Experiences inside the Ubiquitous Oulu Smart City

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The UrBan Interactions (UBI) research program, coordinated by the University of Oulu, has created a middleware layer on top of the panOULU wireless network and opened it up to ubiquitous-computing researchers, offering opportunities to enhance and facilitate communication between citizens and the government.

Ubiquitous-computing research traditionally has concentrated on smart homes and smart offices, where the physical dimensions of the smart space are constrained within a building or a small geographical area. However, with the deployment of urban wireless infrastructures in cities all over the world, the vision for developing smart cities is finally taking shape.

Moreover, unlike other ubiquitous-computing research topics that are primarily motivated and driven by academic or industrial groups, the research on smart cities has brought together a diverse group of participants, including governments, urban planners, sociologists, and traditional ubiquitous-computing researchers. Several governments have already undertaken ambitious programs to build smart cities by augmenting existing city infrastructure with embedded sensing as well as communication and interaction technologies.

One such endeavor, the First International Open Ubiquitous City Challenge, offered international ubiquitous-computing researchers the opportunity to implement and evaluate innovative applications and services for the Open Ubiquitous Oulu testbed, a real smart-city environment located in Oulu, Finland.

SMART CITIES AROUND THE WORLD

The vision for smart cities originated as a natural evolution of research in smart homes and other smaller-scale smart spaces. The Universal City project[1] envisioned smart cities as a means of extending ubiquitous-computing services beyond the traditional smart home environment, forming the basis of interaction within an entire community on a much larger geographical scale. In that environment, smaller smart spaces such as smart homes interoperate with each other and interact with other external infrastructure components such as embedded outdoor sensors and mobile terminals while providing a unified and personalized interface for their residents.

Unlike other projects in which smart cities are being built from the ground up, the Amsterdam Smart City project's goal (www.amsterdamsmartcity.com) has been to integrate smart technologies into an existing historical city to make it more eco-friendly and energy-efficient. A key achievement of this project has been the installation of green energy infrastructure such as solar panels, household wind turbines, and electric-car charging stations in an attempt to reduce the city's carbon footprint. These in turn become a part of a smart grid system that includes the virtual power plant concept, in which households can sell excess energy generated from domestic solar panels, wind turbines, and biomass plants to the city to generate income.

 Published by the IEEE Computer Society

This not only provides a medium for citizens to have a say in citywide initiatives to encourage environmentally friendly behavior but also gives them an incentive to actively participate in such efforts.

The SmartCity initiative (www.smartcity.ae) is attempting to create a global network in which each smart city is a self-sustained business township with advanced ICT infrastructure. Currently, the SmartCity network consists of three smart cities, one each in Dubai, Malta, and India. The goal is to build each smart city as a cluster of knowledge and talent pools while sharing intelligence, talent, and opportunities with other smart cities in the network.

South Korea has been at the forefront of the development of the *ubiquitous city* concept. A u-city is a smart city in which knowledge and services are available to residents through the use of ubiquitous computing, with sensing and communication resources embedded in urban elements such as residences, building infrastructure, and open spaces.[2] These cities use the information and communications technology infrastructure to provide interlinked services organized within specific domain areas. For example, u-life services provide related functionalities for residents such as home automation and monitoring. U-business provides work-related services such as videoconferencing, information management, and document sharing. U-government provides services that empower citizens by making them aware of traffic and health hazards and enables them to participate in the governance process anytime, anywhere.

A u-city is designed from the ground up to be completely user-centric, providing more personalized yet nonintrusive services for its residents. The first Korean u-city, Hwaseong Dongtan, has been partially completed and is currently operational. Another u-city, New Songdo City, is being constructed on a 1,500-acre man-made island off the coast of Incheon, South Korea. This city is centered on u-life, a proposed lifestyle that utilizes smart cards with RFID technology to provide personalized services and user interfaces for residents anywhere within the city.

Figure 1. A UBI hotspot in the Ubiquitous Oulu Smart City.

OPEN UBIQUITOUS OULU

Open Ubiquitous Oulu enables ubiquitous-computing research in authentic urban settings with real users on a broad scale and in a sufficient time span. Such studies are important because real-world ubiquitous-computing systems are culturally situated and can't be reliably assessed with lab studies detached from the real-world context. By deploying a system for a sufficiently long time, researchers can establish technical and cultural readiness and identify the critical mass of users needed to determine whether the system can be deemed either successful or unsuccessful.[3]

The UrBan Interactions (UBI) program is developing UBI-hotspots, interactive public displays embedded with computing resources such as two cameras, an NFC/RFID reader, panOULU wireless access points, and high-speed Internet access to provide rich interaction between physical, virtual, and social spaces.[4,5] In addition to the UBI-hotspots, the testbed comprises a wide variety of pervasive computing resources deployed across the city, including a panOULU LAN/Bluetooth/wireless sensor network and middleware resources.

The UBI-hotspots alternate between two states. In the passive broadcast state, the entire screen is allocated for the UBI-channel, a digital signage service. In the interactive state, the screen is split between the UBI-channel and the UBI-portal, which can embed any Web service found on the Internet. As Figure 1 shows, the UBI-portal provides access to a wide range of interactive services such as directories, games, a street gallery of new media art exhibitions, sending of UBI-postcards, or uploading of personal photos and videos. Currently, all interactive events such as face detection and launching of specific services by users are logged for reporting and research purposes.

The panOULU wireless LAN is a citywide Wi-Fi network comprising approximately 1,270 IEEE 802.11 access points.[6] The access points provide open and free wireless Internet access to all public users without any limitations. However, comprehensive real-time network traces currently are archived for reporting and research purposes. For example, in February 2011, 26,013 devices used the

Figure 2. A panOULU wireless LAN access point (WLAN AP), wireless sensor network edge router (WSN ER), and Bluetooth access point (BT AP).

network, for a total of 658,742 sessions, culminating in usage of 19.3 million online minutes.

The panOULU Bluetooth network includes 30 access points scattered across the city center. Eighteen of these access points are installed on traffic lights, and they use the panOULU wireless LAN for Internet access. Twelve additional access points are placed inside UBI-hotspots. All access points sniff nearby Bluetooth radios, and the real-time traces are suitably anonymized and used for modeling pedestrian and vehicular flows and networks. The 12 access points inside the UBI-hotspots are also used for pushing multimedia content to mobile devices via Bluetooth.[7]

The panOULU WSN is an IP-based wireless sensor network comprising 13 edge routers (ERs) located across the city. The ERs are equipped with an IEEE 802.15.4 radio on the 2.4-GHz and 868-MHz bands, and the 6LoWPAN protocol stack, which offers low-power wireless connectivity. Twelve ERs are installed inside the WLAN mesh access points, as shown in Figure 2, and one ER is also placed inside a UBI-hotspot. An ER has a line-of-sight in the 500-m range with 1 mW transmission power. The MediaTeam Oulu research group is currently developing the panOULU WSN infrastructure to automatically meter energy consumption in homes[8] and for environmental monitoring using low-power sensors.

These heterogeneous computing resources constitute a large distributed system that's organized with a middleware layer. It provides various resources for supporting technology experiments, developing ubiquitous-computing applications, and managing and monitoring the applications and the testbed.

This kind of a large-scale testbed deployment presents many challenges, including establishing financial and technological viability and sustainability. After the initial capital investment, mostly from public sources, sufficient funding must be obtained to cover operational expenses and renewal. For example, a portion of the capacity of the UBI-hotspots is sold commercially to generate revenue, which in turn conflicts with research use. A practical challenge is the operational execution of maintenance, which is expensive and time-consuming and is an area in which research organizations typically aren't efficient.

Another important challenge is the measurement of success, whether it's assessing the socioeconomic impact of the testbed or the merit of any application or service deployed within it. These assessments are difficult due to the shortage of comprehensive data over a sufficiently long period and the lack of a universally accepted methodology for evaluating real-world deployments. Finally, any deployment in a city center is subject to daily scrutiny by the general public and media, which can become ill-tempered and impatient at times.

To strengthen the testbed's long-term prospects, the UBI program is integrating it into OULLabs (Oulu Urban Living Labs; www.oullabs.fi), a regional living lab initiative. This project brings together a range of testbed and human resources to facilitate various activities such as user-driven open innovation in developing and testing new technologies and applications in authentic urban settings with real users.

THE UBI CHALLENGE

Because they realized that few researchers have access to such a versatile u-city testbed for development, deployment, testing, and learning purposes, the MediaTeam Oulu research group wanted to make this testbed openly available to as many researchers as possible. The First International Open Ubiquitous City Challenge (www.ubioulu.fi/en/UBI-challenge), or UBI Challenge, is being organized for this purpose in collaboration with several leading international ubiquitous-computing experts. This competition challenges the global R&D community to design, implement, deploy, and evaluate novel applications and services in real-world settings in the city of Oulu.

The motivation for the challenge is to stimulate global research collaboration on urban informatics in a concrete manner and provide the international research community with an opportunity to transfer ideas from labs into real-world urban environments where they can make an impact. The goal is also to support the development of metrics for evaluating urban computing infrastructure and applications in real-world settings.

Participation was encouraged by advertising that up to five proposals would be selected as finalists for deployment in Oulu, with each group receiving grants of up to 10,000 euros and having the opportunity to present their research at the International Conference on Mobile and Ubiquitous Multimedia (MUM 2011). Out of the numerous proposals received, the international jury invited four to compete in the finals. All four finalist teams will arrive in Oulu in mid-2011 to finalize the implementation and deployment of their services. Thereafter, the jury's Oulu-based members will meet and assess each of the services in situ according to various performance and usability metrics.

MOTIVATING CITY RESIDENTS TO EXERCISE

A sedentary lifestyle increases the likelihood of developing obesity, diabetes, and cardiovascular disease. Estimates indicate that the healthcare cost of these chronic diseases is rapidly approaching US$1 trillion and that a strong association exists between increased physical inactivity and the emergence of chronic diseases in 21st-century industrialized societies.[9] Private companies have found that they can reduce healthcare costs by offering employees cash to quit smoking or by serving healthy food in the cafeteria.

Some governments are also following a similar model. For example, the government of Nova Scotia, Canada, offers economic incentives to parents who register children in sports or recreation activities that offer health benefits. Recently, the US Department of Health and Human Services announced that it's devoting economic resources to encourage citizens to participate in health improvement programs (www.letsmove.gov).

Smart cities can become the cornerstone for promoting healthier lifestyles by using their urban wireless infrastructures to implement mechanisms that directly encourage residents to play sports and exercise or serve as tools to measure actual involvement in exercise programs.

During recent years, several tools have been developed for tracking performance while exercising, especially while running, walking, hiking, or biking. Tools like Nike+, RunKeeper, Endomondo, Strands, and Nokia Sports Tracker help users keep records of information pertaining to their sports activities, such as duration, distance, pace, speed, elevation, calories burned, and the course traveled on a map. This information is uploaded to a Web-based cloud service where participants can share statistics and make detailed comparisons. Most of these applications seek to keep different kinds of users motivated by offering personal or collective challenges—for example, men versus women, aiming to complete 10 miles a week or run a total of 500 miles, or competing against the user's own previous workouts or against other people's workouts along a route. However, these applications usually require carrying a GPS-enabled smartphone, which discourages many potential users due to the cost of the device. Moreover, a user who wants to update his or her position and statistics on the Web-based service in real time must maintain a persistent data connection to the cloud.

One way to keep participants motivated to exercise is to create social networks in which they can share their performance with their friends and also compete against them. Developers can enhance existing tools with related features supported by smart city infrastructures. For example, instead of using a GPS device, it's possible to use the urban wireless infrastructure to keep track of a user's performance. Moreover, smart cities are designed to be adapted to their specific environment and the target user base. Exploiting this characteristic can stimulate people to engage in sports activities because their friends and acquaintances who use the system are located in the same area. Participants also can be encouraged to compete against others in a similar physical condition or to follow a regimen that's suitable for their level of fitness.

The goal is also to support the development of metrics for evaluating urban computing infrastructure and applications in real-world settings.

RunWithUs

We're designing RunWithUs, a service that will be deployed in the Ubiquitous Oulu Smart City, with the goal of motivating citizens to practice jogging, letting them

- select a route according to length, difficulty, groups or friends currently following it, number of runners in a similar physical condition who usually follow this route, number of runners in the area, and weather conditions or pollen levels;
- compare differences in performance between runners following the same route, competing with other users' performances, or competing against one's own previous workouts (phantom runner); and
- promote sports practice and social life by establishing rankings: for example, biggest group of the month, most regular group of the month, and so on.

Figure 3 shows the RunWithUs system architecture, which includes Wi-Fi-enabled phones or tags that are connected to the wireless infrastructure and tracked by the UBI middleware, weather or other environmental sensors, and user interfaces such as a UBI-display or a Web browser on a PC or a smartphone.

Because RunWithUs was selected as one of the four finalists in this year's UBI Challenge, we'll have the opportunity to implement the system in a real-world smart city, thereby identifying difficulties and user concerns related to the location methodology's precision as well as issues related to privacy.

Location methodology

Implementing these features requires estimating each user's location. For this purpose, we're using the panOulu wireless infrastructure to locate personal Wi-Fi devices such as mobile phones and MP3 players. We're also taking advantage of existing Ubiquitous Oulu and social networking APIs to offer several user interfaces (top layer in Figure 4) to configure the system, including

- city displays that show a map with information about groups of runners, statistics, or promotional videos and animations, and users can join a group at any moment, even when they're already running;
- a website providing the same information as in the urban displays, including a special version for mobile devices; and
- a Facebook interface to share results, comments, and so forth with friends or other runners.

In a typical use case, a new user who wants to access RunWithUs must register using a UBI-hotspot. The user provides a login, a password, and a MAC address, usually from the mobile phone's Wi-Fi, an MP3 player, or a Wi-Fi badge. This MAC address tracks the user throughout the city. Once registered, the user can log into the system through any of the available interfaces.

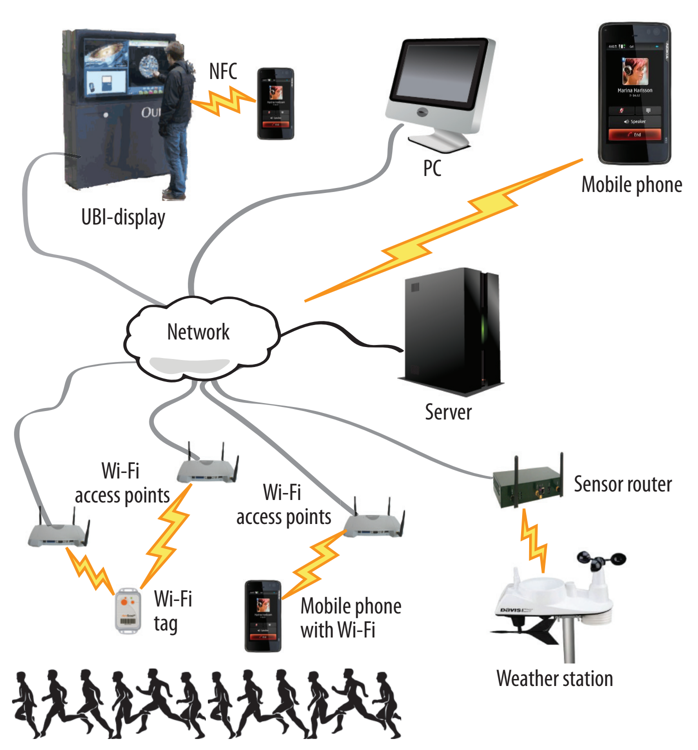

Figure 3. RunWithUs system architecture.

Privacy

Naturally, users might be concerned that such a system could track them while they aren't running or when they don't desire to. Initially, we implemented a procedure to activate and deactivate the tracking service, for example, pressing a "Start Running" button in the RunWithUs user portal. This action allows the infrastructure to check the MAC address location and start tracking until the user presses "Stop Running." These actions are needed to differentiate when users are running versus when they're engaged in other nonexercise-related activities. When users are engaged in other activities, although the infrastructure could still detect their MAC address, the system won't update their location information. But since it's highly likely that users will forget to stop the tracking service, we implemented a timer to stop it by requiring users to select the amount of time they're going to run when they start the service.

Currently, the system uses panOULU Wi-Fi access points to track runners. Following an increasing trend, a recent report indicates that approximately 15 percent of the total number of mobile phones in Finland has Wi-Fi support.[10] A user who doesn't own a Wi-Fi-enabled phone or doesn't want to carry it while running could use a smaller Wi-Fi tag such as AeroScout, Ekahau, or RedPine. By using Wi-Fi access points for tracking, a runner's location can only be roughly estimated based on an access point's coverage area, but the hypothesis is that this will be adequate for this use case. Nevertheless, the deployment in Oulu will reveal whether or not this supposition is correct. For example, because we expect poor Wi-Fi coverage in parks, we'll need to adapt RunWithUs to overcome this limitation. Bluetooth access points could provide a finer-grained location, but the low number of currently installed units will likely reduce their effectiveness.

Figure 5 depicts the various elements that comprise the RunWithUs service. The different user interfaces provide unregistered users information about the system such as routes, statistics, or public events. Unregistered users can also get some minimal and anonymous information about who's running right now or what the most popular routes are at a given time. There are two main reasons for making this information available. The first is to make the service attractive to potential future registered users; the second is to help tourists find a place to exercise comfortably and safely by finding appropriate routes suitable for their physical condition in safe areas.

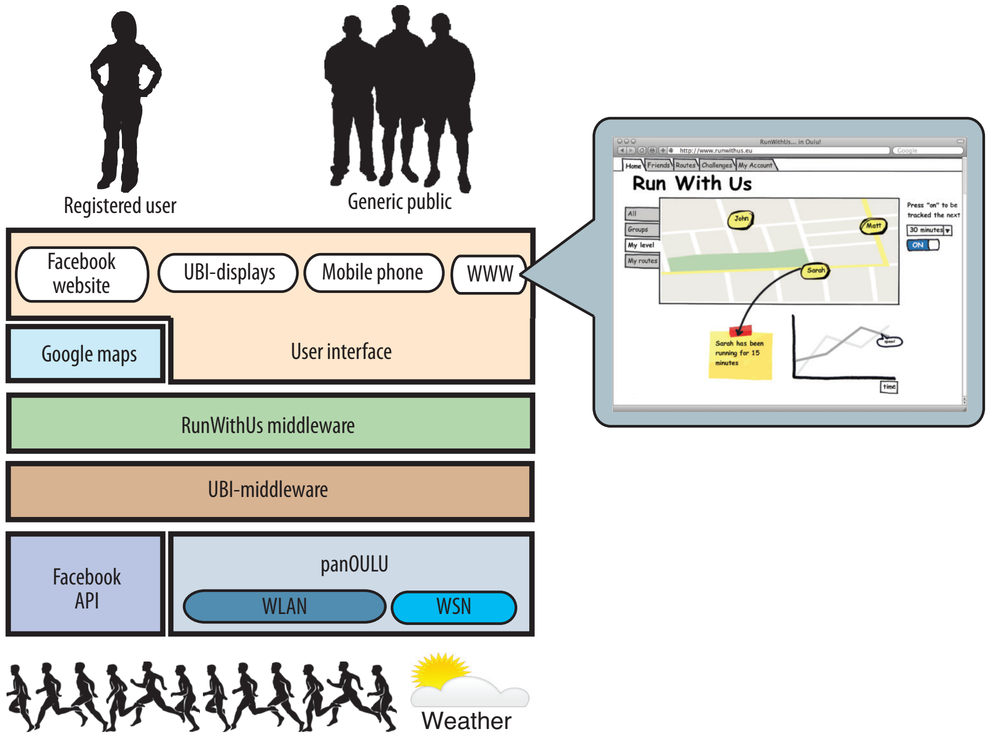

Figure 4. RunWithUs software stack.

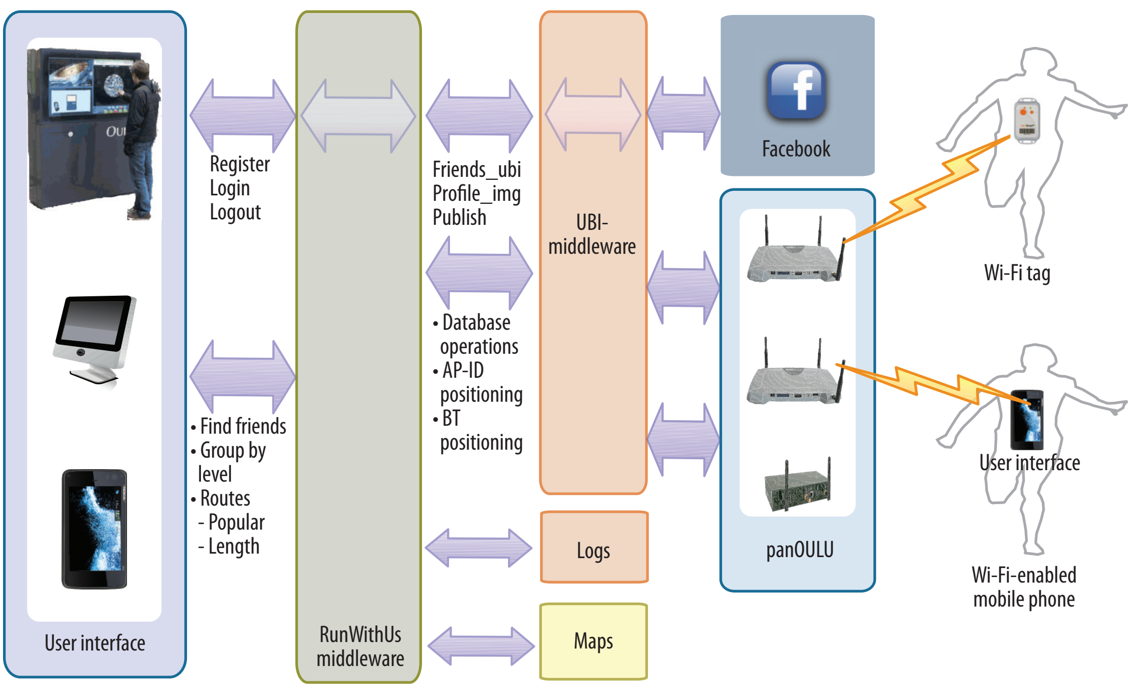

Figure 5. RunWithUs in operation.

In addition to the information provided to unregistered users, registered users can get information their friends want to share, such as their favorite routes or their performance. Registered users can also view who among their friends is running now, including their names, physical condition level, and corresponding location. Users also can determine who intends to go jogging at a particular time in case they want to join their friends.

The RunWithUs service's middleware layer tracks runners and uses that information to create routes and recommendations. This layer is also responsible for creating dynamic webpages for the different user interfaces. Routes and runner positions are overlaid on maps using the Google Maps API. For registered users, the system can filter results from their Facebook friends or publish statistics as text or images. Personal statistics such as total distance traveled, fastest kilometer, and so on can also be published according to user preferences using the Facebook API.

RunWithUs is still in its early stages, but we've already confronted several challenges. Implementing a multiscreen application designed to operate in devices with different sizes, resolution, and input interfaces isn't a trivial endeavor. Furthermore, applications developed for smart cities should be adapted to the environment in which they're going to be installed, making it necessary to perform onsite tests, especially when using APIs and interfaces interacting with citizens or mobile devices. But for RunWithUs, the main challenges are related to using Wi-Fi to track users. This technology can only offer precision at several hundred meters, and the fastest person in the world needs only roughly 10 seconds to cover 100 meters, making it necessary to find the optimal periodicity of location requests to offer maximum precision without overloading the servers. The low precision also makes it necessary to use postprocessing and additional information to determine whether users are following a predefined route, running together, or creating teams, or to store precise information about the track.

As the number of smart cities continues to increase, the number of related research initiatives is also increasing rapidly. However, it's still difficult for researchers to get access to a full-featured real-world testbed. Thanks to initiatives such as the UrBan Interactions research program, it's now possible to create and test smart-city applications and services designed to provide benefits to the community at large, discovering limitations that were not foreseen during the design phase and iteratively refining them until they become a ubiquitous and helpful part of people's daily lives.

References

1. T. Yamazaki, "Beyond the Smart Home," *Proc. Int'l Conf. Hybrid Information Technology* (ICHIT 06), vol. 2, IEEE Press, 2006, pp. 350-355.
2. S. Lee et al., "Towards Ubiquitous City: Concept, Planning, and Experiences in the Republic of Korea," *Knowledge-Based Urban Development: Planning and Applications in the Information Era*, T. Yigitcanlar et al., eds., IGI Global, 2008, pp. 148-170.
3. S. Greenberg and B. Buxton, "Usability Evaluation Considered Harmful (Some of the Time)," *Proc. Conf. Human Factors in Computing Systems* (CHI 08), ACM Press, 2008, pp. 111-120.
4. T. Ojala et al., "Open Urban Computing Testbed," *Proc. 6th Int'l ICST Conf. Testbeds and Research Infrastructures for the Development of Networks and Communities* (TridentCom 10), ICST, 2010, pp. 1277-1288.
5. T. Ojala et al., "UBI-Hotspot 1.0: Large-Scale Long-Term Deployment of Interactive Public Displays in a City Center, *Proc. 5th Int'l Conf. Internet and Web Applications and Services* (ICIW 10), IEEE Press, 2010, pp. 285-294.
6. T. Ojala et al., "Supporting Session and AP Mobility in a Large Multi-Provider Multi-Vendor Municipal WiFi Network," *Proc. 3rd Ann. Int'l ICST Conf. Access Networks* (AccessNets 08), ICST, 2008, pp. 89-101.
7. H. Kukka et al., "BlueInfo: Open Architecture for Deploying Web Services in WPAN Hotspots," *Proc. Int'l Conf. Web Services* (ICWS 09), IEEE Press, 2009, pp. 984-991.
8. T. Ojala et al., "UBI-AMI: Real-Time Metering of Energy Consumption at Homes Using Multi-Hop IP-Based Wireless Sensor Networks," *Proc. 6th Int'l Conf. Grid and Pervasive Computing* (GPC 11), to be published in 2011.
9. F.W. Booth et al., "Waging War on Modern Chronic Diseases: Primary Prevention through Exercise Biology," *J. Applied Physiology*, vol. 88, 2000, pp. 774-787.
10. A. Riikonen, "Mobile Handset Population in Finland 2005-2009," 2010; www.netlab.tkk.fi/tutkimus/momi/publications/Riikonen_2010_Mobile_Handset_Population_2005-2009.pdf.

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