Building a Sensor Network of Mobile Phones

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ABSTRACT

Mobile phones have two sensors: a camera and a microphone. The widespread and ubiquitous nature of mobile phones around the world makes it attractive to build a large-scale sensor network using the phones as its sensor nodes. There are several interesting challenges in realizing such a system, such as providing efficient methods for the sensor nodes to make their data available to the network, allowing the sensor network applications to access the data from potentially disconnected and highly mobile devices, ensuring that privacy constraints are met, and allowing application developers to program the sensor network as required to build new applications. We demonstrate an initial system prototype that addresses some of these concerns.

Categories and Subject Descriptors: C.2.4 Computer Communication Networks: Distributed Systems

General Terms: Design, Experimentation

Keywords: human sensor network, shared sensors, planetary network

1. INTRODUCTION

All mobile phones have a microphone, and most have a camera. Other sensors can be connected to a phone using Bluetooth. Mobile phones are connected to a network. They have a relatively predictable power supply, based on human user initiated charging. They are present in large numbers covering a vast spatial expanse, making them suitable to be used as a large scale sensor network.

Using such mobile devices as sensors has a significant advantage over unattended wireless sensor networks in that deploying the sensing hardware and providing it with network and power is already taken care of. Secondly, mobile phones can provide coverage where static sensors are hard to deploy and maintain. No single entity may have the access rights to place sensors across the complete coverage domain required by an application, such as a combination of subway stations, public parks, and shopping malls. Thirdly, each mobile device is associated with a human user, whose assistance can sometimes be used to enhance application functionality. For instance, a human user may help by pointing the camera appropriately at the target object to be sensed.

Our goal is to enhance the utility of the existing swarm of mobile devices by presenting it as a physical sensing substrate that sensor networking applications may program for their sensing objectives. Several applications can be enabled using sensor networks of mobile phones, such as instant news coverage for an unplanned interesting event, residential area noise mapping, urban mood inference, trail condition updates after storms, dynamically updated street side imagery overlays for maps, and other enterprize applications that use the audio-visual feeds to compute metrics of interest for various business dashboards. Other works have also considered building sensor networks using mobile phones [1, 2, 3]. Sensor networks where the sensor nodes are mobile and carried by people or vehicles have also been proposed [4, 5].

IPSN'07, April 25-27, 2007, Cambridge, Massachusetts, USA.
ACM 978-1-59593-638-7/07/0004.

2. SYSTEM DESCRIPTION

We build a sensor network of mobile phones that is used as a shared system, as opposed to a system where a single application owns and uses a dedicated set of mobile devices carried by users or vehicles directly involved with that application. In the shared context, the phones are carried and used by their respective owners as they need. The sensor networking applications use the mobile devices when available. The key advantages of a shared system come from the vast coverage expanse achieved that a single dedicated system may never be able to match, and the re-use of physical resources by multiple applications. The related trade-offs are difficulty in providing performance guarantees and limitations in control of the sensor nodes.

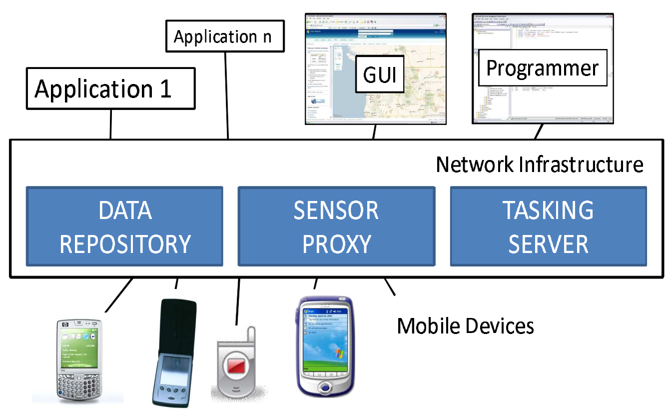

Figure 1: A shared sensor network of mobile phones.

The system (Figure 1) consists of the following key entities:

1. Sensors: mobile devices that sense the physical world
2. Network Infrastructure: In our system, this includes: a data repository that stores all the sensor data provided by the mobile devices, a tasking server that enables applications to program the sensor network as per their requirements, and a

sensor proxy that allows disconnected operation for sensors while making their data available to applications.

3. Users: the applications that access our shared sensor network, or human users who access the sensor data through a graphical user interface

We demonstrate the following aspects of this system.

2.1 Sensor Data Sharing

We have developed a data sharing framework that makes the sensor data from mobile devices available to network applications. The mobile devices may be only sporadically connected, or stay behind firewalls. A web-service standard based approach is used to allow many different types of devices use the network.

The data sharing framework uses three components. The first is a *publishing client* on the mobile phone that collects samples from the sensors on the phone, applies predefined filters to the data, buffers the data locally, and uploads the data as per network availability using a web service interface. This client runs in parallel with other applications on the phone and can be activated or deactivated as necessary. The client allows the user to configure whether data may be automatically collected or only when the user initiates a sample capture. The client also includes functionality that allows remote applications to program the phones, as described later. We have developed the client software GUI to use only the phone keypad and the small phone screen.

The second component is the *data repository* which hosts the web service to accept data samples from the phones and uses a database to index the uploaded data.

The third component is a *sensor proxy* that acts as an online representative for the mobile sensors. This proxy provides a fixed sensor URL that can be used by applications to access a specific sensor device directly. The actual sensor may remain disconnected or not host any server that can be reached from remote applications. The proxy is always available and provides the entire sensor data stream up to the most recent data upload from the sensor.

2.2 Location Based Indexing

A salient feature of the mobile phone sensor network is that each sensor node is mobile and the motion pattern cannot be easily controlled. Most applications are unlikely to be interested in the data collected by a specific device but rather need data from a specific region and time window. The device identities of the devices that contributed that data may only be of secondary importance. Thus, it is very important to index the uploaded data by location and time. This also helps applications avoid any overheads in discovering specific mobile phones, tracking their motion, or waiting for the device to be connected to the network.

In our prototype we obtain location information using:

1. **Cell-tower triangulation:** The cell-phone network typically knows the location of a phone using signal strength measurements from one or more cellular base stations. The location accuracy varies from several meters to over a mile depending on the number of base stations in range. Certain cellular operators such as Sprint in the US, and Teliasenora in Europe already allow non-operator owned applications to access this location data. Our prototype implements the functionality to obtain location from these operators.

2. **Phone GPS:** Many recently released and forthcoming mobile phones have built in GPS receivers. The GPS based location information is accurate to several meters when the phone has good GPS satellite visibility, such as under open sky. We use GPS location also in our prototype.

There are other methods to obtain location in mobile devices such as using WiFi based location for mobile devices with WiFi capability (based on triangulation or simply the location of connected access point), or using human entered keywords attached to data samples, such as a landmark name entered for an images sample.

2.3 Programming

Our system enables sensor network application developers to deploy their applications without ever deploying a physical sensor. Instead, the developers may program our shared mobile phone sensor network to carry out required sensing tasks. This is enabled using the *tasking server* that is part of the network infrastructure. We allow mobile phone users to share their sensing resources to varying degrees based on their resources and involvement in the sensor network application. We also allow the applications to program the network without knowing the identities of any specific devices in their region of interest or the device capabilities.

The tasking server presents the sensor network as a single object to the applications. Applications can call this object's methods to carry our their required sensing tasks, specifying their spatio-temporal region of interest, measurement tolerances, and delay constraints. These methods may also allow requesting human user assistance in capturing data samples to a limited extent as configured by the mobile device user. Web-service based standards are used to make this object interface available to programmers, allowing significant flexibility in terms of programming languages used by the programmers.

The tasking server internally determines the individual devices that must receive the resultant sensing commands and makes those commands available to the sensing devices as per their network connectivity. Currently, simple sampling tasks using the phone's camera and microphone are implemented. Ongoing work includes developing more sophisticated programming tasks, involving sampling, data processing, and event based responses to commands while ensuring that the mobile device remains secure and continues to serve its local user without loss of performance.

3. CONCLUSIONS

We present a first attempt towards understanding and realizing a programmable sensor network that uses the large deployed base of mobile devices as its sensing infrastructure. Several challenges need to be addressed in building such a system. Our prototype demonstrates initial design choices in addressing some of these challenges and helps reveal related issues.

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