Comparison of Market and Threshold based techniques for energy distribution

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***Abstract*— Energy allocation problem among distributed agents is a very common problem which is going to become a significant hurdle in the near future. With rising emphasis on using clean and free alternate energy resources, there is a need of making a smooth transition from the standard fossil fuel sources to them. However, as the alternate energy sources like sun and wind do not provide guaranteed supply, the current use of them is fairly limited. In this project, we describe a novel technique using which we can effectively strike a balance between energy used from the standard source (fossil fuels) and from the alternate source in real time. Specifically, market based and threshold based techniques are designed for the purpose. The performance of the two algorithms under different scenarios is observed, the trade-offs involved are investigated and conclusions are drawn.**

I. INTRODUCTION

The goal of the work was to determine a method by which the different distributed energy stations are able to decide either in a completely distributed manner or in a centralized manner which energy source to utilize to meet the demand. This is a very common problem observable at various scales; from distribution of energy to cities down to distribution of energy from one central battery to various sensors. There are other ways of circumventing the problem, such as storing the excess energy and using it later, but the research area is relatively new and the main focus of research is still on smaller fuel cells [4] and the traditional inverters are not scalable. Hence, it might be some time before we are able to efficiently store and reuse large amount of electrical energy. Such *fluctuations* have to be minimized as the application may penalize any interruption in supply of energy, which is true in most cases, such as continuous data capturing sensors or distribution to electricity to cities.

In this work, the problem is abstracted and simplified for ease of simulation, but still is flexible enough to model most energy distribution scenarios efficiently. Though the techniques described here concentrate on Energy-Demand scenario between alternate energy sources and fossil fuel sources, the method described is scalable and the same could be used for different allocation purposes.

II. MODELLING

The problem is modelled as a decision problem between a group of *nodes* which act as distribution stations. They have as input the *demand* which they have to meet, and the *alternate energy* which is available. The supply from the fossil fuel source is assumed to be constant, as is generally the case (for limited periods of time). At each time step, given the demand at that moment and the alternate energy available (both possibly noisy), a decision is made to either utilize some energy from the fossil fuel source or to use only the available alternate energy to meet the demand. Note that the nodes are assumed to have no information about the noise they perceive. Hence, this is a fairly simplified model, but is still able to provide reasonable results. How much can we improve over this base line performance by having more knowledge could be an interesting question which could be investigated later.

A. Assessment criteria

The assessment of performance is done on following two competing fronts:

- **Efficiency** or the fraction of nodes meeting the demand, and,
- **Cost** or the fraction of total fossil fuel energy being used.

It is easy to see that both of these are contending criterion, as to attain higher efficiency, one can utilize more fossil fuel energy, and in an attempt to keep the cost down, the node may be unable to meet its demand.

In some time critical applications, it might be necessary to maximize the efficiency while is some energy sensitive applications, it might be necessary to limit the energy used for the source maximally. Depending on these, the solution chosen may differ. Both the approaches are analysed below.

B. Environment modelling

Finally, we model the availability of the alternate energy source on the same basis as the sun's availability. The availability is an approximation of the step function, with a $1/2$ duty cycle, to model the night and day and some added noise to model cloud cover, and other unpredictable variations.

$$E_a(t) = \frac{4}{\pi}\left(\sin t + \frac{1}{3}\sin 3t + \frac{1}{5}\sin 5t + \frac{1}{7}\sin 7t\right)$$

Also, the distribution of noise is assumed to be zero mean Gaussian. Apart from this, to further simplify the model, both the fossil fuel supply and the demand for each node is assumed to be constant, though these restrictions can be easily removed.

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III. APPROACHES

In the simplified scenario, the problem is analogous to a task allocation problem [1], for which the most common approaches used are *threshold based* and *market based* [2]. Both the approaches have proved successful in particular domains and our work attempts to assess their performance at the particular task of resource distribution in an noisy environment subject to maximizing efficiency and minimizing the cost incurred. The noise in task perception and in accessing one's location corresponds to the noise in demand, and in the noise in the alternate energy perceived. Also, the assessment criterion are also in suite with the definitions used in [2], efficiency corresponds to the tasks performed, while the cost corresponds to the distance travelled by the individual agents.

However, communication between the agents is not modelled quite analogously, but the unreliable communication link between the auctioneer and the nodes loosely corresponds to limited communication range of the agents. Moreover, instead of the tasks appearing at random locations and at random times, they occur at each time step.

A. Market based approach

It is a centralized approach to solving the problem, when each node *bids* for a share in the fossil fuel's store. The bids are proportional to the energy deficit that the node has. Then there are different ways the *auctioneer* (the centralized deciding entity) can choose to distribute the energy among the bidding nodes. However, for this, we require some mode of communication among the nodes, which might be unreliable in itself.

1) Auctioneer models: There are two possible ways in which the auction can be carried out. According to the first model, the node which has the largest deficit is satisfied first, which corresponds to the maximum bidder winning the auction. However, in the evaluation criterion which we use to assess the performance, this does not give us any advantage. The other model would be to satisfy first the lowest bids, and this results in the higher efficiencies in some cases. However, a possible extension of the algorithm could be to prioritize the nodes which have a higher deficit. Hence, both the models were tested.

Advantages

- Can provide guarantees for optimality in some cases

Disadvantages

- Computationally more expensive
- Requires communication

B. Threshold based approach

In this approach, all the nodes make independent decisions depending solely on the input that they have. This approach is heavily handicapped, as it has no information about the choices made by the other nodes in the system. However, it does not require any external communication to make decisions. The stimulus is related to the energy deficit non-linearly, hence, by design, the nodes which have a larger energy deficit tend to use the fossil fuel source with a higher probability. The exact probability of choosing the fossil fuel source is:

$$P = \frac{s^n}{s^n + \theta^n}$$

Where θ is the threshold and is adaptively set every time the node fails to meet the demand. The behaviour of the probability (with $n = 10$) can be seen in figure 1.

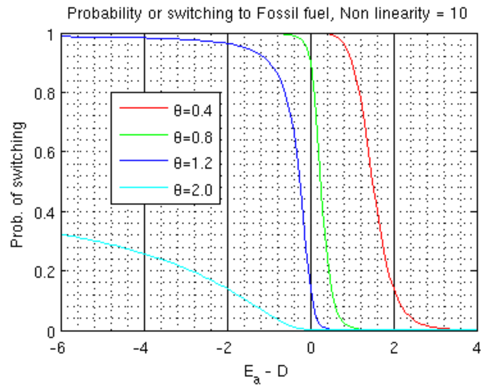


Fig. 1. Behaviour of probability with different thresholds

The threshold changes in a sample case is illustrated in the simulation section later (figure 2).

Advantages

- Robust to environmental changes
- Very quick response time
- No communication needed

Disadvantages

- No guarantees can be provided
- The performance is entirely probabilistic, hence, very bad decisions are possible

IV. IMPLEMENTATION

The entire implementation is done in MATLAB and was done with possible extensions in mind. The infrastructure can be easily extended by minimal changes in the source code and with small changes in the relevant functions.

A. Environment

The environment data structure (ENV) contains many adjustable parameters, including the following:

- *Ef0*: Total Fossil fuel energy.
- *RUNS*: Number of runs of simulation.
- *DEMAND_NOISE*: σ of noise added to demand.
- *ER_NOISE*: σ of noise added to alternate energy.
- *tmax*: Time steps in a simulation.
- *Nnodes*: Number of nodes.

There are two sub structures in ENV for market specific parameters and threshold based parameters. The important parameters are:

- *MARKET*:
  - f: Communication failing probability
  - *type*: Kind of auctioneer to invoke.

- *THRESHOLD*:
  - *NL*: Non-linearity in the stimulus.
  - *ADAPTIVE_AMT*: Adaptive change on failure.

These are the primary parameters to be tweaked to alter the results of the simulation. Besides these parameters, the per time step change in the alternate energy is done using the function *changeA* and in the demand, using *changeD* function.

Hence, the simulation can be easily altered to fit most general scenarios.

B. Results obtained

For easy and fair comparison, both the methods are run simultaneously on the same input both with and without noise and results for both are returned from the function *runEnvironment* in a *RESULTS* structure.

RESULTS structure contains many fields the important ones being the following (averaged over the runs of the simulation):

- *mean_market and mean_threshold*: Number of nodes meeting demand at each time step.
- *fossil_fuel*: Fossil fuel used at each time step.

Besides these, samples of various variables are also stored and returned.

V. SIMULATION RESULTS

Many runs were performed to find the ideal parameters for the threshold based and the market based methods ideally the task should be performed using GA or other evolutionary algorithms but owing to lack of time, we had to remain limited to testing the model by hand. Thus, we hand picked the parameters which performed the most reasonably for the market and the threshold based methods for the no noise scenario and chose to perform the tests on those. The results presented will be the output produced by the techniques for these values of the parameters.

A. Adaptive vs not adaptive threshold approach

In the presented graph (figure 2), it can be seen that as the alternate energy deteriorates, θ comes down, to favor the fossil fuel energy more, and vice versa when the alternate energy source recovers.

Upon observing the evolution of the threshold for the scenario being investigated, it is easy to observe that no constant value of θ will be able to provide the same performance as an adaptive θ in the general case. Indeed, θ ranges from $[0.8, 1.9]$ even when noiseless information is available to the nodes.

B. Individual performance adaptive threshold vs standard auctioneer

In this simulation configuration, the difference in global performance between the two approaches were not of high magnitude. The graphs in figure 3 show the performance of the algorithms for the same input.

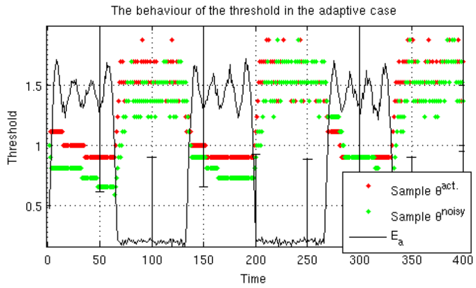


Fig. 2. Adaptive threshold

C. Individual performance adaptive threshold v/s enhanced auctioneer

Using an auctioneer that gives fossil fuel first to the lowest bidder (model 2), even with not very realistic if we compare this mechanism to the real market economy ones, improved significantly the efficiency of the market-based approach. The reason for the increase is that, when the lowest bidders get fossil energy first, the source can be divided into more pieces, allowing more nodes to meet the demand. However, this also implies that the cost might increase a little as more nodes will be satisfied.

D. Noise sensitivity assessment

In order to evaluate rigorously the influence of noise, we launched our simulations over multiple runs (10 runs) with increasing level of noise then used the average and standard deviation to assess the performances (see figure 4). The primary conclusion here is that until a noise level as big as several times the signal level itself, the market-based algorithm performs better than the threshold based one. An interesting effect is that the cost actually seems to drop for the market case as the noise increases as decreasing efficiency ensures that less fossil fuel is used as well.

Nevertheless, the global performance of both approaches decreases as the noise level get higher. In extremely noisy condition, the threshold-based approach outperforms the market one. The negative influence of noise onto the allocation of resource observed for the market approach in line with what is observed in the market economy: distortion in the real auctions value perception induces resource losses. It is also noticeable here that the actual performance drop in relation with the noise level is not as high as expected. In conclusion, both algorithms seem quite robust with an advantage for threshold based algorithms under heavy noise.

E. Communication sensitivity assessment

The Achilles heel of market-based approach is definitely it dependence on communication. The effect of communication failure was implemented as follows: the fraction of nodes for which communicating with the auctioneer might fail is set for the simulation and then, the nodes that are not able to communicate are randomly selected. This means that a node can fully communicate or not at all. In case a node cannot communicate but has enough alternate energy to meet the

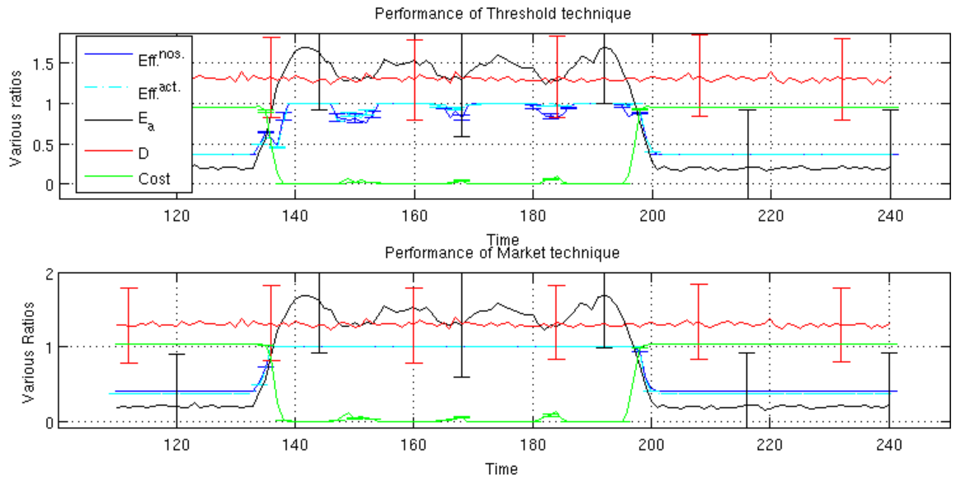
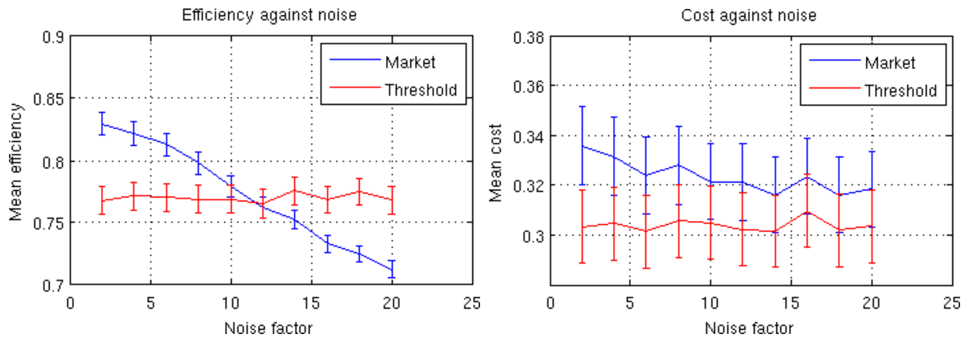


Fig. 3. Performance of the algorithms for the same input



(a) Efficiency with noise

(b) Cost with noise

Fig. 4. Performance with noise

demand, the evaluation variable is actuated as a success. It is then possible to see that the communication is of significant importance for the market-based approaches.

F. Cost of communication sensitivity assessment

As we are not dealing with real system here, assessing the communication cost is not possible in a rigorous manner. Therefore, we can only emphasize on the fact that the higher the need for fossil fuel, the higher the need of communication. This relation can be consider as an amplifying feedback that will cause large drops in performance in the case of a real system.

G. Comparing performance

To compare the performance of the algorithms with respect with the assessment criterion we had defined before. The comparison is shown in figure 5. As is expected, the performance of Market based algorithms is better with perfect communication and little noise in the perception, where the threshold based algorithm is fairly robust to noise. Hence, the performance of the market based algorithms is given with respect to the threshold based algorithm's performance.

The graph in figure 5 show the amount by which the performance of market based methods is better (or worse) than the performance of the threshold based algorithms and the standard deviation associated with each. The ideal test would be comparing the ratios of the cost and the efficiency of the two approaches, but unfortunately, as per our definition of *cost*, if the energy used by the threshold based method is zero, then the ratio becomes meaningless. The graph presented is comparing the performance excluding such points of data where the ratio is meaning less. However, we can compare the two algorithms by taking the signed difference in the respective values of the cost and then normalizing that value. In both cases, the efficiency being an dimensionless ratio, is easy to compare.

The graph on close observation reveals many interesting results.

- **Configuration 1:** With noisy data and full communication, the market performs better, in terms of efficiency, but also used more resources. An interesting fact (on the difference index graph) is that while the efficiency of market based strategy varies from the better than threshold to worse, the cost of using market based strategies here is almost always greater than the threshold based strategy, giving us an insight in the trade-offs involved.
- **Configuration 2:** With noisy data and bad communication, the cost involved (on the difference graph) is much

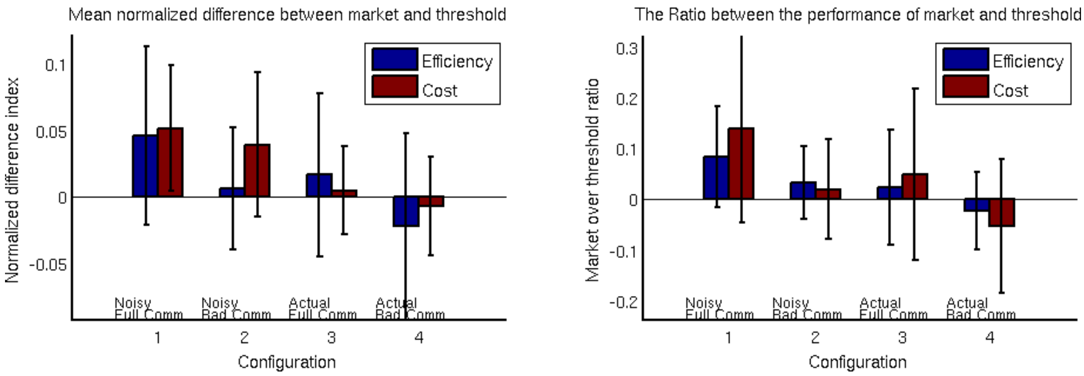


Fig. 5. Comparing the performance of Market with respect to the threshold based algorithms

more than the compared increase in efficiency. On the ratio graph, however, the situation is reversed, because we had to remove many data points where *cost* incurred by the threshold based strategy was zero. Hence, the ratio comparison is not conclusive in this case.

- **Configuration 3:** With no noise data with full communication, the market is able to out-perform the threshold based strategy (on the difference graph). The ratio graph, however, presents an interesting observation because we are assured of the optimality of the market based algorithms. Whenever the threshold by using based strategy operates as zero cost, so does the market based strategy. Hence, the increase in the efficiency requires a large corresponding increase in cost, illustrating another important point in the trade-off.
- **Configuration 4:** With noise and bad communication, the market based strategy performs worse than the threshold based strategy, as expected.

H. Performance vs Scalability

While not testing the explicitly the this aspect in our simulation, the scalability of the method must be taken into account for comparison purposes. Indeed there is a major difference between the two algorithms. As the number of nodes grows, the computational power required for the auctioneer increase in a proportional manner. This means that when $ENV.Nnodes$ tends towards infinity, computational power required for the auctioneer to operate will also tends toward infinity. This emphasize advantages of threshold approach for systems with very high number of nodes: the computational cost remains the same as it is fully distributed.

VI. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

The conclusions here from the results are in line with the earlier conclusions that the market based algorithms perform better with reliable communication and perfect information. However, as soon as we introduce limited communication abilities, and noise in the environment, the performance of the market based algorithms suffers significantly, while the threshold based method continues to perform well. An interesting trade-off is observed between efficiency and cost and analysis reveals that it is difficult to decide upon the which of the methods is better without modelling the situation in detail and determining the characteristics of the desired solution.

B. Future Works

The current implementation is fairly open to extension in almost every possible way. Hence, it would be interesting to remove some of the assumptions that we had and make the system more general. An interesting idea would be to provide the threshold based mechanism a small battery in which it could store some energy, but not for long period of times. This would provide limited backup for some period of time while the threshold is adapted to the new deficit. This could significantly improve the efficiency of the threshold based methods.

Also, this can also be viewed as a multi objective optimization problem and investigations (using NSGA or other) to find the Pareto-optimal front can be conducted to see what is the nature of trade off between the efficiency and the cost. This might give us interesting insights into the guarantees which the systems can provide.

VII. ACKNOWLEDGMENTS

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