Poster Abstract: Virtual Sensing Range

Emiliano Miluzzo
Computer Science Department
Dartmouth College, Hanover, NH, USA
miluzzo@cs.dartmouth.edu

Nicholas D. Lane
Computer Science Department
Dartmouth College, Hanover, NH, USA
niclane@cs.dartmouth.edu

Andrew T. Campbell
Computer Science Department
Dartmouth College, Hanover, NH, USA
campbell@cs.dartmouth.edu

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1 Introduction

The vast majority of work in sensor networks to date has focused on static sensor networks and scientific and industrial monitoring applications, where humans are out of the loop. There is growing interest in enabling new applications based on human-centric sensing applications where people are not only in the loop but serve as the central architectural building block that can be exploited to offer opportunistic sensing at scale [1].

In this poster abstract, we describe one new service that is enabled using a people-centric opportunistic sensing paradigm, one that exploits the mobility of people and is responsive to sensing coverage limitations. The ability to sense any arbitrary region within the sensor field is a fundamental requirement of a sensor network. Sensor devices have a sensing coverage area limited by the sensitivity of the sensing instrumentation (e.g., acoustic, temperature, light ranges). Because of the sensing range limitation there are many instances when an application needs to acquire sensor data beyond the range of a given sensor. In this poster abstract, we propose to extend the sensing range of a mobile or static sensor based on an opportunistic sensing approach [1]. We refer to this extended sensing range as a node's virtual sensing range (VSR). In what follows, we provide an overview of VSR, its implementation using TinyOS and Tmote Invents, and an initial result that shows the approach is promising.

2 VSR design

In static sensor networks sensing coverage is achieved by the physical placement of static devices across a sensor field. In this manner coverage is assured via the physical presence of static sensor devices and their density and distribution across the sensor field. In contrast people-centric sensing relies on coverage based on the mobility of humans or vehicles (e.g., a cross enterprise, town, or city). Here coverage is probabilistic in nature because complete coverage is unlikely at any moment in time (e.g., there may be no sensors in an area of interest at a particular moment in time, and then in the next moment there may well be sensors that have moved in). Given the mobile nature of sensor devices carried by people, we propose to leverage sensor mobility to extend the sensing range of a node beyond the physical capabilities offered by its modalities. Based on existing static data-centric sensor approaches whenever a request is received for data from an area where no sensors are present, the request cannot be serviced and is dropped. VSR attempts to resolve this problem by delegating the sensing task to a secondary node if this secondary node, being mobile, is heading towards the region of interest indicated by a VSR query issued by the sensing range limited originating node. For example, let us assume that a series of sensors are placed in fixed locations along a city street and, moreover, assume for certain modalities that the sensing regions of these static nodes are far apart and do not overlap. Given this scenario it is clear that for some areas on the street, namely those between two consecutive fixed sensors and out of the sensing range of these sensors, it is not possible to retrieve sensed data. Such a situation can be considered a general predicament of mobile sensor architectures that are evolving [1]. In fact a node's sensing range is likely to be smaller than its radio range in many cases, and this is particularly true when moving from a 802.15.4 short radio range, currently adopted by most commercial sensors, to Wi-Fi or even cellular technologies.

In what follows, we provide an overview of VSR. We name the fixed nodes, or gateways, *callers* and the mobile nodes *callees*. We use the term callee because some mobile nodes may be tasked to provide sensing on behalf of a caller. In Figure 1, the caller is the sensor which has been tasked to provide sensing about its surrounding environment. The caller might be a sensor residing in a gateway between the wired infrastructure and the sensor field, thus the caller is capable of processing any query requesting sensed data from the region where a caller is located. VSR exploits the likelihood that mobile sensors pass through or by the location of a caller. For example, assume each of these nodes that traverse a caller's area is characterized by velocity vector $\vec{v}$. In Figure 1 the transmission range T_r and the sensing range S_r are shown as disks only for the sake of simplicity, but the VSR algorithm supports non-uniform sensing and transmission range patterns as found in real systems.

The caller, which announces its presence by periodically beaconing, runs a selection algorithm to pick the best subset

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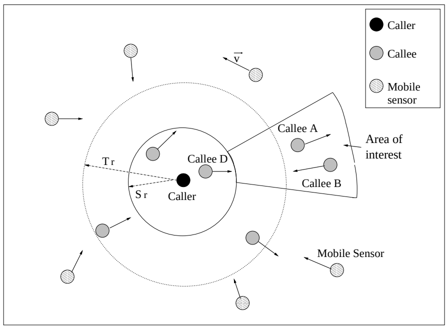

Figure 1. Virtual Sensing Range realization.

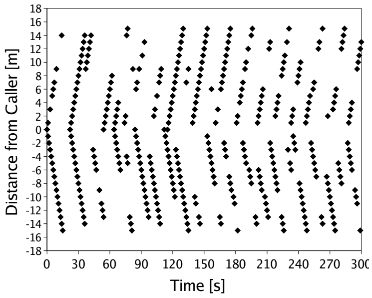

Figure 2. Sensor readings distribution over time and space.

of mobile nodes to task for sensing beyond its S_r. The metric whereby the caller selects mobile nodes is based upon two factors: *i)* the Link Quality Indicator (LQI) of mobile nodes' periodic beacons which start being delivered as soon as the caller's radio range is crossed, and *ii)* readings from a compass mounted on each node, piggybacked in each beacon the mobile node sends to the caller. The caller, which is also equipped with a compass, selects nodes heading toward the area of interest among all the mobile sensors in its radio coverage. As soon as the LQI of a candidate mobile sensor starts decreasing, indicating that the candidate is leaving the caller's radio range, the caller tasks the candidate if the candidate is still moving in the required direction. If, for example, in Figure 1 callee D is moving from left to right, callee D is a good candidate because it is heading toward the area of interest. As soon as callee D approaches the caller's radio coverage edge, callee D's LQI computed by the caller starts decreasing. At this point the caller tasks callee D to start collecting sensed samples. The LQI measurements are taken per node and are smoothed by applying an exponential weighted moving average to avoid false positives.

In our experiment, the callee uses the Tmote Invent's accelerometer to infer the distance covered from the point of tasking. The callee takes samples and stores them in the flash until the distance specified by the caller has been covered. The callee probabilistically relies on other mobile nodes heading in the opposite direction to mule data back to the caller once out of the caller's radio range. In what follows, we illustrate the tasking of a sensor to provide continued virtual sensing range and the muling of sensed data back to the caller once the requested data has been acquired. In Figure 1, callee A tasks callee B to provide sensing along its path toward the caller and, at the same time, callee A passes the data collected so far to callee B. Once within the caller's radio range, callee B delivers its own sensed data and callee A's sensed data to the caller. Through opportunistic delegation and muling [1] we have virtually extended the caller's sensing range to the area of interest, indicated in Figure 1; this area is beyond the caller's physically limited sensing range. VSR becomes more useful as the density of mobile nodes per time unit area increases. For example, in a dense urban environment VSR could be leveraged to reduce the cost of deploying a fix sensor network infrastructure. While both the accelerometer and compass have been used in the past to realize sensor applications [2] [3], to the best of our knowledge they have never been exploited in the design of a distributed algorithm such as VSR.

3 Experimental evaluation

We have implemented VSR on TinyOS and Tmote Invents (which mount a 2-axis accelerometer) for our preliminary experimental evaluation. Because the Invents do not have a compass, we are planning to integrate a digital compass on them. We conducted a simple experiment in a building hallway removing the need for a compass (we exploit only one-dimension type of motion). With the compass integrated with the Tmote Invent we will be able to run the VSR over a 360 degrees angle around the caller. We reproduced the setup shown in Figure 1 where the caller is placed in the middle of a 40 meters long hallway. Five people carried a Tmote Invent along the hallway for five minutes. For this experiment the sensing modality we refer to is the light sensor since light is space dependent and a light reading is only meaningful in the immediate proximity of the sensor that made the reading. Figure 2 shows some initial results for this simple experiment. Each dot on the plot represents a sensor reading. The x-axis shows the duration of the experiment and the y-axis the distance from the caller, which is considered the reference point and is placed at position 0 m. The caller's transmission power is set up such that its transmission radius is approximately 7 meters. The caller tasks the five callees to collect light readings for 15 m as soon as the callees receive the task. The caller light sensor in this experiment presents a sensing radius of approximately 2 meters. As shown in Figure 2, by introducing VSR it is possible over the duration of the experiment to retrieve sensed data from mostly every distance within 15 m from the caller on both sides of the hallway. The amount of readings and the timeliness of their delivery to the caller would increase with the number of mobile nodes passing the caller. This result, while preliminary for a fairly simplistic scenario, shows that VSR is a promising technique that supports the notion of opportunistic sensing in people-centric mobile sensor networks [1].

4 References

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