Sensing Data Market

Chun Tung Chou[1], Nirupama Bulusu[2], Salil Kanhere[1]
1 University of New South Wales, Sydney, Australia
2 Portland State University, USA
ctchou, salilk@cse.unsw.edu.au, nbulusu@cs.pdx.edu

Abstract
This paper proposes the *Sensing Data Market* (SenseMart). It leverages the existing sensing and communication infrastructure for a low capital investment cost. The goal of SenseMart is to facilitate and provide incentives for the *exchange* of sensing data among users (as in a marketplace) and can be seen as the "BitTorrent" of sensing data.

1. Introduction
Wireless sensor networks (WSNs) [2] [3] --- have been labeled as a disruptive technology by many technology analysts. A common assumption in WSN research is the deployment of *dedicated* WSNs, requiring capital investment of sensing and communication infrastructure. Recently, an new paradigm has emerged for WSNs wherein the key idea is to leverage the existing communication infrastructure [13]. The driver of this new paradigm is the near ubiquity of mobile phones in many countries. The cameras and microphones on mobile phones can be used as video and acoustic sensors. Projects proposed in this area include Participatory Sensing [4], MetroSense [5] and CarTel [14].

This paper proposes the *Sensing Data Market* (SenseMart). Similar to Participatory Sensing, SenseMart leverages the existing sensing and communication infrastructure. Its unique defining characteristic is that users are encouraged to share their sensing data with each other to accomplish a high level task. SenseMart facilitates the *exchange* (as in a marketplace) of sensing data and can be viewed as its "BitTorrent". The idea is to provide incentives to users proportionate to their contributions to encourage data sharing, and monitor user contributions to maintain data quality and integrity. We believe that SenseMart can revolutionize the landscape of Internet-based sensor data sharing.

2. Motivating Applications
The Internet and wireless communications have made information-on-demand a reality. The aim of SenseMart is to provide useful real-time sensing data to the community via peer-to-peer communication. Two applications motivating and enabled by SenseMart are:

Application 1: Real-time road traffic flow information distribution.
On-board car electronics such as the GPS navigator and other on-board sensors (the existing sensing infrastructure in this case) can readily compute the local traffic condition, e.g., the average speed and direction, vehicular density in the neighborhood. This local traffic information can be distributed to other road users using the existing communication infrastructure, e.g. mobile phone networks, WiFi, the Internet, or possibly

inter-vehicular communication networks [15] in the future (see Cartel [14]). SenseMart can facilitate exchange of such real-time information, leading to better route decisions.

Application 2: Collaborative radio sensing for cognitive radio application.
Allocating radio spectrum by governing authorities has resulted in a very low utilization of radio spectrum, (in fact, less than 20% [9]). *Cognitive radio* [10] enables a wireless node to change particular transmission or reception parameters based on observations of various environmental factors such as the radio spectrum, user behavior and network state. It has been shown that[11] that a simple energy detector cannot guarantee accurate detection of signal presence and more sophisticated spectrum sensing techniques are required. Spectrum sensing information must be exchanged between neighboring nodes regularly. SenseMart is an ideal candidate for such collaborative spectrum sensing tasks. Nodes in the vicinity of the transmitter and receiver can cooperatively sense parts of the complete radio spectrum and report their readings to the communicating nodes. This will allow the nodes to judiciously pick a suitable frequency band with the least interference.

3. Architecture and research challenges

The above sample applications showcase the features of the SenseMart framework. With the rapid development of communication technologies, we believe that bandwidth will be plentiful in the future for mobile users and reliable real-time delivery of streaming data to mobile users, as in SenseMart, will no longer be a technical barrier. With this assumption, SenseMart is effectively a peer-to-peer network whose goal is to deliver real-time data collected by sensors (the data producers) to the users who are interested in the data (the data consumers). Compared to peer-to-peer file sharing, the problem of peer-to-peer real-time sensory data sharing has a number of new features:

- *Real-time streaming data:* The data consumers must be able to locate and download their desired data producers within a time-limit since the utility of real-time data diminishes with time.
- *Dynamic consumer-producer relationship:* Consider the traffic information application as an example. A data consumer may need the data from different data producers at different part of his journey. This dynamic imposes constraint on the delivery of data and how the producers can be matched to consumers.
- *Heterogeneity and time-dependence in benefits:* Sensory information that is of benefit to one person at a given time may not be of equal benefit to someone else, e.g. the traffic information at one location may not be relevant to other users.
- *Critical number of data producers:* A user may only derive reasonable benefit if a critical or minimal number of users contribute sensory data, e.g. a user in the traffic information application will want to know the traffic information on all the possible routes that he will take to reach his destination.
- *Quality of information (QoI):* A user, besides deciding whether to contribute data or not, can also choose to contribute data of varying quality. The user can choose to sample at different rates and resolution. Another dimension that QoI manifests itself is due to real-time sensory data whose utility diminishes over time.
- *Legality of data:* This addresses the questions: Is the data genuine or fake? Can the data be trusted? How can we know that the data has been sampled at the given location at the given time?

3.1 Architecture

The system architecture for SenseMart must take into consideration the above new features. In a centralized (or hierarchical) architecture, a central data server (or data servers) is used to collect all user contributed data and disseminate the raw or aggregate spatio-temporal data to the users. In addition to collecting and distributing data, the data servers need to ensure the legality of the contributed data so that other receivers trust the received data. Another function of the servers is to ensure that the Quality of Information is maintained. To encourage data sharing, the servers will also need to calculate incentives to reward data producers depending on the utility of their contribution.

Whether a SenseMart application should use the hierarchical or distributed architecture depends strongly on the application requirements. For the traffic application, we expect that the hierarchical architecture will be easier to implement due to the potentially large number of users, constantly changing requirements of data consumers for traffic information, mobility of users etc. However, for the collaborative radio sensing application, a distributed SenseMart is ideal since only local communications are needed.

3.2 Research Challenges

Incentives: Since SenseMart relies on users contributing sensing data to be shared among the users, a very important issue is that there must be an incentive to share. Otherwise, it is well known from the "Tragedy of the Commons" [8] that most users will tend to be free-riders rather than contributors. The free-rider problem has been empirically observed in file-sharing in the Guntella peer-to-peer networks where it was found that 25% of users share no files at all [1]. The incentives can be barter-linked, i.e. data in exchange for data, or monetary. The literature on incentive-based mechanisms in peer-to-peer networks is immense [7]. These include making the file sharing an *excludable* good and reward those users who contribute more files. However, the SenseMart incentive problem has a number of features not present in peer-to-peer file sharing.

In SenseMart, the utility derived from the contributed data depends on the temporal-spatial contributor distribution. How can incentive schemes be designed to ensure both sufficient user contribution and that the aggregate data collected from the network is of high user utility? The analysis of the existence and properties of Nash equilibrium will be challenging due to the scale and heterogeneity of user preferences and requirements.

In contrast to the peer-to-peer file sharing systems, a user in SenseMart can decide on the quality of the data to be contributed in addition to deciding whether to contribute data or not. This gives rise to the following important research questions: How can we quantify the quality of sensing data? How can an incentive mechanism be designed such that the users are motivated to share high quality sensing data? Would it be possible to exploit mechanism design to encourage users to "reveal" high quality sensing data? How can the incentive mechanism take into account the heterogeneous requirement of different users? How can the incentive mechanism take the time-sensitive nature of the data into account?

Quality of Information (QoI): Assuming that the incentive problem can be solved and users are happy to contribute high quality data, it will be important for SenseMart to maintain a good QoI. Since SenseMart relies on user contribution, we will not be able to ensure that all the locations of interest are covered. For example, in the traffic flow application, it may not be possible to obtain an accurate measure of traffic flow rates on a desolate road. Instead of missing or insufficient data, SenseMart may also face the problem of redundant data. Some relevant questions are: How do we deal with missing, sparse or insufficient data at locations of interest? How do we adjust and negotiate data sampling rates with individual data producers in response to users entering and leaving the network? How can the data server efficiently balance the quality of information and communication resources needed to transmit high quality data?

4. Conclusion

We have proposed *SenseMart* to facilitate peer-to-peer sharing of sensor data among people. The major research challenge in SenseMart is achieving a desirable Quality of Information for the application. This can potentially be realized with incentives for rewarding contributing users, and reputation rankings to maintain data integrity.

Acknowledgements ---- This research is sponsored by the Australian Research Council Discovery Grant DP0770523.

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