Fingertips of the Network: Featherweight Communicators and Sensors

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Abstract

Hewlett-Packard has a business opportunity in low-power, general-purpose, networked, 'featherweight' computing devices that act as sensors or user interaction tools. We have designed and built a set of very small devices targeted to hospital applications. The first device assists caregivers with patient management in a Neonatal Intensive Care Unit. Each patient in the unit has a battery-powered wireless 'clipboard' that stores and displays medication plans, messages, and other patient-specific information. The clipboards use IR to communicate with Pocket PC iPAQs carried by the staff and low-power 802.15.4 radios to communicate with a back-office data server. Hospital trials commence in 2005. In conjunction with MIT, a later deployment is planned for hospital emergency room patients.

The Small Device Opportunity

Hewlett-Packard's product line spans large servers to PDAs. Our work with customers has convinced us that many applications require computers small than PDAs: 'featherweight' devices with low-power wireless communication and long battery life. Featherweight devices are a rapidly expanding field where HP is well-positioned to provide network infrastructure in a variety of horizontal and vertical markets. HP may not make all the devices in this space, but we will deploy them, connect them, and manage them.

There are many application areas of featherweight computing: biosensors, environmental sensors, authorization and identification tags, mobile storage, tracking people and equipment, data aggregation and storage, personal communication, and asset management. These devices have value in monitoring large buildings, military operations, emergency response teams, security, hospitals, home healthcare, and public venues such as conventions, museums, and amusement parks. In turn, the successful and productive deployment of featherweight devices requires an infrastructure that provides external connectivity and information/location-based services.

A natural question is why cell phones, handhelds computers, and notebook computers are inappropriate for featherweight computing applications. Cell phones are inflexible, inextensible and heavily regulated. Notebooks and handhelds are too cumbersome and power hungry. Our group has been working for several years on solutions for the problems of mobile professionals; i.e. people who are constantly on the move. In [1], we described the integration of location-tracking with SIP-based telephony, instant message and presence to enhance communications between mobile professionals. One thing brought home to us by that study was how consistently users shut off their notebook and handheld computers to save battery power.

In the past, devices in the featherweight category had negligible computation, storage, and networking capacity, limiting their broader utility. Advances in low-power computing and wireless chipsets make it possible to build capable low-cost, wirelessly networked devices using general-purpose computing and standards-based networking—which is exactly HP's area of expertise. The business opportunities for HP are in services, consulting and integration (design and deployment of semi-custom devices and applications), standards-based network equipment, servers, and management software. Challenges in this space include rapid turnaround of semi-custom designs, low-power reliable networking, location-based computing, device security, and scalable deployment and management of devices, infrastructure and applications. We are exploring the opportunities and challenges by building and deploying devices and infrastructure tailored for hospitals.

Over the past year we have identified a number of promising venues for testing featherweight device technology. We will be conducting trials in two hospitals in 2005. The objective in these two trials is improving patient care by better management of information flow for patients and hospital staff. This paper focuses on the first trial with a description of the devices we have constructed and our planned deployment. The paper concludes with a description of the second trial and a discussion of future work.

Figure 1. Clipboard and 8-way charging station.

First Hospital Trial

The MetroWest Medical Center Neonatal Intensive Care Unit (NICU) is located in Framingham, MA. It provides specialty care for premature infants who need extra help or close monitoring (a Level 2 facility). It supports 20 infants and is staffed by a large, rotating population of physicians, nurses, residents, and interns. Each nurse cares for 6 infants; each infant sees at least 4 different nurses per week. Infants in the NICU are regularly moved among stations (crib, warmer, incubator). Since they are wrapped in blankets and placed in enclosures that make it difficult to read their ankle tags or tell one infant from another, they are identified by a paper sign taped to their station. Patient notes are hand written and stored in binders kept at one end of the facility.

The NICU staff have the challenges of (a) providing timely medicine, food, and care, (b) communicating with each other, particularly during shift changes, and (c) maintaining medical records. Working with the NICU staff, we devised the solution of co-locating an inexpensive electronic “clipboard” with each child.

The clipboard has the following features:

(1) An ‘always-on’ display screen that shows upcoming medications and messages associated with the child, e.g., ‘Ampicillin due in 20 minutes’, ‘Contact Primary Medical Doctor’.

(2) A simple user interface that allows staff to mark off medicines that have been administered, schedule new medicines, record basic biometric data (e.g., weight), and leave messages.

(3) Wireless communication so data can be retrieved and updated without a docking station. There are two scenarios: a physician or nurse who wishes to synchronize clipboard data with a PDA and the back-office NICU server that periodically retrieves and updates patient information on the clipboard.

(4) A battery life of 6 weeks, the longest typical stay in the facility by a child. Wired power solutions were ruled out early on by the hospital staff due to concerns about getting power cords installed without interfering with existing medical equipment or creating an entanglement hazard.

At first glance, an iPAQ PDA appears to be the ideal electronic clipboard. Unfortunately, battery life is a major problem. PDAs are not optimized for weeks of screen-on/radio-on operation, which is necessary for any device that provides continuous visual reminders and information. Cost, size and battery life are driven by the display, CPU, and wireless communication components. Our approach is to select only the components required for the application and package it in a standardized, but compact fashion.

For this trial we are building electronic clipboards, wireless access points that connect the clipboards to the wired infrastructure, desktop charging stations, and a software suite that runs on handheld PDAs and desktop servers.

Hardware

The current clipboard design (see figure 1) is a small device with a monochrome, 160x120 pixel LCD, 4 buttons, a TI MSP430 microcontroller with 10KB RAM and 48KB Flash, IrDA transceiver, Zigbee radio (802.15.4), 2 Mbit Flash memory, and a 750mAh rechargeable Li-Ion battery. Patient information and medication data are stored in the flash memory. In normal, display-on operation, the battery lasts 6 weeks between charges.

An important requirement for physicians is to have the clipboard easily exchange data with their own PDA. We wrote Pocket PC software to edit and update clipboard patient information. IrDA allows the physician's PDA to communicate with a clipboard without requiring a special cable. IrDA is ubiquitous on PDAs and laptops and requires virtually no power in standby mode on the clipboard.

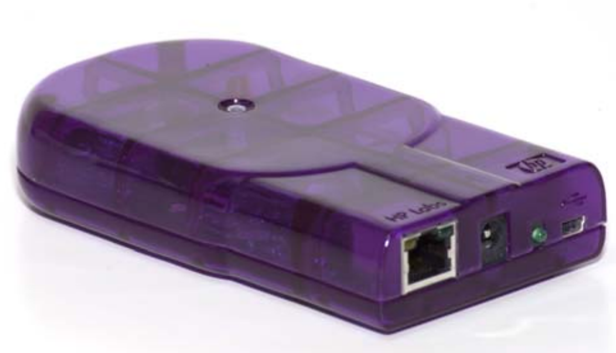

Figure 2. Zigbee Access Point (ZAP)

IrDA does not allow for remote updating of clipboards with messages and lab results. This led us to IEEE Standard 802.15.4 [2], a relatively new, low-cost, spread-spectrum RF radio technology designed for low-power, low-bandwidth, short range (10m) operation. Zigbee is a developing communication standard that runs on 802.15.4. Bluetooth was considered for RF communications, but it is optimized for 'cable replacement' and does not work well in a cell-based or ad-hoc wireless infrastructure. 802.15.4 has better power characteristics than Bluetooth and a more flexible network architecture at a comparable cost.

We developed a Zigbee Access Point (ZAP) to connect 802.15.4 devices with the wired infrastructure (figure 2). The first ZAP prototype consists of a TI TMS 320 DSP, 100BaseT Ethernet, 802.15.4 radio, and 16MB Flash. It can run on 802.3af Power-over-Ethernet (POE). The ZAP acts as an access point for communicating with clipboards and as an RF-location system that tracks the physical position of featherweight devices in real time and provides location services (described in [1]).

Software

In keeping with our goal of developing a rapid process for creating and testing featherweight devices, we are using TinyOS [3] as our base operating system. TinyOS was designed for microcontroller-based wireless sensor nodes. TinyOS abstracts hardware from software and provides a framework for component-based applications while still optimizing for minimal memory and power use. ZAP, which has more memory and a faster processor, runs Linux.

We use IrCOMM over IrDA for simple communications with the devices and a lightweight implementation of standard TCP/IP protocols over 802.15.4 for addressing and communicating over RF; the clipboards are treated as small, but first-class citizens in a networked world. We have implementations of the 802.15.4 MAC layer and of internet protocol over 802.15.4 for both TinyOS and Linux. We are using HTTP, SIP/RTP, and SNMP for featherweight device communication, configuration and management. Use of standard internet protocols enables these devices to be integrated more easily with standard applications and management tools.

We have been working with the NICU staff to co-develop the Pocket PC and Win32 software for the physician PDAs and back-office server. By using industry-standard PDA software, physicians are able to deploy clipboard-related applications on their personal equipment.

Current Status and Future Work

We have completed a build of 20 clipboards for the MetroWest deployment. We are currently finishing the clipboard and iPAQ applications. We have been testing mock-ups of the user interface with the end-users as we go along. Our trial deployment at MetroWest will begin in late spring 2005.

In addition to the MetroWest deployment, we are collaborating with MIT to investigate the use clipboards to track and communicate with patients admitted to the Brigham & Women's Hospital (BWH) Emergency Department in Boston. The BWH emergency department would like to be able to track and communicate with each patient after they leave registration. Depending on the symptoms presented upon registration, they would like to monitor vital signs such as pulse, blood oxygen saturation, and ECG. Our plan is to give each patient a Metro clipboard. The staff will be able to locate the patients in the facility, to send them messages, and to monitor their condition; the patients will be able to respond to questions and to get general information such as waiting time. BWH would also like to locate hospital staff and equipment (e.g., crash carts, wheel chairs) and to provide text and voice communication services among the staff.

Given the requirements of BWH, we are building a several new devices which will be tested in 2005:

- A Zigbee-enabled access tag or sensor node (ZTag). The ZTag is designed to be attached to a crash cart or gurney so the location of the equipment can be tracked in real time. Planned battery life is 6 months.
- An enhanced Zigbee access point (ZAP2) with four 802.15.4 radios and an 802.11b radio. In many deployments it is not possible or too expensive to pull Ethernet cables everywhere an access point is needed. The 802.11 backchannel will route IP traffic between the featherweight devices and the wired infrastructure. In addition, the ZAP2 will have an optional battery for rapid emergency deployment.
- Zigbee-enabled biosensors, including pulse oximetry and ECG.
- A voice communicator & identity 'badge' similar in size to the current clipboard, but adding a color LCD, fast microprocessor (Analog Devices Blackfin DSP), and an audio codec. It will support compressed voice communication over 802.15.4. It will also support cryptographic authentication and encryption operations so that it can act as a verifiable identity badge. We are investigating both badge and wrist-mounted form factors.

In conjunction with the new physical devices, we will be working on scalable deployment and management tools. Managing an infrastructure with hundreds or thousands of small wireless devices is a clear challenge. We are looking at using OpenView for core device management and integrating location tracking services and end-user deployment tools.

Conclusion

In this paper, we discussed the value of low-power, wireless featherweight devices and the infrastructure and services opportunity for HP. We have built a set of devices suitable for healthcare applications including a featherweight communicator and an 802.15.4 access point. We have demonstrated that these devices can use standard internet protocols, making them first-class network citizens despite their limited CPU and memory. We are working with healthcare professionals to test these devices in the healthcare industry.

References

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[3] TinyOS: An Open-Source Operating System for Wireless Embedded Sensor Networks (http://www.tinyos.net)