UBI-hotspot 1.0: Large-scale Long-term Deployment of Interactive Public Displays in a City Center

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Abstract—We present the design, implementation, deployment and evaluation of a novel urban computing infrastructure called UBI-hotspot. It is effectively a large interactive public display embedded with other computing resources. We have deployed a network of UBI-hotspots around downtown Oulu, Finland, to establish a public laboratory for conducting experimental ubiquitous computing research in authentic urban setting with diverse real users and with sufficient scale and time span. We focus on the first version of the UBI-hotspot which offers a wide range of services via different interaction modalities. We analyze the usage and user acceptance of the UBI-hotspots from qualitative and quantitative data collected over a period of eight months. Our first observations show that this type of infrastructure may be a useful addition to the urban space.

Keywords- urban probe; urban computing; living lab.

I. INTRODUCTION

The contemporary urban landscape is currently undergoing a paradigm shift, where shared public spaces are becoming increasingly saturated with new types of pervasive computing technology. The deployment of ubiquitous high-speed wireless access networks, powerful mobile devices, large public displays and different types of sensors is bridging the gap between physical, virtual and social worlds, and altering the ways people behave in urban spaces. Coupled with urbanization, the paradigm shift has given rise to urban computing, an emerging multidisciplinary research field studying the use of pervasive computing resources in public urban spaces.

Since the inception of the ubiquitous computing in the 1980's, we have seen an immense research investment in ubiquitous (or pervasive) computing. However, while this investment has produced numerous scientific publications, very few visible and lasting contributions to the urban digital fabric have emerged. This lack of coherent progress motivated the 2005 UbiApps workshop at Pervasive 2005, where 25 researchers from academic and industry were invited based on their position papers. In their summary of the position papers Sharp and Rehman [24] identified several reasons underlying the crisis in the international ubiquitous computing research. One of them was the well-known fact that the research community values novelty over high-quality implementations and good engineering practices. This has led to 'reinventing the wheel' in tiny increments, which may

have been worth yet another publication, but very little else to the community, as they have not been shareable due to their poor engineering. The consensus was that the research community should reward good engineering and encourage research that constructs open, reusable infrastructure for the wider community's benefit.

We second this sentiment and argue that the lack of visible and lasting results is partly due to the mainstream research on ubiquitous computing suffering from a distinct lack of longitudinal, real-world case studies of system usage. Such studies are important because real-world ubiquitous computing systems are culturally situated, which cannot be reliably assessed with lab studies detached from the real-world context. Infrastructure and time are needed to establish the required technical and cultural readiness and the critical mass of users, before a ubiquitous computing system can be evaluated '(un)successful' [3]. The vast majority of mainstream research consists of studies that typically last a few days or weeks at best. Further, from the viewpoint of urban computing these studies are often executed in artificial settings such as labs and university campuses. While they allow execution of cost-effective and controlled experiments, they inevitably fail to address the real-world urban context.

Figure 1.   Outdoor UBI-hotspot at downtown Oulu.

Interestingly, while many research communities have made long-term large-scale investments in shared infrastructure to support joint and transparent research, such

as radio telescopes and networking testbeds, no such attempt has been made by the ubiquitous computing research community. We have launched an ambitious initiative of establishing an open urban computing testbed in a city center [17]. A key component of our laboratory is a novel concept called UBI-hotspot (later hotspot, Fig. 1). In our long-term vision the urban space is populated with hotspots, which provide rich interaction between the physical, virtual and social spaces. Our hotspot is effectively a large public display embedded with other co-located computing resources such as wireless access points. It offers a range of infotainment services realized with well-known Internet components.

We do not offer our hotspots as solutions to particular (research) problems at downtown Oulu, which undoubtedly would survive just fine without the hotspots. Instead, we promote our hotspots as 'heavyweight' urban probes [19] and research enablers. A probe refers to an instrument that allows measurement of an unknown, producing hopefully useful and interesting data. In our case the unknown is the urban landscape, where new technology is emerging and where complex social roles of the urban communities, people's movement and traces through cities, and people's interactions with place and public artifacts intersect. An urban probe is a direct constructive intervention to the urban landscape, to alter or disrupt the usage, actions or flow within the urban space. An urban probe must be an artifact that does not blend into the landscape, but is provocative enough to elicit direct reaction and promote immediate discussion about it. By assessing the reaction and interaction of people and place with the new artifact we hope to learn more about the urban landscape.

Further, the hotspots enable in-situ urban computing research with real users and with sufficient scale and time span. The hotspots are effectively versatile computing platforms, which facilitate provisioning of a diverse range of services to the general public in authentic urban setting. By deploying a number of hotspots for a sufficiently long time we wish to establish the technical and cultural readiness and the critical mass of users needed for determining whether this kind of computing infrastructure and services would be an useful addition to the urban landscape or not.

In this paper we describe the design, implementation and deployment of a network of hotspots in Oulu, Finland. We focus on the first version of the hotspot which offers a wide range of services via different interaction modalities including mobile. We analyze the usage and user acceptance of the hotspots from qualitative and quantitative data collected from June 2009 till January 2010. We conclude with a discussion on main findings, challenges and future work.

II. RELATED WORK

A rising trend is seeing large public displays being built as integral parts of public urban spaces, ranging from the giant wall-sized displays at Times Square to digital boards in public transportation stops, interactive touch-screen displays in taxi cabs, service directories in malls, and so on. The powerful visual capacity of these urban screens is typically employed solely for commercial broadcast and digital signage. These types of displays tend to elicit so-called display blindness, so that people either quickly glance or completely ignore the displays [6, 14].

The attractiveness of public displays may be enhanced by providing co-existing usage models and interactive affordances. Different types of interactive displays have been developed by both industry and academia [13, 25, 27]. For most parts, deployments of interactive public displays have been carried out by research organizations, although some commercial interactive display installations do exist, e.g. BBC Big Screens. Examples of research prototypes include the CityWall [20] installation in downtown Helsinki, where researchers focused on analyzing the emerging social interaction patterns in a public setting. Besides identifying interaction roles such as mentoring and ad hoc collaboration, they also verified the so-called honeypot phenomenon, identified also in [2, 4]. It refers to the process where ongoing interaction on a public display serves as an attention incentive for others to also approach the display and shift from passive on-lookers to active participants. Other research projects utilizing large public displays include the iDisplays project where public displays were used to support pedestrian navigation [13], and the eCampus project where a network of public displays with different levels of interactivity were deployed throughout the Lancaster University campus [25].

The explosive proliferation of powerful mobile devices has given rise to an increasing interest in utilizing these devices also in conjunction with public displays. The affordances provided by the high visual capacity of large displays combined with the mobile device as a private UI element and input channel has been studied from different perspectives. Among others, research directions have included distributed multi-user access to a single public display with personal mobile phones [22], migratory user interfaces capable of traversing among different devices, maintaining the state of the application and enabling continuous interactivity regardless of the used terminal [1]; providing multi to a single public UI rendering and language abstractions study the transition of UI elements between heterogeneous device types through UI rendering engines and high-abstraction description languages [16]; and application composition, where architectures commonly make independent decisions on physical and logical composition of the application and its logical parts including the presentation layer during runtime rather than design-time or compile-time [18].

In comparison to these studies, our work differs in terms of scale, time span and the real-world urban setting.

III. ANALYSIS OF USER NEEDS

We started mapping of the user needs that could be satisfied with our hotspots by conducting in situ interviews around downtown Oulu in September 2008. Researchers equipped with a mock-up display, a whiteboard rigged on wheels, asked people to describe their needs and offered them with the possibility to interact with the mock-up display by drawing their ideas of useful services on the

whiteboard. We also solicited for suggestions of locations, where these types of displays would be useful. The interviews were videotaped and researchers also gathered field notes and photographs.

During the course of the two-day study 74 free-form interviews were conducted in four central locations, which we had identified as potential hotspot locations (1, 2, 6 and 7 in Fig. 4). Overall, the feedback received from people was positive, and the need for this type of public infrastructure was recognized. The most often suggested types of services included public transportation timetables (by far the most common), municipal and commercial services, current and upcoming events in the city, news headlines, micro-weather forecasts, free parking spaces around downtown, and status of queues at taxi stops.

The suggestions resemble the traditional ideas of ubiquitous computing applications. People did not dare to innovate outside the box or, more probably, could not conceive the possibilities provided by this type of new infrastructure simply because they had never been exposed to a similar structure and had no previous cognitive models on what would be possible. During the interviews researchers proffered the idea of interacting with the public display using a mobile phone, but the concept seemed to be generally quite hard to grasp.

We also employed storytelling as a non-formal method to both identify user needs and to give our community a chance to actively participate in the innovation process. Right after we received the official confirmation of the funding for the hotspot infrastructure in late October 2008, we published in the local main newspaper a large article, which outlined the concept of the upcoming hotspots and our vision of ubiquitous Oulu in year 2020. The article challenged the citizens to write their own stories of how everyday life would be like at downtown Oulu in year 2020. As a stimulant we wrote a set of our own "Oulu 2020" stories, which were published on the project website. However, even though a raffle with handsome prizes was arranged to entice citizens to write stories, the final outcome was rather disappointing. We received only a handful of stories, ranging from ordinary to the other extreme.

IV. DESIGN

A. Interaction model

In designing the overall affordance of the hotspots, we aimed to integrate three distinctive levels of interaction on a single physical display. First level is passive digital signage, which is currently the de facto use case for public displays. Second, we wanted to support fluid and ephemeral, walk-up-to-use interactions trough the display's touch screen. On the final level, we aimed to support distributed application structures that would utilize the public display in conjunction with data and control from a personal mobile phone. Orthogonal to this layering, we also wanted the display platform to inherently support negotiating the different social configurations taking place throughout the interactions [20].

As a conceptual interaction model, we have used a slightly simplified version of Vogel's framework for interaction phases on public displays [28]. The framework contains four separate interaction phases, ranging from *ambient display phase* to *implicit interaction phase, subtle interaction phase,* and *personal interaction phase*. In our design, phases one, three and four are clearly present, with phase two, *implicit interaction*, missing due to the level of publicity of the displays: on a crowded street, determining whether or not a single person is open to communications from the system is effectively impossible. Therefore we decided to set the first threshold in the *subtle interaction* phase, where the user stops in front of the display and indicates interest in the display by looking at it.

The state machine that controls the allocation of screen real estate to different interaction phases is straightforward: the display alternates between a passive broadcast mode (Vogel's *ambient display phase*) and an interactive mode (Vogel's *personal interaction phase*). The transition between the modes is triggered by the following interaction events: a user touches the display panel, a face is detected from the video feed of the two overhead cameras (Vogel's *subtle interaction phase*) and a user is authenticated via an RFID-based physical user interface. The end of the interaction is determined with a timeout since the last interaction event, after which the hotspot returns to the broadcast mode. We refer to these interaction periods commonly as *sessions*.

Our interaction model differs from Vogel's linear model in that arbitrary phase transitions are allowed. The rationale for utilizing cameras is to identify in real-time the orientation of the persons standing next to the display, as well as to differentiate between other physical objects in front such as bicycles, thus effectively reducing false positives in the state transitions. At the same time we are aware of the limitations of camera-based face detection, especially in challenging lighting conditions. The argument for utilizing RFID-based physical user interface for mobile use was to realize bottom-up application composition, where the user first pairs together the devices desired for the application structure, and then proceeds to launch the application. Recent research suggests that users better grasp the idea of composing together physical devices than performing the same composition on a software level [9].

B. Conceptual software architecture

The modular software architecture (Fig. 2) is designed to allow each hotspot to function individually based on its proximity context. At the same time the hotspots are also networked in a loosely-coupled fashion via an event-based communication overlay, which allows the hotspots to publish and subscribe to events related to their context. This design allows application distribution on multiple levels, from reliance on one hotspot to the utilization of multiple physically separated hotspots simultaneously. This event-based control signaling is indicated with solid lines.

The requirement for allowing each hotspot to function individually based on its proximity context is addressed by decentralizing resource management of the hotspot. Every hotspot has a local resource manager, which communicates with a number of resource wrappers on the local communication bus. Of these wrappers the layout manager is

the most important one, while the auxiliary context wrappers such as the RFID manager function as abstract proximity context producers towards the resource manager. The resource manager is also responsible for negotiating with the mobile clients regarding the utilization of the hotspot in distributed mobile applications. The hotspots and mobile clients use the same event-based communication overlay with a flat addressing space. Within this overlay, events produced by the hotspots and mobile clients are being routed based on their content, relieving the need for referential and temporal coupling of communication endpoints. This design suits well the dynamic behavior of our distributed system, where mobile clients join and leave the overlay stochastically, and hotspots need to be occasionally taken offline. In effect, we wanted the system to have a certain degree of self-organization in order to avoid having to subsequently conduct complete system initializations based on differing device configurations.
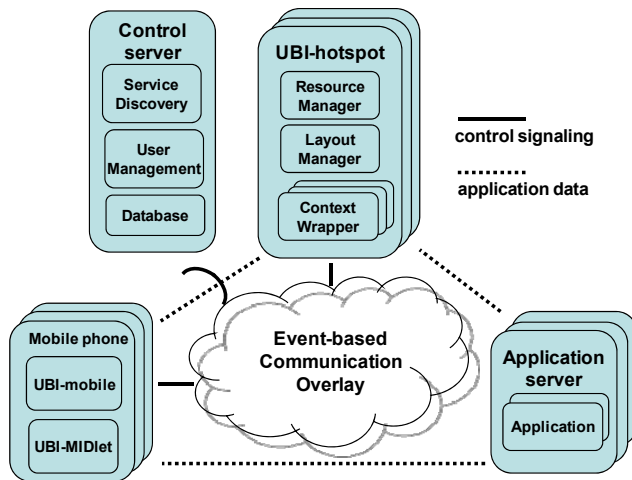

Figure 2.   Conceptual software architecture.

From the viewpoint of distributed applications, the flat addressing space translates to both the mobile clients and the hotspots acting as candidate presentation layer components for applications. The application logic resides on a remote application server, and the mobile clients communicate control messages to the server based on the private UI. The hotspots, on the other hand, are instructed to fetch a certain application presentation from the remote server, and this presentation can be dynamically updated based on the execution of the application. Each application publishes its metadata for the hotspots to examine in runtime. This metadata includes a unique identifier for the application and the address (URL) of the hotspot-side presentation. The application-specific data streams are indicated as dotted lines.

The control server is a collection of server resources responsible for runtime application discovery, authentication of users within the system, as well as hosting application metadata. The detailed description of the control server functionality is out of the focus of this paper.

V.   Implementation

A.   Hardware

The UBI-hotspot comes in two different versions for outdoor and indoor use. They both are customized versions of the Icon57 DID (Digital Information Display) product manufactured by Symbicon Ltd. The customization included both the desired visual appearance and equipping the DID with the additional hardware components. While the indoor version has one LCD panel controlled by industrial grade PC, the outdoor version is two-sided with two LCD panels back-to-back and separate control PC's for each panel. The LCD panels and other components are confined in a weather proof aluminum casing with heating and cooling systems.

A key component of the hotspot is the 57" landscape LCD panel with full HD resolution. The panel is protected by a 6 mm hardened safety glass. Behind the glass is a projected capacitive touch screen foil. The UBI-hotspot is equipped with a set of additional hardware components. A loudspeaker is implemented by a transducer that transforms the front cover to a loudspeaker. A NFC reader is attached behind a plastic window in the front of the case and two cameras are integrated to the top frame of the case. Bluetooth, WLAN and WSN (Wireless Sensor Network) access points are placed inside a special weatherproof equipment box inside the DID case, and their antennas are integrated into the roof of the casing.

B.   Software

Our goal was a cost-efficient implementation utilizing existing open source and Internet components. In the following we briefly describe the implementation of the key components of the conceptual software architecture.

Event-based communication overlay functionality is implemented with the open source FUEGO architecture [26]. It realizes the publish/subscribe communication paradigm together with a content-based routing scheme, allowing the overlay endpoints to self-organize as a loose collection of resources without temporal and referential coupling. In addition, the FUEGO overlay handles the mobility of endpoints, and implements fault tolerance callbacks to allow abnormally leaving endpoints to perform a graceful re-introduction to the overlay.

Resource Manager implements the resource management functionality as a threaded server, which takes input events from different context wrappers and instructs the layout manager according to the management policies set forth in the configuration of the hotspot. For negotiating device compositions with mobile devices, the resource manager employs a notion of lease, which is a negotiated contract between the mobile client and the hotspot, governing the execution of a chosen application. This agreement can be further specified with spatiotemporal constraints, if the management policy of the hotspot so dictates. Leases inherently support multi-user applications involving multiple mobile clients through runtime typing of a lease, as dictated by the metadata of the application chosen by the user. In case of private applications, subsequent leases negotiated to the same hotspot are placed in a FIFO queue

and mobile clients are notified when pending leases from the queue are activated. [8]

Layout Manager takes care of the dynamic partitioning of the screen real estate into virtual screens sandboxed using HTML iframes. The layout manager implements a finite state machine, where explicit states (compositions of virtual screens) are predefined, but not the applications assigned to them. The layout manager provides a web service interface (SOAP) for triggering state changes and assigning virtual screens with URL's of arbitrary web applications. [12]

UBI-mobile is the mobile access point and service discovery interface. It displays the available services at a particular hotspot, and handles the negotiation of leases with the resource manager. As for service discovery mechanism, we're currently utilizing an RFID-based physical user interface to access services [21]. UBI-mobile launches mobile services, implemented as J2ME MIDlets in the current version via the MIDP 2.0 Push Registry mechanism. **UBI-MIDlet** is the underlying light J2ME software layer (aka stub) that provides native service support by inheriting them from the standard J2ME MIDlet application framework. It implements session control, authentication and transparent integration with the server components. The UBI-MIDlet's responsibilities include taking over the control of a lease from UBI-mobile during the startup of a service, thus each application always controls one lease. [5]

C. Services

The selection of services to be provided by the hotspots was partially driven by the findings of the user study and the (un)availability of required content resources. Further, some services were included as provocative interventions to the urban space, to serve as probes for identifying useful services.

In the passive broadcast mode the whole display is allocated to a digital signage service dubbed UBI-channel. In the interactive mode the display is partitioned between the UBI-channel, a touch screen portal called UBI-portal and a window reserved for mobile services (Fig. 3).

Figure 3.   The UBI-hotspot in the interactive mode: UBI-channel in the upper left part, mobile application window on lower left, and UBI-portal in the right half showing real-time bus schedule for the selected busstop.

UBI-channel is a digital signage service, where a playlist comprising of spots (full HD image or HD ready/full HD video) is repeated. In the passive broadcast mode (ambient display phase) the whole screen is allocated to the UBI-channel, while in the transition to the interactive mode (personal interaction phase) the UBI-channel is smoothly squeezed into the upper left hand part of the screen. The UBI-channel is implemented as a separate web page containing an open source JW player. It loads the playlist from an XSPF feed that is generated by the layout manager. All media files referenced by the feed are locally cached and hosted by the local HTTP server. This way the media needs to be downloaded to the hotspot only once and the UBI-channel remains functional also in case of network failure. The playlist can be configured on per hotspot basis.

UBI-portal is effectively a web portal of various information and leisure services. The pages (services) in the portal are referenced by an URL and can reside on any web server in the public Internet. The pages in the UBI-portal can be configured on per hotspot basis. The generic functionalities include language selection, a service specific help page and two buttons for giving "thumbs up" or "thumbs down" for the currently selected application. The portal employs a two-level navigation hierarchy, where the 1st level services are *Map* (starting view)*:* a map-based service and information directory based on Google maps, including bus stops with real-time schedules, restaurants, cafés, hotels, libraries, restaurants, and UBI-hotspots; *Oulu Today*: up-to-date news, events and weather information, provided by the local main newspaper. This service is a prime example of the openness of our architecture, where 3rd party services can easily be integrated into the portal.; *Multimedia:* multimedia content such as images and video, including user generated content uploaded from personal mobile phones; *Fun and Games:* entertainment and leisure services; *Help:* usage instructions and relevant information; and *Survey:* online questionnaire (see section VI.B).

A 1st level tab may have a second level of tabs corresponding to services within the first level category. The 2nd level tabs under *Multimedia* are *Street Gallery* (starting view): an interactive art gallery for presenting exhibitions provided by up and coming new media artists; *Photos:* a collection of images with the tag *Oulu* retrieved from Flickr and displayed with a customized version of the *TagGalaxy* 3D browsing interface; *UBI-photos:* a collection of photos uploaded by users from their mobile phones. The uploaded images are tagged with appropriate tags and stored in Flickr. The photos are also displayed using the TagGalaxy interface; *Videos:* a collection of general videos about Oulu provided mostly by City of Oulu and stored on our own central media server. *UBI-videos:* videos uploaded by users from their mobile phones. Videos are stored in YouTube and displayed on a customized interface. Inappropriate user uploaded content in UBI-photos and UBI-videos can be flagged and temporarily removed by the community for later inspection by a moderator.

The second-level tabs under *Fun and Games* are *Hangman* (starting view)*:* the traditional game of hangman; *UbiPostCard:* a social application where using the integrated

cameras people can take a photograph of themselves in front of a hotspot and send it to a friend by email; and *UbiFridge:* a social word-game application where users can form short sentences by moving individual words represented by refrigerator-door magnets, and can send the sentence to either a mobile phone or to a friend over email. The word magnets are display-panel-specific and the state is maintained between user sessions. Thus a subsequent user can continue the sentences made by a previous user.

Mobile services require the user first authenticating himself/herself by presenting a so-called personal UBI-key to the RFID reader of the hotspot. The UBI-key is effectively an RFID tag paired with the personal mobile phone. The mobile services include *UbiPoker:* a multi-player Texas hold'em game, demonstrating the multi-user capabilities of the hotspot.; *UbiAlbum*: an application for users to manage the content they had uploaded to the displays (add/remove tags from photos, remove photos or videos etc.); *BlueInfo:* a collection of information services including bus schedules, weather information, news from Kaleva and Reuters, and TV programs, all of which can be pulled to a registered mobile device over a Bluetooth connection from the hotspot [11]; and *PlaceMessaging:* a bulletin-board service allowing people to post notes containing text and images from their mobile phone to the display. Each hotspot has its own PlaceMessaging board, thus enabling place-based messaging.

D. Deployment and maintenance

We have installed 12 hotspots around downtown Oulu (Fig. 4), so that hotspots 1-11 were deployed in May-July and hotspot 12 in early November, 2009. The five outdoor hotspots 5-9 cover the entrances and the center of the pivotal walking street area at the heart of the city, while the sixth (2) is placed at the main entrance to the market area. The indoor hotspots are placed in popular public buildings. Valve (3) is the youth and culture center, and Oulu10 (4) is the main municipal service center of the Oulu.
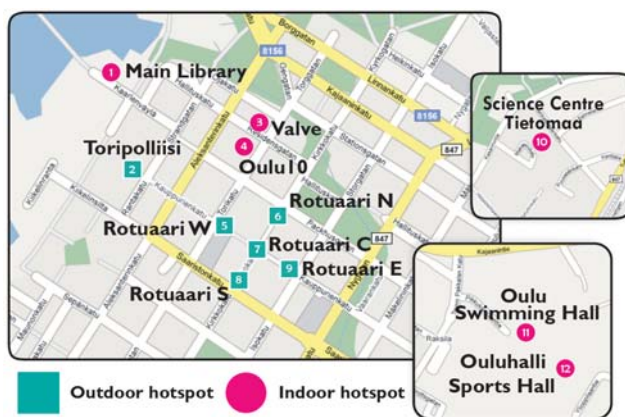

Figure 4.   Locations of UBI-hotspots around downtown Oulu.

Daily maintenance chores include the cleaning of the LCD panel, as a dirty panel would not invite people to touch it. We have deployed open source Nagios for automatic monitoring of the key processes and resources of the

hotspots. Further, a collage of the screenshots from each hotspot is updated every 60 seconds onto a management web page so that we can see what the users of the hotspots see, as recommended in [25]. The most troublesome technical problem we have had is the uneven performance of the touch screen foils, which degrades the usability of the UBI-portal.

VI.   Evaluation

We have systematically collected qualitative and quantitative research data on the usage and user acceptance of the hotspots since June 2009. The qualitative data was collected during a three-month long field trial executed in June-August 2009. The first half of the field trial was used to complete the installation of the 11 hotspots by early July and to finalize the mechanisms for collecting quantitative data, which commenced on July 17, 2009.

The field trial was coordinated from a field trial office placed in the lobby of the Oulu10 service point of the Oulu (location 4 in Fig. 4). The office was equipped with an indoor hotspot and a pool of suitable mobile phones that were loaned out to users. The office was operated by a customer service team of six students. They also were on call at the hotspots, advising people in the use of the hotspots, collecting observations of the use of the hotspots and conducting in-situ interviews of users at the hotspots.

We tried to recruit people as identified test users, which effectively required them to come to our field trial office to collect their personal UBI-key which was paired with their personal mobile phone. Regrettably, we managed to sign up only 80 test users during the field trial. Consequently, the usage of the mobile services that required the UBI-key remained rather minimal. We have to keep in mind that the services of the UBI-portal could be used anonymously without the UBI-key.

We have had hardware failures, mostly nonresponsive touch screen foils, and other issues such as one incident of vandalism, which have temporarily rendered a particular hotspot or panel unavailable.

A. Quantitative data

The actual usage of the UBI-hotspots can be quantified in a very detailed fashion from the logs created by the layout manager and the resource manager. The layout manager records the start of each interactive session (transition from the broadcast mode to the interactive mode) and the clicks of the 'control buttons' (1st level tab, 2nd level tab, language selection or thumb vote) in the UBI-portal (not those 'inside' the services). The resource manager records leases granted to mobile client and the events produced by the context wrappers, e.g. face being detected, screen being touched, or an UBI-key being read by the RFID reader. In this paper we focus especially on the layout manager log and the usage of the UBI-portal. An analysis on the usage of the mobile services is reported in [5].

The graph in Fig. 5 shows the number of daily interactive sessions from July 17, 2009 till Jan 31, 2010. Table 1 provides comprehensive statistics of the usage of individual hotspots during the same 199-day period (A and B correspond to the two panels of an outdoor hotspot). When

we study session statistics, we have to keep in mind the three different mechanisms for triggering the interactive mode and thus the start of a session. The user touching the screen or presenting the UBI-key to the RFID reader correspond to explicit initiation of the personal interaction phase. The hotspot detecting a face in front corresponds to the subtle interaction phase, e.g. someone in a group of people facing the hotspot sufficiently close or just briefly glancing at an interesting spot in the UBI-channel, which is sufficient to either trigger the interactive mode or to reset the 90 s timeout value for the current interactive session. Thus, many interactive sessions do not contain any usage of the UBI-portal and many UBI-portal sessions appear having lasted much longer than they actually did, if only the active usage of the UBI-portal is taken into consideration.
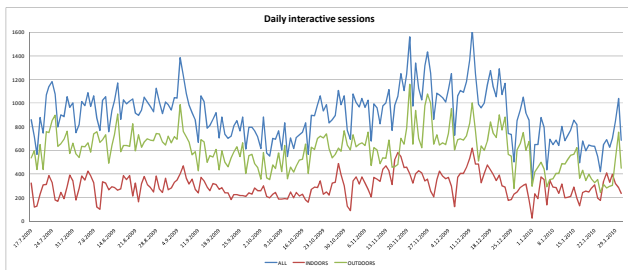

Figure 5. Daily interactive sessions in all 12 hotspots.

We observe a weekly cycle in the usage of the outdoor hotspots with peaks on Saturdays, when people crowd the city center for shopping. The 174505 interactive sessions correspond to an average of 877 sessions per day or 49 daily sessions per panel. In 26 % (32 % indoors, 24 % outdoors) of the sessions the user browsed the UBI-portal after the transition to the interactive state. The proportion of such sessions has dropped from 36 % (30 % indoors, 38 % outdoors) in July 2009 to 20 % (32 % indoors, 12 % outdoors) in January 2010. The arctic conditions in Oulu during the winter months do not invite the users to fiddle with the outdoor hotspots, whose capacitive touch screen foils do not respond to gloves.

Comparing the usage of indoor hotspots 4 and 11 underlines the importance of the location. Hotspot 4 located at the entrance hall of the main municipal service center of the city has recorded only 2.4 UBI-portal sessions per day. Hotspot 11 located at the entrance hall of the main swimming hall of the city has recorded whopping 49.4 UBI-portal sessions per day with double the average number of clicks per session. Compared to the 'businesslike' municipal service center the swimming hall has proven to be a favorable location, as the patrons there are in a relaxed mood with some spare time, either waiting for their training shift to start, a friend to arrive or to come out of the locker room, or their ride home. Sometimes we have observed children queuing up in numbers to play Hangman there. Similarly, hotspot 12 installed at the entrance hall of the indoor sports hall in early Nov 2009 is attracting a plenty of use.

Along the same lines, outdoor hotspot 2 in the market area has had a larger proportion of UBI-portal sessions than the other five outdoor hotspots in the walking street area at the heart of the city. This reflects the fact that while people are busy running errands in the walking street area, they are in much more leisurely mood in the market area, which leaves them with more time to interact with the UBI-hotspot.

Generally, a majority of the users of the hotspots are children and youth, who appear much less inhibited to try out the hotspots than the grown-ups. This shows in Fun and Games being the most popular service category with 31% share of the clicks on the 1st level tabs. In addition to Hangman, UbiPostCard has become a popular service attracting the largest proportion (22%) of clicks on the 2nd level tabs. The 16091 navigations to its page have led to the submission of 4884 cards, which we find quite remarkable. 40% of the cards have been submitted from the two popular hotspots (2 and 11) discussed above.

TABLE I. USAGE STATISTICS OF INDIVIDUAL HOTSPOTS ([1]BROKEN TOUCH SCREEN, [2]INSTALLED IN NOV 2009)

	INDOOR HOTSPOTS							OUTDOOR HOTSPOTS													ALL HOTSPOTS
	1	3	4	10[1]	11	12[2]	total	2A	2B[1]	5A	5B[1]	6A	6B[1]	7A[1]	7B	8A[1]	8B	9A	9B	total	
Days w/ interactive sessions	188	198	197	175	196	71	1025	199	186	199	196	188	169	197	160	171	196	199	198	2258	3283
Days w/ UBI-portal sessions	184	182	126	91	190	64	837	195	185	199	84	187	166	90	130	171	192	195	193	1987	2824
Interactive sessions	10479	12438	9851	2144	15248	3500	53660	8957	10406	14205	10123	9240	6946	11712	12375	8038	9755	9563	9525	120845	174505
UBI-portal sessions	2852	2155	474	420	9673	1851	17425	3556	3920	3547	1061	2870	2097	656	1962	1706	2340	2110	2619	28444	45869
% of all sessions	27	17	5	20	63	53	32	40	38	25	10	31	30	6	16	21	24	22	27	24	26
Per day	15.2	10.9	2.4	2.4	49.4	26.1	17.0	17.9	21.1	17.8	5.4	15.3	12.4	3.3	12.3	10.0	11.9	10.6	13.2	12.6	14.0
Average duration (s)	465	523	553	684	405	494	450	530	787	359	573	368	394	389	430	480	416	478	371	478	467
Total number of clicks	14530	13300	2292	2337	108817	18460	159736	20049	24068	17053	5662	16434	11098	2821	11390	9056	12425	11047	12480	153583	313319
Clicks per session	5.1	6.2	4.8	5.6	11.2	10.0	9.2	5.6	6.1	4.8	5.3	5.7	5.3	4.3	5.8	5.3	5.3	4.8	5.3	5.4	6.8
1st level tabs	8863	7004	1238	1286	64555	11057	94003	11660	14802	10070	3430	9170	6001	1582	5822	4966	7028	6218	7273	88022	182025
Map (%)	20	15	18	17	17	15	17	17	18	16	18	17	18	14	32	18	17	16	17	18	18
Oulu Today (%)	26	20	26	17	16	15	17	24	26	24	25	23	24	23	0	22	22	21	22	22	20
Multimedia (%)	15	17	21	19	18	17	17	20	19	19	19	19	18	18	22	19	19	19	20	19	18
Fun and Games (%)	27	36	15	37	35	38	34	25	23	28	25	27	28	34	32	29	31	32	30	28	31
Survey (%)	6	6	16	5	7	7	7	7	8	6	7	7	7	6	8	7	6	7	6	7	7
Help (%)	7	5	4	5	7	7	7	6	6	6	5	7	6	5	6	5	5	6	5	6	6
2nd level tabs	2516	3865	373	623	26177	4389	37943	4631	5313	3922	1288	3642	2432	741	2953	2543	3320	3005	3021	36811	74754
Street Gallery (%)	6	5	8	3	5	4	5	9	10	9	9	10	9	8	10	9	10	8	9	9	7
Photos (%)	14	12	16	9	12	10	12	17	18	18	18	16	18	17	17	17	14	16	18	17	14
UBI-photos (%)	9	9	26	12	7	7	8	13	13	13	13	12	12	16	13	13	12	11	13	13	10
Videos (%)	8	7	8	8	8	7	8	9	9	8	8	9	9	7	8	8	8	8	8	8	8
UBI-videos (%)	5	4	6	5	5	3	5	5	5	4	4	4	5	3	7	4	4	5	4	5	5
Hangman (%)	20	26	9	22	20	23	21	13	14	13	12	16	15	14	16	16	16	15	15	14	18
UbiPostCard (%)	19	21	17	21	24	24	23	20	18	21	20	19	19	22	17	20	21	23	20	20	22
UbiFridge (%)	19	17	11	21	19	20	19	13	14	14	14	15	14	12	13	14	15	14	14	14	17

B. Qualitative data

UBI-portal questionnaires and thumb votes. The questionnaire provided on the survey page in the UBI-portal comprised of two demographic attributes (gender and age range) and eight statements randomly drawn from a set of 31 statements. The 31 statements were grouped into eight categories addressing different aspects of Nielsen's system acceptance model [15] (social acceptability, reliability, usefulness, learnability, efficiency, memorability, errors, and satisfaction) so that one random question from each category was included in a particular questionnaire. A respondent was supposed to assess each statement on 5-point Likert scale. The submission of an incomplete questionnaire was allowed.

In total 927 questionnaires were submitted via the UBI-hotspots during the field trial. We discarded 216 such questionnaires that did not contain any answers (155) or had assessed less than four statements (61). Table II summarizes statistics for selected statements by reporting the number of respondents and the percentage of them agreeing (4 or 5) and disagreeing (1-2) with the statement. We can observe a tendency towards accepting the hotspots and services as a useful addition to the downtown area. However, it is obvious that the service portfolio did not completely satisfy the needs of the respondents, as only 25% of them reported that the services in the hotspots have boosted their daily tasks.

1805 thumb votes were cast via the UBI-portal. Map, Oulu Today and Hangman collected 74% of the votes with ups and downs evenly balanced. Only three services scored +60% of votes either way: UbiPostCard (N=71, 👍65-35👎), UBI-videos (N=13, 👍62-38👎) and Photos (N=39, 👍36-64👎).

TABLE II.　　SELECTED STATISTICS OF UBI-PORTAL QUESTIONNAIRES

Statement	N	Agree (%)	Disagree (%)
Using UBI-hotspot in a public space feels natural	62	63	21
UBI-hotspots fit in downtown Oulu	75	61	24
UBI-hotspots make downtown Oulu a more interesting place	124	52	26
In my opinion UBI-hotspots are useful	228	47	36
I got useful information from the UBI-hotspot	216	44	37
The services in the UBI-hotspot have boosted my daily activities	194	25	57
I found the needed information from the UBI-hotspot quickly	138	41	36
I will use UBI-hotspots again in the future	125	66	22

We acknowledge the qualitative nature of this questionnaire data and carefully refrain from drawing too fast conclusions at this point. However, the numbers do support our optimism that the hotspots may be a useful addition to the public infrastructure of downtown Oulu.

Interviews. The members of the customer service team conducted both free-form and semi-structured interviews with people who had used a hotspot. 81 semi-structured interviews were recorded with audio recorders, and transcribed for later reference. The free-form interviews were not recorded, as they were on-the-street conversations in nature. During the interviews, we asked people to give their opinion on the usability and usefulness of the hotspots, and especially the different services provided through them. Among other things, we queried for improvement ideas and

suggestions for new services. We did not hang too tightly to the pre-set interview questions, but rather encouraged a more conversational style where people could address the issues they felt were the most important.

Findings from the interview data identify the map-service as the most useful information service. People especially appreciated the dynamic bus schedule service, often naming it their number one favorite from all services. A possibility for address- and route finding was often requested, and will be implemented in the near future.

"I think the services available here are useful. Bus schedules, weather, and news are interesting when I'm downtown. The map-service was especially good, now I won't have to call home and ask them to google where something or another is. An address-search function would be good to have." – Hanna, 25, female.

People readily agreed that the large form-factor of the hotspots makes finding and reading information easier when compared to using a mobile phone for the same task. People also agreed that the hotspots are apparent in the cityscape, but without being overly distractive.

"This is a welcome innovation. I think it was time people started taking their eyes off their mobile phone… Information has to be available where you can see it; people's lives revolve around their mobiles too much." – Maria, 23, female.

Opinions on whether or not interaction possibilities of the hotspots were apparent were strongly divided. Some had thought that the hotspots were purely commercial advertisement boards, and had not realized the interaction possibilities before seeing someone else using them. Other, on the other hand, had understood that the hotspots are interactive entities from the first glance.

"My first thought was, that instead of just wandering around town, I'll come to the display and search for nearby restaurants." – Raija, 35, female.

Mainly all feedback received during the interviews was positive. The main complaints people had were about non-responsive touch screens and low visibility in direct sunlight.

VII. DISCUSSION

We presented the modular design, the cost-efficient implementation, the large-scale deployment and the first results of the extensive empirical evaluation of the UBI-hotspots in real-world setting. In the design of the service portfolio we did our best to match the user needs identified in the user study. For example the real-time bus timetable service was called for in the user study and has been found useful by the users. The importance of user-created content and social networking is emphasized by the active usage and feedback of the UbiPostCard service. The popularity of the simple Hangman game, which we included as a provocative probe, shows that games and other leisure services have great potential, particularly among children.

We have observed an interesting 'disagreement' regarding the service offering. While pretty much everybody with research background has 'criticized' us for stuffing too many services into the hotspots, the general public has complained about the too limited service offering. We

believe that this dissatisfaction is at least partially driven by the rather limited Google Maps service database used in our Map service. A comprehensive and always up-to-date service and event database of the Oulu region does not exist, much less one with open web service interfaces. In the original plan of our research program we did have a large subproject exactly for the purpose of creating such a database with open interfaces, but unfortunately the subproject was axed by public financiers. Thus we are currently stuck with the existing limited service directories. This dilemma also emphasizes one of our favorite slogans - "content is king" - the user is interested in the content provided by your service, not in the technology behind the service regardless of how fancy it may be. The design and implementation of useful services requires high quality content, which can be expensive and difficult to obtain.

When thinking about the typical research questions related to large public displays, the challenge of enticing the user to interact with the hotspot was very apparent. A number of well educated citizens reported having had no idea that they could actually touch the hotspot. As one mechanism to persuade people to interact with the hotspot we included in the UBI-channel playlist a spot that invited people to touch the display. We did not collect extensive observation data that would allow assessing rigorously display blindness. However, this was implicit in the comments of local residents of whom many had regarded the hotspot by default as some advertising system or some tourist information kiosk. The honeypot phenomenon was very apparent. Many times when a member of our field trial team started fiddling with a lonely hotspot, citizens promptly gathered around him/her, obviously encouraged by someone else using the hotspot and fuelled by their curiosity of what can be done with this peculiar artifact.

As just seven months have passed since the installation of the first hotspot, it is far too early to draw any fast conclusions on the actual impact of the hotspots. Given the early qualitative user feedback and the quantitative usage data we are cautiously optimistic. However, we are still far from rigorously proving our abstract hypothesis of 'making the urban space a better place for people' with the new hotspot infrastructure and the services provided by it. It is fundamentally difficult, because there are no universally accepted metrics for evaluating this kind of a real-world deployment. Usability evaluation that has established itself as the de facto yardstick in mainstream lab studies is not sufficient for assessing real-world systems [3]. Building on recent attempts [10, 23], the research community should engage in a serious attempt at developing and adopting a framework for evaluating real-world deployments.

This kind of large-scale real life deployment comes with a number of challenges. First is balancing traditional academic research with development, public service and commercial use which are inevitable aspects in our work. Second is scalability, to what extent our ongoing infrastructure deployment in a small downtown of a city of about 140000 people would scale up to a really large urban space? Third is sustainability, as every infrastructure deployment is subject to study of its economical and technological sustainability. Many academic infrastructure deployments have fallen apart, because they did not have any long-term financial basis for covering maintenance and further development. While public sources, European Regional Development Fund and the City of Oulu, have covered the capital expenditure of our hotspots, we do not have public funding for their operational expenses. To cover them we are selling a portion of the capacity of the hotspots for commercial use, which in turn imposes obvious limitations on research use. Technological sustainability refers to the expected lifetime of the current infrastructure and the expensive renewal of outdated infrastructure in the future. Fourth is the demand for high quality engineering. Deploying and maintaining in a city center a large-scale distributed system that the user community expects to be available 24 hours a day seven days week is a totally different ball game than presenting a one-shot demo to your sponsors or conducting an evaluation in a controlled environment such as a usability lab. Fifth is urban planning, including the 'battle' for the urban space, the design of the visual appearance and the locations of the hotspots from the cityscape point of view, which is subject to strict formal approval and permit process by the City administration, and prevention of vandalism after deployment. Sixth is the public scrutiny by the general public and the local media, which has been very ill-tempered at times.

We acknowledge the fact that the first version of the hotspot described in this paper is by no means a 'complete' product but just a beginning. We are currently busy designing the version 2.0 to be launched for summer 2010. Upcoming enhancements include a slightly refined interaction model, revised login mechanism, possibility to personalize the look and feel of a hotspot, interactive UBI-channel, widget-based browsing interface for the UBI-portal, and more seamless distribution of the UI between the (private) mobile UI and the (public) display UI. A range of new services will be developed, primarily into the UBI-portal, by us and 3rd parties.

We are also still analyzing the vast amounts of log data being continuously collected on the usage of the current version 1.0. In this paper we used click counts to compare the usage of different UBI-portal services. While the click counts are certainly indicative, we are trying to develop more robust statistics reflecting the actual usage (viewing) times of individual services (pages). However, as discussed in Section VI.A, the current interaction model produces interactive sessions of varying nature, which introduces ambiguity in the analysis. It is one of the reasons for refining the interaction model so that just glancing at the hotspot will not be sufficient for triggering the interactive mode.

We wish to emphasize the openness of the hotspots. As demonstrated by the Oulu Today service provided by the local newspaper, we can embed any 3rd party web service into the UBI-portal, as long as it fulfills certain design criteria. Our goal is to provide the hotspots as open horizontal resource accessible by the R&D community to facilitate large-scale innovation of new services. We cannot ourselves presume to foresee all the possibilities created by this new infrastructure. Thus open and transparent access to

the infrastructure is crucial in finding the killer applications that will make the hotspots irreplaceable to the community.

We have a number of activities to make the hotspot available to the whole R&D community and to stimulate innovation of novel services. Students build new services to the hotspots as their course works. We provide businesses with opportunities to purchase rights to offer commercial services in the hotspots and thus also generate revenue for covering the operational expenses. We are executing a national "UBI-challenge" where individuals and businesses are challenged to develop novel services to the hotspots.

The hotspots are a key infrastructure component of our open urban computing testbed [17]. Our long-term vision is to develop the testbed into shared research infrastructure to support joint and transparent urban computing research. An international "UBI-challenge" prepared with a number of leading international researchers will be organized in 2010-2011, inviting the international research community to show what they are able to do atop our testbed.

VIII. ACKNOWLEDGMENTS AND NOTE

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