Application of agent technology to next generation wireless/mobile networks*

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ABSTRACT

Wireless communication systems beyond the third generation will be diverse. It can be expected that several different radio technologies as well as several classes of mobile devices running a variety of applications will be deployed, while the Internet Protocol (IP) will play the role of the unifying architectural component. To cope with the described diversity, networking paradigms like programmable / active networking should be incorporated into the vision of "beyond 3G" wireless / mobile networks. Particularly, we propose to evaluate agents as one enabling technology for active wireless / mobile networking. Therefore, we highlight some key properties of agents and discuss their potential advantages, disadvantages and tradeoffs for a "beyond 3G" network scenario.

Keywords: mobile and intelligent agents, active / programmable networks, "beyond 3G" wireless / mobile networks

1. INTRODUCTION

Todays trends in telecommunications can be structured into different levels:

- **solutions –** solution areas such as electronic business and mobile business; communities and entertainment; collaborative work in virtual organizations; mobile support; knowledge management; advanced process control support; and enterprise applications.
- **content and services** – solutions are enabled by underlying content and services. Important trends in this area include location dependent services, personalization of content and services, and a change in quality of services: from the mere provision of information to user interaction and to (legally relevant) transactions.
- **devices** – new devices are characterized by becoming smaller and more powerful, supporting the trend of unification of telephony, computer and entertainment, multi-modal and multi-media access.
- **networks** – the different kinds of networks are converging: telecommunication, Internet, TV and local area networks; the user is always connected to services and content, like in GPRS, UMTS and beyond the third generation.

In conclusion, these trends characterize the increased mobility in our global society: the mobility of humans, devices, and software. However, to realize the potential created by technological innovations, some important requirements for the next generation of networks need to be satisfied:

- to provide users with added-value and to help them navigate through the massive content and service offerings, we need ubiquitous personal assistance, and reachability anywhere at anytime;
- to exploit the potential of multimedia, large bandwidth access to content and services, the user needs to be supported with intelligent user interfaces over multiple devices, like mobile phones, next generation Personal Digital Assistants (PDAs), web pads, and PCs;
- The more devices carry personal information such as user profiles, and the more computers turn into personal assistants that will carry out legally relevant transactions, such as purchasing or signing contracts, the more security issues become critical, and the more security mechanisms need to be built in into intelligent telecommunication infrastructures.

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- as networks are becoming more complex and dynamic, new ways of designing and managing them are required: network management systems supporting scalability through self-organization and hand-over between different networks are needed;

The promise of agent technology in telecommunications is to be a key vehicle for:

- achieving enriched, higher level communication;
- enabling more intelligence in service provision and network management e.g. by personalization and integration of different services to value-added services and negotiation of QoS;
- dealing with the enlarging amount of information and functions, and
- allow self-organizing networks.

To be able to fulfil these promises, agents need to communicate to discover their peers, to negotiate and to co-operate in open environments where everybody can add their contribution when and how it is deemed appropriate. Most importantly, agent systems will need to build on an interface with a variety of existing and upcoming developments and standards at the underlying network systems level. This includes support for a wide range of devices, but also for the integration of telecommunication, Internet, TV and power line communication, self-organization and software defined radio, and, particularly, intelligent hand-over from local communication channels, like Bluetooth, to hot-spot coverage (WLAN) and cellular networks (UMTS and beyond). Thus, agents will only be widely accepted if they provide a standardized, open and generic infrastructure (for standards efforts for agents see [13 , 14]).

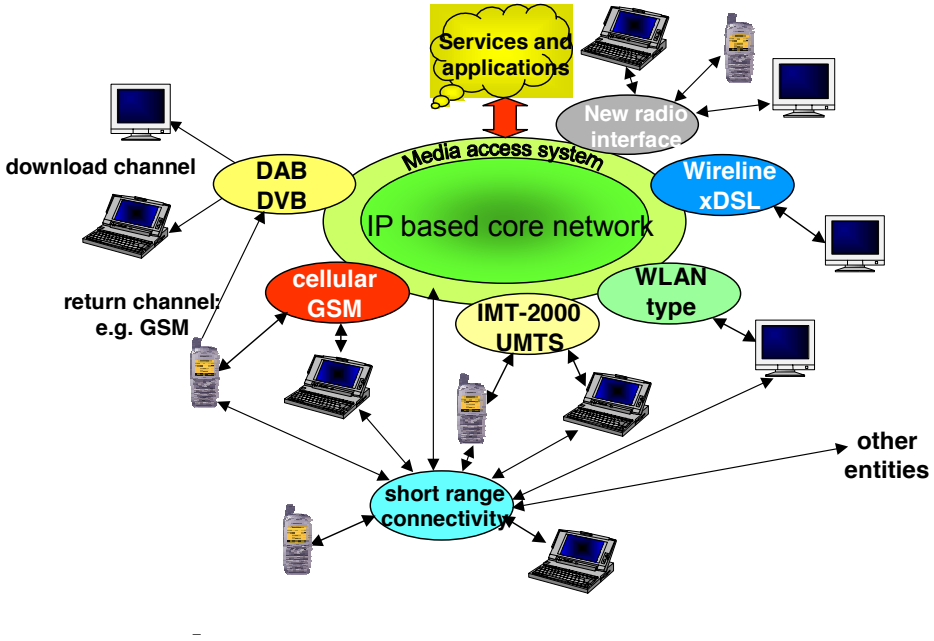

Figure 1 Seamless network of complementary access systems.

This implies that the network systems level needs to offer some degree of *programmability*. Programmable networking aims at opening low-level access to network elements (routers, switches, base stations) by defining appropriate interfaces. These interfaces can then be accessed by various entities (protocols, agents) to offer advanced and customizable services. This concept can then be extended with (agent-based) mechanisms for distributing and executing code which programs the interfaces on behalf of individual applications (including those running on end systems). The new paradigm has been called *active networking*. Until now, however, research work in the literature either considers *existing* wireless / IP networks to demonstrate the viability of active network or agent-based concepts themselves (proof-of-concept) or aims at demonstrating

potential benefits for the particular existing network scenario. We, in contrast, want to outline some thoughts on how *agent-based active networking* could influence the design of the next generation of wireless packet networks.

Figure 1 shows the basic scenario we anticipate for "beyond 3G" wireless / mobile networks: various different mobile devices (with different processing capabilities) are attached to an access network which in turn interfaces to a core network. A variety of wireline and wireless access network technologies is used including legacy and novel cellular technologies, wireless LAN and broadcasting technologies like DVB-T. While the individual building blocks within the scenario are not well defined yet, the fact of heterogeneity of devices and network technologies is foreseeable. Here, we believe, agent-based active networking could be an enabling technology for "beyond 3G" networks (covering all levels of the multi-sphere model defined in the WSI/WWRF [1]).

The structure of the paper is as follows: in section 2 we give a brief overview over relevant research that fully or partly covers the described context. Then, in section 3 we outline our approach, including the identification of two potential application areas. Section 4 concludes the paper.

2. STATE OF THE ART IN THE AREA

An intelligent agent is "*a computer system, situated in some environment, that is capable of flexible, autonomous action in order to meet its design objectives*." [10]. *"A multi agent system is a dynamic federation of software agents that are coupled through shared environments, goals, or plans, and that cooperate and coordinate their actions"* [11]. It is this ability to communicate, coordinate, and cooperate that makes agents and multi agent systems a worthwhile metaphor in computing and that makes them attractive when it comes to tackling some of the requirements in next-generation telecommunications systems.

A very interesting type of agents are mobile agents, i.e., software agents that are able to migrate between multiple hosts and to carry out computations on different hosts, following an itinerary. In [7], the authors present an analysis of current trends in the Internet which in their opinion opens the path for the deployment of mobile agent technology. Mobile agents distribute code to proxies at the edge of the wireless network as well as to the mobile device. Thus the number of necessary network transactions to provide a service can be reduced by local processing as well as local service customization. This in turn might lead to less bandwidth consumption and lower latency. Examples for mobile agent platforms, i.e. the software for managing the mobility and task execution of the agents, are MOLE [15], IBM Aglets [16], Objectspace Voyager [17], the OMG-MASIF initiative [18], Grashopper [19], Semoa [20] and Swarm [21]. The ACTS (Advanced Communications Technologies and Services) EU program [25] has featured a cluster of agent-based telecommunications projects (CLIMATE: Cluster for Intelligent Mobile Agents for Telecommunication Environments). The individual projects in CLIMATE have been organized according to the following topics:

- intelligent networks and mobility
- communication and management
- agent systems
- agent platforms

CLIMATE projects involve strong industrial participation, including Vodafone / Mannesmann, Motorola, Siemens, Sony, DTAG, NEC, Alcatel, Hitachi, British Telecom, Swisscom, and Philips.

The area of active, self-organizing networks is e.g. represented by the DARPA-sponsored Active networks program, the Active Networks project at MIT [23] and the self-organizing network activities at EPFL. The EU-sponsored project FAIN (Future Active IP Networks) [24] aims at developing an open, flexible and reliable network architecture based on active networks. However, only few research work has been done with particular emphasis on wireless / mobile networks: Kulkarni and Minden [5] provide a taxonomy for active protocol components called "protocol classes". They also propose to deploy such components to the edges of the wireless network. In particular, the usefulness of adaptive error control as well as application-specific filtering is highlighted. Providing adaptive QoS support for wireless / mobile hosts is also the focus of the middleware toolkit Mobiware [8]. Adaptivity is particularly important because of the time-varying link quality. The work covers active networks in the sense that objects providing adaptive transport can be injected into network nodes. Lower layers in the protocol stack (down to the MAC layer) offer programmable interfaces. Besides providing an introduction to programmable / active networks in the context of wireless / mobile networking, Chin [8] emphasizes the potential benefits of active networking for mobile hosts, particularly in the context of mobile IP.

In the WWRF, active networking [2,4] as well as agent technology [3,4] have been mentioned as potential enabling technologies and one particular example (routing for ad-hoc networks [2]) has been outlined. In the following we want to add to this activities by focusing on an agent-based approach for active wireless / mobile networks.

3. APPROACH

In this section we want to highlight some key properties of agents. We believe that these key properties could enable a novel design for the next generation of wireless / mobile networking, particularly due to the anticipated heterogeneity for the "beyond 3G" networks.

Software agents are software components characterized by **autonomy** (to act on their own), **reactiveness** (to process external events), **proactiveness** (to reach goals), **cooperation** (to efficiently and effectively solve tasks), **adaptation** (to learn by experience) and **mobility** (migration to new places) (see e.g. [26]-[31] for details on agent technology).
Messages are highly structured and must satisfy standardized communicative (speech) acts which define the type and the content of the messages (agent communication language (ACL) like FIPA-ACL [13] or KQML [32, 33]). The order of exchanging messages of a certain type is fixed in protocols according to the relation of agents or the intention of the communication.
The real strength of agents is based on the community of a multi agent system and the negotiation mechanisms and coordination facilities. A multi agent system is a dynamic federation of software agents, coupled by common environments, goals or plans, which cooperate with each other or coordinate their actions. Dividing functionality among many agents provides modularity, flexibility, modifiability, and extensibility. Applications requiring distributed computing are better supported by multi agent systems, since agents can be designed as fine-grained autonomous components acting in parallel. However to support multi agent systems, an appropriate environment has to be supported, namely an infrastructure has to be established specifying communication and interaction protocols, which is open and not centralized, and contains agents being autonomous, adaptive and cooperative.

In the following we will have a closer look at specific properties of agents:

Agent mobility is the capability of transporting objects which include code and state[1] to a network element. We see the major advantages in the rapid deployment of new network protocols and mechanisms. (Mechanisms in our definition cover local processing, like queue management, scheduling, link quality measurement, etc.). It should be emphasized that this specifically also covers only *partial* deployments. That means that on one hand also proprietary protocols could be deployed and tested to some extent in a live network. On the other hand, protocols which have been widely accepted could be deployed on-the-fly to network domains where they are currently needed, leading to less resources being consumed in the network nodes.
However, we also clearly see the problems associated with agent mobility. The access to internal network resources must be very well secured. Security has to play a major role in the design of the software environment supporting the agent deployment (the agent platform, see above). Also, cost in terms of agent migration overhead and local processing needs to be taken into account. Finally, the compatibility of agent platforms in terms of code and interfaces needs to be assured, as it is the basis for the simplicity of protocol deployment outlined above.
As an example agent mobility can enable the transfer of objects to support host mobility. If only protocol state is transfered, agents can help to improve the efficiency of a deployed protocol like Mobile IP. If state and code is transfered and executed, an active networking approach to support mobility is realized.

The second key property we would like to emphasize is **agent autonomy and intelligence**. We define this property as the capability of autonomous decisions particularly as a reaction to events in the network. In the context of networking we believe that autonomy and intelligence are interconnected: if an agent is intelligent but cannot or must not make local decisions, remote entities need to be contacted. This then undermines the appealing properties of agents to reduce network control traffic, to react quickly in response to local network behaviour and to sustain some level of operation under adverse network conditions. If an agent is capable of decision making, however its local intelligence is not sufficient, a similar problem arises.
Again, we need to emphasize the security risks associated with agents: giving an agent a great degree of autonomy and intelligence also increases the risk of damage in the event of a malfunction or when such an agent is used for an attack.

[1] "State" in our definition could cover e.g. the state of a process, a protocol state machine or information on active connections.

An example for the described property of autonomy and intelligence is an agent which, having carried and deployed air interface software for one radio technology, may autonomously requests software from a repository for another technology before a vertical handover.

Both described properties point to the general tradeoff of a local versus a centralized network organization. If more emphasis is put on local aspects, the needed network resources for control traffic are lower, customization is easier and a relatively high local processing power is needed (the opposite arguments apply to a centralized approach). For the local approach, the available processing power then dictates the degree to which functionality in a node can be active, programmable or needs to be fixed.

We believe that the described agent properties and depicted application areas are particularly useful for next generation wireless / mobile networks due to the mentioned *heterogeneity* (Figure 1). While it seems to be pretty well established that "beyond 3G" networks will be all IP-based networks, it also is very probable that several radio network technologies will have to coexist in the future. Additionally, current and future applications have in common that they are IP-based and thus are shielded from the particularities of the underlying network. However, the properties and thus network transport requirements of these applications are diverse, which points to the necessity of adaptation within the network (and agents as a potential enabling technology for this). Another argument for network-based adaptation is the increasing gap between optical and wireless link bandwidths. Finally when looking at standardization we can also identify a trend to heterogeneity: the "walled garden" model of standardizing all major components of a system and their interactions is moving towards a model of standardizing generic components which can be combined (and re-used) in various systems.

3.1. Agents for the management of wireless/mobile networks

Mobile agents appear to be an interesting way to exploit synergies between current research on network management and agent-related research. While network management looks for new ways to overcome the limitations of current client-server technology, mobile agents and peer computing provide technologies and architectures to enable decentral, peer-to-peer communication. The main advantages of agent technology are the following:

- **Distribution of Management Code:** As an alternative to carry large amounts of data to management stations via the network, mobile agents can transporting network management code to the SNMP agents. This saves bandwidth, reduces bottlenecks, and makes the architecture more scalable, which is of particular importance considering the scarce resources in a wireless network.
- **Decentralization:** Mobile agents can effectively decentralize network management functions. They can proactively and autonomously carry out administration tasks such as installing and upgrading software, or periodically monitoring the network. Moreover management can be decentralized using marketing mechanisms. Decentralization is most interesting in a network scenario where the traffic needed for management must be minimized.
- **Dynamically changing network policies:** As networks change dynamically, the rules underlying network management (the so-called policies) need to be changed from time to time. In current network management systems, this is done following a complete „rewrite, compile, run" cycle; using agents, these adaptations can be done dynamically and incrementally, by replacing agents or agent functions one at a time.
- **Network monitoring:** Mobile agents are beneficial for surveillance of SNMP variables and long-term monitoring of network elements. This is important for wireless networks as the node configuration might change over time (considering e.g. ad hoc networks or a variable number of users in a single cell of a cellular network).
- **Data collection:** Agents can search, collect, and filter network data. They can be used to process data-intensive requests from network elements. Here, the agent acts as a "smart query" that visits the data and performs the necessary computation locally, instead of passing large chunks of data over the network.
- **Reactiveness:** Agents can react quickly to local events, such as the breakdown of a link.
- **Robustness:** Agents can perform their tasks at least to a degree, even if parts of the network are not reachable temporarily. This makes them particularly valuable for mobile computing, where links are expensive and unstable.

3.2. Agents for the support of micro-mobility

The Radio Access Network (RAN) could be a particularly beneficial deployment area for agent technology, because in a RAN, the radio technology-specific protocols and mechanisms need to be deployed and *dynamically* adapted to the core network. The needed functionality includes e.g.:

- reprogramming of the air interface (software defined radio), including e.g. air interface-specific error control (FEC/ARQ) (at the mobile terminal and the base station)

- segmentation / reassembly from IP packets to radio frames and vice versa (at the base station or another RAN node)
- application-specific processing (transcoding) to accomodate the bandwidth mismatch between the wireless and the access network (at the base station or another RAN node)

When the mobile terminal moves and a seamless handover needs to be enabled, the location of the processing modules described above needs to be moved to a new location and adapted to the new environment (e.g. another radio technology). That means that mobile agents offer the possibility to install and execute these modules only when and where needed. Thus the initial configuration of a network element (mobile terminal, base station, RAN node) is very lightweight. Dependent on the degree of mobility, however, the delay due to necessary agent movement and code execution needs to be taken into account (some pre-configuration of adjacent cells might be needed).

4. CONCLUSIONS

In this paper we have tried to sketch how agent technology could be applied to "beyond 3G" wireless / mobile networks. We have identified some key properties of agents which could be important for the design of such networks, particularly with regard to the anticipated heterogeneity in terms of radio technologies and applications. Network management and micro-mobility have been identified as two areas where the deployment of mobile agents could be particularly beneficial.

As research tasks we propose to look closer at the trade-offs of agent technology including but not limited to the described two areas. In addition to shaping some vision of an agent-oriented wireless network, research might give feedback both to the agent community (e.g. with regard to the agent platform design), the active networking and the IP community. An interesting aspect is also to try to show how a transition path to agent-supported wireless / mobile networking might look like. Finally, networked applications which are not or only with difficulties possible to realize without agent technology should be identified.

5. REFERENCES

1. IST WSI project, The Book of Visions 2000 – Version 1.0, November 2000
2. K. Cooreman, T. Lambrecht, B. Duysburgh, P. Backx, B. Dhoedt, P. Demeester, "Active Routing in Mobile Ad Hoc Networks", Proceedings of the WWRF Kick-Off Meeting, WG 3, Munich, March 2001
3. Y. Raivio, "Enabling Technologies for the System Beyond 3G", Proceedings of the WWRF Kick-Off Meeting, WG 3, Munich, March 2001
4. G. Gallassi, "4G: the framework for the convergence of evolutionary trends in the distribution of intelligence", Proceedings of the WWRF Kick-Off Meeting, WG 4, Munich, March 2001
5. Amit Kulkarni, Gary J. Minden, "Active Networking Services for Wired/Wireless Networks", Proceedings IEEE Infocom, New York, NY, March 1999
6. K.-W. Chin, "An Investigation into the Application of Active Networks to Mobile Computing Environments", PhD thesis, School of Computing, Curtin University of Technology, Bentley, Western Australia, March 2000
7. D. Kotz, R. Gray. "Mobile Agents and the Future of the Internet", ACM Operating Systems Review, Vol. 33(3), pp. 7-13, 1999
8. O. Angin, A. Cambpell, M. Kounavis, R. Liao, "Open Programmable Mobile Networks", Computer Networks and ISDN Systems, Elsevier Science, Vol 31., No 7, 1999
9. http://leap.crm-paris.com
10. Jennings, N.R., Sycara, K., and Wooldridge, M.J. A Roadmap of Agent Research and Development. Autonomous Agents and Multi-Agent Systems, 1(1):7-38, 1998.
11. Huhns, M.N. Multiagent Systems. Tutorial at the European Agent Systems Summer School (EASSS'99), 1999.
12. Etzioni, O. Moving Up the Information Food Chain: Deploying Softbots on the World Wide Web. Proceedings of AAAI-96 (Abstract of Invited Talk), 1996.
13. FIPA: http://www.fipa.org
14. OMG: http://www.omg.org
15. MOLE: http://mole.informatik.uni-stuttgart.de/
16. Aglets: http://www.trl.ibm.com/aglets/
17. Voyager: http://www.objectspace.com/products/voyager/
18. MASIF: http://www.omg.org/cgi-bin/doc?orbos/97-10-05
19. Grashopper: www.grashopper.de
20. Semoa: http://www.igd.fhg.de/igd-a8/projects/semoa/
21. SWARM: http://www.swarm.org

22. Hayzelden, A. and Bigham, J. Software Agents in Telecommunications Network Management: An Overview. In Knowledge Engineering Review, 1999.
23. ACTNET: http://www.sds.lcs.mit.edu/activeware/
24. FAIN: http://www.ist-fain.org
25. ACTS: http://www.infowin.org/ACTS/
26. Müller, J. P. The design of intelligent agents. Lecture Notes of Articial Intelligence, Vol. 1077. Springer-Verlag, 1997.
27. Bradshaw, J.M.(editor): *Software Agent*s. AAAI Press/ The MIT Press, Menlo Park, CA, 1997. ISBN 0-262-52234-9.
28. Caglayan, Alper, and Colin Harrison, Agent Sourcebook, John Wiley & Sons, New York, 1997
29. Huhns, M.N. and Singh, M.P. Agents and Multiagent Systems: Themes, Approaches, and Challenges. Readings in Agents, pp. 1- 24, Morgan-Kaufmann, 1998.
30. Odell, J. ed., *Agent Technology*, OMG, green paper produced by the OMG Agent Working Group, 2000x
31. P. Maes, and R. Kozierok, Learning Interface Agents. In Proceedings of the 11th Nat Conf on Artificial Intelligence, AAAI, MIT-Press/AAAI-Press, 1993.
32. Finin, T.; Fritzson, R.; McKay, D. and McEntire, R.: KQML as an Agent Communication Language, Proceedings of the Third International Conference on Information and Knowledge Management (CIKM'94), ACM Press, November 1994)
33. Finin, T. and Fritzson, R.: KQML - a language and protocol for knowledge and information exchange, In Proceedings of the 13th Intl. Distributed Artificial Intelligence Workshop, LNAI 890, Seatle, WA, USA, 1994