Software Agents in Mobile telecommunication services

Agent technology has the potential to play a key role in building and supporting future telecommunication systems. In this article **BERNHARD BAUER** and **JÖRG MÜLLER** give an overview on the actual trends in telecommunication, namely on solutions, services, intelligent user interfaces, and networks and relate them to the current state in agent technology. Therefore, they first of all define the requirements that have to be satisfied to realize the potential created by actual technological innovations, next a closer look at the different kinds of software agents is given and afterwards their application and benefits in the above-mentioned areas is shown. An assessment of agent technology in the area of telecommunication systems closes the considerations.

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Introduction

The world is becoming more and more connected. The Internet usage is growing exponentially. Mobile data services are reaching users worldwide at any time, and businesses are moving to the Web to connect with their customers, suppliers and partners. Modern telecommunications technology is driven by and facilitates the globalization of markets.

The current trends in telecommunications can be structured into different levels:

- **Solutions**[1] — 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 or UMTS.

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 need to be satisfied:

- 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.
- 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 any time.
- 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, such as 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 (concerning for example, personal data or manipulation of data) become critical, and the more security

[1] **In our context solutions summarize applications, integration of existing software, customizing of software, etc.**

mechanisms need to be built in into intelligent telecommunication infrastructures.

Agent technology is believed to be able to play a key role in this 'revolution' by automating daily processes, enriching higher level communication, enabling more intelligence service provision, and network management, e.g. by personalization and service integration to value added services, to deal with the enlarging amount of information and functions, and to allow self-organization of networks.

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* [1].

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* [2].

It is this ability to migrate, 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 telecommunication systems.

This paper is structured as follows: In the next section, we give a short overview on software agents. Then, we provide a selection of examples for the usage of agent technology in telecommunications, grouped by the categories of (content and) services, user interfaces (and devices), and networks. We end this paper with a summary and conclusion.

Software agents

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. References [3][4][5][6][7][8][9] for details on agent technology).

Often, agents are subdivided into three functional sections with different functionality:

The *agent body* wraps a software component and controls it through its software API. Such a software component may be a database, a calendar or an external service. Connected to an external software, the agent acts as an application agent transforming the application API into agent communication language (see later) and vice versa.

The *agent head* is responsible for making the agent intelligent. It is connected to the body on one side and to the communicator

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on the other side. The agent head contains knowledge bases storing knowledge of certain types like facts, beliefs, goals or intentions, preferences, motivations, and desires concerning the agent itself or associated ones. The world model contains an abstraction of relevant states of the real world. It is updated by information from other agents or through real world interfaces such as sensors. The agent head is able to evaluate incoming messages with respect to its goals, plans, tasks, preferences and to the internal world model.

The *agent communicator* converts logical agent addresses into physical addresses and delivers messages on behalf of the agent head through appropriate channels to the receivers. Furthermore, the communicator runs an event loop listening for incoming messages, which are forwarded to the agent head. The agent behavior should be benevolent which means that they at least understand the interaction protocols and react accordingly.

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 [10] or KQML [11][12]). 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.

Furthermore having the property of mobility, the agents migrate from one machine to another. Different kinds of migration can be supported, like usual software download, like with Java applets, up to process migration transferring the complete execution state of an agent.

Software agents can be seen as a design pattern for distributed software systems. Tools, languages, and environments can be specifically developed to support the agent-based pattern. However, the agent design pattern can be implemented using object oriented tools, languages, and environments. But usually these object oriented methods do not support autonomy, interactivity and adaptively. The primary reason agent-based tools are preferable is because the agent design patterns are inherent in the paradigm rather than a programmer has to explicitly program them. In other words, object technology can be used to *enable* agent-based technology, but the autonomous, interactive, and adaptive nature required by agents is not currently supported within object technology. While these properties can be (and are being) added to the object oriented approach, the design patterns for agents and agent-based software are not fully and directly supported. So a new kind

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of middleware, called agent middleware, is necessary to support the agent-based applications and network services [13], [14]. Orthogonal to the distributed object oriented middleware, agent middleware and the applications, development environments, like agent platforms or specification tools are necessary. Moreover, frameworks like those for network management or electronic business applications, are pulled over these three layers.

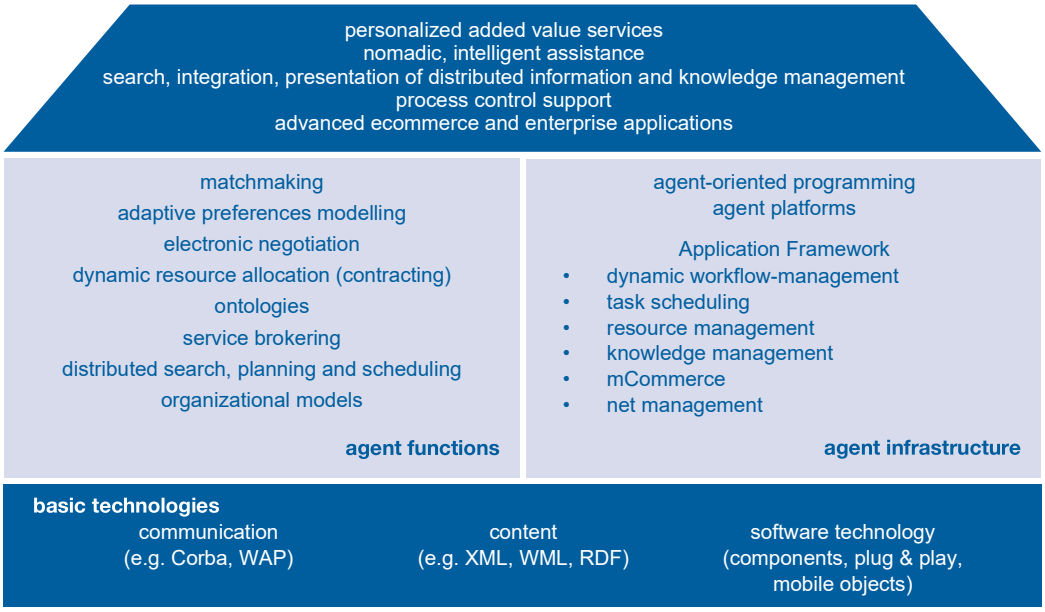

Figure 1 Pillars of agent-based applications

In other words, agent technology is based on some existing basic technologies, like software technology, e.g. components (Corba Components, Enterprise Java Beans, DCOM [15]), or plug-and-play technologies (UPNP [16], JINI [17]). The content is described using standards like XML or RDF; existing communication mechanisms, like CORBA or WAP, are applied within agent technology. But agent technology adds additional features to these technologies. On the one hand additional functionality is added, like matchmaking, or an adaptive preferences model is used, as shown in Figure 1. On the other hand the supported agent infrastructure consists of application frameworks that can be instantiated for special purposes. Moreover, agent platforms allow an easy implementation of agent-based applications and services. These pillars of agent technology result in personalized added value services, supporting the (nomadic) user with intelligent assistance, based on search, integration and presentation of distributed information and knowledge management, advanced process control support, and mobile and electronic commerce and enterprise applications (Figure 1).

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

- achieving enriched, higher level communication;
- enabling more intelligence service provision, and network management, e.g. by personalization and integration of different services to value-added services [18];
- dealing with the enlarging amount of information and functions, and
- allow self-organizing networks.

To realize this potential, 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 and 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 integration of telecommunication, Internet, TV and power line communication, self-organization and software defined radio, and intelligent hand-over from local communication channels, like Bluetooth [19], to wide-area communication channels, like GSM or UMTS [20].

Thus, agents will only be able to fulfill their potential if they provide a standardized, open and generic infrastructure (for standards efforts on agents see References [10][21]. Another important requirement for the acceptance of agent technology as a major key role for an infrastructure are generic services, like for virtual organizations or teams, mobile business and location (in)dependent services. Such services are designed for multiple reuse and cover areas where higher levels of intelligence are needed and agents seem more relevant than ever.

Beyond these mobile and cooperating agents in the literature additional kinds can be found:

Search agents; e.g. search engines that scan the WWW to store the information in local databases in order to allow efficient keyword search. Examples of such search engines are Verity [22] or AltaVista search [23].

User agents; on the one hand Microsoft Office agent supporting the user during work with the product and given some pre-defined information to the user according to his/her interaction. Microsoft Agent is a set of software services that supports the presentation of software agents as interactive personalities within the Microsoft Windows interface. The conversational interface approach facilitated by the Microsoft Agent services is an extension and enhancement of the existing interactive modalities of the Windows interface. On the other hand user agents can be more expressive planning the tasks for a user or adapting the preferences of the user according to the user's behavior.

Avatars are another approach of user agents. They are usually applied within Web pages guiding the user to find some information on the Web site or giving him/her additional information. Avatars are some kind of personalization having some 'personal outlook', e.g. being some comics figure, and talking to the user like real persons.

Agent-based services

As devices are becoming more powerful and supporting additional features as multi-modal and multi-media support and general purpose computation environments such as Java Virtual Machine. Software agents can run directly on these new devices, i.e. additional services can be supported. While the computing capabilities of these agents may be restricted for the time being, such a

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thick-client approach can be complemented by server-side agents wrapping more complex services, such as access to and analysis functions over large multimedia content repositories, or the solution of complex combinatorial problems (e.g., agent auctions and marketplaces [24][25][26][27][28]).

The Lightweight Extensible Agent Platform (LEAP for short) [29] is the precursor of the second generation of FIPA-compliant platforms [10]. It represents a major technical challenge - it aims to become the first integrated agent development environment capable of generating agent applications and executing them on run-time environments implemented over a large family of devices (computers, PDAs, mobile phones, etc.) and communication mechanisms (TCP/IP, WAP, etc.).

LEAP being a further development of JADE [30] for small devices, developers can use JADE/LEAP to migrate existing applications to, or develop a new generation of applications for small wireless devices. The LEAP applications like virtual mobile team management or knowledge management are a good illustration of these new capabilities.

Another agent platform designed for small end user devices is the Cognitive Agent Architecture called Cougaar [31] sponsored by DARPA. While the focus of Cougar is on small-scale robots rather than end-user devices, the underlying agent platform could be fairly easily adapted to provide users of mobile devices with agent-supported negotiation capabilities.

Agent-based user interfaces

Considerable research activity has been going into the endeavor to build user interfaces that are easier to use, personalized, and support a variety of devices and input/output modalities. Two core areas within the discipline of intelligent user interfaces include intelligent dialog systems, and believable virtual personalities.

Artificial Life [32] is a software company that develops, markets and supports intelligent software robots that automate and simplify certain business-related Internet functions. The so-called ALife-SmartEngine technology is the core component that gives Artificial Life products the expertise to communicate with users in natural language text or speech. The softbots are designed so that users, especially enterprises, can adapt them to their own applications' needs by adding user or company-specific knowledge and by customizing the softbots. Still, the human effort needed to customize an Artificial Life system for an application is considerable, leaving the company at the high-end sector of the market.

7th Level [33] offers a relatively low-cost character animation software called Agent 7. This product constitutes a kind of voice activated, Internet software for making and running broadcast quality, lip-synched, re-usable animation on the Web as well as from within major desktop applications for word processing or slide-show presentation. Characters can be choreographed and lip-synchronized to create animated characters. Users can change a character's dialog by recording a new voice track with a microphone plugged into a PC. Users can select from a cast of characters created by 7th Level and insert animation into other programs. Animation features include 2D and 3D animations, as well as photomontage.

WIP [34] is a knowledge-based software tool for automating the design of multimedia presentations. This advanced multimedia authoring tool generates interactive and coordinated presentations combining text, graphics, animation and speech. In contrast to conventional hypermedia-based approaches, WIP does not use any canned texts or graphics. Rather, a presentation planner is used to design multimedia presentation using a knowledge base providing factual and rule knowledge.

Reference [35] provides an approach for agents that interact with standard applications via user interfaces rather than via Application Program Interfaces, and that lend themselves to better instructability.

The academic research activities in the area of anthropomorphic interface agents have already led to new commercial developments. The Persona project at Microsoft Research [36] is working on the technologies required to produce conversational assistants, i.e. life-like animated characters that interact with a user in a natural spoken dialogue. The prototype system integrates spoken language input, a simple conversational dialogue manager, reactive 3D animation, speech output and sound effects to create Peedy the Parrot, a conversational assistant who accepts user requests for music titles and plays the corresponding CDs.

Microsoft Agent, another Microsoft product [37], is a set of software services that supports the presentation of user-controlled applications as interactive personalities within the Microsoft Windows interface. These interface agents are meant as an extension and enhancement of the existing interactive modalities of an application's conventional graphical user interface. Character-based interaction can be blended with the conventional interface components such as windows, menus, and controls. In addition to providing animation services for the cartoon-style drawings, Microsoft Agent supports input using keyboard and mouse as well as speech interfaces.

Perspecta [38] is offering a product family that is designed to organize, structure and present information dynamically on the World Wide Web. The products provide a framework for building intelligent user interfaces that serve as a sort of virtual domain expert for a given corporate database of information such that database content is quickly and efficiently served to the end user. The Perspecta system is a client-server architecture composed of several products.

The blaxxun [39] Avatar Studio provides a tool for building virtual identities in Cyberspace. An avatar, a personal 3D character, can be used to represent a person in 3D communities. Hairstyle, body, clothing and so on can be defined in every detail and without technical know-how. blaxxun Avatar Studio was developed by CANAL+ and Le Comptoir des Planetes and is distributed by blaxxun. Blaxxun's focus is clearly on animation, and not on intelligence.

Virtual Personalities [40] are creating intelligent user interfaces featuring verbally interactive characters called Verbots or 'Verbally Enhanced Software Robot'. These likable, helpful agents make deep communication with technology a breeze, for beginners as well as experts. They are developed with Virtual Personalities' using artificial intelligence, natural language, and real-time animation. A Sapphire WebHost can be used for personalizing Web pages. Sapphire can be customized to represent the image, values and personality of some company. Sapphire knows the site visitors by name and greets them personally and therefore it records information about each visitor. Sapphire is a class of Verbot.

At the level of underlying representations, SMIL, the Synchronized Multimedia Integration Language (see Reference [41]), is a major standard supported by W3C [42]. SMIL is an XML [43] application for synchronizing television-like audio and video with text and animation. It can be expected that this new representation format will also have an important influence on future software solutions for multimedia information presentation within intelligent user interfaces.

Agent-based network management

The evolution of network management to what it is today and what it promises to be in the near future, has been in close communion with the way in which networks themselves have evolved - from a limited interconnected homogenous set of computers under one domain to a large heterogeneous distributed communication environment spanning across multiple domains. Network management and in this case Telecommunication network management, too, refer to the task of managing increasingly complex networks that often incorporate an elaborate mix of multi-vendor, multi-protocol, and sometimes global resources.

With telecom networks becoming more intelligent, distributed, and larger every day, new management network architectures are emerging to fill a compelling need for making carriers more competitive. The International Telecommunications Union/European Telecommunications Standards Institute (formerly CCITT [44]) has created a network management framework and standards known officially as the Telecommunications Management Network (TMN) for operations, administration, maintenance, and provisioning.

Around mid 1988, there were two broad efforts in the area of Network Management: the Simple Network Management Protocol (SNMP [45]) and the Common Management Information Protocol (CMIP). A decision was taken to adopt SNMP as the standard for Network Management. Since then various extensions SNMP have been proposed and implemented.

Another management standard is Desktop Management Interface (DMI) which has been around for a while in the PC environment. There is also some effort on extending DMI to provide remote management capabilities. A new trend in SNMP-based Network Management is RMON (Remote MONitoring [46]). A RMON device sits on a network and gathers information on network traffic, and also records SNMP traps. RMON devices may also be instructed to perform some automatic actions based on SNMP messages they see. A NMS may communicate with a RMON device to obtain information from it or instruct it on what to do. A new standard has been defined to represent the Management Information Base (MIB) parameters supported by RMON devices.

Another trend is the use of Web technology in Network Management which is seen in the initiative WBEM (Web-Based Enterprise Management [47]).

These are actual standards and trends in network management without using agent technology. However, a very interesting type of agent for network management applications are mobile agents [48], i.e., software agents that are able to migrate between multiple hosts and to carry out computations on different hosts, following an itinerary. 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 transport network management code to the SNMP agents. This saves bandwidth, reduces bottlenecks, and makes the architecture more scalable.
- 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.
- 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.
- 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.

Examples for the mobile agent platforms are MOLE [49], IBM Aglets [50], Objectspace Voyager [51], the OMG-MASIF initiative [52], Semoa [53], Swarm [54] and Grasshopper [55]. A good (if somewhat outdated) overview of agents in network management is Reference [56]. The latter article focuses on non-mobile, stationary agents. Examples for the area of active, self-organizing networks, are the DARPA-sponsored Active networks program (e.g., the Active Networks project at MIT [57]) and the self-organizing

network activities at EPFL [58]. Two prototypes are available from the first project, namely ANTS, an Active Networking Toolkit, and PAN, a prototype high performance Practical Active Network.

The EU-sponsored project FAIN (Future Active IP Networks) [59], [60] is a three year collaborative research project among universities, research establishments, manufacturers and operators starting in May 2000. The project aims to develop an open, flexible, programmable and dependable network architecture based on novel active node concepts. The generic architecture for active networks is an innovative integration of active networking, distributed object and mobile agent technology. The project will contribute to the establishment and operation of a worldwide active networks and services test bed.

The ACTS (Advanced Communications Technologies and Services) EU program [61] [62] features a cluster of 16 agent-based telecommunications projects (CLIMATE: Cluster for Intelligent Mobile Agents for Telecommunication Environments [63]). The individual projects in CLIMATE are organized according to the following topical areas [64]:

- intelligent networks and mobility (AMASE, CAMELEON, MARINER, MONTAGE and SCARAB): include mobile devices and smart cards using mobile and intelligent agent platforms. New ubiquitous applications were developed and tested, including video-on-demand, UMTS virtual home environment, customer profile management, mobility support, financial services and dynamic provider selection
- communication and management (MIAMI, IMPACT, FACTS, MARINER and MONTAGE): successfully addressed the challenges of decentralized management, made possible by the use of agents and the adoption of management-on-location techniques. These projects focused with significant success in areas such as IN/SS7 load control, connection admission control for ATM networks, accounting and charging services for fixed and mobile environments and service reservation.
- agent systems (OCEANS, ABROSE, DICEMAN, MODEST and OSM+): analyzed selected design topics in relation to agent negotiation, knowledge representation and human-to-agent interaction. Prototypes validated the proposed design solutions.
- agent platforms (MIAMI, FACTS and MARINE): the projects promoted amongst other things, extensive comparison of the characteristics of existing platforms like Objectspace Voyager, IKV++ Grasshopper, IBM aglets, Mitsubishi Concordia, General Magic Odissey, contributing to their enhancement.

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

Conclusions and Outlook

Intelligent agent technology has the potential to play the role of an important enabler for next generation highly distributed and complex telecommunications solutions, services, and networks. However, for agents to satisfy the expectations there are some important preconditions. Firstly, the research community needs to establish a focus on pragmatic solutions that build on existing standards. Secondly, existing solutions and technologies need to be used efficiently and enhanced incrementally instead of re-inventing the wheel. Thirdly, for some areas, such as telecommunications networks, new architectures and methods will be required to achieve the necessary level of scalability and flexibility. Self-organizing networks whose nodes consist of autonomous collaborating agents seem to be appropriate building blocks for these solutions.

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[62] FACTS: http://www.labs.bt.com/profsoc/facts/.

[63] CLIMATE. http://www.fokus.gmd.de/research/cc/ecco/climate/.

[64] ACTS final report: http://www.infowin.org/ACTS/RUS/PROJECTS/FINAL-REPORTS/acts-final-report.pdf.