/sell any demand or excess left over to the utility company.

3 Evaluation

The evaluation of this prototype is made with three metrics.

Individual Goal is measured by the profit of an individual agent. When acting as a seller, maximising profit is the goal. When acting as a buyer, minimising money spent and satisfying energy needs is the goal.

Society Goal is measured by the minimising the amount of unclean energy purchased. However, energy generation conditions mean that there is not always enough renewable energy available to meet demands therefore unclean energy that is bought to meet this demand when no alternative renewable source is available is not counted. Similarly, clean energy that is sold to a utility company when no potential buyers (at any price) exist on the market is not counted.

Computational Efficiency is measured by the number of messages sent between agents. Messages sent to the logging agent for output are not counted.

3.1 Control

Table 1 is a control dataset from the prototype running at default settings of 10 agents and 1 auctioneer and random settings from the environment agent.

The mean profit of sellers is 6.23 with a standard deviation of 2.28.

The mean spent by buyers is 20.97 with a standard deviation of 12.77.

The mean amount of unclean energy bought is 0.5 units with a standard deviation of 0.85.

The mean number of messages sent is 233.6 with a standard deviation of 42.6.

With default settings, we achieve a high society goal with only three units of unclean energy being bought in favour of renewable energy over ten runs.

Individuals do not attain particularly high goals with low profits and high costs incurred by buyers. This high cost might be attributed to the fact that in all runs except two there were more buyers in the market than sellers, leading to buyers being forced to purchase expensive unclean energy when renewable sources ran out. This is supported by the low amount of spent and highest profit in all runs being achieved in run 3 where the percent of buyers in the market was 20%.

The low standard deviation in profit suggests that all sales take place at a similar value. Whereas, the high standard deviation present in buyer's costs suggests a larger variation. As each bidder/offer pays/receives exactly what

Run	Average spent	Average gained	Buyers/Agents	Society	Messages
Run 1	-10.4	6.5	0.55	0	203
Run 2	-7.4	8.6	0.5	0	219
Run 3	-9	10.25	0.2	0	312
Run 4	-36.13	5	0.8	0	292
Run 5	-7.2	6.75	0.55	0	201
Run 6	-32.66	1.66	0.66	0	264
Run 7	-29	6.33	0.66	2	178
Run 8	-23.33	6.33	0.66	0	233
Run 9	-40	4.66	0.63	2	215
Run 10	-14.6	6.25	0.55	1	219

Table 1: Control Dataset

is bid, we would expect these values to be very similar if the alternative of buying/selling non-renewables was not available. We can infer therefore from the higher deviation in costs that the average cost for buyers when buying non-renewables is much higher than the average cost for renewables whereas sales take place at an average price closer to the average price that can be attained by selling to a utility company.

This suggests that compared to simply selling to a utility company, sellers do not gain a lot from engaging with this system whereas buyers would have reduced their costs more significantly.

Across all runs with 10 household agents each, there is a mean average of 23.36 messages sent per agent which we'd consider reasonably efficient.

3.2 Effects of a Single-Unit Auction

The first experiment seeks to demonstrate the increase in computational efficiency that occurs with a multi-unit auction. In this experiment, the prototype is altered such that the auction protocol only allows the transfer of one unit of energy at a time.

It is expected that a single unit auction will use more messages and be less efficient as each transfer requires two messages and will be repeated for every single unit of energy that would be transferred. For example, in a multi-unit auction, a buyer bidding for four units that matches with a seller selling four units would require a single message to each to trade all four units. A single-unit auction would be expected to require four messages to both buyer and seller for each unit of energy by the auctioneer and after each transaction, the buyer/seller would need to submit another bid/offer at the same price.

Run	Average spent	Average gained	Buyers/Agents	Society	Messages
Run 1	-54.66	2.5	0.6	0	332
Run 2	-63.43	4	0.77	0	313
Run 3	-27.66	2.75	0.6	0	249
Run 4	-39.33	3.66	0.66	0	276
Run 5	-31.6	8.75	0.55	0	268
Run 6	-39.66	6.66	0.66	4	291
Run 7	-52.83	3	0.75	0	263
Run 8	-59.2	2.2	0.5	1	270
Run 9	-6.5	10.25	0.2	0	252
Run 10	-16	9.33	0.4	0	257

Table 2: Single Unit Auction Dataset

Table 2 shows the output from 10 runs with this change.

The mean profit of sellers is 5.31 with a standard deviation of 3.13

The mean spent by buyers is 39.09 with a standard deviation of 18.89.

The mean amount of unclean energy bought is 0.5 units with a standard deviation of 1.2 .

The mean number of messages sent is 277.1 with a standard deviation of 27.19, with a mean of 27.71 messages sent per agent.

Compared with our control dataset, there is an increase in mean messages sent by 43.5 with each agent sending a mean increase of 4.35. This is as expected and demonstrates the computational efficiency offered by a multi-unit auction mechanism.

We find a similar mean profit (-0.92) and a similar standard deviation (+0.85) for sellers between this and our standard parameters dataset, suggesting that a single or multi-unit auction does not affect the individual goal of an agent.

Contrary to this, there is an increase in mean spent by buyers by 18.12 and an increase in standard deviation of 6.12. This suggests that a multi-unit auction may be better for buyer agents. However, this may be due to variance in the run conditions as set by the environment agent.

We also find a similarly high attainment in the society goal with 5 unclean energy units being bought over 10 runs. This is very similar to our default settings, change of +2, indicating that multi-unit and single-unit auction mechanism are similar in terms of our society goal.

Run	Average spent	Average gained	Buyers/Sellers	Society	Messages
Run 1	-9.33	7.86	0.3	0	247
Run 2	-17.66	7	0.3	0	219
Run 3	-10.33	9	0.3	0	248
Run 4	-9.33	10.14	0.3	0	247
Run 5	-17.66	7.14	0.3	0	274
Run 6	-18.33	5.14	0.3	1	255
Run 7	-8.33	6.86	0.3	0	264
Run 8	-18.66	4.86	0.3	0	260
Run 9	-9.66	8.29	0.3	0	256
Run 10	-38.33	6.14	0.3	5	308

Table 3: Higher proportion of sellers in market

3.3 Effect of Surplus Sellers on Market

To ascertain if the high standard deviation for buyers in our control set was due to an excess amount of buyers, our second experiment will alter the environment agent such that there are always 7 sellers and 3 buyers in each run.

We would expect that an excess of sellers on the market would lead to lower costs for buyers on average. We would also expect sellers to benefit less and for the variation in profit to be lower as excess energy is sold to the utility company at a flat rate per run. Computational efficiency and society goals are not expected to be affected.

The mean profit of sellers is 7.24 with a standard deviation of 1.64.

The mean spent by buyers is 15.76 with a standard deviation of 9.04.

The mean amount of unclean energy bought is 0.6 units with a standard deviation of 1.57.

The mean number of messages sent is 257.8 with a standard deviation of 22.78, with a mean of 25.78 messages sent per agent.

Compared with our control, we see similar results for our sellers and buyers. Buyers do well of in a seller heavy environment with lower costs (-5.21) and a lower variance in prices. The small increase in average profit is unexpected. The small decrease in standard deviation (-0.64) is line with expectations but the size is small enough that both may due to variance.

We see a small increase in messages sent with a lower deviation.This may be due to there being a greater number redundant messages being sent to the auctioneer when no more bidders exist in the market due to their needs being met.

NumAgents	Messages	Messages Per Agent
10	268	26.8
50	1324	26.48
100	2603	26.03
500	12635	25.27
1000	25203	25.203

Table 4: Message Scaling

3.4 System Scalability

Table 4 shows that the number of messages sent per agent as the system scales stays similar indicating that our system is scalable.

However, our system uses a single central auctioneer which must process every bid and offer. This is a bottleneck that is not shown by number of messages. In an expanded system, multiple auctioneers which communicate could be implemented to ease this bottleneck.

As demonstrated by our first experiment, our multi-unit solution is more computationally efficient than a typical single-unit auction.

4 Conclusion

As mentioned in our section on ”System Scalability”, our system maintains a similar number of messages per agent as the system scales. This means that in a large system, the individual agents which would be expected to run on low-power smart meters would have similar performance irrespective of the size of the market they are participating in. This is of particular note as it allows for the standardisation of these smart meters and prevents individual users from being discriminated against in larger markets by those with more powerful machines.

A potential solution to the bottleneck that is presented by a central auctioneer would be to use multiple auctioneers that could co-ordinate. For example, an auctioneer could match all agents within an area and refer any outstanding bids/offers to other auctioneers. Additionally, using local auctioneer agents would prioritise local trading first preventing the need for long distance energy transfer which can often cause power to be lost in transmission.

There is little to no protection against false bids or offers and ’ghost’ transactions. In a real world system, protection measures are needed to guarantee the safety of the system and the users within it. There is ongoing research using technologies such as blockchains (Yildizbasi, 2021) that could be used.

There was a failure in data collection for this report in that we did not distinguish between the profit and costs for renewable energy and for non-renewable consumption when an excess or dearth of renewable energy exists in the system. As such, we had difficulty determining meaning in the individual goals of our agents.

In our system, across different conditions, we see a consistently high society goal with the majority of runs having zero non-renewable energy being bought when a renewable alternative is available. In a real system, this would be expected to be similar. However, as our bidding strategy is dictated by the prices given to the agents by the non-renewable utility company, the market could be externally manipulated into low individual goal attainment thereby disincentivising participation.

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