Integrating Mobile Telephone Based Sensor Networks into the Sensor Web

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Abstract— **Leading mobile telecommunications vendors are continually looking at innovative ways to exploit their technology. Sensor networking is an application receiving much attention from these vendors, including Nokia and Siemens. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has, together with students from the University of Tasmania, developed a mobile telephone sensor network concept demonstrator that enables mobile telephone handsets to harvest observations from Bluetooth-enabled sensor devices. The harvested information is updated to a central database via an Open Geospatial Consortium (OGC) web service interface (Sensor Observation Service (SOS)). This enables the integration of sensors into an OGC Sensor Web and discriminates this from other mobile telephone sensor network applications because it is highly scalable.**

I. INTRODUCTION

There are a number of sensor web applications that focus on the scientific user for collection of their research data, and to date, the bulk of work has been focused on environmental and agricultural monitoring [1], [2]. Our application seeks to involve the general public in the collection of data that is relevant to the society through interaction with the sensor web in the same way that many of these other applications do.

Jayaraman et al., [2] discuss how the use of mobile and existing elements enable sensor data collection, and propose that existing technology should be incorporated into new systems in a sensor network. We have taken this argument, and provided a context with which to integrate a similar sensor network into the Sensor Web.

Detailed water usage monitoring can be of benefit for water saving consciousness and behaviour changing education. However such fine grade monitoring raises challenges in energy consumption, communication load, data memory and processing in the resource constrained sensors. We designed energy efficient data reporting and communication algorithms to minimise resource demands while still maintain an acceptable level of data fidelity.

In this paper we will demonstrate the concept of this system, as well as the beginnings of an efficient sampling algorithm involved in energy conservation on the sensor.

II. SENSOR WEB ENABLEMENT

A Sensor Web may be defined as a group of interoperable web services which all comply with a specific set of sensor behaviors and interfaces specifications [3], providing multimodal observation across different spatial and temporal scales.

Sensor Web Enablement (SWE) is an Open Geospatial Consortium (OGC) initiative that extends the OGC open web services framework [4] by providing additional services for integrating web-connected sensors and sensor systems. SWE services are designed to enable *discovery* of sensor assets and capabilities, *access* to these resources through data retrieval and subscription to alerts, and *tasking* of sensors to control observations [5]. SWE is not restricted to sensors/sensor systems but also refers to associated observation archives, simulation models and processing algorithms. SWE enables interoperability between disparate sensors, simulation models and decision support systems. It acts as a middleware layer that connects physical assets, geo-processing applications and decision support tools.

A. SWE Information Model

The SWE initiative has developed draft specifications for modelling sensors and sensor systems (SensorML, TransducerML), observations from such systems (Observations and Measurements) and processing chains to process observations (SensorML) [6], [7]. The draft specifications provide semantics for constructing machine-readable descriptions of data, encodings and values, and are designed to improve prospects for plug and play sensors, data fusion, common data processing engines, automated discovery of sensors, and utilisation of sensor data.

B. SWE Services Model

SWE provides four types of web services: Sensor Observation Service (SOS), Sensor Alert Service (SAS), Sensor Planning Service (SPS) and Web Notification Service (WNS) [9]–[12]. The SOS provides a standard interface that allows users to retrieve raw or processed observations from different sensors, sensor systems and observation archives. The SAS provides a mechanism for posting raw or processed observations from sensors, process chains or other data providers (including a SOS) based on user-specified alert/filter conditions. When subscribing to a SAS, users not only define the alert conditions but also the communication protocol for disseminating alerts via the WNS.

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The WNS provides a standard interface to allow asynchronous communication between users and services and between different services. A WNS is typically used to receive messages from a SAS and to send/receive messages to and from a SPS. The SPS provides a standard interface to sensors and sensor systems and is used to coordinate the collection, processing, archiving and distribution of sensor observations. Discovery of OGC and SWE services is facilitated by the Sensor Web Registry Service – an extended version of the OGC Catalogue Service [8].

C. *Mobile Technologies*

Mobile phone technology as we use it today began in the early 1980s. This was used in 1G telephones that worked on an analogue network that only supported voice transfer and were large and heavy.

The analogue system was replaced in 1991 when the 2G network was introduced; this included the GSM and CDMA systems. These phones were far more portable and had far more efficient power usage. At this time, data services like SMS were first introduced.

2G phones then evolved to become 2.5G phones that supported packet switching as well as the traditional circuit switching methods, and this meant that it could support the transfer of more types of data though the speed was not increased.

In 1999, Internet access was introduced to mobile telephones. Bluetooth was first introduced, as a replacement for cabled connections to transfer files between phones, and PCs, and later for wireless headsets and other peripherals.

2.75G phones increased the speed of data transfers, and theoretically meet the requirements to classify as 3G telephones. 3G telephones can support data transfer of up to 2Mb/s and a wide range of data transfers. The purpose of mobile phones has changed greatly during over the years and has evolved into a device that is not just a telephone but a portable computer.

Power consumption has been an issue since the introduction of 3G networks and Bluetooth, however, [15] conclude that this need not be taken in to consideration when using mobiles as sensors since mobile devices can easily be recharged.

Thanks to this process of evolution, smart mobile telephone handsets (smart phones) present an opportunity for ordinary users to interact with Sensor Webs, which until now have been the preserve of the scientific community. Generally the full capability of their mobile handset is seldom exploited, but the ubiquitous nature of mobile devices makes these ideal for pervasive sensing.

III. RELATED WORK

While the idea of mobile phone based sensor networks is not new ([2], [13]–[16]), we have designed a novel application that allows for home users to use such a system for monitoring household resources, with the intention and motivation of inducing behavioural change.

The University of Cambridge is currently involved in developing a system, as part of the Mobile Environmental Sensing System Across Grid Environments (MESSAGE) project group, that uses mobile phones and Bluetooth sensors to monitor the quality of air [17]. Using pedestrians and cyclists to gather information about air pollution, they forward the information to a central database for display on an internet based map. The main principle of our system is the same, however, we maintain a more significant focus on the development of an urban, and suburban, community based system, rather than for the scientific community. Our system focuses on a ubiquitous structure and smaller, and less obtrusive hardware components.

Operating as a researcher in the field often amounts to a requirement to carry equipment without the aid of a vehicle. It is for this reason, that it is important to have highly portable equipment. Tilak [16] argues that portable mobile devices are essential for environmental monitoring observation systems. This provides a particularly strong argument for our case, as we are trying to broadly monitor a lot of data using many people to get it done quickly.

Through examining use cases with relation to tablet PCs, PDAs, and smart phones with user interfaces, they have determined that mobile telephones have a role to play in sensor networks and environmental monitoring [16]. They propose further research into developing sufficiently intelligent systems that will allow for more than just data gathering, and instead develop a system of data visualisation and interaction. We intend to implement such a system, that provides a social networking interface for the home user, and encourages them to become involved with data collection.

Bluetooth is a suitable medium for transference of data among some sensor networks which exchange 'unpredictable bursts of data during a limited time frame' [18]. This suits our project, as transfer of data will occur at random intervals, and contain only small amounts of data. The user does not need to be in range of their mobile phone carrier until they wish to send the data. This means that data can be collected from sensors outside of the urban environment, or in the centre of the city without the need for potentially expensive wireless setups.

Our belief is that it is far more valuable to utilise an existing infrastructure that suits the data collection requirements. Mobile telephones and Bluetooth are viable for developing a portable system that is lightweight and ubiquitous

IV. USE CASE SCENARIOS

To demonstrate the concept of this system, the following scenarios have been considered. They cover a variety of applications for this system, and demonstrate its usefulness and practicality in society.

A. *Use Case Scenario I*

Home user: A home user can be defined as anyone collecting data for domestic, rather than industrial or scientific uses. This system was initially designed with the home user in mind. Our goal was to determine a way for the user to take ownership of their water consumption by including them in the data collection process, and providing them with near real-time data. By involving the user, it would mean that the data can be collected more readily than is standard now, and can be displayed immediately to the user and the community at large.

In this case, the home user loads the mobile device application to their phone, and the application runs in the background. It does not impede on the user in any way, and the mobile device gathers information from Bluetooth enabled sensors autonomously. The system will be distributed by a website, that will allow the user to install software, request installation of the ArduinoBT board, and monitor their resource consumption in near real-time. Data will be collected from any enabled sensor that the user passes, the data will be stored securely on the mobile device, and at a designated time, will be transmitted to the SOS.

B. Use Case Scenario II

Farmer: From an agricultural perspective, this application is also highly useful, practical and adaptable. Many farmers in Australia are concerned with water usage, or have limited supplies, due to the current and long lasting drought. Our proposed method of water conservation is to monitor the moisture of the soil, using soil moisture probes, and provide the land with the least amount of water required for growth and sustainability. For a farmer to measure this sort of information, bulky and heavy equipment is not practical, and requires concentrated attention on that task. With the Bluetooth enabled application however, they are able to take their mobile handset with them into the field, and measure soil moisture levels, while conducting other tasks. The data can be collected regardless of the presence of mobile phone coverage.

Along with measuring soil moisture levels, the farmers can also monitor their water levels using water meters. This is useful in gauging water input versus output, and assists in controlling consumption.

This information can later be transmitted to their home base either by the internet, to a central database, or by transferring the files from their mobile phone to their computer using wireless, Bluetooth, or cables.

C. Use Case Scenario III

Research Scientist: For a scientist, in a woodland environment, there will often be a lack of easy vehicle access to the data collection site that they are visiting, and therefore, equipment must be minimised. Generally, this is reduced to a laptop computer and some accessories. With our system though, it is possible for the scientist to collect the data from Bluetooth enabled data gathering devices with their mobile phone, and take it back to the base station for delivery and interpretation. By simply walking past the sensor, or while undertaking routine hardware checks, with their mobile phone in their pocket, the scientist is able to gather the data.

V. METHOD

This project was initially developed as part of a university third year software engineering unit. The aim was to provide a proof of concept for a system that could collect data from household water meters using Bluetooth and mobile phones and upload this data to a standardised database where users could access their data through a webpage. It was hoped that this would involve everyday Australians in water conservation and help induce behavioural change in the larger population.

During the university project, an application was developed using a Symbian S60 [19]device (Nokia 6120c), and Java 2 Platform, Micro Edition (J2ME). This worked well for a prototype, and the deliverable of our project, but did not provide us with the finer aspects, such as background tasking. We then redesigned our application, and chose to work with Python for Series 60 (PyS60) to rapidly prototype the system. Our motivation, was to prove that an entirely ubiquitous and pervasive system was possible, while improving data collection for water meters and introducing soil moisture sensing.

After the completion of the university project, we wanted to further develop the system, and integrate it completely into the sensor web. To do this, it was important to look at background tasking and Bluetooth connections, as well as inserting observations into the SOS. A more efficient reporting algorithm was also developed which would ensure better power consumption on the sensors.

We conducted trials to determine best and worst case scenarios for background Bluetooth connections, developed a new sampling algorithm that meets the energy consumption requirements of the ArduinoBT board [20], and installed water meters in the Tasmanian ICT Centre for further research and testing of the levels of water consumption in an office environment.

VI. RESULTS

We have provided proof of concept that this technology allows for integration of mobile telephones into the Sensor Web. It has a wide range of applications, and can be used in many circumstances, to the benefit of businesses, communities, scientific organisations, and researchers.

Our software has been successfully tested in an urban water metering application in which a Symbian S60 based mobile handset harvests daily household water consumption data from a domestic water meter connected to an ArduinoBT board. We have tested this setup with one mobile phone, one water meter, and many interfering Bluetooth devices. These data are pushed to a central database via a SOS.

Bluetooth connection times vary depending on the number of interfering Bluetooth devices and other structures in the vicinity. The tests were conducted in a controlled open environment with no other Bluetooth devices.

We found that sensors can be discovered from up to 38 metres away, however, connection is less reliable. For testing purposes, we limited our searches to 25 metres away. As distance increased, there was a trend for the time to increase. Figure 1 demonstrates the average, minimum and maximum times our tests showed it takes to connect to the sensor and harvest data.

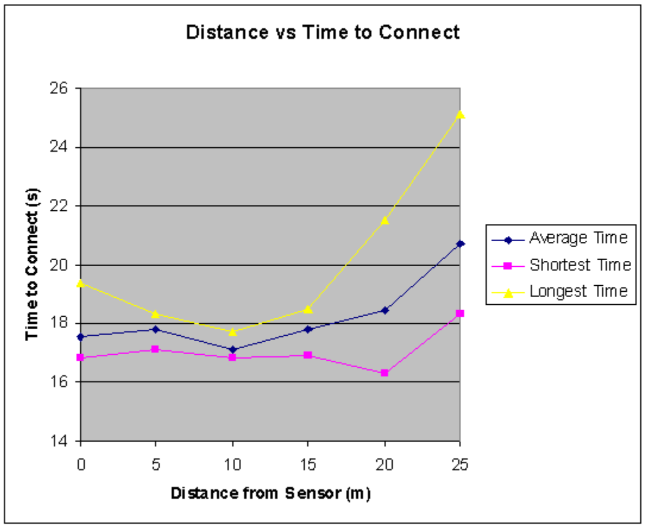

Fig. 1. Distance vs Time to connect a Bluetooth enabled mobile phone to a Bluetooth sensor, and harvest data.

Based on our findings, the user can connect to the sensor while walking within 26 metres of the sensor, at a standard walking pace. Figure 2 demonstrates how the collection of data is possible in less than 40 seconds, as the user walks past the sensor.

This range is more than sufficient for a meter to be harvested by someone within the household during everyday activities. We are in the process of trying to reduce connection time by either limiting the connection time cycle, or number of devices that can be found. We are able to conserve power by restricting the Bluetooth radio range when harvesting is not required.

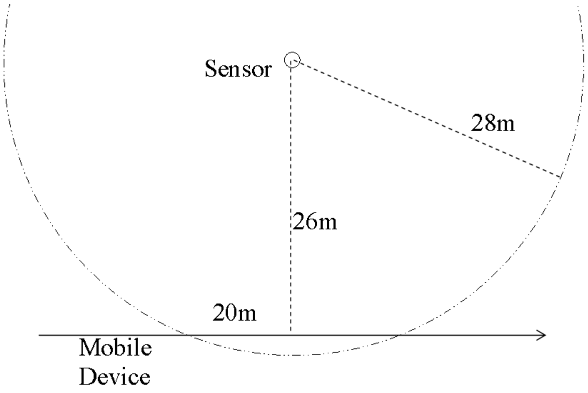

Fig. 2. Connection according to range and walking pace. User walks parallel at standard walking pace (4km/hour)

VII. Discussion

Issues have arisen with power consumption of the ArduinoBT boards, particularly the high energy cost of the Bluetooth transceiver. Resource efficient algorithms are being devised to compress the sensed data locally and reduce Bluetooth communication load. The objective is to minimise memory usage and energy consumption in the sensor boards while maintaining acceptable data fidelity.

A. Distributed Efficient Reporting via Interval Clustering Algorithm (DERIC)

The water usage readings come in ”ticks”, i.e. electromagnetic pulse converted into interrupts in the Bluetooth processor board. One way to measure the usage is to record the timing of every tick. This detailed recording is precise but not cost effective in terms of memory usage and communication cost. In practical water usage measurements, the ticks are likely grouped in clusters, with wide idle gaps between clusters, and the ticks within a cluster are likely to be (near) equal-spaced.

DERIC is designed to process raw tick data locally at the sensor board to reduce memory usage and communication costs. The idea is to group ticks into clusters of equal-spaced ticks, and report only cluster parameters, i.e. the number of ticks and average interval length, instead of raw tick data. These two values could replace tens or hundreds of readings, reducing memory usage and communication costs.

B. Low Power Bluetooth Communications

Measurements show that Bluetooth is the major source of energy consumption in the sensor board. An important fact is that even when Bluetooth is not transmitting packets (in idle listening state), the energy consumption is almost as high as packet transmitting. As the Bluetooth is in a passive state most of the time, listening for new devices turns out to be the main source of energy consumption. It is essential to reduce this passive listening in order to achieve low power communications.

A specialised board may be developed in the future to help cut down on the cost of the board and its power budget.

VIII. Conclusion and Future Work

Through the generation of appropriate case studies and prototypes, we have developed a system that is suited to installation throughout the community. We determined that Bluetooth mobile handsets are highly appropriate for the system, and that issues of Bluetooth range and energy consumption are not critically disabling for the system.

Sensor networks involving mobile handsets are appropriate for, not only home users, but also scientists and businesses, in monitoring their water consumption. This system is adaptable to monitor other resources such as power, gas, and air pollution, and it is envisioned that homes will have a network of sensors to monitor all their utilities that are able to communicate with mobile handsets to gather the data.

We hope to further our research by developing systems that complement the iPhone, Android, and Windows Mobile platforms. This may involve developing a system that allows the user to interact with their information directly on their handset, as they would on their home computer. Also, applications for Windows, Mac, and Linux platforms could be developed that would encourage further user involvement, and hopefully entice them to collect more data.

Further work is to be undertaken on DERIC, and community based testing is due to be conducted in the near future. This testing, will be used to ensure that our system can be operated in a real world environment.

Upon completion, our system will be low-power, ubiquitous, and able to support a wide range of sensor inputs for integration into the community.

ACKNOWLEDGMENT

The authors would like to thank Luke Hovington and Andrew Pratt for their contribution to the development of the mobile telephone sensor network concept demonstrator. This research is jointly funded by the Australian Government through the Intelligent Island program and the CSIRO Water for a Healthy Country Flagship. The Tasmanian ICT Centre is jointly funded by the Australian Government through the Intelligent Island Program and CSIRO. The Intelligent Island Program is administered by the Tasmanian Department of Economic Development and Tourism.

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