Design and Experimental Evaluation of Market Mechanisms for Participatory Sensing Environments

(Extended Abstract)

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ABSTRACT

Participatory Sensing concerns the sharing of sensor information within user communities, forming a body of knowledge that can be beneficial to the community itself, either directly or through specialized applications. We introduce a framework for a marketplace where such applications can sell and buy sensor information. We focus on the buyers' side and we use various ideas from the cost-sharing literature, to propose three classes of mechanisms. We evaluate them experimentally, comparing their performance according to metrics such as social efficiency, cost coverage and budget deficit, as well as metrics related to encouraging participation.

Categories and Subject Descriptors

K.6.0 [**Management of Computing and Information Systems**]: General—*Economics*

General Terms

Economics, Experimentation

Keywords

Participatory sensing, Mechanism Design, Cost-sharing

1. INTRODUCTION

Personal mobile computing is undergoing a major revolution and has significantly changed the way humans interact. People have already started participating in sensing, instrumenting and analyzing aspects of their lives, eventually becoming consumers and producers of data. These developments are creating a compelling need for new mechanisms to support such a participatory community-sensing environment, where users, business actors and applications dynamically interact and share sensor information.

Current work on participatory sensing systems mainly focuses on solving the technical challenges of the physical environment. However, what has been undermined is the fundamental economic issue of why should users share or exchange such information that is costly to them and what is the necessary technology that can facilitate this aspect.

2. OUR MODEL FOR THE SENSOR MARKET

We view as our main contribution the design of the market model itself. The framework for the marketplace, is one of the first attempts to define such a large-scale sensor market. Our model consists of the following features:

- **The sensor goods:** A set $I = \{1, ..., k\}$, representing the different sensor *basic types*, e.g., GPS, temperature, CO_2, etc. We consider the case where 'buying' a sensor consists of buying the right to have access to the sensor information for a given time slot. The information provided by a sensor can be thought of as a "digital good" that can be simultaneously bought by more than one buyers.
- **The supply side:** A set $M = \{1, ..., m\}$ of suppliers, the owners of sensor data. Each supplier can specify the minimum price he is willing to charge for a particular sensor in order to supply its sensing information. We assume that the supplier sells the rights for accessing his sensors to some intermediary, in our case, the market operator.
- **The demand side:** A set $N = \{1, ..., n\}$ of potential buyers. These are agents who have a demand for some sensor data. Different types of demand (e.g., elastic vs inelastic, or single tuple vs multiple tuples) can be examined.

Mechanisms used: The main focus of our experimental evaluations is on two important criteria, namely *i) Budget balance*, which means that for every instance, the payments assigned to the customers cover exactly the cost of the provider, and *ii) Social Welfare*

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(SW) maximization. The *SW*, is defined as the sum of all involved agents' net benefits and hence equals to the sum of their utilities minus the cost of serving them. Within this framework, we focus mostly on the buyers' side proposing three classes of mechanisms, satisfying different properties each:

1. Mechanisms that achieve budget balance. For this we adapt ideas from the work of Moulin and Shenker (MS) [1], into our setting. The trade-off with these mechanisms is that they tend to produce suboptimal SW.
2. Cooperative mechanisms that maintain budget balance and aim towards achieving higher SW, by having 'richer' agents subsidize other agents who cannot afford their cost-share. The incentive behind such a move is that it increases the demand in the system and hence it may lead to a reduction of the average cost of sensor access. Such altruistic behavior even by a small set of agents can be important for enhancing participation, increasing the SW of the market and its long-term sustainability. For this, we adapt the MS mechanisms, assigning to them 'altruistic' characteristics.
3. Mechanisms that achieve optimal welfare. For this we apply the well-known Marginal Cost (MC) mechanism [1]. It is known that such mechanisms cannot balance the budget and we will therefore evaluate MC in terms of its budget deficit. We also use heuristics to approximate the optimal welfare, in settings where the problem is computationally intractable.

3. EXPERIMENTS

3.1 Setup - Data generation

So far, we have studied two simple orthogonal scenarios regarding the demand of the customers. In both scenarios, the market operates in discrete time.

- **Scenario 1: Inelastic demand** We consider a basic scenario of inelastic demand, in which each buyer $j \in N$ is interested in a subset $S(j) \subset I$ of sensor types, and requests access to a single tuple of sensors from $S(j)$. As an example, he may request a tuple of the form (speed, accelerometer).

- **Scenario 2: Elastic demand** All bidders now have the same type of demand, i.e., they ask for the same type of tuple, and they are still inelastic as in Scenario 1, regarding the type of tuple. However, now each buyer j also specifies a maximum number, m_j, of tuples that he is interested in acquiring. The demand m_j is elastic in the sense that buyer j does not mind receiving a number of tuples less than m_j. Along with the parameter m_j, each customer also specifies his willingness to pay for each tuple, by a vector of marginal utilities.

All the implementations were carried out in Matlab. To test the mechanisms we produced numerous instances using various distributions on certain parameters. The number of buyers in our simulations ranged from 5 to 300. A typical range that we used for the number of basic sensor types, i.e., for $|I|$, was the set $\{5, ..., 10\}$, reflecting the typical number of sensors available in current devices. We generated 3 families of instances regarding the utilities. In the first one, utilities were uniformly distributed. In the second, and third, we had a biased separation between "poor" and "rich" buyers. The second family contained $p = 70\%$-80% poor buyers and the rest were rich; we had the exact opposite separation for the third family. Note also that the first family corresponds to an even mix of poor and rich buyers with $p = 50\%$. Finally, the prices of the suppliers for each of their sensors were produced from the uniform distribution in $[0, R_{max}]$, where R_{max} is the max. price a supplier could ask for each sensor. In order to relate the prices of the suppliers to the buyers' willingness to pay, and their demand, we employed a parameter α (and associated equation to derive it), which we call the *economy factor*. This was used in determining the maximum price asked by the suppliers.

3.2 Results

1. Market satisfaction ratio. Defined as the percentage of customers that are offered service. The main conclusion is that the altruistic and the MC mechanism achieve quite high satisfaction ratios. This is not so much the case for the MS based mechanisms. Thus, despite their nice theoretical properties, the MS based mechanisms may fail to ultimately promote participation.

2. Budget deficit of the MC mechanism. Here we investigated the percentage of the cost that MC manages to cover for various simulation runs and values for the economy factor α. Our results reveal that the MC mechanism covers on the average a small percentage of the actual cost, and thus it is not appropriate to use it. In order to have a better variant of the MC mechanism, one would need to impose some additional flat fee to the buyers. We leave the exploration of such ideas for future work.

3. Welfare performance of the MS-based and the altruistic mechanisms. In Figure 1, we can see that the altruistic mechanism significantly outperforms the pure MS-based mechanisms (denoted as $M(\xi)$ in the figure, as it is based on the egalitarian cost-sharing method ξ). In fact, it is important to note that the altruistic mechanism attains in many cases the optimal social welfare. Same conclusions apply to Scenario 2.

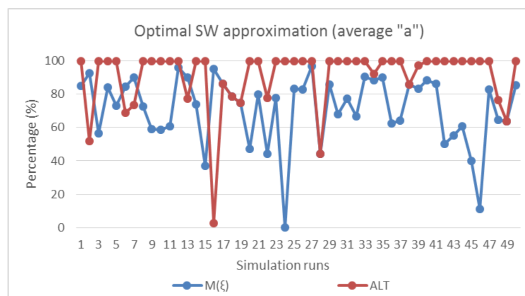

Figure 1: Approximation of optimal welfare by $M(\xi)$ and ALT in Scenario 1.

4. Overall Conclusions. To summarize, the MS based mechanisms did not perform that well in terms of satisfaction ratio, while also attaining suboptimal SW. MC, which is optimal in terms of welfare, has poor cost-covering properties, which can be improved with the introduction of an additional fee. The altruistic approach seems to yield a mechanism that strikes a balance: it has good satisfaction ratio, very good approximation to the optimal welfare, and it is budget-balanced. The downside is that the amount of subsidization required by a rich agent might be too high in some cases, at least in the early stages of such a market before participation raises. We believe that milder forms of subsidization (e.g., thresholds on the maximum imposed subsidy, or using only a small percentage of agents as potential subsidizers, even on a voluntary basis) can be promising and are worth further investigation.

4. REFERENCES

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