Future Broadband Radio Access Systems for Integrated Services with Flexible Resource Management

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ABSTRACT

The current challenge in radio networks is to provide integrated broadband services to everybody. The realization of this goal is dependent on both the development of products for the mass market and the improvement of the systems that support these products. New cellular mobile, fixed terrestrial, and satellite systems are being developed to provide broadband integrated services. The users of these new systems will not need, or even want, to know which particular systems are used to access the requested services. The users may negotiate terms of delivery, such as data rate and quality of service, but the actual system of delivery should be transparent. In order to both achieve transparent service delivery and ensure efficient use of the radio frequency spectrum, a flexible and scaleable resource management system is needed. This article highlights the development trends that will form the basis of future network systems and presents some suggestions for the management and control of these systems.

INTRODUCTION

The rapid evolution of the global information society is being fostered by the increasing demand for seamless, integrated broadband services. Customers are becoming more demanding in terms of service availability and network performance. In the past, system and network solutions tended to be developed in a closed and independent manner, providing specialized architectures with limited flexibility. However, due to rapid evolution there is now an increasing need for integration and convergence of network functions. The success of any new system depends on the provision of a low-cost and flexible solution for coping with increasing demands. The challenge is to provide a large set of options in terms of services, terminals, and network access that is able to cope with different requirements, and provide for flexibility, modularity, and scalability.

Radio systems provide a good platform for meeting this challenge. Radio solutions offer an excellent means of creating scalable systems that are user-friendly, can be tailored both economically and technically to varying-sized communities, and can provide a diverse set of broadband services. A prominent trend in multimedia systems is the convergence of broadcasting, telecommunications, and content. To be economically viable, a platform must offer affordable broadband services tailored to people's actual service requirements and be flexible enough to cope with dynamically changing capacity requirements.

As shown in Fig. 1, a new system called *broadband radio* will provide the large capacity achieved by local multipoint distribution systems (LMDS), broadband satellite multimedia (BSM), or mobile broadband systems (MBS). It also offers high mobility, as provided by the Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS).

This article presents development trends for mobile, fixed terrestrial, and satellite access and key elements of a multimode future broadband access solutions. It also considers the resource management issues associated with flexible provisioning of future broadband network systems.

Development Trends for Mobile, Fixed Terrestrial, and Satellite Access

Mobile Systems

The early days of research into UMTS took place parallel to the commercial development and deployment of GSM. A widely accepted assumption at the time was that the core network of UMTS would be based on broadband integrated services digital network (B-ISDN), asynchronous transfer mode (ATM), and intelligent network (IN) techniques. B-ISDN was regarded as a key technology in the wide area network, and UMTS was seen as having the capability to achieve fixed-mobile convergence.

During this period, the Internet was still confined to a small community of scientists and engineers in universities and research institutions. Since then the World Wide Web has generated a new mass market for an increasing number of information services. Making these services available for everyone, anywhere, and at any time, including people on the move, is now regarded as a major driver for UMTS. The convergence of mobile cellular technology and the Internet world is already happening. For example, General Packet Radio Service (GPRS) has extended the mobile world toward IP (i.e., the Internet) in two major ways:

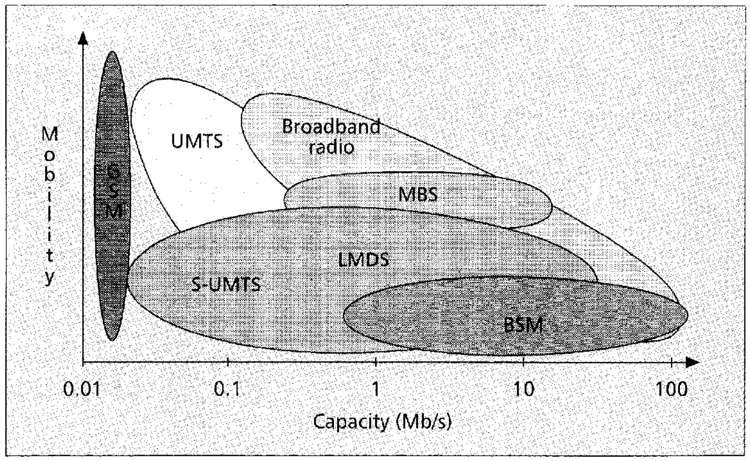
- It has given IP connectivity to the mobile station, and has introduced IP technology in the mobile core network.
- It has forced mobile operators to play the role of Internet service provider and thus changed their traditional business model.

Moving to UMTS release 99, the key decision for the provision of IP connectivity was to attach the newly designed UMTS Terrestrial Radio Access Network (UTRAN) directly to the GSM infrastructure. As a result, the core network in UMTS release 99 is composed of two separate domains: a circuit service domain based on mobile switching centers, and a packet service domain built on gateway support nodes.

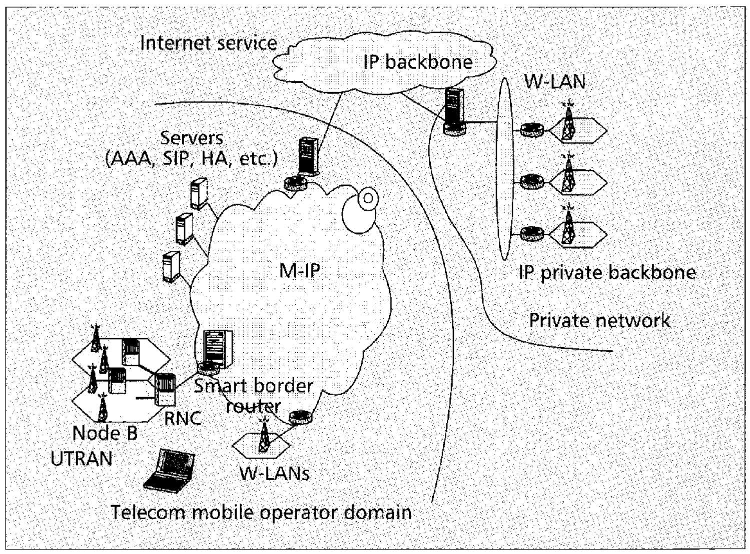
Further releases of UMTS driven by strong focus groups, such as 3G.IP and European Research projects, utilize IP as the integrating factor. This integration is achieved by providing different IP-based services in the user terminal and extending the core network features with Internet Engineering Task Force (IETF) protocols. The IETF protocols provide basic voice and data connectivity as well as advanced multimedia services. This solution is under specification by the Third Generation Partnership Project (3GPP) [1].

The solution adopted by UMTS for integration with the Internet gives IP connectivity to the mobile station and introduces IP technology inside the mobile systems. However, this solution does not provide complete integration. The reference architecture depicted in Fig. 2 illustrates a solution that achieves a deeper level of integration between mobile systems and IP [2].

The basic approach adopted is to reuse state-of-the-art UTRAN and attach it directly to an enhanced Mobile IP backbone through a standard interface. The GPRS nodes are no longer present, but specialized border routers are required. This approach is possible because of the full separation achieved in UMTS between the signaling devoted to the UTRAN (access stratum signaling), which remains unchanged, and the signaling between the terminal and the backbone (non-access stratum signaling), which may be heavily modified in an ad hoc manner [3, 4].



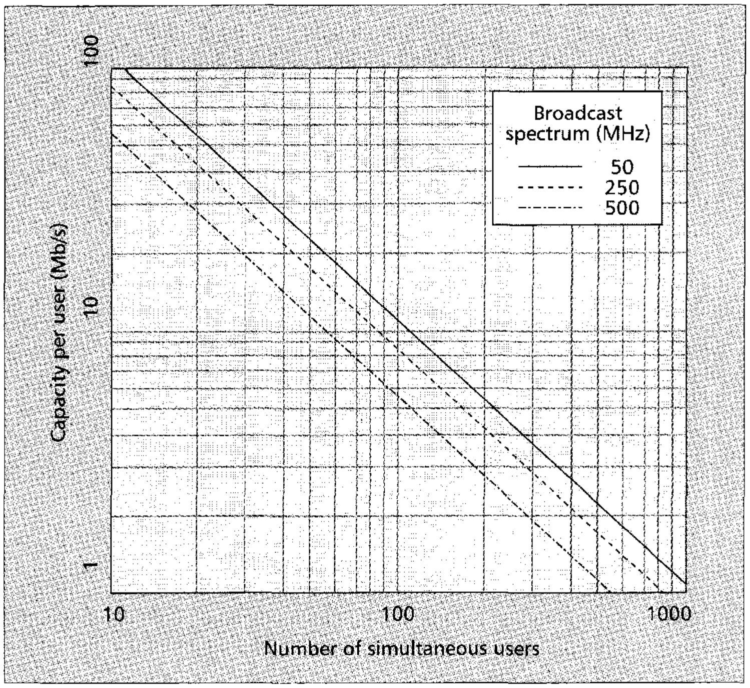
■ **Figure 1.** *Typical capacity and mobility aspects of some radio access systems.*



■ **Figure 2.** *A mobile system and IP integration reference architecture.*

The major advantages of using this architecture relate to session, mobility, and authentication. For example, authentication becomes a network service using UMTS SIM, and the user is no longer forced to perform double authentication at the UMTS and application levels. The same concepts apply to the mobility features. These advantages are not duplicated at the IP and UMTS levels, because the two levels are fully integrated into the UMTS wireless Internet. Additional integration is also obtained with other IP networks, such as fixed LANs and wireless LANs (W-LANs).

In order to achieve full integration between the Internet and mobile/wireless communications, this architecture requires the partial modification of certain characteristics of IP protocols



■ **Figure 3.** *Individual capacity per gigahertz for cellular systems operating at frequencies above 20 GHz where part of the spectrum is used for broadcasting.*

in order to adapt them to the requirements of mobile/wireless systems. This will require influencing the development of the IP protocol suite for mobile system use.

TERRESTRIAL FIXED WIRELESS ACCESS

Broadband terrestrial fixed wireless access (FWA) solutions developed so far essentially consist of LMDS and some radio-link-based point-to-multipoint (P-MP) systems (at frequencies above 20 GHz). Such systems are typically designed with cell sizes on the order of 1–5 km in diameter, depending on the number of users in the area and propagation conditions (e.g., rainfall and topographic, building, or vegetation obstruction).

LMDS was originally introduced in the United States, where it was launched as a TV distribution system. However, it has also gained a prominent position in the rest of the world [5] mainly as a system for converged broadcasting, content, and telecommunications. While the system was designed to operate at 28 GHz, there are several other bands in which LMDS-like systems can operate. In Europe there is a particular focus on 40.5–43.5 GHz, but other bands at 24, 26, and 32 GHz have also been made available. LMDS and P-MP are part of the high-density fixed service, to which the World Radio Conference (WRC 2000) allocated about 10 GHz in bandwidth above 30 GHz [6]. This allocation and those between 20 and 30 GHz represent very high transport capacity potential when used in a cellular architecture with efficient frequency reuse. A four-block frequency plan can be used for such a system since the users have narrow beam antennas. Assuming a regular base station location pattern, which represents the worst-case scenario, the plan results in a carrier-to-interference (C/I) ratio of 14 dB or more,[1] depending on user location relative to the base stations. In fact, half of the potential users have a C/I of about 28 dB or better [7]. As illustrated in Fig. 3, it is possible to provide very high individual capacity to a large number of users simultaneously.[2] Three curves have been given for various options of broadcasting spectrum, which of course is also available for everybody.

While the large amount of bandwidth made available for broadband services provides great possibilities, development of systems suitable for the mass market has been somewhat delayed. The primary delaying factor is the lack of internationally agreed standards. This is probably a result of the decision to first provide the small and medium-sized business market with a broadband network, and then the mass market. Thus, equipment has evolved from traditional radio link technology. However, there is an alternative approach based on interactive broadcasting technology targeted for the mass market. This solution is currently limited by its low return link capacity.

Development in this area is moving toward a system that combines the idea of broadcast services for P-MP systems and higher return link capacity for broadcast-based systems. Since many services are asymmetric, the ability to make efficient use of the frequency resources is crucial and has resulted in renewed interest in time-division duplex (TDD) systems. From a user's point of view a radio system can then be operated dynamically asymmetrical, depending on user demand and type of service.

At frequencies below 20 GHz the interest is the lower range where line-of-sight paths are not necessary. At low frequencies (below a few gigahertz), the bandwidths are clearly much more limited, but utilizing the right technology these bands may provide broadband services to many users (e.g., multiple-input-multiple-output, MIMO, techniques utilizing multipath propagation).

SATELLITE SYSTEMS

Satellites remain a good option for cost-effective broadband services. They ensure the ability to redeploy capacity, provide communications infrastructure, and provide overall flexibility and reliability. Presently the development focus is on broadband access represented by the work on the return channel (digital video broadcast return channel via satellite, DVB-RCS) and the search for a satellite UMTS (S-UMTS) solution for mobile applications.

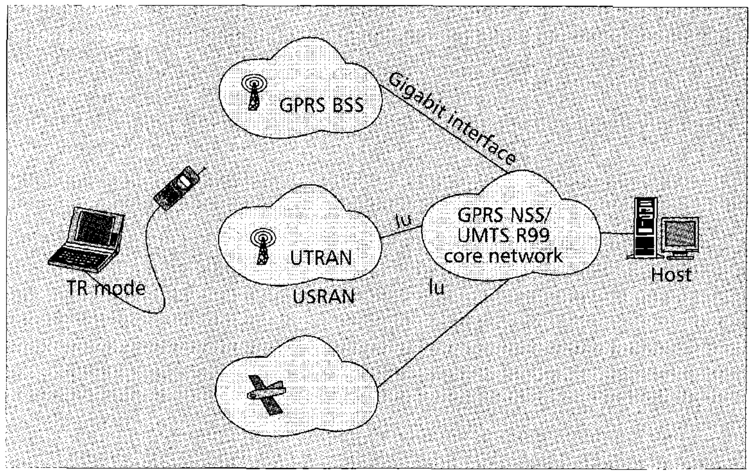
Satellites are increasingly used to provide high-speed Internet service in P-MP configurations. In Europe, there has been great interest in providing services over DVB carriers. DVB is not merely a standard for digital broadcasting, but defines information *containers* which allow the seamless transport of IP packets and support any type of service. Satellite systems compliant with the DVB via satellite (DVB-S) standard have been developed to include encapsulation techniques that allow MPEG-2 data packets to carry UDP/TCP/IP traffic, and work together with a dialup return channel. A further step has been the development of the DVB-RCS standard. This

*[1] By using a commonly proposed quadratic rectangular base station location pattern it is easily seen that the minimum C/I is 20*log(5) = 14 dB.*

[2] A spectrum efficiency of 1.5 bit/s/Hz (e.g., with QPSK modulation) was used for 50 percent of the users and 3 bit/s/Hz for the rest. It was assumed that antennas with good cross-polar discrimination can be used allowing dual-polarization frequency deployment.

standard will enable users to have a two-way broadband satellite data communications channel to their own premises via low-cost Ku/Ka-band terminals. Currently speeds up to 50 Mb/s on the forward channel and 2 Mb/s on the return channel are envisaged. In the future, the speed of the return channel is expected to increase to 8–10 Mb/s. From a technological standpoint, the advances in satellite onboard processing technologies will certainly provide further opportunity for the evolution of the direct return channel.

Satellite systems provide wider coverage than traditional terrestrial, allowing coverage in less accessible areas. Any migration path for cellular systems from second to third generation should take into account the supporting role provided by satellite. In order to accomplish this, the key issues for satellite support must be identified and standardized. The objective is to integrate the terrestrial and satellite segments while guaranteeing integration with the second-generation terrestrial cellular system (i.e., GSM/GPRS). A reference scenario is shown in Fig. 4.



■ **Figure 4.** *The satellite and terrestrial integration reference scenario.*

In this scenario the satellite network can be considered an integrated extension of the access network. This solution provides seamless transition of the user among different segments (intersegment roaming).

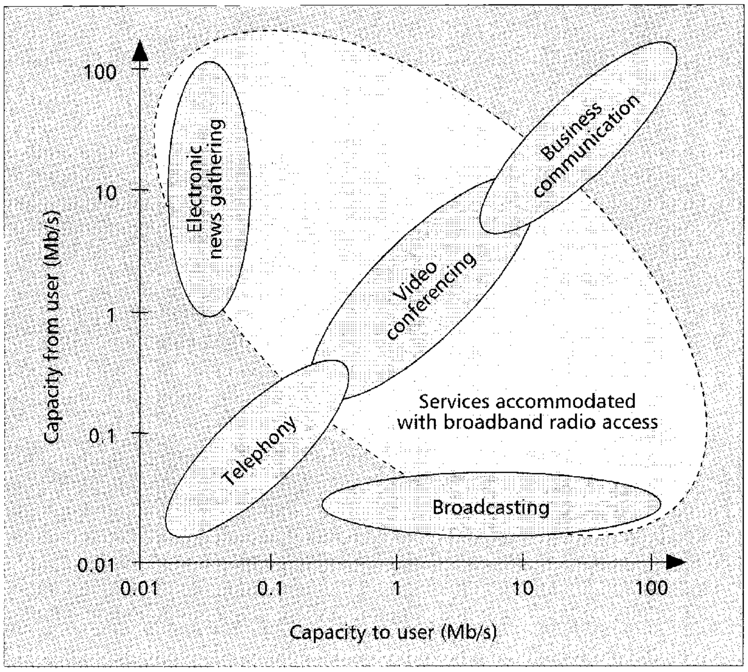
A universal user access interface for BSM services open to different system implementations is important. The motivation for this type of interface is to open up and expand the market for satellite user terminals by harmonizing common satellite access network functions while allowing flexibility for optimized or proprietary air interfaces to satellite systems. The BSM system concept being developed supports a range of multimedia applications with varying data rate requirements (up to 150 Mb/s). The objective is to allow access to different core network types in order to offer broadband terrestrial wireless or wired access services. The separation of higher-layer radio-technology-independent (RTI) access network functions, which "hides" the lower-layer radio-technology-dependent (RTD) functions [4] from the user and the core network, is a key strategy for the BSM. The common RTI layers in the user and hub stations are devoted to IP transport across the system, and connection to alternative customer premises and core networks. The RTI layers should be transparent to a full range of IP-based multimedia services. Different RTD layers are intended for different satellite systems (e.g., low earth orbit and geostationary earth orbit constellations) and different radio access schemes, such as time-division multiple access (TDMA), frequency-division MA (FDMA), and code-division MA (CDMA), within the access network and will each support an extensive but different subset of the services of the RTI layer, suited to particular markets.

Key Elements of a Future Multimode Broadband Access System

A future broadband radio access system will consist of several interconnected/integrated subsystems, and will seamlessly provide services to both fixed and mobile users. Such a system may include FWA, MBS, and BSM. These components will serve much the same market, but may well be based on different architectures, broadband access technologies, and coverage.

Broadband radio access networks have traditionally developed in different directions for the different areas they have addressed. They have been associated with standards for existing networks like interactive cable or interactive satellite networks. User flexibility and interoperability between networks will require harmonization of operation, service provision, and network management. The user should be allowed to move between the different segments. Common management for services, network resources, and customers, covering both fixed and mobile segments, has started to become a necessity. It requires a strong focus on network integration in the ongoing development process. The following discussion describes development work in the field of radio access, contributing to harmonized development of multimode broadband access for everyone.

It is now commonly accepted that the provision of services like interactive TV, Internet, tele-education, and advanced home office services is necessary for development and growth. The development of a low-cost millimeter broadband radio access system for fixed and nomadic users will help ensure that as many people as possible have access to these services. Broadband radio systems would be able to achieve higher penetration than twisted pairs or cable systems. The market will range from residential to small and medium-sized businesses, including organizations, schools, and local authorities. With a broadband system, entertainment and business services will be provided on the same platform. The high return capacity available will allow new business to develop, making use of the new technology in delivery of the services. The traditional market segments, such as residential and business, no longer adequately describe the new combined market. Some typical services and corresponding uplink/downlink data rates are illustrated in Fig. 5.



■ **Figure 5.** *Capacity to and from the user for various services.*

ARCHITECTURE

To obtain a low-cost system for such a mass market it is necessary to focus on the development of architectures with efficient allocation of radio resources and high coverage. Also, flexible provision of services is required and relies exclusively on seamless integration of the components of the system.

One implemented architecture uses a system that combines broadcast technology and high-speed communication technologies to achieve an interactive system that can easily scale with an increasing number of users. The interactive broadcasting system with point-to-area distribution and a point-to-point (P-P) return channel (e.g., LMDS), offers an efficient method for combined provision of video and audio over the Internet, as well as telephony. It demonstrates convergence of services on widely available platforms. For the incumbent operator, LMDS complements existing systems such as very high rate digital subscriber line (VDSL) and interactive cable systems. For new operators it represents the potential to obtain a dominant role in broadband access.

An MBS architecture can be specific to each of the segments, while being a set of radio access technologies equivalent to UTRAN that share a common all-IP core network [8]. Due to the high number of cells necessary to cover a larger area, base stations will have to be installed on buildings and lampposts using an efficient network topology. This may require remote installation of the radio functions with direct transmission of the RF signals over fiber to reduce network costs.

BSM addresses satellite systems that are intended for high-quality interactive (two-way) multimedia communications. The connections can be asymmetric, and both transmission paths need not follow the same path or provide the same capacity. Transmission rates are expected to range from hundreds to thousands of kilobits per second.

BROADBAND ACCESS TECHNOLOGIES

For the high RF end, the DVB-RCS standard from the satellite area with a multiple-frequency TDMA uplink solution also provides an attractive option for terrestrial access. The flexibility and scalability ensure that the radio resources, time slots, and frequency bands are efficiently used. However, the terrestrial solution can be simplified, particularly with respect to synchronization and handling of guard times. The first systems developed are frequency-division duplex (FDD)-based with limitations on efficient capacity use, imposed when demand is strongly varying and asymmetric in nature. TDD may well provide a better solution for future systems. This is particularly important with respect to the total capacity for the downlink compared to the uplink. Present work is concerned with both the TDD vs. FDD issue and the problems introduced by interference. The MBS radio interface should be effectively designed to support symmetric and asymmetric services with dynamic allocation of radio resources. It may operate in FDD or TDD mode and be based on TDMA or orthogonal frequency-division multiplex (OFDM). TDMA requires a fast adaptive equalizer, while OFDM requires large processing power for fast Fourier transform (FFT) calculations and linear power amplification. The ACTS project SAMBA [9] demonstrated that single-carrier modulation using an equalizer was feasible at transmission rates up to 34 Mb/s.

Communication with the user is IP-based. This covers all communication and control traffic. It also covers the case of multicast. As mentioned in the previous section, the MPEG transport stream is also used to carry IP traffic. Innovative solutions for IP traffic that exploit the concept of route diversity are being developed.

Broadband satellite access networks will complement wired and wireless access systems. These will deliver telecommunications services into and within residences and businesses. They are particularly suited to areas of low population density or with a poor terrestrial infrastructure.

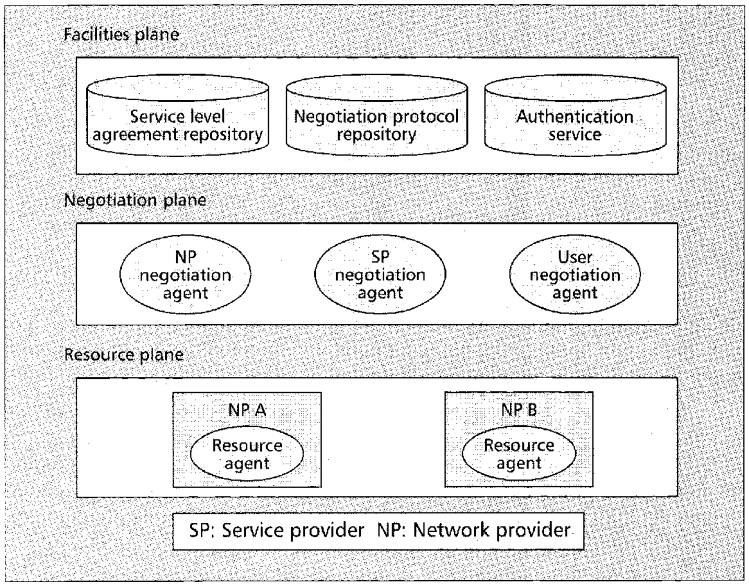
Work is in progress on interactive DVB and ATM-based communications via satellite, but a complete and universal standard for satellite systems is not yet available. Satellite standards would benefit from being global and could increase the use of BSM communications by exploiting the interoperability with terrestrial systems.

COVERAGE

A mass market solution requires that every house and person can be served. High-capacity coverage will be attained using dense cellular patterns along with innovative frequency allocation schemes. A coverage optimization tool for frequencies above 20 GHz is being developed [7] to help planners with detailed design at minimal cost. The tool takes into consideration the frequency plans, terrain and demographic data, propagation information, and cost of key hardware elements. The propagation study at 40 GHz in the ACTS project CRABS [10] provides a large number of results on the effects of precipitation and vegetation.

MBS are seen as providing complementary capacity/coverage to UMTS in indoor and outdoor environments. They range from customer premises networks (e.g., WLANs) to public networks, possibly including a satellite segment. Using microwave and millimeterwave frequency bands implies a higher attenuation of the radio signals, leading to smaller cells ranging from a few meters to 1000 m for the terrestrial segment. At certain frequencies oxygen and water vapor absorption may also play a major role. Hot spots may be covered by MBS, but continuous and national coverage may not be provided. This imposes the need for mobile terminals to provide handover between different bands and technologies.

BSM systems will be able to provide broadband access to the Internet to address a mass market and cover large regions. Most such systems are expected to use Ku and Ka-bands with fixed terminals (FSS). Most filings focus on Ka-band at 20/30 GHz, but in general low-rate return channels at frequencies below Ku-band should not be excluded. There are also filings at V-band.



■ **Figure 6.** *A three-plane architectural model for agent resource management.*

FLEXIBLE RESOURCE MANAGEMENT

In multimode broadband access for integrated services a common resource management approach is essential. The geographical distribution and scalability requirements of resource management in heterogeneous networks lead naturally to considering architectures with distributed autonomous components. A possible solution for flexible and scalable resource management is found in the use of intelligent agents. Intelligent agents have been used in many domains, from workflow management to buying and selling on the Internet. The advantages agent technology can bring to the telecommunications domain are well documented [11], primarily in the fixed network domain. Factors such as autonomy, distribution of knowledge, and social interaction are all useful products of using agent technology; thus, work is now being done to extend these advantages to mobile networks.

A defining characteristic of mobile networks is that the point of attachment to the network changes. Therefore, hot spots can appear in areas where the network was not dimensioned to supply such a capacity, but overdimensioning is certainly not acceptable. The expected provision of flexible higher-bandwidth services in the mobile environment leads to increased complexity in resource control and resource management[3] because of the variable and unpredictable bandwidth requirements of applications. Such complexity requires the use of sophisticated control and management techniques.

Heterogeneity has another dimension induced by the different behaviors of the competing service providers (SPs) and network providers (NPs) and their individual business models. The deregulation of telecommunications sectors throughout the world means users are likely to buy services from various SPs, who in turn buy capacity from various NPs. Examples of this trend can be seen today in fixed telephony service, where, for example, customers can select a different SP on a call-by-call basis. Management of resources is inextricably linked to the business strategies of these providers. Any service and resource management system has to be flexible enough to accommodate possible future business models as well as the specific details of managing radio spectrum.

To further explore the use of intelligent agents in resource management, the following section will provide a skeletal outline of an agent architecture suitable for use in heterogeneous networks.

A FUTURE ARCHITECTURE FOR RESOURCE MANAGEMENT

This architecture is based on a loosely coupled community of agents distributed through the domains of a UMTS network. Although the approach described has been developed for the management of UMTS resources, the same type of agent-oriented solution can support scalable heterogeneous resource management for a variety of different network technologies. The agents compete or collaborate with each other in the pursuit of their own goals. Agents are deployed as representatives of their owners, and are thus assigned specific roles that aim to achieve best value for a particular type of owner. The individual agent framework used combines control and management functions within the agent by having a reactive part (to ensure a fast response), a deliberative part (for optimization of allocation among cells), and a cooperative part for coordination between agents. A key requirement of such an agent system is real-time response. This can be managed by giving *all* the agents involved in call setup and resource management fast reactive layers that communicate with each other. The procedures used in the reactive layers are generated as a result of policy decisions in higher deliberative layers of the agent.

The community of agents introduced above resides at different levels in the three-plane architectural model introduced in Fig. 6:

[3] Resource control is seen as a short-term response to events, whereas resource management is seen as a longer-term mechanism.

The example architecture uses distributed co-operating agents owned by a NP to manage the distributed resources of that NP and negotiation components to manage the interaction between competitors.

- The *facilities plane* incorporates the entities that ensure secure interactions in the negotiation plane. Facilities are provided to allow the agents in the negotiation plane to participate in indirect trading relationships as well as provide infrastructure services.
- The *negotiation plane* is where all interaction between the customers, SPs, and NPs takes place. This layer offers an interface for the agents to communicate with each other as well as with the services offered by adjacent layers. Issues such as business models and service level agreements (SLAs) feature in this plane.
- The *resource plane* is where the NP manages its resources both across and within individual radio cells. This layer lodges all low-level network services, including handover and cell selection management, cell size management, and offloads to other networks.

The majority of agents in such a system will reside within the negotiation and resource planes. *Separate* business interactions to establish agreements on capacity between SPs and NPs occur offline.[4] In mobile networks, it is important to stress that, because of the scarcity of the radio resource (unlike the fixed resource in, e.g., IMPACT [12]), it is unlikely that SPs will reserve capacity from NPs.[5] Rather, SPs may lease a *right to access capacity*, governed by some form of SLA using probabilistic performance as the measure of conformance.

Negotiation in a flexible resource management system is one of the key issues in establishing 3G services. An agent negotiates in order to either receive services or sell services. There are several factors that affect the decision making process during the negotiation of services. One such factor is the reputation of other entities with a particular agent. For example, an agent may keep records of how well previous transactions were dealt with and adjust the reputation rating of that entity accordingly. Another factor affecting negotiation is the business model of each business entity. The business model affects high-level issues such as when negotiation occurs and which budget negotiations are allowed. These can be formalized to provide agents with policies that provide guidelines on how to conduct their negotiation. Each agent will need mechanisms through which they will be able to dynamically change their negotiation policy (algorithms they use in order to maximize their benefit) in order to cope with a shifting market environment.

The resource plane is the province of the NP, and it is here that the NP manages the network at a detailed level. If there is no congestion, the network operates as provisioned. However, if load is building up or congestion has started to appear, the network operator's resource agent can take context-dependent actions [13].

Resource management is becoming increasingly important as networks become more strategically and physically complex, and applications become more demanding in terms of bandwidth. The example architecture uses distributed cooperating agents owned by an NP to manage the distributed resources of that NP and negotiation components to manage the interaction between competitors. This architecture is scalable and can be engineered to meet the fast real-time response needed at call request.

Conclusions

An overview of the trends in integrated broadband system development has been provided. Approaches that are currently the focus of five European cooperative research projects from the areas of cellular mobile, terrestrial, and satellite systems have been highlighted.

The new broadband radio access systems under development struggle with many of the same fundamental problems, such as efficient resource use and management, quality of service issues, scalability and operational flexibility, and reliable IP networking. A strong focus on similarities and interoperability issues is important for a successful system.

Additionally, flexible and efficient resource management is identified as crucial to the success of a solution where resources, such as radio frequency, are limited. A real-time architecture involving cooperative and competitive agents has been outlined. Although the approach described was developed for the management of UMTS resources, the same type of agent-oriented solution can support scalable heterogeneous resource management for a variety of different network technologies.

Acknowledgments

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[4] *Offline is used to indicate that these negotiations may not occur between the agent entities, but rather between business entities.*

[5] *A simple calculation shows that if there are four SPs, each reserving the same capacity from an NP, the maximum capacity anyone could have in a 2 Mb/s picocell is 0.5 Mb/s; this fixed reservation is clearly unsatisfactory and dynamic allocation is needed.*

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BIOGRAPHIES

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AGNE NORDBOTTEN (agne.nordbotten@telenor.com) is a member of the research team of Telenor Research and Development, Kjeller, Norway. He is primarily involved in work in the areas of broadband radio access and multimedia satellite systems. He was coordinator of the ACTS project CRABS; Cellular Radio Access for Broadband Services, which developed and demonstrated an LMDS, and took active part in the development process for the DVB-RCS, the interactive satellite system. Presently he is also involved in work on mobile multimedia satellite systems.

MARCO ANNONI [M'91] (marco.annoni@tilab.com) received his Dr. Ing. degree in electronic engineering from the Polytechnic of Turin in 1984. He joined CSELT (now Telecom Italia Lab), the R&D laboratory of the Telecom Italia Group, in 1985 as a research engineer in the satellite communications area. He contributed to several European and international projects such as the ESA/ESTEC TST/SS-TDMA system, the ESA/ESTEC OBP system, and the Motorola IRIDIUM project. Since 1992, he has been responsible for the Telecom Italia Lab R&D projects in the satellite area (including, among others, the EC ACTS SINUS and INSURED projects and the current EC IST BRAHMS and VIRTUOUS projects). He was a member of the EC COST 253 Action.

ENRICO SCARRONE (Enrico.Scarrone@tilab.com) received his doctorate in computer science from the University of Turin in 1992. The same year he joined CSELT (now TILAB), the R&D laboratory of the Telecom Italia Group. He contributed to main research projects (Eurescom P302, P506 and P810, RACE MAGIC and MONET, ACTS RAINBOW and INSIGNIA, IST WINE GLASS and VIRTUOUS) and standardization activities (ETSI, ITU-T, ATM Forum, 3GPP, 3G.IP) in the fields of ATM signaling first and then UMTS and its integration with IP. He his presently leading the mobile systems and services architecture group in TILAB, characterized by a position of excellence on GPRS, UMTS, and the integration of UMTS with IP.

SIMONE BIZZARRI [M'01] (simone.bizzarri@tilab.com) graduated in electronic engineering from the University of Pisa in 1990. In 1992 he joined SOGEI in the Network Department as a data network designer in an IBM environment (SNA) and contributed to the deployment of an experimental fault-tolerant data network. In 1993 he joined Telecom Italia Lab (ex CSELT) as a member of the Satellite Services Department and has been involved in the following fields: satellite constellations, modeling and simulation, and S-UMTS issues. He also contributed to several international projects such as the IRIDIUM, EC ACTS INSURED and IST VIRTUOUS projects.

LAURISSA TOKARCHUK (laurissa.tokarchuck@elec.qmul.ac.uk) is lecturer in the Intelligent Systems & Multimedia Group at Queen Mary, University of London. She received her B.A. in classics and B.Sc. (Honors) in computer science from the University of Saskatchewan, Canada. Her primary research interests include intelligent agents, user modeling, knowledge representation, and learning.

JOHN BIGHAM (john.bigham@elec.qmul.ac.uk) works on the application of agent technology to the management of telecommunications systems. Recent work has been on the real-time agent control of admission to ATM networks and on agent management of resources in 3G networks. Particular research interests are learning methods and reasoning under uncertainty.

CHRIS ADAMS (c.j.adams@rl.ac.uk) is a professor of computing at Buckingham University and a senior researcher at the Rutherford Appleton Laboratory. His interests are in high-speed multiservice networking and video systems, and in particular the performance of video-on-demand systems. He has worked in many national and international collaborations including projects UNIVERSE and UNISON in the United Kingdom, and the STELLA project with CERN and ESA. He took part in the CHARISMA and INK European projects in Frameworks 3 and 4, and worked in collaboration with the Technical University of Graz on high-speed satellite networks. He coordinates the Network Interconnection tasks of the FP5 EMBRACE project.

KEN CRAIG (k.h.craig@rl.ac.uk) received his B.Sc. degree in mathematics and physics from the University of Glasgow in 1974 and his D.Phil. degree in theoretical physics from the University of Oxford in 1979. He is head of the Radio Communications Research Unit at Rutherford Appleton Laboratory, United Kingdom, which he joined in 1982. He is responsible for a number of groups working on propagation measurement and modeling, communications systems, and remote sensing. His interests mainly lie in millimetric systems, numerical modeling, and the development of prediction tools for system design and spectrum management. He coordinated the propagation modeling work of the FP4 CRABS project, and coordinates the network availability and performance work of the FP5 EMBRACE project.

MANUEL DINIS (mdinis@ptinovacao.pt) received his B.Sc. degree in electronics and telecommunications from the University of Aveiro, Portugal, in 1990. He is currently working toward his Ph.D. degree at the same university in the field of mobile broadband communications. In 1994 he became a collaborator of the Institute of Telecommunications where he is now one of the scientific coordinators in the radio and microwave R&D area. In 1996 he joined Portugal Telecom Inovação, where he leads the Radio Technologies group. Since 1994 he has been responsible for various national and European R&D projects on advanced terrestrial and satellite mobile networks. He has published more than 50 technical papers.

Although the approach described was developed for the management of UMTS resources, the same type of agent-oriented solution can support scalable heterogeneous resource management for a variety of different network technologies.