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***Abstract*—The abstract goes here.**

***Index Terms*—IEEE, IEEEtran, journal, LaTeX, paper, template.**

I. Introduction

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Free market provide energy at lower prices

mds
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II. Background work

Many different mechanisms have been proposed to enable local trading of electricity among users.

For trading energy, sellers needs to be matched to consumers, such that matched sellers and consumers trade energy with each other. Auction [1], and double auction [2], [3] are commonly used mechanisms for matching sellers with consumers in P2P trading. In auction the sellers submit their tentative energy prices/ bids to DSO, whereas in double price auction both sellers and consumers submit their bid to energy brokers[1]. In auction mechanism, all the seller post their bid on a auctioning board with DSO. Consumers approaches sellers on the basis of their bids and negotiate the energy prices; after both parties agree, energy is traded between them. DSO is involved in managing the auctioning board and act as guarantor of the price agreed upon by the parties to trade energy. DSO also act a mediator trading, and consumers rely on DSO to determine amount of energy available with seller. DSO can collude with a group of sellers and direct consumers to purchase energy from them at prices set by these sellers. Relying on DSO during trading also creates a single point of failure and reduces reliability of system. Double auction mechanisms proposed in [2], [3] take care problem of single point of failure by relying on group of users called energy brokers to manage. However, energy prices in this model can be easily manipulated by brokers. These brokers regulate the demand and supply profile for consumers and seller. A demand profile of a particular consumer c_i implies, how much energy c_i will demanded from which seller, whereas supply profile contains information about how energy is to be distributed among the requesting consumer. A broker can modify demand and seller profile to direct electricity demand to particular group of sellers. These selected group of sellers can demand high prices from consumers. Apart from price manipulation, DSO and energy broker need to be compensate for managing trading process. This increases the price at which energy is being traded.

To reduce energy prices and providing a free market[2] for trading, the use of mediators for matching should be replaced by a distributed system where sellers and consumers directly interact with each other. Many distributed algorithms [4], [5], [6] for matching two different groups have been proposed in past. In these algorithms unmatched members of one group iterate through members of the second groups in order of their preference list. If the member approached (in second group) is unmatched, it will accept the matching. If the approached member is matched, he can either say no or break existing match on the basis of his preference list. This process continues until either all the members in first group get a match or they have exhausted all options in second group. Mechanism proposed in [4], [5], [6] differ in the constraints under which matching takes place, e.g., In stable marriage mechanism [4] a group 2 member can be matched to a single member of group 1, whereas in college admission problem [4], [5] a group 2 members can be matched to multiple members of group 1. However these mechanism cannot be used for P2P trading. Above mechanism cannot implement many-to-many matching: A single members of one group cannot be matched to multiple members of other group, and vice-versa. These mechanisms do not take care of different supplies and requirements of sellers and consumers, respectively. In this paper, we propose a distributed mechanism that can implement many-to-many matching of different capacity sellers with consumers having different demands.

III. Energy Matching Framework

We propose a framework in which energy is bough and sold in blocks, where a block is the minimum amount of energy that can be traded between a buyer and seller. A consumer can purchase blocks from same or different seller; similarly a seller can sell its blocks to same or different consumers. Energy matching framework groups sellers with buyers for trading energy blocks. We formally define the model for energy matching in the subsequent subsection.

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[1]Energy brokers are users with high computational power, which act as broker between seller and consumer.

[2]The system where supply and demand determine the price of energy

TABLE I: Background Work

(a) Studies and frameworks for P2P energy trading

Work	Contribution	Approach	Application
[7]	Survey on energy trading	Discusses existing techniques and mathematical models for trading energy	Smart grids
[8]	Reviews blockchain technology in energy sector	Discusses advantages and potential of blockchain usage in energy sector	Micro grids
[9]	A software platform, Elecbay, for P2P energy trading	Elecbay is used to collect bids from consumer, manages issues between seller and consumer, and generated electricity bills	Micro grids
[1]	Decentralized system for P2P energy trading	Proposes a blockchain based framework for carrying out energy trading. This system can securely carry out transactions without need for trusted third party.	Smart grids
[10]	Decentralized system for P2P energy trading	Blockchain is integrated with cloud based energy management system that is more decentralized and self executing	Smart grids

(b) Mechanisms for matching sellers with consumers in P2P energy trading

Work	Contribution	Approach	Limitation
[1]	Auction mechanism	DSO collects the prices of energy quoted by by different seller and shares them with consumers. Based on prices quoted, consumers contact and negotiate with different sellers for purhasing electricity .	1) This system has low reliability because DSO is a single point of failure. 2) This system unsuitable for free market[1] implementation because energy prices can be manipulated by DSO 3) This system increases energy prices because DSO needs to be compensated for its services.
[2], [3]	Double price auction mechanism	Group of users called Energy Brokers act as brokers to match sellers with consumers. They collect prices quoted by sellers and consumers, and then match them accordingly.	1) This system unsuitable for free market[1] implementation because energy prices can be manipulated by energy brokers. 2) Users have to brokerage charges, which increases overall energy prices.

(c) Distributed algorithms for matching two groups

Work	Contribution	Application	Limitation
[4]	Stable marriage algorithm	Matches men with women	Can match one seller with only one consumer
[4]	College admission algorithm	Allocated prospective students to their colleges	If extended to P2P trading, it can only multiple consumers to single seller, but cannot match same consumer to different sellers.
[5]	Rural hospital matching algorithm	Allocates doctors to the hospital	If extended to P2P trading, it can match multiple consumers to single seller, but cannot match same consumer to different sellers.
[6]	Common goods matching algorithm	Matches group of buyers with sellers	An seller can sell commodity only to one buyer.

[1] The trading system in which price are determined by demand and supply with no central control. Such systems promotes economic growth and transparency

A. Model

A P2P trading market can be represented by $(\mathcal{S}, \mathcal{C}, \mathcal{D}, \mathcal{B}, >_\mathcal{S}, >_\mathcal{C})$. Its components are described as follows.

- $\mathcal{S} = \{s_1, \cdots, s_N\}$ and $\mathcal{C} = \{c_1, \cdots, c_M\}$ denote the set consisting of N sellers and M consumers respectively.
- $\mathcal{D} = \{d_{s_1}, \cdots, d_{s_N}\}$ and $\mathcal{B} = \{b_{c_1}, \cdots, b_{c_M}\}$ are sets containing information about number of blocks available and demanded respectively in trading market. d_{s_i} are the number of blocks available with s_i and b_{c_i} are the number of blocks demanded by c_i.
- $\forall c_i \in \mathcal{C}$ and $\forall s_i \in \mathcal{S}$, $\mathcal{A}_{c_i}$ and $\mathcal{A}_{s_i}$ are sets representing allocated and allocation lists respectively. $\mathcal{A}_{c_i} = \{a^{c_i}_{s_1}, \cdots, a^{c_i}_{s_N}\}$, where $a^{c_i}_{s_i}$ are the number of energy blocks allocated to c_i from s_i. $\mathcal{A}_{s_i} = \{a^{s_i}_{c_1}, \cdots, a^{s_i}_{c_N}\}$, where $a^{s_i}_{c_i}$ is the number of energy blocks allocated by s_i to c_i.
- $>_\mathcal{S} = \{>_{s_1}, \cdots, >_{s_N}\}$ and $>_\mathcal{C} = \{>_{c_1}, \cdots, >_{c_N}\}$ represent the preference profiles of all sellers and consumers

respectively. Any consumer c_i has a strict preference relation $>_{c_i}$ over $\mathcal{S}$, and any seller s_i also has strict preference relation $>_{s_i}$ over $\mathcal{C}$. The strict preference relation for consumer (or seller) implies that their can not be two or more sellers (or consumer) which are equally preferred by it. The priority list with consumer is fixed and already know to it. We have proposed a generalized system which cn take any preference list. For ease of understanding we define the follwing preference listThe consumer gives priority to the nearest seller, so as to save on transmission cost charges: Greater the distance, higher is the infrastructure usage, thereby increasing transmission cost. Unlike priority list with consumer, priority list is not calculated by seller in advance. The seller prioritize consumer on the basis of the bids received from consumers. In case of tie, the nearest consumer is given more preference.

B. Problem Formulation

Energy matching implies matching sellers with the buyers. It is formally defined as follows.

Definition 1 (Energy Matching). *For a given set of sellers* ($\mathcal{S}$) *and set of consumer* ($\mathcal{C}$)*, energy matching is a mapping* $\mu : \mathcal{S} \cup \mathcal{C} \rightarrow 2^{\mathcal{S}} \cup 2^{\mathcal{C}}$*, such that:*

1) $\mu(s_i) \subseteq \mathcal{C}, \ \forall s_i \in \mathcal{S}$*: A seller can sell energy to more than one consumer.*
2) $\mu(c_i) \subseteq \mathcal{S}, \ \forall c_i \in \mathcal{C}$*: A consumer can purchase energy from more than one seller.*
3) *For any consumer* c_i *and seller* s_i*,* $c_i \in \mu(s_i) \iff s_i \in \mu(c_i)$*.*

C. Stable matching

Sellers and consumers are selfish and rational. They will break-off their matching if they receive better choices: Seller will break matching, if it can sell energy at higher price than offered during matching. A stable matching implies that there is no pair of seller and consumer who both prefer each other to their current choices.

Definition 2 (Feasible Energy Matching). *An energy matching is feasible if*

D. Toy Example of Energy Matching

As shown in Fig. 1, there are 4 consumers (1 to 4) and 3 sellers (A to C). The energy demand of consumers and supply by sellers is represented in terms of blocks. A block is smallest unit of energy that can be traded. In Fig. 1a, seller A is selling 3 blocks of energy, whereas consumer 1 requires two blocks of energy. A seller (or consumer) can sell (or purchase) blocks from same or different users, but half blocks cannot be traded.

The energy matching problem implies matching each blocks on the seller with blocks on the consumer side. Each matched block of a consumer with seller implies that consumer will purchase that block from the seller: In Fig. 1a, round 4, two blocks of seller B are matched to consumer 2, whereas remaining blocks are matched to consumer 1, implying that B will sell two blocks each to 1 to 2 respectively. The matching is done on the basis of priority list with consumers and sellers. The priority list is obtained as follows.

- **Consumer's priority list:** The consumer prefers seller which is nearest to it, so as to minimize transmission cost. In Fig. 1, the seller A is nearest and seller C is farthest from consumer 1. Therefore 1 will give highest preference to A, then B, and least priority to C. The preference list of A is represented as $< A, B, C >$ in Fig. 1. Similarly the preference list of all the other consumers are decided and presented in Fig. 1.
- **Seller's priority list:** A seller's preference list is decided on the basis of price at which consumer bids for energy. We assume that prices bids of consumers $1, \ 2, \ 3,$ and 4 for each block are $0.4, 0.4, \ 0.6,$ and 0.7 dollars respectively. All sellers will give first priority to 4, and then 3. As their is tie in bid price for consumer 1 and 2, seller gives priority to nearest consumer. 1 is nearer to seller A, while 2 is nearer to B and C. Unlike priority list of consumer, the seller's preference list are not available with seller at starting of the matching process, because they do not know the bids of consumers. These lists gets updated dynamically as the bids arrive at the seller. The final preference list (after bids from all the consumers have arrived) for sellers A, B, and C are $< 4, \ 3, \ 1, \ 2 >$, $< 4, \ 3, \ 1, \ 2 >$, and $< 4, \ 3, \ 2, \ 1 >$ respectively (Fig. 1).

The energy matching starts by propagating information about sellers across the network. A seller informs DSO, its nearest neighbors, and frequent consumers that it will act as seller. As sellers are reluctant to disclose their trading information, they do not disclose the amount of energy available with them. The consumers, download list from DSO, and nearest neighbors and consolidate these list to construct a preference list of sellers. Thereafter, they start bidding for energy at start of every round. The round is a time-period during which consumers submit its bid to a single seller, and sellers allocate their resources to one or more consumers on the basis of their priority list. The clock of sellers and consumers are synchronized with DSO to start and end the round. In the first round consumers will submit bid to the seller with the highest priority. If they receive energy blocks equal to their demand they will not bid in the second round, else they submit their bid to the seller which is second in the preference list. A consumer may not require to bid in current round, but it may have to bid in later round if seller receives bid higher than the bid of c_i. In that case the consumer may submit its bid to next seller in preference list after s_i. The energy matching process differs depending on the supply and demand of energy blocks. There can be three different matching scenarios which are discussed as follows.

1) Number of blocks to be sold is equal to blocks demanded: Fig. 1a, shows energy matching when equal number of blocks (9) are available with both seller and consumer. In the first round, a consumer submits its bid to seller which is at top of its priority list. Consumers 1 and 2, request 2 blocks from seller A, whereas 3 and 4, request 4 and 1 block from C. If blocks available with seller are equal to blocks demanded from it, then blocks are distributed among the consumers. In case of insufficient blocks, seller will allocate blocks to highest bidder: Seller C receives higher bid from 4, so it is given priority in allocation. In case bids are same, then seller prefers nearest consumer: A prefers 1 over 2 as 1 is nearer to A. After the first round, list of prospective buyer for a given seller's block is shown by name of that consumer on that block, where the prospective seller who from a given block is to be purchased is represented by seller's name on it (round 2 in Fig. 1a). As blocks of consumers 2 and 3 remain unmatched during first round, they again bid for energy in the second round. In this round, A receives higher bid from 3, and it matches its blocks to 3. Consumer 1 and 2 submit their bid to next seller (B) in their priority list. The blocks of all the consumers get matched in round 4, and the matching algorithm terminates.

2) Number of blocks to be sold is greater than blocks demanded: 10 blocks are available with seller and 8 blocks are requested by consumer (Fig. 1b). The process of matching is similar to process discussed above. The algorithm terminating when all the blocks of consumers get matched; but in this scenario there will be some unmatched blocks of sellers.

3) Number of blocks to be sold is less than blocks demanded: Sellers have 6 energy blocks, and consumers request 9 blocks (Fig. 1c). Initially, the same process repeats, as in the earlier cases. After the second round, all the blocks of consumers 3 and 4 get matched, whereas some blocks of 1 and 2 remain unmatched. During the subsequent rounds, unmatched consumers bid for the energy form the remaining sellers in their priority list. After the fourth round, the algorithm terminates because 1 and 2 have exhausted all their matching options. The matching completes with some of the blocks with consumers remaining unmatched

IV. How to perform matching

In this section we propose energy matching (EM) algorithm that stably matches sellers with buyers based on their preference list. A consumer is matched implies that its demand has been completely satisfied: All the energy blocks required have been matched with the blocks available with seller. A consumer is unmatched, if it contains one block that is not matched with seller. Initially only consumers know about their priority list $>_{\mathcal{C}}$, and seller does not know about its priority list. In Algorithm 1, a seller does not explicitly maintains its priority list. A seller s_i directly updates its mapping list $\mu(s_i)$ based on the bids received by the consumers. This algorithm is run each time buyers and sellers need to form groups among each other.

The group formation or energy matching starts by sellers propagating information across the network that they want to sell energy. A seller informs DSO, its nearest neighbors, and frequent consumers that it will act as seller. As sellers are reluctant to disclose their trading information, they do not disclose the amount of energy available with them. The consumers, download list of sellers from DSO and nearest neighbors and consolidate these list to construct a preference list of sellers $>_{\mathcal{C}}$. Thereafter, they start bidding for energy to different sellers at the beginning of every round of Algorithm 1. The round is a time-period during which consumers submit its bid to a single seller, and sellers allocate their resources to one or more consumers on the basis of their priority list. The

Algorithm 1 Energy Matching (EM) Algorithm for Grouping Consumers with Sellers

Input: Consumer's preference list $>_{\mathcal{C}}=\{c_1,\cdots,c_M\}$, energy blocks demanded by consumer $\mathcal{B}=\{b_{c_1},\cdots,b_{c_M}\}$, and energy blocks available with sellers $\mathcal{D}=\{d_{s_1},\cdots,d_{s_N}\}$.
Initialization: $\forall c_i\in\mathcal{C}$, latest service provider $L_{c_i}=\phi$, matched energy blocks $e^{\mathrm{mtc}}_{c_i}=0$, unmatched energy blocks $e^{\mathrm{umtc}}_{c_i}=b_{c_i}$, and unprocessed list $\mathcal{P}_{c_i}= \ >_{c_i}$, where $>_{c_i}\in>_{\mathcal{C}}$.
$\forall s_i\in\mathcal{S}$, current requester list $\mathcal{R}_{s_i}=\phi$.
$\forall c_i\in\mathcal{C}$, c_i sets every element of the allocated list $\mathcal{A}_{c_i}$ to 0, and $\forall s_i\in\mathcal{S}$, s_i sets every element of the allocation list $\mathcal{A}_{s_i}$ to 0.
Output: Energy mapping μ.

```
while ∃ c_i who is unmatched, and P_{c_i} ≠ φ do
    for all unmatched consumers c_i with P_{c_i} ≠ φ do
        if If some seller gets removed from μ(c_i) in last iteration and it is not latest service provider then
            Add latest service provider in consumer c_i's unprocessed list, i.e., P_{c_i} = P_{c_i} ∪ {L_{c_i}}.
        end if
        s_i = the most preferred seller in P_{c_i}.
        Consumer c_i proposes to seller s_i for e^{umtc}_{c_i} blocks.
        Add c_i to seller s_i's current requester list, i.e., R_{s_i} = R_{s_i} ∪ {c_i}.
        Remove s_i from consumer c_i's unprocessed list, i.e., P_{c_i} = P_{c_i} \ {s_i}.
    end for
        for all sellers s_i with R_{s_i} ≠ φ do
            Seller s_i cannot accept more than d_{s_i} requests from most preferred requester in R_{s_i} ∪ μ(s_i). It rejects other requests.
            Seller s_i updates its mapping list μ(s_i), i.e., μ(s_i) = R_{s_i} ∪ μ(s_i).
            Seller s_i updates number of blocks allocated to each requester, i.e., it updates its allocation list A_{s_i}.
            Seller s_i clears its current requester list, i.e., R_{s_i} = φ.
        end for
            Based on updated seller mapping μ(s_i), ∀s_i ∈ S, buyers update their energy mapping μ, i.e., ∀c_i ∈ C μ(c_i) are updated.
            Based on updated mapping, every consumer modifies its latest service provider, number of blocks received by different service providers, matched and unmatched energy blocks i.e., ∀c_i ∈ C, using μ(c_i), L_{c_i}, A_{c_i}, e^{mtc}_{c_i}, and e^{umtc}_{c_i} are modified.
        end while
    return μ
```

clock of sellers and consumers are synchronized with DSO to start and end the round.

In the first round consumers will submit bid to the seller with the highest priority. After receiving bids from the consumers, a seller s_i will decide its mapping list $\mu(s_i)$. The mapping list contains information about prospective consumers. Seller s_i will also update its allocation A_{s_i}, *i.e.*, number of blocks allocated to different sequesters. The number of blocks allocated to consumers requesting s_i cannot be greater than the blocks d_{s_i} available with s_i. In case, the requests received are greater than d_{s_i}, the d_{s_i} blocks are allocated among the requesters in decreasing order og the priority. After d_{s_i} blocks are mapped, the remaining requests are rejected by s_i. At the end of the round, based pn the sellers preferences, consumers determine whether or not they will be receiving blocks from the requested seller. They also come to know, how many blocks they will be receiving from the seller. If all the energy blocks required by a consumer are matched to a seller (seller promises that it will provide all the energy blocks demanded by a consumer) then this consumer will not bid in the second round, else they submit their bid to the seller which is second in the preference list. The number of blocks demanded from second seller in equal to blocks that remains unmatched. A consumer may not require to bid in current round, but it may have to bid in later round if seller which promised block, receives bid higher than the bid of c_i in future. In that case the consumer may submit its bid to next seller in preference list after s_i. Similarly, for a seller, if ti receives new bids and it has unmatched energy blocks it will directly allocate them to the requester under the constraint that total blocks allocated should not exceed block available. If a seller does not have unmatched blocks, it will check the preferences (prices) of the new consumer with consumers that have been already promised blocks. If current bidder is higher in preference list, it will be reallocated blocks of the old consumers. In this way both consumers and sellers continue to update their mapping list in every round. This algorithm continues to run until all the consumers have been matched to seller or the unmatched consumers have exhausted their preference list. After the Algorithm 1, we get stable matching pairs between consumer and sellers in the network.

The energy matching process differs depending on the supply and demand of energy blocks. There can be three different matching scenarios which are discussed as follows.

Proposition 1 (**Computational Complexity**). *The energy matching algorithm converges with computational complexity of $\mathcal{O}(MN)$, where M and N are number of sellers and consumers respectively.*

Every buyer will have list of all severing nodes. Each unmatched buyer after requesting a seller will remove it from the list. Thus each unmathced buyer

In the worse case, every buyer will request every seller once. There can be M requests generated by a buyer, and there are N buyers in the system. At max $M \times N$ requests will be generated in the system before a stable match is found. Therefore computation complexity of the algorithm is $\mathcal{O}(MN)$.

Proposition 2 (**Stability**). *Refer both the spectrum matching papers to write down the results*

V. We have to hide true identity of seller and consumer

Unmatching It may happen that some of the users may remain unmatched: Unmatched seller implies that some or all of its blocks may not get matched, i.e., remain unsold; Unmatched consumer implies that it may partially or do not receive energy blocks. Users remain unmatched because number of blocks demanded and available not equal.

The major difference between energy matching and college admission problem [4] is that while a consumer can purchase energy from more than one seller, a student cannot get admission in more than one college. This increases the overall complexity of the problem

We divide total electricity to be purchased or sold into blocks. Electricity is traded in block, such that for one transaction single block is traded. A seller or a buyer can sell more than one block to same or different buyer; similarly a buyer demand more than one block from same or different seller. Let their be N blocks to be sold and M blocks that are demanded in a network, then N may or may not be equal to M. If $N = M$, then total demand in local P2P network is equal to supply. In case of demand supply mismatch, additional requirements are met from main grid: If $N > M$, surplus electricity is sold to main grid; If $N < M$, additional electricity is purchased from it. If we include main gird in group of buyers and sellers, then number of blocks sold and demanded are equal: $N = M$.

We need to match N blocks of buyers with N block of sellers in a distributed setting. The buyer quote a tentative price at which they are ready to purchase that block, and seller

The selling price provided to seller by main gird is less than P2P trading, as main grid suffers from transmission losses. Similarly due to these losses, buyer has to purchase electricity at higher prices from main grid. If we assume that users immediately want to sell or buy energy and they are willing to sell or purchase energy in it is not available form P2P trading then net supply and demand is equal ; and we can assume number of blocks sold and demanded are equal: $N = M$.

VI. Conclusion

The conclusion goes here.

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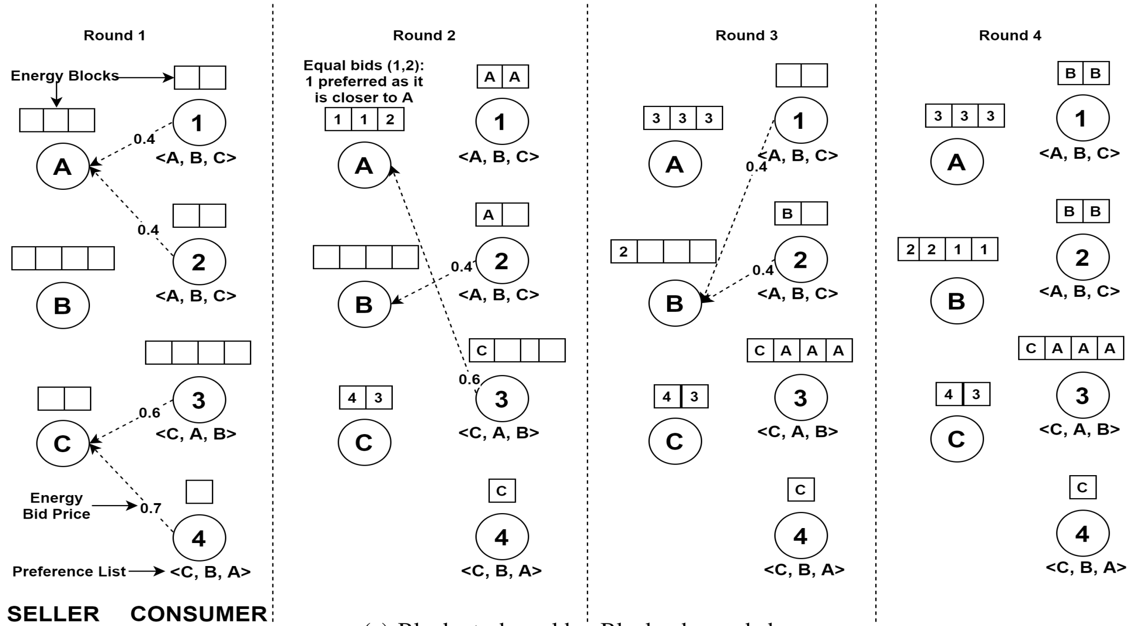
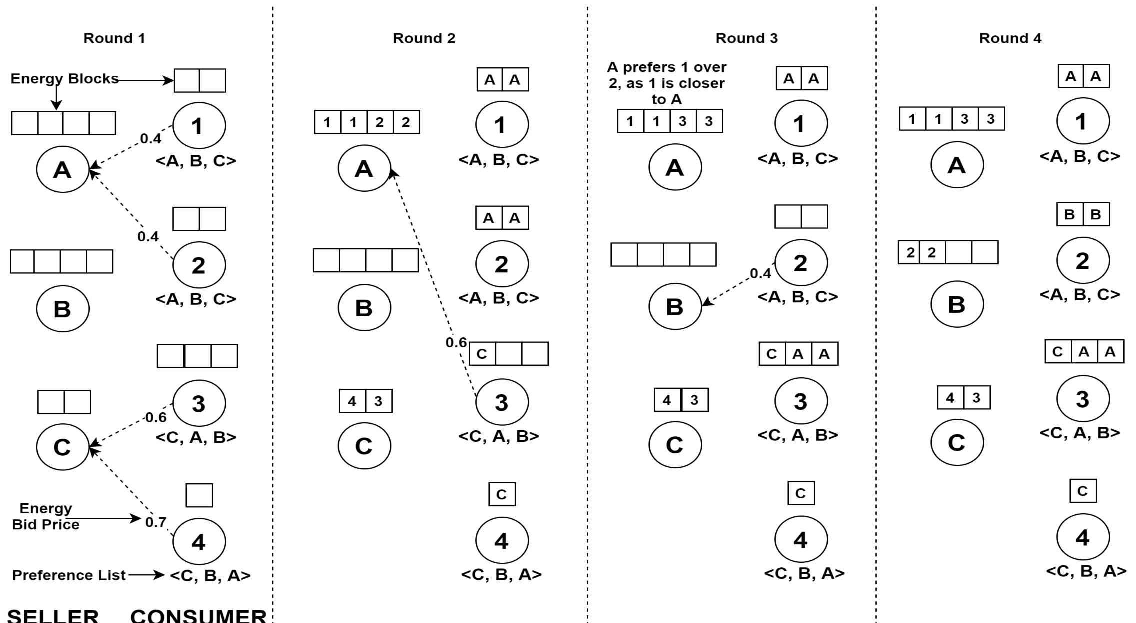
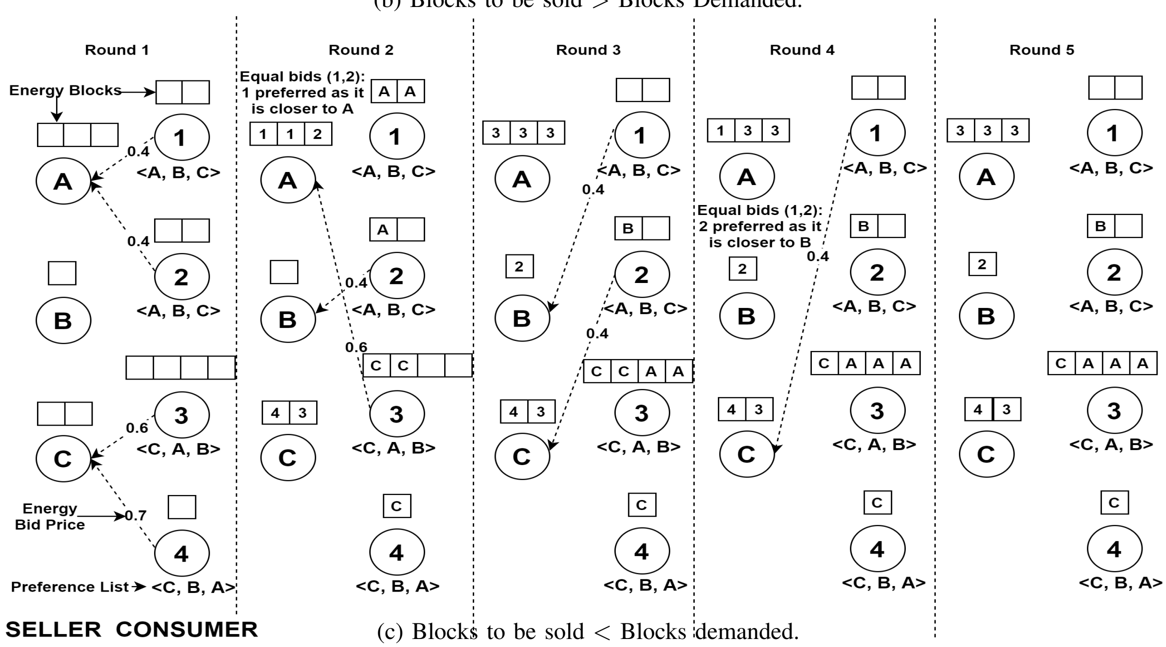


(a) Blocks to be sold = Blocks demanded.



(b) Blocks to be sold > Blocks Demanded.



(c) Blocks to be sold < Blocks demanded.

Fig. 1: Energy Matching: Matching sellers with consumers

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