

# Lightweight Economic Models for Resource Sharing in Wireless Networks

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## Introduction

Wireless sensor networks are becoming increasingly widespread in various contexts. For example, sensor nodes have been deployed on wildlife for tracking purposes [4], and could be used on vehicles for exchange of traffic information [8]. The nature of sensor networks introduces several challenges, including limited battery life, frequent network disconnections, and limited resources. Similar issues arise in peer-to-peer (P2P) networks where users join the network, request resources, use them and then leave. In this case, we are not pressed by the energy-efficiency problem, but we still have to consider the instability of the network in terms of dis- and reappearing peers. The ultimate goal in both sensor networks and P2P network is the efficient use of resources and transmission of data.

The problem we address is that of managing resources in a sensor network. Similar work has been done on P2P systems in [7]. In their work Turner and Ross point out that nodes often do not have an incentive to participate in resource sharing. Therefore they propose an economic market as a possible motivation; in this market nodes can offer and request resources in exchange for some monetary value. We take this idea and adapt it to the sensor network context. In our model there is a universal payment currency and each node receives the same initial budget. Sensor nodes request resources without specifying the ◆seller◆ they would like to buy it from. In a moderately dense network, on many occasions several potential sellers are available to serve the same request. Consequently, the main focus of this work is the design and implementation of algorithms for optimal decision between sellers.

Overall, the contributions of this work are the following:

- ◆ We built a software simulator, Atrium, which mimics the interactions between nodes in a wireless network. Atrium allows for the evaluation of node and system behavior.
- ◆ We proposed and implemented two algorithms for decision -making when a client node requests services from a seller node.
- ◆ We investigate both stationary and mobile sensor networks, and we take advantage of real mobility data gathered by the ZebraNet project [4].
- ◆ We achieved an average improvement of 10% over the baseline case in terms of percentage of completed requests in the system.

The remainder of this paper is organized as follows. Section 2 discusses some related work. Section 3 presents the software implementation of the Atrium simulator. Section 4 presents the baseline and newly proposed decision algorithms. Section 5 presents our experimental results. Finally, Section 6 presents our conclusions and future work.

## Related Work

Several projects have suggested the usage of economic models for resource sharing in both sensor and P2P networks [8] [7] [2] [6]. One of the main benefits of setting up a market economy is that it provides us with a decentralized control of resources [3]. This is of key significance in wireless networks since it is more efficient and appropriate than the centralized model.

Most works in the area agree on the basics of such economic models: the existence of currency and budget allocation, as well as a pricing scheme. The work in [7] introduces the lightweight currency paradigm in which

exchange of fake money is in the core of the network economy. In [7] peers are allowed to have their own virtual currencies but it is not clear what the advantage to that is. Therefore, we prefer to use the simpler scenario where the entire system has a single currency.

In different scenarios, a resource can be shared either on individual bases or as part of a combined resource need. For example, [2] proposes a model in which nodes pay for a combination of resources, needed for the completion of a single task. Currently our system only considers the case when one specific resource is requested, but we plan to add the option of having combinational request in future work.

In terms of pricing, different projects take various approaches. In [1] and [3] resource prices depend on supply and demand. Therefore nodes gather information about the popularity of a resource and its availability in the system. Then a decision is made on how much the given resource costs. In [8], since the resource in question is information that the seller possesses, the price is determined based on relevance to the potential buyer. In [2] the auctioning model is used and potential client nodes determine their bids based on how important their request is. One common concern missing in all these models is that of energy. In our work we propose a pricing scheme that adjusts the resource price based on how much energy the seller has. Intuitively, it is reasonable that a sensor that has little energy left will demand a higher price for its services compared to a node which has battery to spare. This pricing scheme causes the system to have a more balanced usage of nodes and prevents the fast energy failure of nodes. A similar concept is proposed in [5] where the price of a service need is directly related to its energy cost.

As mentioned above, [1] and [2] discuss auction schemes as a way for a seller to choose between buyers. What these works as well as [8] and [7] do not address is how one client node can pick between different sellers. It is entirely possible that the same type of resource is offered by several neighbors and the buyer has to make a choice. In our work we consider the case of multiple sellers and propose several decision-making schemes.

## Implementation

Atrium is a software simulator implemented in Java. It creates a distributed network of nodes, where the size of the network and the number of nodes are configurable. Each node in the simulated system owns one type of resource, say a radio transmitter. In addition each node begins the experiment with a budget allocation of 100, full battery, and a rating of 10. Atrium events are triggered by a trace file and so is mobility. The events that are currently supported are movement of node, request for resource, battery charge, node rating calculation, and node resource failure. The simulator processes the list of events, updating node attributes and keeping statistics about the network's performance.

In order to take into account the energy-constrained environment of wireless sensor networks, we devise a scheme in which resource prices are adjusted based on energy. When the nodes in the network start running low energy, they become more valuable and pricing reflects that.

To reward nodes that are reliable and actively service requests, and to punish nodes that often fail, we have developed an e-bay style rating system. Nodes are judged on the number of accepted and the number of successfully completed resource requests.

Overall, pricing and rating the two important aspects of Atrium which allow us to devise

## Decision Algorithms

Since the main question we want to answer with this project is, *What would be a good way to decide between several potential seller nodes offering the same resource?* we propose two different decision schemes. Using Atrium we were able to test the two algorithms and compare them to a baseline one. We conduct separate experiments for stationary and mobile sensor networks. Below we describe the three decision schemes.

### *Baseline Algorithm*

In the baseline algorithm, a client node that is requesting resources always chooses the seller node with the lowest ID. This ensures that the decision scheme is completely oblivious to any characteristics that might differentiate potential sellers. An alternative scheme that might be used as a baseline is random choice of seller.

## Price-Only Algorithm

Exploring the economic idea that cheap goods will allow for greater purchasing power, we devised an algorithm in which nodes always pick the resource seller with the lowest price. Intuitively this is a reasonable choice because spending less money on each transaction in the system will allow nodes to complete a greater number of transactions. We predict that such an algorithm will perform very well in systems where cheap nodes have high availability. Unfortunately, the likelihood of operating in such a network is low, since quality usually comes at a greater price. A network where low-priced nodes have high rates of failure will cause the price-only algorithm to perform badly.

❖ Judging from real life economic models, we would expect networks of nodes where quality comes at a higher cost. For this reason we propose a scheme that takes into account not only the price of a resource but also the quality rating of the seller offering the resource.

## Price/Rating Algorithm

In this algorithm we consider both the resource price and the overall rating of the seller node. The intuition behind this is that a rich node is willing to pay more for quality service. Therefore as a node's budget changes we assign different weights for the price and rating components. ❖ As the wealth of a client node increases, the importance of price decreases. On the other hand, if a node is running low on currency, then it is willing to sacrifice quality of transaction and pay an affordable price.

## Results and Observations

This section presents our experimental results. We compare the baseline, price-only, and price/rating schemes in both the stationary and mobile network domains. For the latter we use two mobility models: Manhattan, which produces simulated mobility traces, and ZebraNet, which produces pseudo-simulated data based on real mobility traces. Below we show the performance of both. The main metric in our experiments is the percentage of resource requests completed by the system.

In a stationary wireless network, applying a non-baseline algorithm for selection of resource sellers improves the performance dramatically. (Figure 1) In many cases the system successfully completes 20% more resource requests compared to the baseline decision scheme. Therefore, the adaptive decision making (both price-only and price/rating schemes) allows for efficient and balanced resource usage.

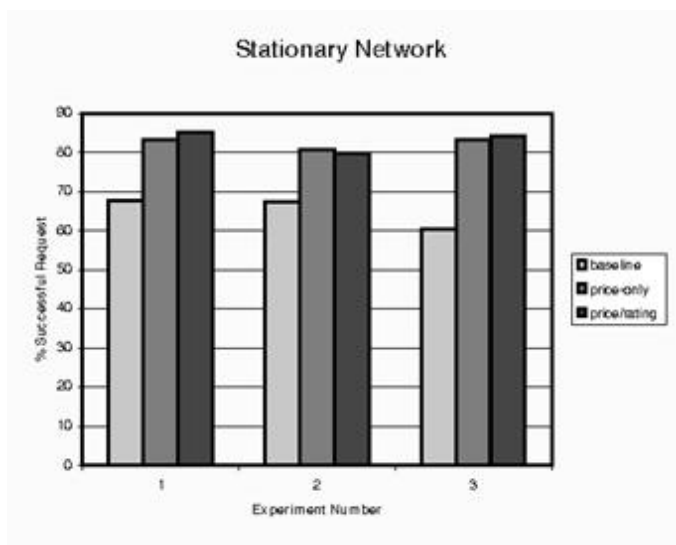


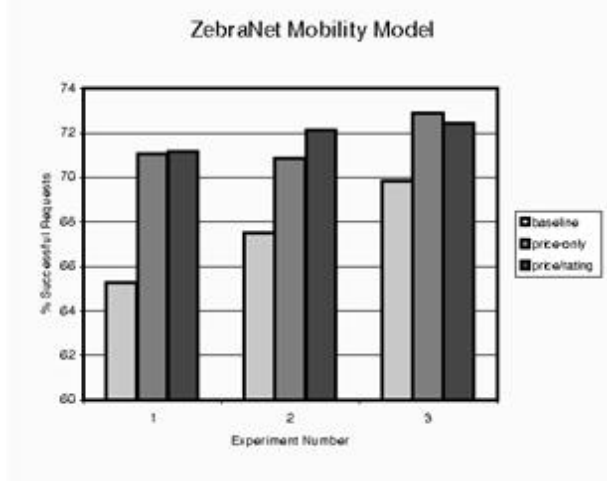
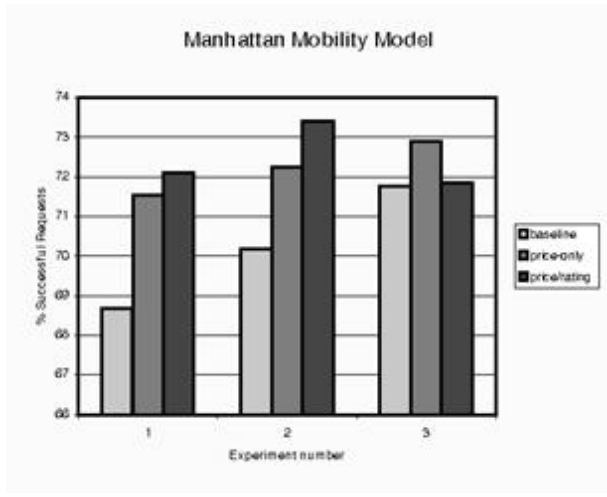
Figure 1

In both versions of the mobile wireless network (Figures 2 and 3), the baseline algorithm underperforms compared to its more intelligent counterparts. But the difference is small compared to the stationary case. The

difference between baseline and intelligent algorithms is not as drastic for several reasons:

- \* mobility helps the baseline algorithm by shuffling nodes around
- \* mobility often causes clients to be in range of fewer potential sellers
- \* mobility breaks communication between cooperating nodes

For stationary wireless sensor network, employing a scheme for selecting sellers increases the overall ability of the network to share its limited resources. When movement is added to the equation, behavior of nodes is more unpredictable and therefore there are more factors to be considered. We believe that more refined price formation models are needed in order for the price-only and price/rating schemes to be differentiated.



Figure



Figure 3

One discovery that we made during the run of our experiments is that adding a simple seller cache decreases the energy overhead for the system. We let nodes in the network to keep track of the last three successful client-seller transactions; then, when a new resource is requested, the client node first attempts to negotiate with sellers it has used before. If that fails, the client node would go through the normal process of querying neighbors and choosing the best seller, but if it succeeds when using the cache, then some overhead energy is saved. Figure 4 below represents our cache results.

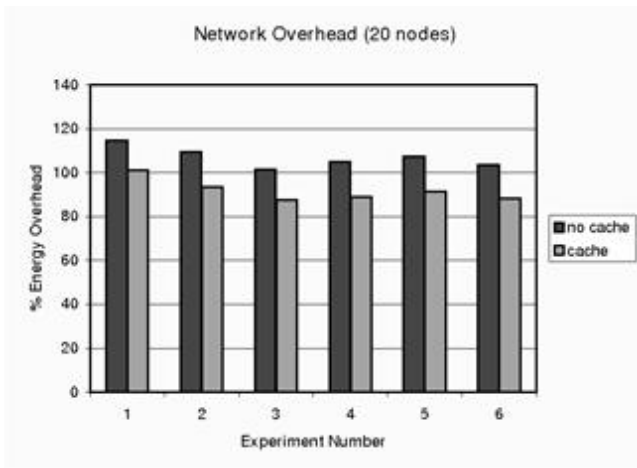


Figure 4

## Conclusion

This paper has presented the implementation of Atrium, a software simulator used to investigate resource sharing algorithms. We have also introduced two schemes for choosing between sellers offering the same resource. We have showed that a careful consideration of both node's quality and price performs better than a baseline scheme. In the work leading to our final results we also developed an e-bay style node rating scheme, as well as a cache system for decreasing energy usage.

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