

mTag – Architecture for Discovering Location Specific Mobile Web Services Using RFID and Its Evaluation with Two Case Studies

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Abstract

This paper introduces mTag, a distributed event-driven architecture for discovering location specific mobile web services. Service discovery is initiated by touching a fixed RFID reader with a mobile passive RFID tag attached e.g. to a phone, which results in information of available services being pushed to user's preferred device. We present a deployment proposal and prototype implementation, which is evaluated in form of two case studies in the true environment of use. The case studies show that mTag provides a promising approach for service discovery with mobile devices.

1. INTRODUCTION

Pervasive computing refers to a paradigm where the environment of the user is filled with computational capacity in order to produce services that are not possible with traditional ways of computer based systems usage. The research agenda of pervasive computing expands the previous generations' computer system evolution; distributed systems and mobile systems. According to Satyanarayanan [1], the pervasive computing introduces challenges such as smart spaces, invisibility, localized scalability and masking uneven conditioning.

We present mTag, a distributed event-driven architecture for discovering location specific mobile web services, which addresses two of the aforementioned challenges, smart spaces and localized scalability. The principal idea of mTag is that when the user touches a fixed RFID reader with his personal RFID tag, the system pushes to the user's preferred device information associated with the reader. This information can for example be a link to a web service

which is relevant to the user's location. Our hypothesis is that touching is a natural and robust way to indicate willingness to access location specific services. At the same time the system obtains reliable information of the user's current location, which can be utilized in provisioning other location-aware services.

mTag increases the computational capacity of the user's environment, thus addressing the pervasive computing characteristic *smart space*. RFID readers in the environment are connected to a back-end system, which is aware of the touching events recorded by the readers. Examples of the existing reader applications include building access systems, theft protection, commuting ticket systems, and goods flow monitoring. Areas covered with RFID readers can be thought as active environments, where mobile passive RFID tags initiate service events.

Opposite would be passive environments, where the user or the user's device is responsible for collecting the information and initiating services. This could be realized by equipping e.g. mobile phones with a RFID reader, which would be used for reading RFID tags distributed into the environment.

The main motivation for using fixed RFID readers installed to the environment, instead of having RFID reader carried by the users, is that the penetration of RFID readers in commercial mobile devices is currently negligible and it probably will take quite some time before they reach critical mass. As we show in the two case studies, the mTag architecture can be realized with current off-the-shelf products. Further, existing RFID readers in our living environment can be employed to connect them to a back-end system such as mTag.

Localized scalability refers to a service being more relevant and more easily available when the user is near to the physical focus point of the service. This is

incorporated in the mTag system, as the user needs to touch the reader, i.e. to be physically present to access the service. As the user moves away from the reader, touching is no longer possible. Thus, the user has to rely on discovering the service with other means, such as browsing the web, which may be difficult with a mobile device of limited HCI capabilities.

This paper is organized as follows. Section 2 reviews some of the related work. Section 3 introduces the conceptual mTag architecture and a deployment proposal. Section 4 presents the first case study, CampusTag, where the mTag system was deployed at a university campus. Section 5 reports the second case study, CityTag, conducted in a city center. Section 6 discusses the findings of the case studies and provides an analysis of the mTag architecture. Section 7 concludes the paper.

2. Related work

In the following we briefly discuss selected earlier studies on discovering location specific services and content based on touching an object with a mobile device.

Välkkynen *et al.* [2] define physical browsing, which is based on inexpensive information tags which are attached to objects without interference with the actual object. The tag contains an URL that is transmitted to the user's device for the purpose of retrieving digital content from the web. In the same research initiative Ailisto *et al.* [3] compare currently available technologies applicable to physical browsing, including RFID, IrDA and barcodes, for example.

The WebStickers system introduced by Ljungstrand *et al.* [7] is a concrete realization of the physical browsing paradigm. In their work users create mappings between physical and virtual worlds by attaching barcode stickers to real world objects and associating URLs to the barcodes.

Riekkii *et al.* [22] present a reference model for requesting services by touching objects in the environment. The objects are marked with small passive RFID tags having a particular visual appearance illustrating the service associated with the object. Objects are touched, i.e. tags read, with a mobile phone equipped with an RFID reader, resulting in the requested service being launched.

The general approach presented in these papers is opposite to mTag in the sense that in them passive tags are planted in the environment to be read with a mobile

device equipped with a reader, resulting in service discovery. In mTag fixed readers are planted in the environment and they are touched with a passive tag attached to a mobile device for the purpose of service discovery. Even though these two approaches have apparent similarities with respect to the services provided to the end user, they have distinct strengths and weaknesses which we discuss in detail in Section 6.

Earlier studies employing fixed RFID readers and mobile RFID tags include the LANDMARC indoor positioning system by Ni *et al.* [8]. The system also uses fixed tags as reference points to enhance positioning accuracy. Römer *et al.* [9] propose two frameworks for realizing ubiquitous computing applications based on fixed RFID readers and mobile RFID tags. Hall *et al.* [10] use fixed multi-mode (Bluetooth, RFID) readers and mobile RFID tags attached to mobile devices to enhance Bluetooth service discovery. The Bluetooth radio of a mobile device stays in a low-power standby mode until a reader is touched with the tag, resulting in reduced power consumption and improved spatial accuracy.

In a more general setting, Kindberg discusses mapping of physical objects to hyperlinks or URLs in [4] in the Cooltown project [5]. He introduces a scheme for binding unique identifiers to resources, together with an identifier resolution service that can be deployed in the web. The URL resolution is independent of whether the user or the environment provides the active reader. Merged with Hawke's TANN scheme Kindberg's work has led to the Tag URI proposal [6].

3. mTag architecture

The purpose of the mTag is to facilitate mobile discovery and retrieval of location specific content such as links to web services and multimedia presentations. More specifically, when the user touches a RFID reader with a RFID tag attached to a mobile device, the mTag delivers spatially relevant multimedia content to a mobile user's preferred device whenever the user tags an RFID reader with his personal RFID tag. We first present the mTag architecture on a conceptual level, followed by a more concrete deployment proposal.

3.1. Conceptual architecture

Figure 1 illustrates the conceptual mTag architecture with a functional diagram containing an interaction sequence demonstrating the system behavior. Term “function” in the image refers to an abstract high-level functionality that is not dependent on the implementation.

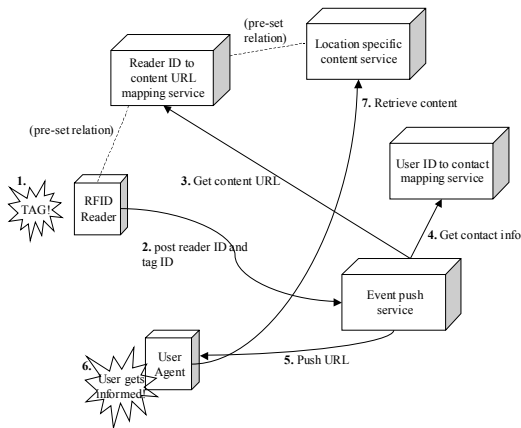


Figure 1: Conceptual mTag architecture presented in form of a functional diagram.

1. User tags an RFID reader (identified by a unique ReaderID) with his personal RFID tag (identified by a unique TagID).
2. The RFID reader transmits the TagID and its own ReaderID to the Event Push Service (EPS).
3. EPS retrieves the URL of the content associated with the reader, i.e. the content is deemed to be spatially relevant with the location of the reader.
4. EPS retrieves the contact information associated with the TagID, to identify the user's User Agent (UA).
5. EPS pushes the content URL to the UA.
6. The UA informs the user and depending on the implementation either automatically retrieves the content or waits for user's command.
7. UA retrieves the content to the user.

Pre-set relations refer to the mappings between RFID readers and the URLs of services associated with the readers. Creating and updating these mappings is a part of the content production process.

3.2. Deployment over Internet

Figure 2 shows a proposal for deploying the mTag architecture in Internet. Design goals have been global access, re-use of existing hardware and favoring software solutions supported by established open source projects.

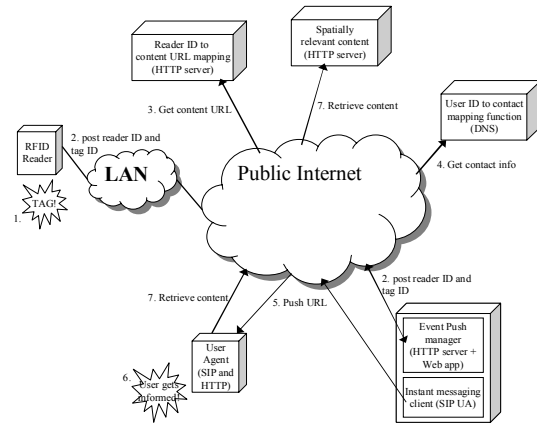


Figure 2: Deployment proposal.

The general principle in the deployment is to use HTTP POST (over TCP) requests to reach publicly available servers residing in the Internet and SIP MESSAGE request to reach the UA [11]. The usage of HTTP can be easily argued due to the massive usage of HTTP servers in the existing web infrastructures. SIP, however, does not have similarly overwhelming penetration and there are currently other competing technologies available such as Skype and MSN. They are not open systems, but both offer programming interfaces for utilizing the service infrastructure.

In the following we briefly describe each component:

LAN (Local Area Network) is probably the most common deployment environment for the RFID readers. It is sufficient that the Network Address Translators (NAT) and Firewalls (FW) allow outgoing HTTP requests, as the LAN edges are typically configured.

Public Internet is the common medium for all the functional components is the public Internet allowing unrestricted traversal of IP packets between public hosts.

HTTP server processes the HTTP over TCP/IP requests. HTTP server should have support for server

side scripting languages (e.g. for database utilization) and in the case of Event Push manager, support for either hosting independently running application threads or for making remote procedure calls in order to execute the Instant messaging client. Suitable freeware HTTP servers are available for download in the Internet (e.g. Apache [12], Tomcat [13]).

DNS (Internet Domain Name System) is one of the largest distributed naming services deployed today. In this deployment, firstly the DNS is used to resolve the host addresses of HTTP servers, possibly including dynamic DNS load balancing. Secondly, the DNS is used to resolve the instant messaging servers, especially the SIP proxies in order to reach the tag owners user agent. Thirdly, if the user has multiple contact identifiers and a globally standard phone number, the DNS can be used for the Electronic Numbering (ENUM) service [14]. ENUM offers mappings of user's phone number to variety of contact records. The benefit of having several contact records is that it gives the EPF more delivery options.

Web application and SIP UA are needed by the EPS. EPS receives HTTP post indicating that a user has tagged a reader. EPS retrieves the URL of the content associated with the reader and the contact information associated with the TagID via HTTP requests (see Figure 2). EPS then employs instant messaging (IM) client (SIP UA) to push the content URL to the user's device. The SIP UA should maintain the state of registration to the back-end SIP system. It is possible that the EPS's UA registers every time a touching event is processed but this would create a massive message transaction overhead. Maintaining the registration requires a server process listening to incoming SIP requests, which means that the EPS server either needs to be able to host worker threads or to be able to control a remote process.

4. Case study #1: CampusTag

The first case study took place in conjunction with a large-scale field trial named SmartCampus, which was conducted on the campus of the University of Oulu in April 2005. In the field trial a range of different prototype mobile multimedia services were tested by university students, staff and visitors. One of these services was CampusTag, a prototype implementation of the mTag architecture.

4.1. System implementation

Figure 3 illustrates the system architecture of the CampusTag service. The readers were connected within a single LAN with a single EPS (CampusTag server). The CampusTag database contained all the pre-defined mappings between the RFID readers and location specific content associated to them. MyCampus server was used to authenticate users for allowing them to change their settings via a web interface. Messaging service provided the functionality of pushing content to the user's mobile device, which in this deployment was realized with WAP Push Service Indication (SI) messages. The servers were built on Tomcat with MySQL databases.

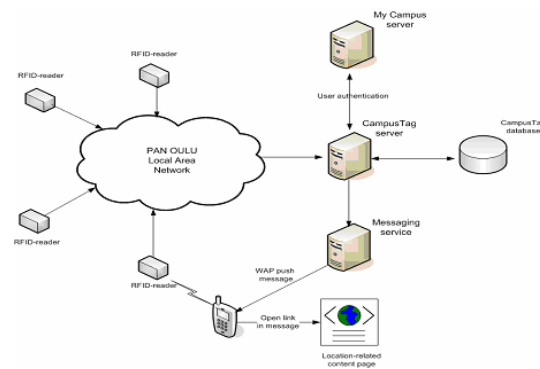


Figure 3: CampusTag system architecture

Idesco Access 7 CE [18] was employed as the RFID reader due to its Ethernet connection capability. The readers were connected to the Internet via the panOULU public wireless local area network [19]. Each reader was configured to have a static IP address, which also served as the ReaderID. Each reader was framed with an A4 size sign having a distinct black-and-white graphical design as shown in Figure 4(b).

The tags were Philips 13.56 MHz I-Code [17] stickers, which each had a unique TagID. Given the electromagnetic interference caused by the phone's battery and the low reading range of the tags, the tags were attached on the outside of the rear exterior of the phones, instead of hiding them inside the phone, as depicted in Figure 4(a).

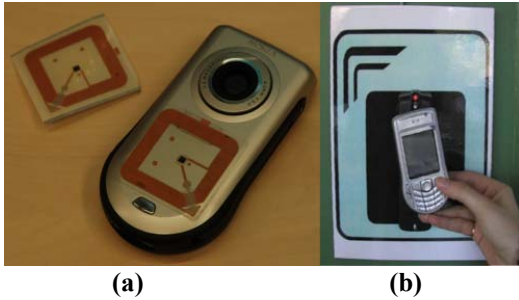


Figure 4: (a) A phone with an attached RFID tag; (b) A RFID reader is tagged with a phone.

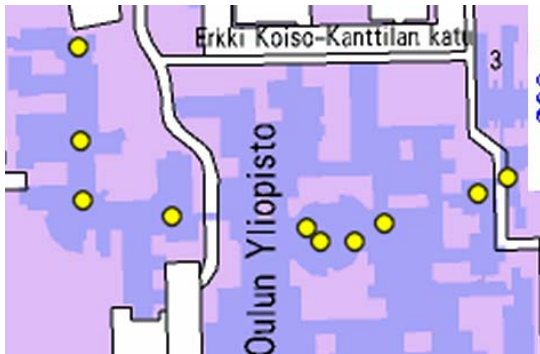


Figure 5: Locations of the readers on the campus.

As shown in Figure 5, ten readers were installed on the campus at pivotal locations such as main entrances, the bookshop and the main library. Each reader was associated with a web page, which contained links to web services relevant to the location of the reader.

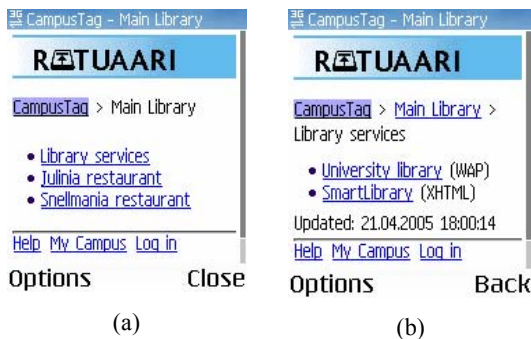


Figure 6: (a) Listing of the web services relevant at the main library; (b) Links to "Library services".

As an example, Figure 6(a) illustrates the services associated with the reader installed nearby the main library, naturally the mobile library services, and the menus of the two nearby cafeterias. Following link "Library services" the user easily obtains links to the mobile library services, as shown in Figure 6(b).

Using the SmartCampus services required user authentication with a username and a password which was based on Liberty Alliance Single-Sign-On (SSO) specification for federated network identity [20]. SSO was chosen to provide all SmartCampus services under one common identity federation service. SSO defines an identity provider that provides user authentication and manages user profiles (MyCampus server in Figure 3). The identity provider and service providers form a "circle of trust" defining the sources of user-authentication that can be trusted. Given this "circle of trust", the user can be automatically authenticated at a service provider, such as CampusTag, by having authenticated previously at the identity provider.

To activate the CampusTag service, the user had to conduct the following sequence via the CampusTag web interface:

1. Enter the phone number and TagID of the tag attached to the mobile phone, for the purpose of associating the tag with the phone number.
2. Confirm the association by touching any of the readers.
3. Response to a confirmation SMS message that was sent to the phone, to prevent registration of a wrong phone number.

When a reader detected a tag, the reader opened a telnet connection to the CampusTag server to transmit the TagID. The IP address of the transmitting reader was used to identify the reader. If the received TagID was valid (i.e. the CampusTag service was activated for this TagID), the corresponding phone number was fetched from the database. Then the messaging service sent a WAP Push service indication message to the phone number, containing the URL of the content page associated with the tagged reader. By browsing to the web page designated by the URL the user discovered the location specific mobile web services as shown in Figure 6. This process is equivalent to the one described in section 3.1.

4.2. Field trial setup

The SmartCampus field trial was coordinated from a field trial office. The staff at the office recruited

volunteers as test users, loaned out phones, provided guidance and collected feedback from test users. The general public was motivated to sign up as test users by rewarding each respondent with a cup of coffee and a pastry, and by conducting a raffle among all respondents.

Test users were able to loan a mobile phone for two working days from the office, together with instructions for activating the services. Different phone models based on Nokia S60, S80 or S90 platforms were available, equipped with either GPRS or 3G network connection. Each model was equipped with an XHTML browser and was capable of receiving WAP Push messages. An RFID tag with a unique TagID written on the tag was attached to each phone. Alternatively, test users could also use the services with their personal phone, in which case they could pick up an RFID tag from the office.

Qualitative data on user behavior and user experience was gathered with a questionnaire, which contained both open-ended and closed questions. The latter were presented as a series of statements on five-point Likert scale. General verbal feedback was also observed at the office although not recorded systematically.

Quantitative data was collected with server-side logging, providing statistics of principal actions such as tag activation, tagging a reader and viewing of content pages.

4.3. Main results

In total the SmartCampus field trial had 202 respondents returning a completed questionnaire. 52 of them stated in the questionnaire that they had used the CampusTag service, and about 50% of them reported having used the service only two times or less. However, log data reveals that only 30 user accounts really used an activated tag. Thus, over 40 percent of users faced insuperable problems in actually using the service with their personal account.

Activating the CampusTag service appeared to be the most difficult part hindering the actual usage. One reason is that the users found given instructions inadequate (“*activation of the service was really complicated*”, “*quick start instruction was really poor*”). Testing of several other SmartCampus services, each including their own instructions, at the same time also seemed to confuse the test users.

As the chart in Figure 7 shows, the CampusTag service received rather positive user acceptance, once the users had managed to complete the activation. Accessing location specific web services by tagging the RFID reader with the mobile phone was in overall considered easy. 40% of the users gave score 4 or 5 to the easiness of accessing location aware content and 48% of the users gave a score 4 or 5 to the general easiness of use.

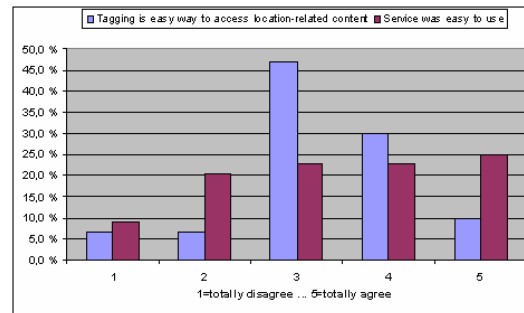


Figure 7: User feedback on CampusTag

Test users regarded the number (10) of readers to be insufficient for the campus. Suggested new reader locations included main lecture halls and all main entrances. Some users reported having difficulties in spotting the readers and requested the readers to have a more pronounced appearance.

A more versatile selection of web services was also requested. Of the available services bus schedules were considered as the most useful. Restaurant menus were also found useful but also criticized to be somewhat redundant, as the menu of a close-by restaurant could be obtained quite easily in a paper format as well. Some users inquired the possibility to have a personalized service selection, which is facilitated by the SmartCampus framework and is a potential topic for future work.

As expected, the data transfer rate of the network connection had a major impact on the user experience. With a 3G phone the access to the web service was obtained in less than 10 seconds after tagging. However, nearly 30 seconds were needed with a GPRS phone, which irritated many users (“*It was World Wide Wait*”).

Some users were confronted with poor service reliability (“*sometimes browser showed just a blank page*”), which was attributed to problems with Tomcat

installation and was estimated to cause negative bias to the feedback.

5. Case study #2: CityTag

The second case study took place at the downtown of City of Oulu in September 2005. The implementation of the CityTag service was based on the same system architecture used in CampusTag (Figure 3).

5.1. Field trial setup

The main differences between the two case studies attribute to the experimental setup as follows.

1. A group of 34 persons served as test users, instead of recruiting them from the general public.
2. The experiment was conducted as a task-based user evaluation, instead of relying on the test users using the service on their own.
3. The activation of the service was done beforehand, so that the test users did not have to do it themselves.
4. Availability of a comparative Bluetooth based service.

The comparative service is a pre-commercial product we call “BluetoothBox” in this paper. It is similar to the TeliaSonera iJack employed in one of our previous case studies [21]. The BluetoothBox works so that when a user enters the proximity of the box, it pushes location specific content such as links to useful web services to the user’s phone over Bluetooth. The phone contains a dedicated client application for receiving content from BluetoothBoxes, notifying the user with an audio signal upon receiving new content. The content in BluetoothBoxes is updated over GPRS; hence they do not require a fixed Internet connection, which allows rapid installation.

Four CityTag readers were installed around downtown. Naturally, the content was different from CampusTag, including for example links to movie trailers of a nearby cinema, opening hours and other information of nearby stores, and a listing of the active exhibitions of the nearby Science Centre. The Bluetooth Boxes offered the same content as CityTag readers, together with some additional content provided by the vendor of the boxes.

5.2. Main results

The evaluation was task-based so that the test users were given written instructions to walk a given route at downtown covering the four CityTag readers and use the web services provided by the readers. The route covered approximately an area of ten city blocks. Six BluetoothBoxes resided along the path so that they were not visible to the users. Upon completing the route the test users were asked to fill a questionnaire.

Ten out of the 34 test users were not able to use BluetoothBoxes due to technical problems with the server; hence their response is counted only for CityTag. All test users were students of mainly 18-24 years in age, and 62% of them were male. The chart in Figure 8 shows that the test users found CampusTag and Bluetooth Box equal in terms of learning to use the service. The chart in Figure 9 reveals that the test users found Bluetooth Box somewhat easier in accessing location specific information. However, when the 24 test users having successfully used both services were specifically asked which service they would prefer using, 50% voted for CampusTag, 38% for BluetoothBox and 12% could not make up their mind. Apparently, more tests are needed to explain this slightly contradicting result.



Figure 8: It was easy to learn the service usage.

When we compare the charts of Figures 8 and 9 to those of the CampusTag service in Figure 7, we can see that CityTag fared better. This is at least partially explained by the removal of the laborious service activation process.

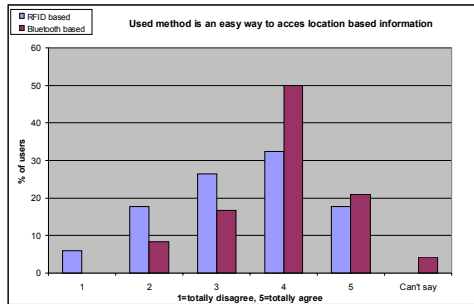


Figure 9: Used method is an easy way to access location specific information.

Statistical analysis of the respondent data is not plausible with the small sample size of 34. Instead we provide selected user feedback on CityTag: *“I was positively surprised about the functioning of the service”, “Too slow connection”, “Nice service for a tourist”, “Smart because user can select what information user wants”, “Interesting in theory. If usage becomes common, one could get used to it quickly”, “Too mechanical, wireless services are better”.*

6. Discussion

6.1. Main findings from case studies

The case studies pointed out few basic rules of thumbs for deploying the service. First, easy service activation is a must. Second, the readers should provide a comprehensive coverage in the intended environment of use. Third, the readers should have a prominent appearance. Fourth, allowing the users to personalize their location specific service portfolio should be considered.

6.2. Strengths and weaknesses

In the following we discuss strengths and weaknesses of the mTag architecture, reflecting it in particular with the scenario where mobile devices would be equipped with RFID readers and RFID tags would be spread in the environment. The infrastructure is assumed to be deployed in as proposed in 3.2.

Economic mass deployment by using existing readers. RFID readers are the key component of the

mTag architecture. Employing numerous existing readers could result in an economic large-scale deployment. This would require patching the reader software and equipping them with an Internet connection. There are a number of readers on the market with different capabilities for upgrading the software. It can be assumed that if new business would start to develop around the mTag concept, the reader manufacturers would be more willing to upgrade their products. If the reader is unable to handle a standard IP-connection, e.g. over Ethernet or WLAN, the touching event can be proxied via an intranet server host. An example of this scenario is a door access control, where the readers are connected with direct wiring from the reader to the server, which then has the needed Internet connection. If the existing readers cannot be harnessed for mTag usage, the deployment of new, dedicated readers must be planned carefully to keep the costs down. A potent approach is to connect new devices to the back-end system with wireless links.

Independence of user hardware. To access web services in the mTag system the user needs a device with suitable communication and browsing capabilities such as a modern smart phone, to which the passive tag is attached. In the opposite scenario all users would have carry-on readers and tags would be spread to the environment. However, upgrading user devices is much greater effort than the one suggested by our mTag concept. It will take many years to reach the state where all mobile devices have the reader capability, if ever.

Zero power consumption of passive tags. Whereas a RFID reader embedded to a mobile device consumes power, a passive tag does not. This is a very important advantage for mobile devices operating on limited power supply.

Real-time monitoring of online readers. The mTag architecture allows real-time monitoring of RFID readers whereas it is difficult to (even globally) monitor passive RFID tags spread to the environment. To address the NAT and firewall issues, online readers can be configured to send periodically heartbeat HTTP requests.

Need for push event infrastructure. There is not yet a de facto solution for pushing events to mobile devices facilitating large-scale deployment. The widely used push messaging systems include WAP Push, Microsoft Messenger and Skype. Part of the challenge is the fact that messaging user agents need persistent IP

connection, which in the case of mobile devices may be challenging. With the current state of technology, it is easiest with WAP Push (although definitely not the cheapest) since it is implemented into the mobile phones by default.

Installation logistics. RFID reader is much more complicated and expensive to install than the RFID tag.

6.3. Performance and scalability

The following performance and scalability analysis is derived from the Internet deployment scenario presented in Section 3.2 because the system performance is directly relational to the performance of individual components and the communication medium between them.

The EPS's HTTP server is the first potential bottleneck for the system, since all readers send the tagging event messages to a centralized EPS server. This traffic can be distributed to multiple instances of EPS servers with DNS load balancing [15]. Similar approach can be applied to the server mapping the readers with the URL's of the web services associated with the readers. In addition, DNS has built-in mechanisms for geologically global distribution, which enables the scaling and high performance of mapping the users with their contact information.

The performance of the IM user agent at EPS also benefits from distributed deployment. With SIP based system the user agent can be replicated to multiple hosts. In addition, the SIP core infrastructure supports similar load balancing technologies as used with HTTP servers.

6.4. Security and privacy

We bootstrap the analysis by stating the security and privacy requirements. The spatially relevant information is located in the Internet and is thus available to all users; hence protecting the URLs of the web services is not needed. Also, the identity of the reader can be public since its main reason is to be mapped to one or more web URLs.

The most critical security aspect is the information of the user location, user actions and the personal RFID TagID. If the HTTP request from the reader is not encrypted, it is possible for third party to eavesdrop the tagging event and thus deduct where and when the user is located. This can be tackled by implementing TLS support [16] to the readers. Further, when the EPF

sends the event notification to the user's UA, the content must be encrypted. Less critical information are the mapping requests, where the mapping of a reader to web URLs reveals that somebody is currently nearby a particular reader. Respectively, the DNS query for mapping user ID to contact info (originated from a known EPF server) reveals that particular user's contact information is currently under query. The latter is not as obvious for the eavesdropper in terms of gathering location information as the former since the DNS system is used for other services as well, like placing VoIP calls in the case of DNS based ENUM.

One more privacy threat is the RFID tag since it is personal to each user. The idea in mTag is to use really close range near field RFID tags with sensing range of approximately 1 cm. This means that counterfeiting the tag requires physical interaction with the user's tag, as opposed to sniffing the tag stealthy from a distance.

7. Conclusions

We have introduced a conceptual architecture for discovering location specific mobile web services using RFID tags attached to mobile phones. The principal advantage of the proposed architecture is that it can be realized with today's off-the-shelf commercial products. We presented a proposal for an Internet based deployment and two case studies, where prototype implementations were empirically evaluated in the true environment of use.

The case studies showed that the service was found as an easy way to access location based mobile web services. Users were satisfied with the possibility to fully control the information pushed to their devices, in comparison to the automatic location based information delivery of the comparative Bluetooth based service in the second case study.

In our future work we aim to collect more data on user experience with larger experiments. In terms of technical implementation we will explore replacing WAP Push with instant messaging solution, allowing the users to personalize their location specific service portfolio, and combining RFID and Bluetooth for service discovery.

Acknowledgements

The financial support of the National Technology Agency of Finland and the GETA Graduate School in

Electronics, Telecommunication and Automation is gratefully acknowledged.

References

- [1] Satyanarayanan M (2001) Pervasive computing: vision and challenges. *IEEE Personal Communications* 8(4), 10 – 17.
- [2] Väikkynen P, Korhonen I, Plomp J, Tuomisto T, Cluitmans L, Ailisto H, & Seppä S (2003) A user interaction paradigm for physical browsing and near-object control based on tag, *Mobile HCI 2003 Conference, Physical Interaction (PI03) – Workshop on Real World User Interfaces*, Udine, Italy.
- [3] Ailisto H, Korhonen I, Plomp J, Pohjanheimo L & Strömmer E (2003) Realising Physical Selection for Mobile Devices, *Mobile HCI 2003 Conference, Physical Interaction (PI03) – Workshop on Real World User Interfaces*, Udine, Italy.
- [4] Kindberg T (2002) Implementing physical hyperlinks using ubiquitous identifier resolution, *Proceedings of the 11th international conference on World Wide Web*, Honolulu, Hawaii, USA, 191-199.
- [5] Kindberg T, Barton J, Morgan J, Becker G, Caswell D, Debaty P, Gopal G, Frid M, Krishnan V, Morris H, Schettino J, Serra B & Spasojevic M (2002) People, places, things: web presence for the real world. *Mobile Networks and Applications* 7 (5):365-376.
- [6] Tag URI, <http://taguri.org/>.
- [7] Ljungstrand P, Redström J & Holmquist LE (2000), *WebStickers: using physical tokens to access, manage and share bookmarks to the Web*, Proc. Designing Augmented Reality Rnvironments, Elsinore, Denmark, 23-31.
- [8] Ni LM, Liu Y, Lau Y C & Patil A P (2004) LANDMARC: indoor location sensing using active RFID. *Pervasive Computing and Communications*, 10(6):701-710.
- [9] Römer K, Schoch T, Mattern F & Dübendorfer T (2004) Smart identification frameworks for ubiquitous computing applications. *Pervasive Computing and Communications*, 10(6):689-700.
- [10] Hall ES, Vawdrey DK & Knutson CD (2002) RF Rendez-Blue: reducing power and inquiry costs in Bluetooth-enabled mobile systems. Proc. Eleventh International Conference on Computer Communications and Networks, 640-645.
- [11] Rosenberg J, Schulzrinne H, Camarillo G, Johnston A, Peterson J, Sparks R Handley M & Schooler E (2002) SIP: Session Initiation Protocol, RFC 3261.
- [12] Apache HTTP Server Project, <http://httpd.apache.org/>
- [13] Apache Jakarta Tomcat, <http://jakarta.apache.org/tomcat>.
- [14] Faltstrom P & Mealling M (2004) The E.164 to Uniform Resource Identifiers (URI) Dynamic Delegation Discovery System (DDDS) Application (ENUM), RFC3761.
- [15] Brisco T (1995) DNS Support for Load Balancing, Internet Engineering Task Force Request for Comments 1794.
- [16] Rescorla E (2000) HTTP Over TLS, Internet Engineering Task Force Request for Comments 2818.
- [17] Philips 13.56 MHz I-Code, RFID sticker tags <http://www.semiconductors.philips.com/markets/identification/products/icode/ic/index.html>
- [18] Idesco Access 7 CE, Ethernet connected RFID readers <http://www.idesco.fi/products/pdf/access7ce.pdf>
- [19] Public Access Network panOULU <http://www.panoulu.net/>
- [20] Liberty Alliance Project Specifications <http://www.projectliberty.org/resources/specifications.php>
- [21] Ojala T, Korhonen J, Sutinen T, Parhi P & Aalto L (2004) Mobile Kärpät – A case study in wireless personal area networking. Proc. Third International Conference on Mobile and Ubiquitous Multimedia, College Park, MD, 149-156.
- [22] Riekkö J, Salminen T, Hosio S & Alakärppä I (2005) Requesting services by touching objects in the environment. Proc. 11th International Conference on Human-Computer Interaction, Las Vegas, NE.