TITLE: An Application Architecture for Mobile Interactive Spaces

AUTHOR: Theo Kanter

E-MAIL: theo.kanter@era.ericsson.se

ADDRESS: Ericsson Radio Systems AB, SE-16480 Stockholm, Sweden

TEL: +46 (8) 585 34514

FAX: +46 (8) 404 7020

ABSTRACT:

Abstract. This paper characterizes the properties of fourth-generation wireless networks (4G). We show that it is easy and cost-effective to build those networks, with our testbed for new applications in Mobile Interactive Spaces, which was created using wireless extensions to a public Gigabit IP-network. Given the properties of 4G, we need a plug- and play Internet, where users, mobile artifacts, and (potentially intelligent) virtual objects are able to meet and engage in communication in Mobile Interactive Spaces. Thus mechanisms are needed that enable ad-hoc application level communication, not requiring prior knowledge of the existence or attributes of other entities. In this paper I propose and describe the application architecture for Mobile Interactive Spaces together with the eXtensible Service Protocol that has these necessary properties. In conclusion, our prototyping efforts regarding mobile applications in a Mobile Interactive Space on a fourth-generation wireless network, shows the feasibility and importance of our results.

KEYWORDS: wireless, 4G, mobile computing, adaptive, applications

An Application Architecture for Mobile Interactive Spaces

Theo Kanter

Ericsson Radio Systems AB, SE-16480 Stockholm, Sweden
theo.kanter@era.ericsson.se

Abstract. **This paper characterizes the properties of fourth-generation wireless networks (4G). We show that it is easy and cost-effective to build those networks, with our testbed for new applications in Mobile Interactive Spaces, which was created using wireless extensions to a public Gigabit IP-network. Given the properties of 4G, we need a plug- and play Internet, where users, mobile artifacts, and (potentially intelligent) virtual objects are able to meet and engage in communication in Mobile Interactive Spaces. Thus mechanisms are needed that enable ad-hoc application level communication, not requiring prior knowledge of the existence or attributes of other entities. In this paper I propose and describe the application architecture for Mobile Interactive Spaces together with the eXtensible Service Protocol that has these necessary properties. In conclusion, our prototyping efforts regarding mobile applications in a Mobile Interactive Space on a fourth-generation wireless network, shows the feasibility and importance of our results.**

Keywords: wireless, 4G, mobile computing, adaptive, applications

I. Introduction (4G)

This section contains an introduction and background describing trends towards a fourth-generation Mobile Internet featuring broadband wireless communication (4G), and outlines its properties, thus providing the motivation for the application architecture which is the issue of this paper.

A. Convergence

Presently, the telecom and datacom industries are converging in different ways. In particular, with respect to mobile communication, the operators and vendors of cellular networks and services foresee a smooth migration path towards third-generation cellular networks, where packet-network access (GPRS, EDGE) is added to GSM-systems. In this scenario, GPRS and EDGE will thus complement a voice-centric network with packet-data to provide additional functionality, such as on-line personal information management, news services or messaging. However, previous work [1] has shown that multimedia services, including voice, can be delivered over wireless links with end-to-end IP-connectivity, in addition to the data services that the Internet already provides. This means that the services can be agnostic about the network link layer provided that minimal conditions for delivering the service are met (e.g., latency, bandwidth, upper-boundary for packet-loss, etc.). As a consequence, a third-party application provider can deliver an application to an end-user by any network that meets the minimal requirements of the application.

B. Cellular Networks

Concerning wireless networks, the restricted bandwidth in cellular networks created an opportunity for the Wireless Application Protocol (WAP) [2], the intention of which is also to move the point of integration of these services *into* the cellular access network. This in marked contrast to the fixed voice network, which is moving services out of the network with Voice over IP (VoIP) and SIP [3]. WAP-gateways can be used to adapt and convert Internet information, so that the mobile terminal can be used for interacting with a wider range of network-centric services (e.g. electronic payment, subscription to information services, unified messaging, etc.). However, WAP is neither intended nor well suited to transport multimedia content, but rather was targeted at simply extending GSM networks with low-bandwidth data services. Further, mobile devices can only be connected to services on the Internet through WAP-gateways. Therefore, *WAP excludes mobile users from directly interacting with Internet content*. On the other hand, simple low-bandwidth GPRS (General Packet Radio Service) is just being introduced in GSM-networks, which will provide direct Internet access to mobile users. GPRS enables the development of multimedia applications for the mobile device. These applications can directly integrate content that resides *anywhere* on the Internet. EDGE (Enhanced Data-rate for GSM Evolution), the successor of GPRS, will increase the bit-rate and thereby further relax the limits on the mobile applications and their use of Internet content, thus bringing even more multimedia applications to mobile devices.

C. Fourth Generation Wireless (4G)

In addition, so-called 'hot spots' equipped with wireless LAN extensions to the Internet are becoming available, and today provide us with even higher bandwidths (e.g. 11 Mbps in IEEE 802.11b). This is particularly important, since broadband Internet access is being provided in a rapidly increasing number of public locations and homes in urban areas. The later via Gigabit-Ethernet network access to housing co-operatives, providing 100 Mbps network access to each apartment at low cost [4,5]. The provisioning of broadband Internet access is carried out by power companies, transportation companies, housing co-operatives, joint-ventures of municipalities, etc., all of whom have a radically different business model than traditional telecom vendors and operators of cellular networks. Extending this packet-switched infrastructure with wireless access points, such as IEEE 802.11b Wireless LAN is straightforward. In addition, mobility solutions and IPv6-migration paths are available to provide the necessary scalability that accommodating millions of users and devices will require [6,7]. Furthermore, solutions for direct access to Internet (not requiring an existing subscription, but rather a direct settlement, e.g. with E-cash) are available. Consequently, users with mobile devices can, in principle, use any service from any third party, without any intervention by the operator that provides the network access. In fact, these operators simply provide IP-access, they *do not* necessarily even need to do authentication, authorization, and accounting (AAA).

Thus, the properties of 4G are such that it provides users with direct Internet Access and thus end-to-end IP-connectivity to third-party service over multiple access (heterogeneous) networks without the need of prior subscription to Internet access with these network operators.

II. Mobile Interactive Spaces

Mobile devices are now becoming available [8] that are able to perform significant computations based on events from various input devices and/or information sources. These events provide information about the user's context and the conditions, which the link is facing. Therefore, applications in mobile devices and nodes attached to the network can co-operate to deliver multimedia services to users by adapting their mode of communication dynamically based on such events. Even more importantly, the service multiplexing due to using IP over the wireless link, in combination with the capabilities of mobile devices to perform computations based on events from various input devices and/or information sources, enables entirely new classes of applications. Thus mobile users will now be able to experience applications that create a common awareness of events and resources. For instance, mobile users can be aware of each other's presence and locality, and share common resources, as would be the case in a shopping mall, where two users A and B can know each other's location. A and B can send each other notes about, or even manipulatable representations of interesting items while conversing using Voice over IP (VoIP). All this traffic is multiplexed over IP over the wireless link. This model of user interaction is referred to as *Conversational Multimedia*.

In my paper [9], I described how a *Mobile Interactive Space* can be created by scaling "Smart spaces" to the size of mobile networks. Smart spaces are ordinary environments equipped with sensing systems (e.g. location, movement, visual, audio, etc.) that can perceive and react to people and conversely, by instrumenting the physical world, we enable people to influence the virtual world. The integration of the physical and virtual worlds is also referred to as mixed-reality [10]. Thus, a Mobile Interactive Space constitutes a general application architecture, which allows any entity to engage in communication by plug and play and to respond (hopefully) intelligently. There exists a close relation between, on one hand, the general application architecture of a Mobile Interactive Spaces and on the other hand specific types of user interaction, such as conversational multimedia, being an event-driven exchange of object information in parallel to isochronous multimedia. In section IX.B and Figure 2, I describe such an application: the context-aware media player.

Furthermore, it should be emphasized that a Mobile Interactive Space is a mixed-reality space as some of the objects exist in real space, whereas others only exist in cyberspace.

III. Problem Statement

Two aspects characterize the resulting fourth generation wireless network scenario (4G). First, the network consists of a conglomeration of heterogeneous networks that provide end-to-end IP connectivity over wireless. In addition, it is a "stupid network" scenario, where the network only provides packet transport, and therefore it is an "operator-less" network with respect to services.

This scenario also implies that the mobile users and devices that participate in communication over 4G must become smarter, i.e., they must be able to respond to a wide range of events:

- Other users, mobile devices, and communication resources may become "visible" in an ad-hoc fashion, either by proximity, or actively communicating.
- Entities (users, mobile artifacts, and virtual objects) may exchange events that range beyond simple invitations to join a session all the way to manipulations of shared virtual objects.
- The communication conditions will vary between and even within access networks. This is especially the case where wireless communication is concerned. Applications must be able to act reasonably with knowledge of their capabilities.

In my licentiate thesis [11] I described how the addition of an Active Context Memory (ACM) to the representational object of entities enables these entities to store responses to events and thus respond intelligently to

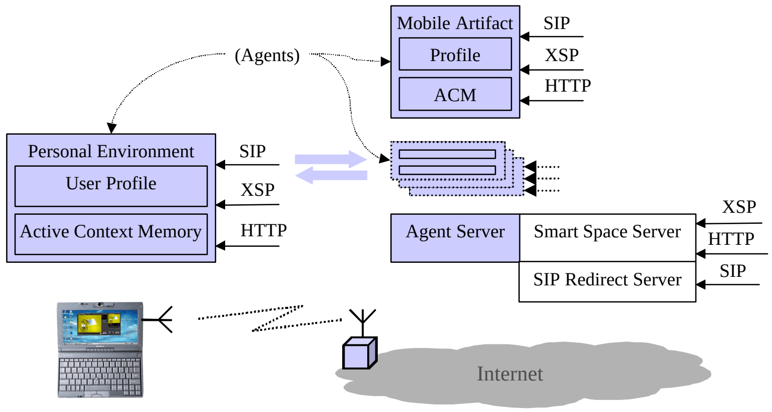

Figure 1. Components in the Application Architecture

the categories of events noted above (and even create unconscious services, by using machine learning). However, the actual exchange of events and mobile service knowledge needs additional characterization to become usable in large-scale, heterogeneous mobile networks that will extend the Internet.

IV. Overview

Figure 1 shows the major components in the application architecture. A SIP redirect server interfaces public URLs to the agents. The Smart Space Server comprises a registration and event communication mechanism allowing for dynamic reconfiguration and loose coupling between entities. The agent server holds the agents and provides mechanism for migration of agents into mobile devices, and resynchronization. Agents can be invited to communication external to the Mobile Interactive Space via SIP. For communication (between agents) within Mobile Interactive Space the eXtensible Service Protocol (XSP) is used. Agents contain an Active Context Memory featuring machine learning to store Mobile Knowledge (section VII.A) about other entities. Agents belonging to end-users are called Personal Environments and contain a Personal Profile.

The remainder of this paper describes the different components in the application architecture that I proposed in [1,12,13] and that are used to create the applications that we will expect in 4G. As we introduce these components we will address the issues that were brought up in this section. The paper concludes by describing our current and future results from creating a fourth-generation wireless network testbed, and prototyping a mobile interactive space, and applications.

V. Personal Environments

Personal Environments represent the user in the Mobile Interactive Space. The user can interact with this personal environment using a mobile device or any of the sensory equipment that is available in this space. Personal Environments consists of data and logic to act on the user's behalf. Technically, it is a mobile agent, which can migrate into the user's mobile device, once the user becomes logically on-line.

The user may "visit" his or her Personal Environment, using a web interface remotely. Naturally, in this case, user interaction is limited to managing user-preferences and information items (e.g. unified messaging), due to the limitations of a web browser interface.

Personal Environments act in the Mobile Interactive Space through communication events. Events are transported between entities using the eXtensible Service Protocol that is described in section VII. Personal Environments contain an Active Context Memory [11], which enables it to respond reasonably to communication events based on machine learning. Personal Environments are locatable through a SIP-URL, thus providing personal and service mobility.

As Mobile Interactive Spaces can be scoped spatially (for example they might belong to an access point), and Personal Environments are allowed to migrate between (agent servers in) Mobile Interactive Spaces, when in this new context they are logically connected to the entities that are present there.

A. Persistence

Consequently, there is an agent server in any Mobile Interactive Space where master-copies of these mobile agents reside, when the user is logically off-line. Resynchronization of mobile data must be done to ensure consistency (e.g., using Java object serialization or in the future perhaps SyncML [14]).

B. Addressing

Agents may use either of two addressing schemas. Agents that are registered with the same agent server can use the addressing and communication services that the

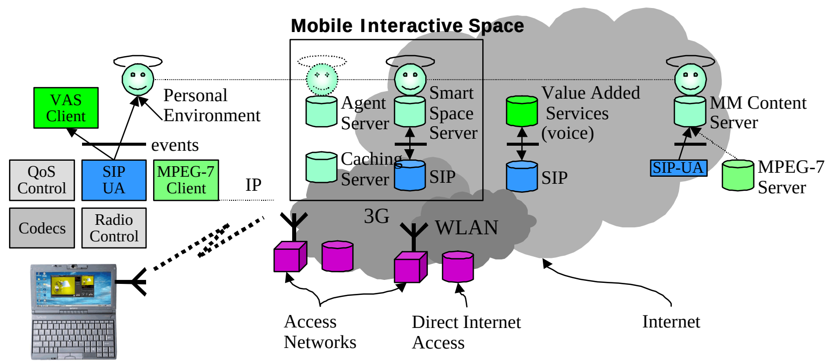

Figure 2. Mobile-Aware Content Mediation

agent server provides. External entities can use SIP since the agents also include a SIP-user agent, and consequently has a SIP URL.

VI. Smart Space Server

When (new) mobile resources become available and are to be used in the communication space, others must be able to locate them and interrogate them (or an intermediary) about their capabilities. In addition, there must be a naming and localization schema.

The Smart Space Server comprises a registration and event communication mechanism akin to a tuple-space (blackboard) system [15], allowing for dynamic reconfiguration and loose coupling between entities. Events are transported by means of the eXtensible Service Protocol (XSP). The events are stored on the Smart Space Server running an event-loop enabling it to handle subscriptions to events. Entities can register with the Smart Space Server using a SIP-URL and subscribe to events using XSP. The advantage of this approach is that it is open-ended in terms of what can be discussed. Besides the capabilities of a UpnP or JINI-based system, this system can store any type of events signifying knowledge, facts, or actions pertaining to the entities participating in this mobile interactive space.

VII. An eXtensible Service Protocol

The eXtensible Service Protocol (XSP) addresses the same problem area as KQML [16] and KIF [17] or RKRL [18], but uses a different approach. The challenge it addresses is to provide a vehicle for accumulating specifications of entities regarding capabilities. As such it has minimal assumptions about the properties of entities, but this allows for more complex definitions to build based on simpler entities. This model is open-ended and therefore this protocol is eXtensible.

XSP facilitates notification, announcement, and subscription to events in the Mobile Interactive Space, but most importantly it transports and defines Mobile Knowledge, by defining its minimal properties. Entities communicate solely by exchanging event messages. These event messages are either notifications of the occurrence of an event or containers of Mobile Knowledge.

A. Mobile Knowledge

Mobile Knowledge in its general form is a taxonomy of classes, in which object instances have executable methods. Process objects (facilitators) can represent processes such as ‘IRC’ or ‘telephony’ involving several entities. Mobile Knowledge is not specified, but arises from interaction between entities. Also process objects can be created ad-hoc by either showing (or sending such knowledge) how they can be part of the process in question. Mobile Knowledge notation is based on XML [19]. Such as a description of a location server:

```
<LocationServer>
    <owner>BRF Bågen</owner>
    <url>http://brf.net/ls/</url>
    <req>getName(X),sndLoc(X)</req>
</LocationServer>
```

B. Active Context Memory

XSP enables the transportation of Mobile Knowledge (MK) between entities that store knowledge in the Active Context Memory of the entity’s agent (which in case of an end-user is also referred to as a Personal Environment). Mobile Knowledge is thus a subset of the entire specification of an entity. Mobile Knowledge of resources, localization, and capabilities characterize how knowledge is stored in Personal Environments. These Active Context Memories creating essentially a Service Management Information Base.

See also important work regarding Cognitive Radio involving the accumulation of radio knowledge (RKRL) using learning mechanisms in mobile devices in [18].

C. *Service Discovery and Location*

XSP is needed to create local Mobile Knowledge through discovery, localization, and negotiations. While JINI [20], UPnP [21] and Corba [22] also provide discovery and localization services they do not assist in any kind of negotiation and therefore lack the flexibility that is needed in Mobile Interactive Spaces. Similar to JINI (where JINI speaks of discovery and joining of a lookup service) an entity will discover a Smart Space Server and register with it, while preserving synchronicity of its data. As the Agent Server provides the identities of other entities, then the agent of the arrived entities can query and learn the capabilities of the agents that are there.

D. *Dissemination*

In certain use cases strategies and algorithms needed for disseminating the local knowledge becomes important. For instance, end-users benefit from unconsciously transmitting Mobile Knowledge about the location of high-bandwidth areas (so-called hot-spots). See also [23].

VIII. Interaction with Legacy Services (Figure 2)

The application architecture for Mobile Interactive Spaces must also be able to interface communication with legacy services, in particular services in existing telecom network.

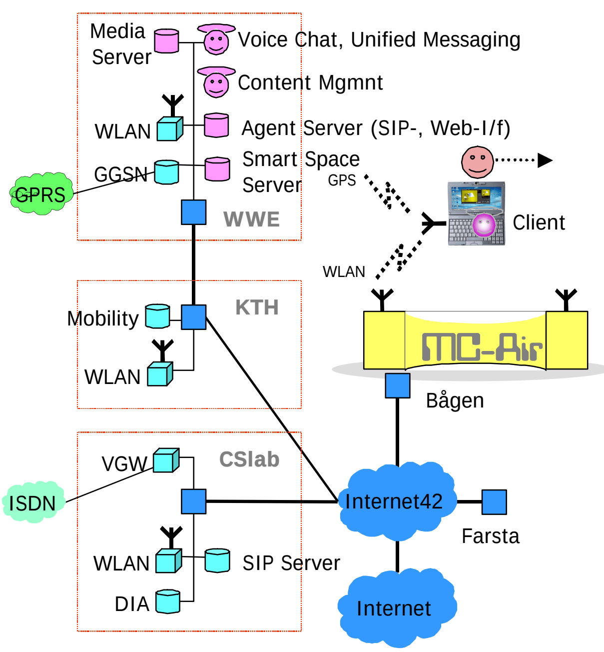

Figure 3 Fourth-Generation Wireless Test Bed

A. *Internet Telephony*

SIP-enabled voice gateways enable us to communicate with users of (mobile) telephony. Quality of Service (QoS) regarding Internet Telephony over wireless links with retained spectrum efficiency for third-generation cellular networks is addressed by mapping of flows on radio bearers and applying header compression [24].

B. *Value Added Services (VAS)*

Furthermore, Common Channel Signalling (CCS) gateways, ensure that users in the Mobile Interactive Space can connect to and interact with Intelligent Network (IN) services in the telecom network. Even more importantly, this also means that we are in the position to move IN and HLR type of services to the Internet. Thus we can provide access to these existing services via a web interface with Unified Messaging functionality, and allow users to manage their preferences and services using a Personal Assistant [25]. Regarding providing such Value-Addedd Services (VAS) on Internet involving SIP-enabled IN-telephony in conjuction with Mobile Agents, see [26].

IX. Experimental Network and Applications

A. *Infrastructure, Testbed*

In order to be able to verify the architecture that has been described in this paper and the applications that are enabled by it, we deployed a fourth-generation wireless test bed infrastructure in central Stockholm and suburbs (Figure 3). The project to put up this fourth generation wireless infrastructure and test bed for mobile applications is called *MC-Air*, involving several parties (Ericsson Radio, Royal Institute of Technology, Telia, and Brf Bågen).

This test bed features 11 Mbps wireless packet data access points (IEEE 802.11b), agent servers, media servers and content management, voice gateways (VGW) with anonymous direct access to Internet (DIA), support for device mobility (Mobile-IP) and service mobility (SIP). We expect to add GPRS later this year. This functionality has been attached to a Gigabit-Ethernet IP-network (Internet42) that is connected to the Internet. Besides points of presence at research facilities (Ericsson Radio, KTH, and Telia) in the Stockholm suburbs of Kista, Älvsjö, and Farsta; Internet42 also has a point of presence in the center of Stockholm. There it provides 100 Mbps accesses to Internet to each apartment in a large housing co-operative, Brf Bågen [4,5]. An interesting outcome of this project was that the effort and cost to provide broadband wireless packet data was very low. As usage grows we can add access points. With a single access point we obtained good coverage in a large public space at the cost of $0.02/m^2 (see Figure 4).

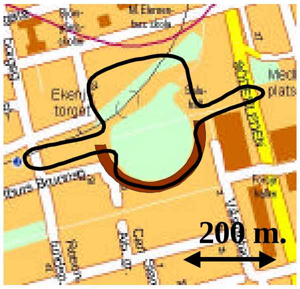

Figure 4. IEEE 802.11b Coverage in Central Stockholm

B. Applications

In this infrastructure we have tested simultaneous SIP-enabled VoIP-traffic and interaction in virtual 3D spaces with end-to-end connectivity over wireless links. Voice uses up 8 kbps of bandwidth and motion and interaction (avatar movement, common manipulation of objects) in virtual 3D-spaces around 20 kbps. Thus a large number of users can be accommodated in this wireless network, even when using advanced and complex interaction, and many more voice only users.

We have started prototyping some envisaged scenarios, which we expect to produce research results regarding the required minimal properties for service protocols in order to explore their dynamic behavior and allowing bootstrapping of functionality.

In a 4G network, heterogeneous network access and ad-hoc appearance (and disappearance) of communication resources, mobile artifacts and users, make it difficult for anyone creating services to foresee communication conditions and context that users will experience.

Therefore a second class of functionality is needed that in the local context of a mobile access network assists in the mediation of multimedia content for mobile users. In the Mobile Interactive Space of our testbed we are currently prototyping a Content Management Server. This server acts as a local resource in the Mobile Interactive Space facilitating the download of multimedia content by end-users, such that it allows the user to move, allow for greatly varying communication conditions, even to the extent that the user may become off-line temporarily. This server builds on our Smart Delivery Architecture [1].

Thus, in the setting of a deregulated wireless Internet providing direct access to Internet with varying bandwidth and communication conditions (e.g., latency, etc.) a first application is a Mobile-Aware Personal Media Player. This application features smart delivery of multimedia content (e.g., MP3), and is thus capable of adapting to communication conditions, user context, and user preferences.

X. Conclusions

This paper characterized the properties of fourth-generation wireless networks as *operatorless*, regarding network access and services. Also, fourth-generation wireless networks will necessarily be heterogeneous but may run applications end-to-end over IP (wireless) links. Fourth-generation wireless systems are not fiction or wishful thinking. Telia's Homerun system already provides wireless LAN access in over 70 public locations in Sweden [27]. We have shown that it is easy and cost-effective to build those networks, especially in light of the availability of fixed broadband infrastructure, the bandwidth of which can easily be resold wirelessly at very low or no cost.

Given the existence this new heterogeneous wireless IP infrastructure, it is important to recognize the need for a plug- and play Internet, where users, mobile artifacts, and (potentially intelligent) virtual objects are able to meet and engage in communication in Mobile Interactive Spaces. Not only do we need ad-hoc networking, but also mechanisms for ad-hoc application level communication. This need can only be satisfied if we provide the necessary mechanisms that do not require prior knowledge of the existence or attributes of other entities. In this paper I proposed and described the application architecture for Mobile Interactive Spaces together with the eXtensible Service Protocol that has these necessary properties.

In conclusion, our prototyping efforts regarding mobile applications in a Mobile Interactive Space on a fourth-generation wireless network, shows the feasibility and importance of our results.

XI. Future Work

During 2000 we will prototype the protocols for the necessary negotiations between agents, agent- and smart space-, and content management server prototypes, as well as an investigation regarding the effectiveness of the proposed agent learning strategies for improved service delivery.

We plan to add MPEG-7 capabilities to further enable the user to manipulate non-trivial multimedia objects, outside the scope of awareness of user context or communication. Another extension to the Mobile-Aware Personal Media Player will be to incorporate our VoIP infrastructure and thus enable "*conversational multimedia*". Furthermore, incorporating spatially scoped presence information enables us to provide mobile awareness for users in a Mobile Interactive Space, allowing them to share discussions, and objects in a mobile aware voice chat.

We are also planning to port our client software to successors of the SmartBadge (a wireless networked wearable device with powerful computing capabilities, I/O-, and sensors) [8]. This allows us to expand on the user interaction to accommodate for mixed reality applications, where we are able to provide anything from spatially scoped background sounds, through augmented reality artifacts (e.g. a front door with personalized on-line multimedia content for visitors), to virtual hockey in the park of Brf Bågen.

XII. References

1 T. Kanter, P. Lindtorp, C. Olrog, G. Maguire, "Smart Delivery of Multimedia Content for Wireless Applications", to be presented during the 2nd International Workshop on Mobile and Wireless Communications Networks (MWCN'2000), May 2000.

2 WAP Forum (Wireless Application Protocol Forum Ltd.), Proposed 1.1 technical documents, http://www.wapforum.org/docs/technical.htm

3 M. Handley, H. Schulzrinne, E. Schooler, J. Rosenberg - RFC 2543 on SIP: Session Initiation Protocol, IETF/Network Working Group – March 1999.

4 Internet42: Public Gigabit-Ethernet IP-network connecting housing co-operative BRF Bågen in Stockholm (http://www.fatburen.org)

5 Dagens Nyheter, "Folke surfar på prov i gräddfilen", April 29th 1998.

6 E. Wedlund, H. Schulzrinne, "Mobility Support using SIP", Proceedings of the 2nd ACM International Workshop on Wireless Mobile Multimedia (WoWMoM'99)

7 A. Campbell, J. Gomez, S. Kim, C. Wan, A. Valko, "A Cellular IP Testbed Demonstrator", Proceedings of the Sixth IEEE International Workshop on Mobile Multimedia Communications (MOMUC'99) (p. 145-148)

8 Mark T. Smith, "SmartCards: Integrating for Portable Complexity", IEEE Computer, August 1998, pp. 110-112, and 115.

9 T. Kanter. "Event-Driven, Personalizable, Mobile Interactive Spaces", Submitted to the 2nd International Symposium on Handheld and Ubiquitous Computing (huc2k), 24-27 September 2000, Bristol UK.

10 H. Tamura: "Mixed reality: Merging real and virtual world," Journal of the Robotics Society of Japan, vol.16, no.6, pp.759-762, 1998.

11 T. Kanter, "Adaptive Personal Mobile Communication", Licentiate Thesis, KTH, March 2000.

12 T. Kanter, "Adaptive Personal Mobile Communication: An Extendable Protocol and Application Architecture for Mobile Interactive Spaces", PhD Thesis Proposal, KTH/IT, May 2000.

13 T. Kanter. "VoIPoW-MM Applications", T/K-00:009 Uen, 2000-01-19

14 White Paper: The SyncML Initiative, http://www.syncml.org

15 TSpaces: The Next Wave", published in the Hawaii International Conference on System Sciences (HICSS-32), January 99.

16 1993 KQML Specification, by The DARPA Knowledge Sharing Initiative External Interfaces Working Group.

17 Knowledge Interchange Format (KIF), draft proposed American National Standard (dpANS), NCITS.T2/98-004.

18 J. Mitola, "Cognitive Radio: an Integrated Agent Architecture for Software Defined Radio", Tekn. Dr. dissertation, Royal Institute of Technology (KTH), 2000.

19 Extensible Markup Language (XML) 1.0, URL: http://www.w3.org/TR/1998/REC-xml-19980210

20 Sun Microsystems Inc., "Jini Architectural Overview", Technical White Paper, — January 1999.

21 Microsoft Corporation, "Universal Plug and Play Device Architecture", Version 0.91, March 2000.

22 Object Management Group, Inc., CORBA/IIOP 2.2 Specification, 98-02-01

23 G. Liu, The Effectiveness of a Full-Mobility Architecture for Wireless Mobile Computing and Personal Communications, Tekn. Dr. dissertation, Royal Institute of Technology (KTH), 1996.

24 L-E. Jonsson, M. Degermark, H. Hannu, K. Svanbro, "RObust Checksum-based header COmpression" (ROCCO), IETF Network Working Group Draft, September 1999.

25 A. Aquilon, G. Bage, A. Danne, J. Gabrielsson and S. Willehadson, "Mobile agent-architecture for robust services – Mars", Proceedings of the XVII World Telecommunications Congress, May 2000.

26 J. Tang, T. White, B. Pagurek, R. Glitho, "Management of Advanced Services in H.323 Internet Protocol Telephony", IEEE Infocom 2000.

27 Telia HomeRun: http://www.homerun.telia.com/