Outline of an Open Mobile Radio Access Network

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Abstract

An open mobile radio access network is described, which differs considerably from current networks in structure, function and in the way it is operated. A flexible radio transmission principle, novel in telecommunications, and brokerage of spectrum and wired resources lead to network architectures and characteristics which permit simple access for users and businesses, negotiable bandwidth and scalable QoS. Most important however, a high degree of connectivity is introduced, which is particularly beneficial in the area of the heterogeneous requirements of wireless LANs and ad hoc networks.

1. INTRODUCTION

The connectivity problems between any mobile communications systems, irrespective of the ‚generation‘ they belong to, appear to be an inherent feature of innovation and technological progress in this area. Increasing bandwidth, new operational frequency ranges and tailored access networks cause considerable incompatibilities for the user- and network end of the communication system. The user is affected because his terminal can attach to the air interface of a single communication standard only, while others are out of technological reach, unless the terminal comprises two different systems. The second problem arises in the interoperation of different standards, i.e. if a call is started in system A and terminates in system B. Mismatch of the information channel characteristics mainly leaves the choice of reducing to the lower capacity/quality system’s parameters [1]. Interesting enough the interconnectivity problem is getting more pronounced with every new mobile communication standard entering the ‘mobile’ stage.

Despite high efforts to reconcile different standards [2] via Interworking methods, the accelerated development of new mobile communication standards increases number and width of the gaps between different systems. Standardization efforts extend over considerable periods of time, and the system operators‘ legitimate desire to exploit systems for another considerable period of time, set the scene for the connectivity drama.

Some mechanism in the way mobile communication systems are conceived and ‚produced‘ appear to lead into the connectivity trap and analysis of the ‚production‘ process reveals a certain schematic: once it is decided what applications are to be provided to the user, spectrum regulating bodies are consulted in order to find a more or less suitable frequency band which, at least on a long term basis, can be cleared for the new service. Due to the unbalanced spectrum demand and offer, the allocated frequency slot is rarely optimal. This is the first handicap, the new system has to cope with. The so acquired radio channel needs to be overcome by an Air Interface largely compensating for the channel’s peculiar imperfections (e.g. fading, delay spread, etc.), which makes the Air Interface unique, rigid and often complex. The scarce spectrum generally available, increases complexity due to high spectrum efficiency requirements, and does not help the Air Interface’s simplicity and flexibility either. The corresponding infrastructure, i.e. the access network, reflects the complexity of the Air Interface by the need of cell/ frequency planning and dedicated protocols, handling the mobile user. The rigid structure of such an access network is not easily changed without impact on capacity and signal interference levels. This process unavoidably leads to the *application - air interface – access network* chain, which in turn, with the application(s) defining radio frequency, bandwidth and QoS, leads to the interconnectivity problem.

Software Defined Radio (SDR) is supposed to be one way to avoid this trap. The authors have however developed views and functional structures of an open mobile radio access network which extend beyond SDR natural limitations.

Contrary to SDR philosophy – accepts the existence of multiple mobile communication standards and undertakes reunification on the technology level - the authors are engaged in the development of Air Interface concepts, which are open to bandwidth-, QoS- radio channel- and also currently unknown, future demands as well as to future technology developments. Together with a simple (parametric) configuration on a per-user-basis in an on-the-fly manner, an application independent, versatile Air Interface is the target. An ultra-wideband radio transmission principle (UWB), derived from radar technology and developed to prototype standard in the USA, is believed to have the potential to form the basis of an Air Interface having the described properties. The very high processing gain involved in UWB reduces resource allocation efforts (frequency planning and management) to a minimum. Such an Air Interface, integrated into heterogeneous networks, made coherent by advanced versions of the Internet Protocol, is equivalent to breaking the application - air interface – access network chain. The broken chain will leave three independent entities, which correspond to service/application, infrastructure (wired and wireless) and user.

Network resources and operation are described in section 2. The principles of UWB transmission are described in section 3 and UWB regulatory issues are addressed in section 4. It is important to note that current regulation efforts (FCC) concentrate on extremely low power emissions, enabling predominatly micro-cellular networks, with however highly flexible cell size for individual users.

2. NETWORK LAYER

Radio Server (radio access point) near-autonomy, enabled by UWB technology, in conjunction with a radio resource commodity (simple, flexible and instant allocation and configuration of radio resources) is the prerequisite for spectrum resource brokerage. Extension of resource trading principles to the fixed network forms the open mobile radio access network. User demands and network offer now can be made match via open market principles. Radio and fixed network resources are limited, and only dynamic allocation, according to open market principles, will be suited to achieve a highly efficient resource utilization, not only in the technical sense, but also economically.

The entity conciliating between user and infrastructure is the Network Services Broker (NSB). Independent of user and infrastructure it will explore the network as to the most cost-efficient manner to satisfy the user‘s specific needs. It will manage the access to the network inclusive of authentication, billing and user support functionality. Authentication will not only be mandatory for users but also for services, which are external to the network, and for radio servers which are added to it. The service contract, installed by the NSB on behalf of the user and infrastructure, will have to be split according to the number of administrative domains (defined by network element ownership) involved in the communication chain. Each sub-network will be represented by one or more entities, which, following contract negotiations with the Network Services Broker, will release appropriate resources and dynamically ensure that the service contract is fulfilled. It must be ensured, that infrastructure owners maintain exclusive authority in their domain(s), allowing - for example - proprietary methods to maximize the efficient use of the owned resource.

This is the function of the Resource Manager. It interconnects Network Services Broker and the transmission system. The NSB views the transport network as a 'black box' which must accomplish the task of providing the service with the requested QoS. The transmission system provides the bits transfer across the air interface. Therefore, the Resource Manager design must aim at optimizing the use of the resource by taking into account the transmission technique on one side and the NSB requirements on the other. The Resource Manager must, under the constraint set by a given QoS request, be capable of handling the resource at its best, e.g. by maximizing the network utility function. The above feature can be implemented either on the radio segment only, e.g. in closed private wireless network environments, or end-to-end by including fixed network segments. We adopt the second approach and assume that the fixed network is based on the IP paradigm which, in its enhanced versions, allows the support of different QoS profiles. A key element of the above choice is the adopted radio transmission technique.

The radio segment, based on UWB technology, exhibits extremely high versatility and excellent performance at high data rates. Therefore, it will not be a bottleneck in the present system, and any service will be offered to the final user with the additional great potential of supporting mobility. In particular, we investigate how to exploit the radio technique potentials, in the design of flexible multiple access providing QoS, within an IP based packet transfer. The above goal is pursued by designing a Resource Manager capable of:

- managing access to the system for multiple users,
- handling resource requests and assigning resource dynamically,
- satisfying QoS requests, end-to-end,
- routing information to any terminal, irrespective of its position in the service area of the network.

The aim of the Open Network proposed is breaking all the wires, physical or logical, which tie users and networks. It goes without saying that the proposed architecture is IP-based, i.e. it must be fully inter-operable with the Internet. In fact, in addition to the present importance of Internet and to the mobile applications, it is foreseen that even the actual circuit-switched traffic will converge towards an IP support. If we assume that IPv6 addresses will be the universal addresses of all the telecommunications networks of this planet, we could unify all the actual addressing schemes. A suitable evolution of the actual Domain Name System (DNS) could allow each of us to choose a "name" by which be reachable anywhere, providing thus a full personal mobility. Such a DNS could locate the actual position and access network of each user by starting from the single universal name that will be mapped to an IPv6 address (including a support for previous E.164 numbers, in a transition period).

In this framework, the improved DNS could distinguish among the available services, and address a call not only towards a given user, but even to a specific terminal belonging to that user (a voice call towards a telephone terminal, an e-mail towards a desk-top computer, a movie towards a video-enabled terminal). In other words, a given user could be globally known by means of a name; it is the task of the DNS to determine the physical address corresponding to a suitable terminal belonging to the user identified by that name, together with the actual location of the chosen terminal.

As IP is the glue that puts heterogeneous networks together, the Open Network concept could be the glue for heterogeneous services and applications. Given the desired characteristics of the Open Network, the following driving concepts have to be taken into account in defining the mode of operation of the higher layers (especially the network layer):

- Backward compatibility: smooth migration path from the actual best-effort Internet to a future QoS capable and mobile global infrastructure.
- Scalability: no state information; handling of traffic aggregates and not single flows.
- Distributed operation: the procedures must have a local target, each network entity or domain does not necessarily have to co-operate with other entities so that: i) all the network devices can operate autonomously, facilitating multi-vendor markets, ii) the exchange of signalling messages is kept to a minimum, iii) the inter-working among different sub-networks/operators is greatly simplified.
- Performance calibration: there must exist a suitable parameter (or set of parameters) which allows varying the level of achieved performance and utilization; in other words, the Resource Manager must provide a "tuning knob" which allows network operators to set target performance levels.

A preliminary step towards the definition of network related issues in the proposed Open Network, which allows providing a pre-defined Quality of Service, relies on the so-called Measurement-Based Admission Control (MBAC), in the framework of Differentiated Services (DiffServ) Internet Architecture.

DiffServ is an approach defined to overcome the scalability limits of IntServ (and of RSVP). In DiffServ, the network does not take into account individual flows. Each router merely implements a suite of scheduling and buffering mechanisms, in order to provide different loss/delay performance to single packets according to the value of a suitable field in the IP packet header. Thus, DiffServ tries to provide different aggregate service assurances to different traffic classes. However, the lack of an admission control scheme means that, upon overload in a given service class, all flows in that class suffer a degradation of service. In other words, the "classical" DiffServ appears to be a way to provide "better-than-best-effort" service, i.e. an intermediate solution between the extremes of hard guarantees and the vagaries of best effort.

Recent papers have proposed distributed techniques to improve DiffServ, by supporting flows with strict quality of service requirements. In these proposals (see e.g. [3, 4] and references therein contained), admission control is provided by means of measurement operations. Upon set-up, end points probe the network to check whether the internal network congestion is sufficiently low to admit a new flow without degradation in the provided QoS. In conformance with the DiffServ framework, routers are stateless, i.e. they are oblivious to individual flows, and thus scalability is guaranteed. In [5], we present a new distributed admission control technique, called GRIP (Gauge&Gate Realistic Internet Protocol), which provides the scalability advantages of distributed admission control operation, along with improved performance advantages, with respect to previous measurement based techniques. Fundamental features of the GRIP operation are its backward compatibility with existing DiffServ routers (at the expense of experienced performance) and the compliance with the objectives stated above.

3. PHYSICAL LAYER

The following is a description of the radio transmission principles forming the basis of an Air Interface which is supposed to largely contribute to the feasibility of the open mobile access network. It provides the wireless physical layer (PHY), which performs information transport over the air between radio servers and radio terminals. The aim is to fulfil the wide range of air interface requirements, which are derived from the service contract and dynamically implemented by the local Service Manager, e.g. by Media Access Control (MAC).

Multiple access can be achieved by using UWB technology, that is the transmission of very short Time Hopping-Pulse Position Modulated pulses which yield ultrawide bandwidth signals with extremely low power spectral densities.

The adoption of this technology is a key point in order to achieve the goal of an open mobile access network with extremely high flexibility for a broad range of data rates, classes of services, and mobility.

The first revolution is about the usable spectrum, as UWB transmission is allowed to coexist with narrow-band signals in dedicated bands. The use of time-hopping codes allows many users (thousands) to transmit in the same bandwidth, and adjacent cells (clusters) to use the same frequency band. In today's wireless mobile networks (e.g. GSM, GPRS, UMTS) capacity is increased through spatial reuse of the same frequency or the same code, and frequency or codes planning is always needed in order to maintain a feasible level of interference between active users, leading to a rigid network structure.

In a mobile radio access network with UWB technology no planning is necessary because of the high flexibility provided by the TH-PPM transmission technique, and the number of cells and their size can be adaptively changed in function of users' needs.

Frequency - and therefore interference - is, in a UWB system, a function of pulse shape, pulse duration, data rates, time hopping codes, etc., and transmission parameters can be chosen and changed "on the fly" in order to meet, in a multiuser environment, system requirements. This implies a revolution (not an evolution) with regards to present networks - either in structure, or in multiple access techniques, or in the connectivity concept, etc. - which leads to the new idea of an ad hoc open mobile access network.

The multiple access technique, which uses time hopping codes with pulse position modulation, is revolutionary compared to today's multiple access techniques in terms of flexibility and number of allocable users. While in TDMA and CDMA a few parameters - time slots and spreading codes - are involved in order to allocate users and fulfill service requirements, TH-PPM Multiple Access implies the possibility (and flexibility) to act on many parameters - pulse shape, pulse duration, hopping codes, pulse repetitions, bandwidth, etc. - to meet the goal of radio services without increasing the interference level.

Thanks to this new transmission technique the connectivity concept must be changed with respect to today's networks, and both, link establishment and mobility management algorithms will have to accomplish the ad hoc needs of many users with different quality of services and variable speed, in a context of a mobile network with a flexible structure.

The structure of this network is based on non overlapping adjacent clusters with flexible size and independent control; a fully distributed approach is adopted for cluster formation and intra-cluster communications.

Coexistence of the new open mobile platform radio layer with existing and planned radio systems, and the minimization of electromagnetic power exposure of the environment, are further boundary conditions. Scalability of terminal functionality must allow very low cost devices (even single use devices) through the implementation of reduced Air Interfaces not suffering from catastrophic loss of connectivity. The technology high end is marked by sophisticated radio servers featuring a fully parameter controlled Air Interface and the ability to adapt to technological evolution.

The PHY functional requirements (regarding data volume throughput, QoS and data integrity, data delay, data security) span orders of magnitude and are to be provided in multitude of radio environments. These not be met by legacy, i.e. narrow frequency band wireless systems.

One possible solution to the above PHY requirements is ultra-broadband radio technology (UBR), more specific ultra-wideband technology (UWB) [6]. The term UWB was coined in the late 80s, but the principles have been known since the 60s namely baseband radio, orthogonal function radio, carrier-free radio or non-sinusoidal radio and impulse radio [7]. As UWB technology has been used in the USA and Russia for military applications, the basic principles of this technology have been proven to perform well in the real world [8,9].

A UWB system is defined as an intentional radio emission having a fractional bandwidth greater than or equal to 25%, where the fractional bandwidth is the -20 dB bandwidth divided by the center frequency. For example, operating at a center frequency of 5 GHz, the emission band could start at less than 1 GHz and exceed 9 GHz. In actual radio environments, the extreme portions of the emitted spectrum behave completely different as regards their propagation characteristics. The problem of channel modelling, especially for the ultra-wideband indoor radio channel has, at present, not been solved [10], though the basic technology of UBW has been known for some years. The influence of multipath radio propagation, atmospheric/man-made noise and other systems' radio interference, for the different environmental scenarios, must be modeled very carefully in order to design the PHY and assess the system capacity in a real world target environment. A variety of systems, operating in different environments, have however been built and tested with considerable success [8]. It is hence feasible to base a PHY design for the new open mobile access network on UWB technology.

The proposed PHY design applies very short impulses (< 1 ns), sent with a low (< 1 %) duty cycle. These impulses represent chips in the classical sense of spread spectrum signalling. Depending on the spreading gain, the number of chips per bit can vary from one (no spreading gain) to values higher than 1000 (approx. 30 dB spreading gain). The position of the chip pulses in time is determined by the so called time hopping code, which is the basic means for channelization and is used for multi-channel communication of a single terminal and for multiple-access of different users and/or terminals. The auto-correlation properties of the time hopping code determine the spectral appearance of the transmitted signal. For a smooth spectrum, which is desirable for coexistence reasons, the code should behave as noise-like as possible. The cross-correlation properties of the code used, determine mutual interference of different channels as the various terminals should not be synchronized to keep the system overhead low. Only the codes used by the same terminal for transmission of different radio channels are orthogonal, i.e. synchronized . The temporal shape of the impulse should be variable within a certain range, which allows a certain freedom in center frequency and bandwidth selection. A powerful forward error correction, suitable for iterative decoding and flexible protection level, complements the UWB modem.

Dynamic adjustment of the PHY parameters, e.g. coding gain, time hopping sequence, duty cycle and temporal pulse shape, as well as code rate and decoding complexity underline the flexibility inherent to UWB. Thus, an extremely adaptive PHY, fulfilling the wide range of requirements can be designed. The described flexibility is not at least achieved by the fact that UWB avoids any intermediate frequency (IF) processing. Considerable care must be taken in the antenna design, because it has frequency and/or spatial filter proprerties.

Due to the application of very short impulses and low duty cycles, a very accurate time synchronisation between terminals participating in a connection is mandatory. It should be noted, that not the whole network must be synchronised, but only radio terminals communicating via air at the moment.

The very low (mean) power operation of UWB devices, yielding a very strong covertness (well suited for tactical military operation) make synchronisation and connection set-up a non-trivial problem. It can however be shown, that sophisticated synchronisation algorithms can cope with typical relative velocities of terrestrial transportation systems.

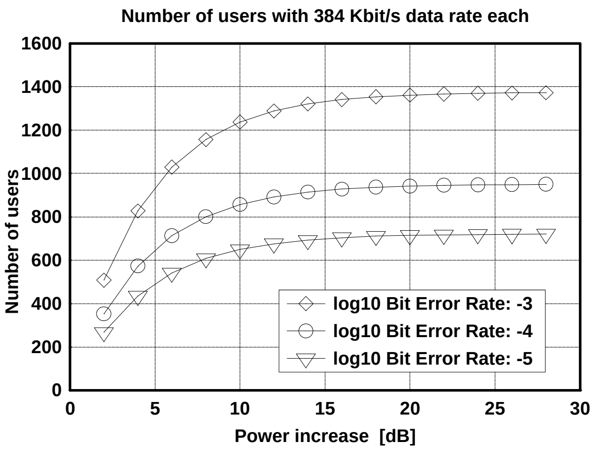

Fig.1 Number of users vs. power increase of each user for different target bit error rates for uncoded transmission and 384Kbit/s single user data rate

The total number of users in a high density UWB system depends on duty cycle, target bit rate and impulse shape as is shown in [11]. There is a maximum number of users supported for a certain target data rate and transmission quality. This can not be increased by increasing transmission power of individual users as seen in Fig.1. This figure applies for correlation receivers under ideal power control and optimum time synchronization conditions in a dispersionless radio channel. Thus the indicated curves can be seen as an upper limit as they are optimistic relative to real operating environments.

In Fig.2 the signal-to-interference ratio at the receiver input for an UWB high density network is shown. An important message is, that, if the number of users grows by orders of magnitude, the SNR of a single user deteriorates only moderately.

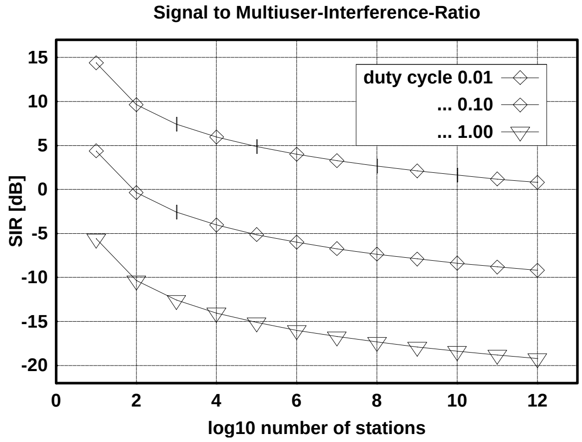

Fig.2 Signal-to-Interference ratio at receiver caused by other users in a high density network, calculation based on derivations performed in [12].

For example, if the number of users grows from 10.000 to 1.000.000, the signal-to-interference ratio degrades only by about 1 dB. This holds for different values of duty cycle, when based on the assumption, that the receiver can only listen to stations within a certain range. The increase of number of users (transmitters) is hence equivalent to an increase in their geographic density. As the SIR figures indicate, for a high number of users, a modulation with processing gain, e.g. spreading of bits into chips, is necessary for reasonable transmission quality in terms of bit error rate. In addition to the inherent interference from the UWB system there is interference from many other existing communications and other electrical systems as well as thermal noise, synchronization offset and strong

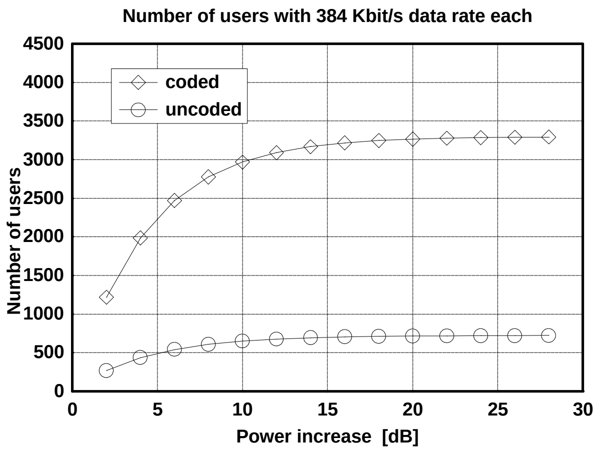

Fig.3 Number of users versus power increase for uncoded and TURBO coded transmission for 384Kbit/s single user data rate and BER of 10-5.**

multipath propagation. If high data rates and/or low power operation are aimed at, e.g. for a class of terminals, a powerful channel coding scheme is advised as in any other communications system. In Fig.3 the total number of users, with and without channel coding, which can be accommodated in a UWB system, is depicted. Applying TURBO coding, as shown, the number of users can be increased roughly by a factor of 5, as the required SNR is decreased by the coding gain of the channel coding scheme.

The described PHY properties offer possibilities for local area high density communications networks with very flexible link features. For different transmission qualities various spreading and/or channel coding options can be employed. Due to missing IF processing, cost efficient devices will be available and the high bandwidth used will enable very low mean power operation at high data rates. As the time resolution is in the order of tens of nanoseconds,communication and accurate positioning of terminals is possible in a simultaneous manner.

4. REGULATION

On May 11th 2000, the Federal Communications Commission (FCC) released a *Notice of proposed Rule Making* (NPRM) [13] as a result of a previously released *Notice of Inquiry* (NOI) which requested information from the public as to the regulation of UWB devices.

FCC observes that UWB technology “may provide for significant benefits for public safety, businesses and consumers”. In particular radar applications, i.e. GPRs (Ground Penetrating Radars) and communications applications, such as phone and computer networking throughout a building or home, were identified as potential applications. Licence-free regulation of UWB under part 15 of the rules is intended. It is further recognised that ‘wide area radio services’ may be developed using UWB technology, treatment is however deferred to when there is more information in the record. Following the comment period, a formal rule making is anticipated, thus permitting widespread commercialization of UWB systems. For example, one of the NPRM key issues is that of potential flight safety impact caused by extensively employed UWB technology. Current FCC regulations do not allow intentional emissions in certain frequency bands currently set aside to protect the aviation community and other services.

In Europe the Short Range Devices Work Group (SRD-WG) of the European Radiocommunications Committee (ERC) is in charge of regulatory issues concerning UWB technology. Topics identified are the definition and sharing impact of ultra-wideband technology, possible exemption from licensing and type approval as well as compatibility studies. In a spectrum investigation report [14] of the European Radio Office (ERO), UWB technology is positively considered and a tentative planning is given suggesting CEPT/ERC regulation of UWB emissions in the course of 2001.

5. CONCLUSIONS

A new open mobile access system structure, it’s constituting entities and functions, and the adopted radio transmission principle have been outlined. From a systems point of view, largely improved interconnectivity of mobile applications has been demonstrated via introduction of flexible, near-autonomous network elements, decentralised architectures and resource allocation mechanisms. The novelty of the physical and logical concepts which govern the open mobile access network, determined this work to lean towards system feasibility and possibilities, rather than to in-depth analysis of selected topics.

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Biographies

Heinz Luediger worked on various research programs and projects in the areas of remote sensing, telecommunications and global positioning. He joined IMST (Institut fuer Mobil- und Satellitenfunktechnik, Germany) in 1995 where he coordinated the development of a wireless LAN (60 GHz/150 Mbps) within the European Commission's ACTS research framework. He received his degree in telecommunication engineering in 1979 and has developed a key interest in radio systems.

Sven Zeisberg graduated from at Dreden University of Technology in 1994. He has been involved in several research projects concerned with the physical layer of communication systems.since. He joined IEEE in 1993 and has published more than 20 technical papers. Interests includ, but are not limited to, digital signal processing, multicarrier- and ultra-wideband communications.

Maria-Gabriella Di Benedetto was born in Naples, Italy, in 1958. She obtained her "Laurea" in Electrical Engineering from the University of Rome 'La Sapienza' in 1981, magna cum laude with publication of her thesis. She went on to specialise in Control Systems Engineering and earned her "Dottore di Ricerca" (PhD) in Electrical Communications also from the University of Rome 'La Sapienza' in 1987. Her professional positions have included Fellowships and Associate professorships- she is presently an Associate Professor of Electrical Communications at the University of Rome 'La Sapienza'. Within Professor Di Benedetto's academic career she also has held various visiting positions, including several posts in the USA, at Massachusetts Institute of Technology and University of California at Berkeley. She has received several academic awards including the Mac Kay Professorship, University of California at Berkeley, in 1994.

Nicola Blefari-Melazzi received his "Laurea" degree in Electrical and Electronic Engineering in 1989, magna cum laude, from the University of Roma "La Sapienza". He earned the "Dottore di Ricerca" (PhD) in Information and Communication Engineering in 1994, also from the University of Roma "La Sapienza". In 1993 he joined the University of Roma at Tor Vergata as a Researcher. Since 1998 he is an Associate Professor at the University of Perugia, where he teaches courses in Signal Theory and Telecommunications Networks. He received several academic Italian awards and has been a member of the Technical Program Committee of the Conferences IEEE Infocom '97, IEEE ATM '96, '97, '98, '99 and IEEE Globecom '99. He is author/co-author of about 50 publications in international journals and conference proceedings.