Aquiba: An Energy-Efficient Mobile Sensing System for Collaborative Human Probes

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Abstract. Portable sensory devices carried by humans—which are referred to as *Human Probes*—facilitate easy-to-use sensing and monitoring of urban areas. In this demonstration, we developed a prototype of *Aquiba* sensing system from off-the-shelf mobile phone. Aquiba involves *collaborative sensing* that helps in achieving high-fidelity sensing while minimizing overall energy consumption. We validated the benefit of collaborative sensing through field experiments.

1 Introduction

Human-Probe sensing, which allows ordinary people carrying sensors to participate in data collection, provides an exciting opportunity to design a novel humans-in-the-loop sensing environment because it eliminates the hindrance of deploying myriad static sensors across a wide area and leads to a fully distributed urban sensing. Human Probes consider not only participatory and opportunistic modes of data capture but also collaboration without community bonds. Such collaboration could take place automatically among strangers, even without them being aware of it. Therefore, this paper focuses on the design and analysis of collaborative Human Probes by exploiting dynamic, emergent, and ephemeral pedestrian groups. We propose a mobile sensing system called *Aquiba* for efficiently collect environmental data in urban areas. In order to minimize total energy consumption while still achieving high-fidelity sensing, Aquiba autonomously adjusts sensing rate of each Human Probe based on the availability of nearby Human Probes which always changes along the time. We develop prototype devices and conducted field experiments in which the results confirm the efficacy of Aquiba system in terms of energy efficiency and sensing fidelity.

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Fig. 1. A prototype of Human-Probe device

2 Aquiba: Collaborative Sensing System

Aquiba considers the following issues which are decided on the basis of the various factors relating to Human-Probe sensing: (i) an environmental sensing system consists of a server, mobile phones, and sensors; (ii) the mobile phones are equipped with cellular and short-range wireless interfaces; (iii) the sensors are either integrated in the mobile phones or positioned at various locations in the environment to capture environmental data; (iv) the server issues a query including the desired *sensing rate* R_i for each data type for each *sensing area* A_i, where i indicates the index of the sensing areas; (v) the mobile phones are able to acquire their current location information. In particular, the Human Probes that we consider perform implicit sensing tasks, i.e., the sensors automatically capture the requested data and the mobile phones upload the data to the server via a cellular network. The mobile phone uses short-range wireless interface to communicate with nearby sensors and other mobile phones.

Upon receiving a query from the server, Human Probe which exists in A_i performs the collaborative sensing by adjusting its sensing rate to $\frac{R_i}{k_i}$, where k_i is the number of Human Probes in A_i. To maintain information of other Human Probes in the same sensing area, a mobile phone uses short-range radio to broadcast beacon packets periodically. Based on received beacon packets, a Human Probe can determine the current number of neighboring Human Probes and accordingly adjust its sensing rate. Each Human Probe needs to set an expiry time for each neighboring Human Probe and delete the expired neighbors from its neighbor table periodically. In our implementation, the determination of the beacon interval and neighbor management is based on those of AODV protocol [1].

3 Prototype Implementation

We developed a platform of *Mobile-phone-based Human Probe with ZigBee (MHPZ)*. The hardware of MHPZ consists of three components: MHPZ body, MHPZ parent (MHPZ-P), and MHPZ child (MHPZ-C) as shown in Fig. 1. The MHPZ body is an off-the-shelf mobile phone and functions as a Human Probe if it is physically connected with MHPZ-P. The MHPZ-P, which is equipped with a ZigBee interface, is connected to the MHPZ body via a serial interface and can communicate with any ZigBee devices. Thus the MHPZ-P functions as a gateway between the mobile phone and various sensors with ZigBee communication capability. Finally, the MHPZ-C can sense and transmit data to the MHPZ-P via ZigBee radio.

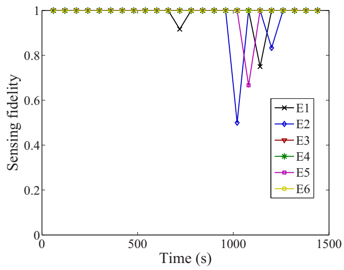
Inside the MHPZ body, we implemented a BREW application software (MHPZ-App) to handle communication with an MHPZ-P and control cellular communication of mobile phone. The MHPZ-App controls and monitors the MHPZ-P through a synchronous command, i.e., the MHPZ-App issues a command (e.g., asking to broadcast a beacon packet) to the MHPZ-P, which in turn sends corresponding replies (e.g., informing neighbor information or sensed data) to the MHPZ-App. The MHPZ-App calculates an appropriate sensing rate based on the Aquiba protocol. In our prototype implementation, MICAz Motes are used for both MHPZ-P and MHPZ-C, and Casio G'zOne W62CA is the MHPZ body.

4 Experimental Study

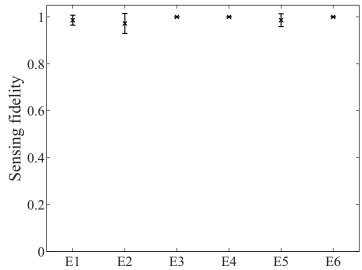
We asked 12 participants to carry the MHPZ platforms and walk in an 156m-by-132m area. The MHPZs collaboratively captured temperature data and uploaded them to a server. There were six experimental scenarios (E1–E6), each of which specified a different walking pattern and stopping probability. Participants walked freely in scenarios E1–E4, while they followed a different sequence of predetermined way points in scenarios E5 and E6. When people run into their acquaintances on the street, they may stop for a short period to say hello and have a conversation. We examined the impact of such a behavior by using different stopping probability in each scenario, i.e., 1.00, 0.50, 0.33, 0.25, 1.00, and 0.33 for scenarios E1, E2, E3, E4, E5, and E6, respectively. Each participant received a trump card, and they stopped when encountering a participant who carry the same trump card. In all scenarios, R_i was set to 12 times per minute, and the beacon packets were broadcast every five seconds.

Human Probes aim to maximize *sensing fidelity* which is defined as a ratio of the sensing rate perceived by the server to the desired sensing rate in a given sensing area. If the total number of packets arrives at the server during the period ΔT is N, the sensing fidelity is $\frac{\min\left(\frac{N}{\Delta T}, R_i\right)}{R_i}$. We also calculate *upload ratio* which is a ratio of the number of uploads carried out by Aquiba protocol to the number of uploads carried out by non-collaborative Human Probes.

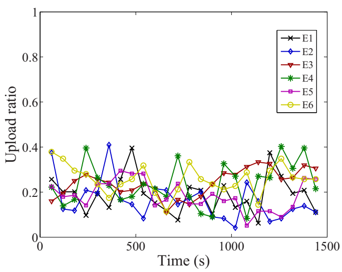
The results of all scenarios are shown in Fig. 2. Fig. 2a shows the variation of sensing fidelity along time axis. For all scenarios, sensing fidelity generally achieves the highest level (1.0) except for the several instances being temporarily below 1.0. The lower sensing fidelity is partially due to stale neighbor information. Fig. 2b shows overall sensing fidelity for the entire experimental period along with 95% confidence intervals. As far as sensing fidelity is concerned, there is no significant



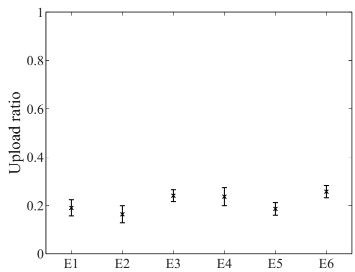
(a) Temporal variation of sensing fidelity.



(b) Overall sensing fidelity.



(c) Temporal variation of upload ratio.



(d) Overall upload ratio.

Fig. 2. Experimental results

difference among all scenarios. The experiments showed that sensing fidelity is not significantly affected by the stopping probabilities and walking patterns.

The temporal variation of upload ratio (Fig. 2c) was normally lower than 40%. Fig. 2d shows overall upload ratio for the entire experimental period along with 95% confidence intervals. The upload ratios of scenarios E5 and E6 (predetermined routes) are significantly different, i.e., the number of uploads is reduced when the stopping probability is high. The upload ratios of scenarios E1, E2, E3, and E4 (free walk) suggests a similar impact of the stopping probability on upload ratio, i.e., higher stopping probability leads to lower upload ratio.

5 Demonstration

In the demonstration, we will prepare MHPZ devices and show how the mobile phones acquire data from sensor, and how the phones find neighbor Human Probes and adjust their sensing rate automatically. Users can check current status and set parameters of Aquiba through GUI of mobile phones. We will also prepare the server to show collected sensor data in real-time.

Reference

1. Perkins, C.E., Belding-Royer, E.M., Das, S.: Ad hoc on-demand distance vector (AODV) routing. RFC 3561, IETF (July 2003)