# Cross-Layer Scheduling Strategy for UMTS Downlink Enhancement

RAMON FERRÚS, LUIS ALONSO, ANNA UMBERT, XAVIER REVÉS,
JORDI PÉREZ-ROMERO, AND FERNANDO CASADEVALL,
TECHNICAL UNIVERSITY OF CATALONIA

## Abstract

This article describes the benefits of including cross-layer information in the scheduling mechanism of a UMTS downlink channel. In particular, the information obtained from the fast power control algorithm is used to properly schedule transmissions. A prioritization function that exploits the short-term channel variations is proposed. This strategy is shown to be a feasible approach to improve system performance in terms of capacity and delay. This enhancement is obtained as a benefit of intrinsic multi-user diversity. The proposal is applicable within the current UMTS radio resource management framework.

## Introduction

In wideband code-division multiple access (CDMA) systems such as the Universal Mobile Telecommunications System (UMTS), advanced radio resource management (RRM) strategies are expected to play an outstanding role in the optimization of air interface usage. Within RRM, scheduling algorithms are key components in the provision of guaranteed quality of service (QoS). QoS requirements are usually defined with parameters such as delay, delay jitter, packet loss rate, and throughput. In order to meet the QoS requirements of every user, scheduling algorithms within the UMTS RRM framework are able to assign radio resources in terms of transmission power ($P_i$) and data rate ($r_{b,i}$) on a frame-by-frame basis (10 ms, or multiples of this for UMTS) for every user $i$ [1]. In CDMA systems, assigning $r_{b,i}$ determines the required transmission power $P_i$ since both magnitudes are coupled by means of the following expression [2]:

$$\frac{\frac{P_i}{L_{p,i}} \cdot \left(\frac{W}{r_{b,i}}\right)}{I + P_N} \geq \left(\frac{E_b}{N_0}\right)_i. \qquad (1)$$

The left side of this inequality is the bit energy over power noise spectral density ratio (equivalent to the signal-to-noise ratio) at the output of the CDMA receiver of user $i$. The numerator of this ratio is computed using $L_{p,i}$ which is the propagation loss between mobile $i$ and its serving base station (the ratio $P_i$ over $L_{p,i}$ represents the received power). The denominator is the total noise plus interference power, where $I$ accounts for both the intracell and intercell interference and $P_N$ is the noise power. Finally, $(E_b/N_0)_i$ is the bit energy over noise ratio that meets the required block error ratio (BLER) target for user $i$. Then the actual bit energy over noise ratio must always be higher or equal to the target value.

Most of the scheduling policies proposed for CDMA-based systems rely exclusively on traffic considerations (traffic class, guaranteed rate, buffer size, etc.) to decide whether a user receives service or not and which transmission rate is allowed [3, 4]. Then, once a given $r_{b,i}$ is decided for user $i$, the transmission power $P_i$ to be assigned can be derived from Eq. 1, taking into account averaged estimations of the propagation losses and interference levels. In this way, long-term variations in the radio channel are captured by the radio resource assignment in the computation of the allocated mean transmission power $P_i$. Furthermore, a fast power control mechanism is used in UMTS to follow the short-term variations of the radio channel and update the transmission power accordingly. Usually scheduling policies provide fairness guarantees that are based mainly on traffic considerations and are irrespective of the conditions of the individual radio channel perceived for each user. Indeed, these channel conditions should also be considered in the scheduling process, and it seems intuitive that such smart scheduling would lead to improved efficiency.

In this article we propose using short-term information obtained from the fast power control mechanism to improve the scheduling strategy in UMTS downlink channels. Specifically, by short-term information we mean the usage of the transmission power variation knowledge at the frame level in order to schedule transmissions. Notice that short-term channel variability will make the instantaneous power allocated to user $i$ fluctuate around the required mean power $P_i$, which is targeted to accomplish the $E_b/N_0$ value. But, as stated above, frame-by-frame short-term fluctuations are not captured by the classical radio resource assignment. Then it is clear that the overall system efficiency could be enhanced if this information is used to prioritize those transmissions with better radio conditions (or whose conditions are getting better). The idea of making use of information about channel conditions in scheduling strategies is, in fact, a cross-layer technique. In the literature there are some studies that describe this idea [5–7]. However, no results are available to prove this concept under the current UMTS radio resource management framework. This article aims to fill this gap.

The article is organized as follows. We describe the proposed scheduling algorithm and the definition of the priority function used. We present the showcase scenario where the evaluation of the proposal has been performed via numerical simulations. The results obtained are shown, and we devote a section to assessing the conclusions.

## The Scheduling Algorithm

In the downlink of a wideband CDMA (WCDMA) system like UMTS, each base station has a certain total available transmission power, $P_T$, which has to be shared among the possible destination active users. Besides, the downlink fast power control mechanism keeps the transmission power $P_i(t)$ needed for each user $i$ to the minimum value to ensure the $E_b/N_0$ required for each time $t$. The base station, using the

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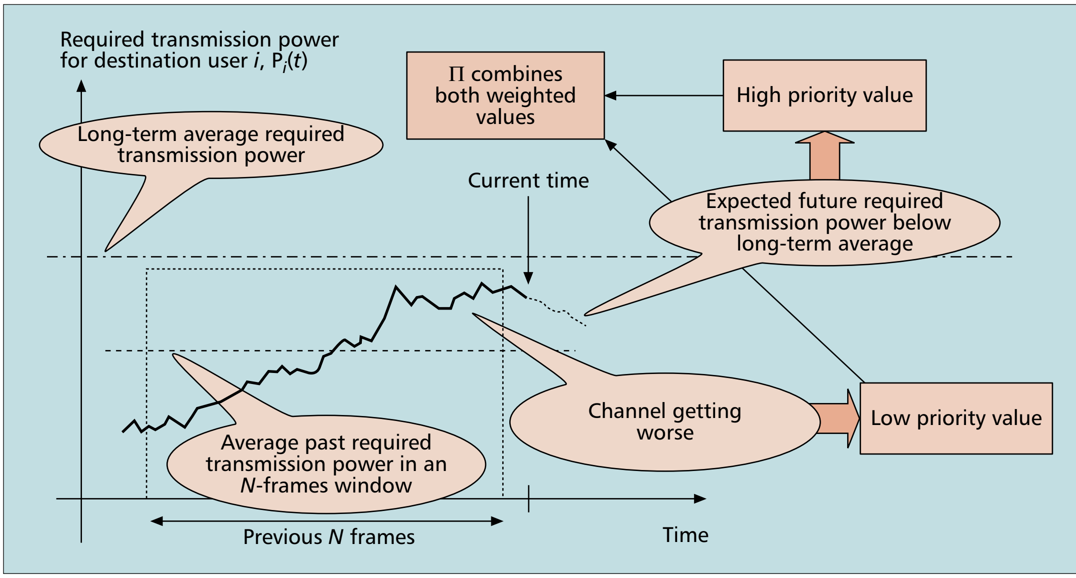


**FIGURE 1.** *Priority function definition.*

power control commands coming from each user, adjusts this power dynamically. Furthermore, this power will fluctuate rapidly around a certain average value that depends on the slow varying radio channel conditions.

Now we define a priority function that will exploit these rapid channel fluctuations. This priority function will be used by the radio scheduler to prioritize transmissions attending its radio channel conditions. It is worthy to remark here that downlink radio channel conditions for each user are inferred by using fast power control information in base stations, so the radio scheduler can assess the downlink radio condition without relying on an explicit signaling overhead channel in the uplink radio interface.

The transmissions will be scheduled in decreasing order of this priority function for each user. That is, the radio scheduler will compute the priority value for each user. Then users will be ordered according to their priority value. The radio scheduler will select users from this ordered list, beginning from the highest priority, until the total needed transmit power reaches the maximum total available power $P_T$. Then the destination users in each frame will be a subset consisting of a certain number of the ones with highest priority. Regarding the priority function, we impose the following characteristics:

- It should give a higher priority value to those users that have better channel conditions, that is, a lower $P_i(t)$.
- It should take into account the tendency of channel variation; that is, setting higher priority to those users whose channel is getting better.
- It should provide *fair* priority for all the users. That is, the priority function has to compensate, to some extent, those users having bad channel conditions along some consecutive frame in order to reduce their transmission delay.

Bearing in mind these ideas, it is clear that there are multiple possible priority functions to fulfill the described characteristics. Among them, we propose one, denoted Π, which has low computational complexity. The proposed priority function is

$$\Pi = \beta \cdot \Gamma + (1 - \beta) \cdot \Theta, \qquad (2)$$

where Γ represents a value that should be proportional to the channel variation tendency in the last previous $N$ frames (a higher value means that the channel is getting better, i.e., the needed current transmission power is lower than the average needed in the last $N$ frames), whereas Θ is a value proportional to the expected future value of the required transmission power. Then β represents an adjustable parameter that allows weighting of the influence on the priority function of the expected power value and its variation. The value for β will range from 0 to 1, where $\beta = 1$ means we will only consider the channel tendency, and $\beta = 0$ means we will only consider the power absolute expected values. Summarizing, the first term in Π takes into account the short-term tendency of the channel conditions, assigning higher priority to those users whose channel is getting better, whereas the second term takes into account the expected transmission power for the next frame (the future expected conditions). The parameter β allows fine setting for specific scenarios.

It is worth mentioning that the value of Θ should be normalized by the long-term average power for user $i$ in order to provide fairness in the priority assignment for users with different long-term needed power.

Therefore, with this priority function, the better the channel is getting for a user (i.e., the required power is decreasing), and the lower the estimated required power for a user in the next frame the higher its priority. In order to illustrate this reasoning, Fig. 1 shows a diagram with a channel variation for an example user and how the values of the terms in Π are read from the graphs to evaluate the priority value. Looking into these two terms of the priority function, Fig. 2 shows all the possible general situations where both of them can take different values depending on channel variation and required transmission power (they are denoted high, medium, and low for the sake of simplicity, although they correspond to numerical values).

Finally, the value of Π, associated with fast power control evolution, will be used in the scheduling criteria to prioritize transmission requests while considering their channel short-term variability. A reference of the obtainable gain for a reference scenario is described next. It is important to remark here that the prioritization achieved by the value of Π may not be the only criterion used by the radio scheduler. Instead, it is expected to use this prioritization combined with other criteria coming from traffic considerations such as service type, transmission buffer size, packet timeouts, and the like.

## Scenario Under Study

Let us assume a scenario in which the total transmission power available for the downlink $P_T$ is shared among $M$ always active users. Actually, the maximum number of users

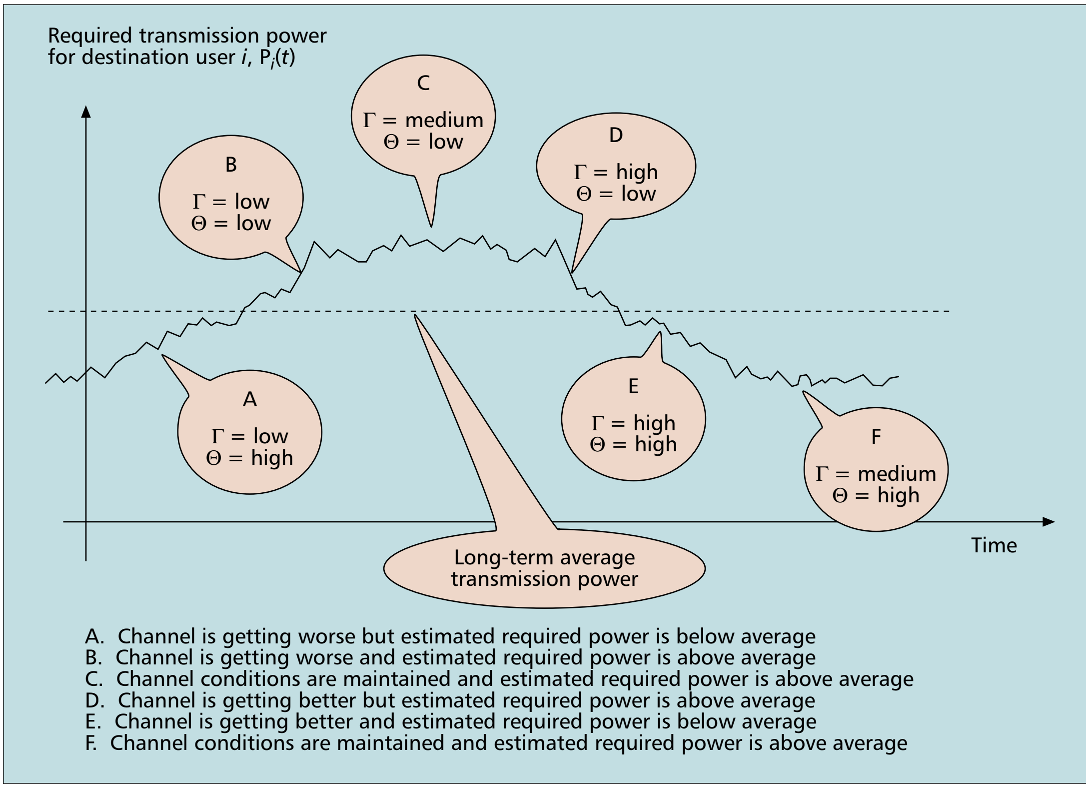


**FIGURE 2.** *Priority function example cases.*

being served in each frame is limited by the condition that the sum of the individual power assignments must be less than the available power $P_T$. Then, in order to assess the capacity gain of incorporating a prioritization criterion based on Π, we select a well-known round-robin (RR) strategy as a reference scheduler [8] and assume that all the users are expected to be continuously served with the same "rights" attending to traffic considerations. Under such conditions, the RR scheduling algorithm will serve the users cyclically, while the proposed scheme will prioritize users exclusively on the basis of the function Π. For the sake of simplicity, we have considered that all the users require the same bit rate $r_{b,i}$ and $\overline{P}_i$. Let us also assume a Rayleigh fading channel, where its coherence time (defined as the delay for getting an autocorrelation value about half the maximum one for zero delay) is inversely proportional to the user's speed. Finally, the base station will estimate the future value for the transmission power as the last known (not estimated) value of the required transmission power, measured from the power control mechanism.

## Simulation Results

Based on the described scenario, numerical simulations have been performed in order to evaluate the gain obtained with the proposed mechanism. As stated above, we have used the RR strategy as a reference. Then, we define the gain obtained (in percentage) as the ratio between the increase of the average number of users that actually transmit in each frame (using the proposed algorithm) and the average number of users that transmit with the RR criterion. Calling $M_\Pi$ the average number of users transmitting with the proposal, and $M_{RR}$ the average number of users transmitting with the reference RR strategy, the gain $G$ is defined as the relative increase in the number of transmitting users using the proposed algorithm with respect to the number of transmitting users with the RR algorithm; that is, $G$ is calculated as

$$G(\%) = \frac{M_\Pi - M_{RR}}{M_{RR}} \cdot 100. \tag{3}$$

First, and in order to get a figure of the gain that can be achieved with the proposed scheme, we consider the case of β = 1, which corresponds to the case where only the channel state variation is evaluated in the prioritization function. Figure 3 shows the values of the obtained gains vs. the mobile speed, when the total power available for the downlink is ten times the average power required for each user, that is $P_T = 10 \cdot \overline{P}_i$. Various curves are shown for different number of users ($M$ = 15 and $M$ = 20) and values of $N$. The carrier frequency has been assumed to be 2 GHz.

As is clearly shown, significant gains are achieved, up to

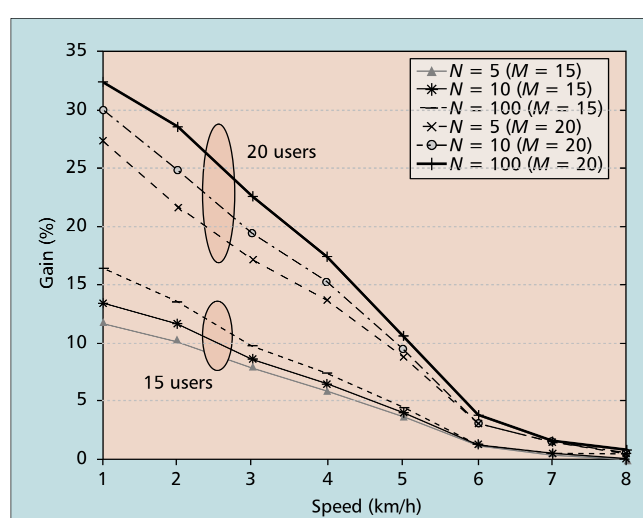


**FIGURE 3.** *Capacity gain of the proposed scheme vs. a round-robin strategy when* β = *1.*

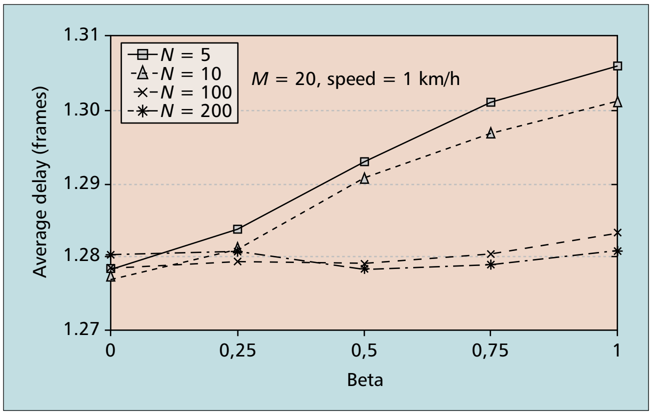


**FIGURE 4.** *Average access delay variation vs.* β.

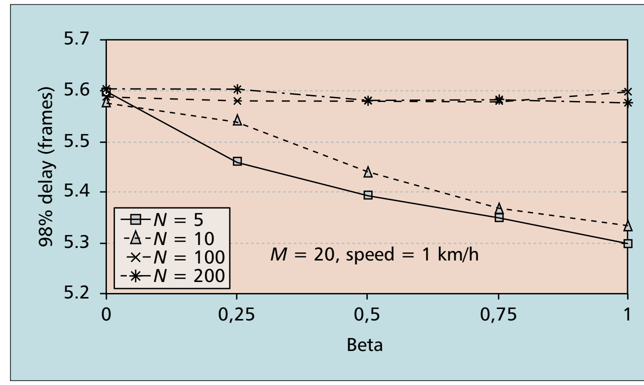


**FIGURE 5.** *98 percent guaranteed delay variation vs.* β.

more than 30 percent for a low-mobility situation. The obtained gain increases with the number of users as the system gets more benefit from multi-user diversity. On the other hand, the gain decreases with the speed of the users as the channel becomes more independent between consecutive frames. As a reference value, for the scenario conditions and the selected carrier frequency, notice that the channel coherence time is about 10 ms (i.e., the radio frame time in UMTS) when mobile speed is 13 km/h. Then for speed values approaching 13 km/h the channel is almost independent between two consecutive frames (10 ms), and then the priority function Π reduces its usefulness. When mobility is low, Π captures the state of the channel seen by every user as well as its time variation, and the scheduling exploits this inherent multi-user diversity providing a significant capacity enhancement.

Regarding the average window $N$ in the priority function (the number of frames in the past we look at to evaluate the average needed transmission power and thus the variation of the channel conditions), we have observed that higher values of $N$ lead to higher gains, since the priority function Π tends to account directly whether the power needed in each frame is above or below the "long-term" average power target $\overline{P}_i$. In fact, if $N$ tends to infinity, the average power calculated in Γ tends to $\overline{P}_i$ and then Γ tends to give the same priority order than Θ.

Regarding the dependence on β, Fig. 4 shows the average delay, or equivalently, the average number of consecutive frames each user is unable to acquire a transmission opportunity, vs. β. A speed of 1 km/h was selected because the dependence on β is clearly accentuated at low speeds since channel conditions remain more stable. We can observe that the average transmission delay increases slightly with β; even this increase is negligible for large values of $N$. On the other hand, Fig. 5 shows the 98 percent delay probability (i.e., the maximum delay guaranteed in 98 percent of the transmissions). It can be observed that the 98 percent guaranteed delay decreases with β and increases with $N$. This apparent contradiction in behavior of the average delay and 98 percent delay is explained by the fact that the distribution of the delay values changes with β. Indeed, the average delay is reduced while some transmissions increase their delay (i.e., users with bad channel conditions for a long period should wait more time), thus increasing the probability of having a sporadic big delay. Then it is clear that a trade-off between average delay and 98 percent guaranteed delay is present. The application-level requirements should select an appropriate value for β. Note that in any case all average delay values are below the value for the RR strategy (which is, for this scenario, 2 frames as $M = 20$ and $P_T = 10$) because more transmissions can be allocated into each frame, so the performance of the system is always enhanced in terms of delay. Taking the worst delay value of 1.3 frames, this improvement represents a 35 percent reduction from the RR reference.

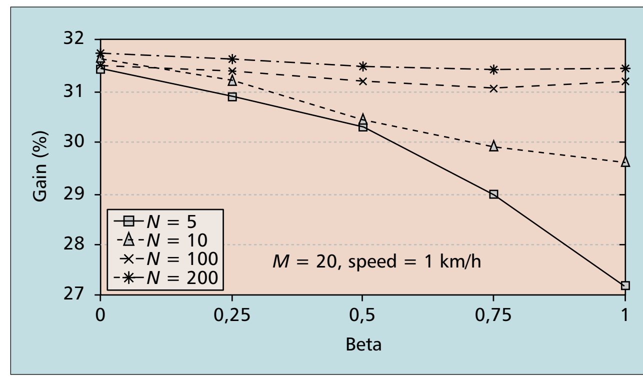


**FIGURE 6.** *Capacity gain variation vs.* β.

Finally, Fig. 6 shows the variation of the gain obtained vs. the value of β for $M = 20$ and for different values of $N$. We can observe that the gain obtained decreases when β is increased, and this reduction is greater for low values of $N$. However, notice that in all cases this variation is small with respect to the gain values. Then this fact adds another criterion when deciding the value for β taking into account the delay trade-off.

## Conclusions

This article proposes a cross-layer technique where downlink data transmissions are scheduled taking into account the fast power control information included in UMTS systems. While the channel state for each user is independent of the other users' channel, the proposal exploits the inherent multi-user diversity and provides significant performance improvement using a smart and low-complexity priority function that takes into account the channel state and channel variation of each user. To evaluate the improvement due to this new strategy, the obtained gains in terms of number of transmissions per frame and average access time have been evaluated. With the proposed scheme, up to more than 30 percent capacity gain and 35 percent reduction in the average access time to the channel can be obtained. These results show that the proposal could be feasible for use in the UMTS system in order to enhance its capacity, even using a very simple priority criterion and a coarse power estimation process.

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## Biographies

RAMON FERRÚS [M'96] (ferrus@tsc.upc.edu) received an Engineer of Telecommunications degree from the Universitat Politècnica de Catalonia (UPC), Spain, in 1996, and a Ph.D. degree from the same university in 2000. In 1996 he joined UPC, where he was an assistant professor from 1996 to 2002. He is currently an associate professor in the Signal Theory and Communications Department. He lectures on mobile communications, data transmission systems, and communication theory. Since 1996 his research field has been mobile radio communications. His doctoral thesis contributed to the study of the radio access and handover mechanisms in cellular systems. Currently his research interest is focused on QoS, mobility, and radio resource management in the context of heterogeneous IP-based mobile communications systems. He has actively participated in several research projects in the framework of European programs ACTS (RAINBOW project) and IST (WINE GLASS, ARROWS, and EVEREST projects) where his main contributions have been focused on the development of real-time hardware/software platforms for the emulation of different wireless access networks.

LUIS ALONSO [M'99] (luisg@tsc.upc.edu) received his Ph.D. in telecommunications engineering from UPC in 2001, where he is an associate professor in the Radio Communications Group of the Signal Theory and Communications Department. He participates in research programs and projects funded by the European Union and the Spanish Government, and also collaborates with some telecommunications companies. His current research interests are in the field of medium access protocols, radio resource management, cross-layer optimization, and QoS features for all kinds of wireless communications systems.

ANNA UMBERT JULIANA (annau@tsc.upc.edu) received an Engineer of Telecommunications degree from UPC in 1998, and a Ph.D. degree from the same university in 2004. In 2001 she joined UPC as an assistant professor, which is her current status. Her doctoral thesis contributed to the design of the network architecture for the integration of packet services in the UMTS system, the 3G mobile communications system in Europe. Her research interest is focused in radio resource, QoS, and mobility management in the context of heterogeneous mobile communications systems. Since 1997 she has participated in several projects founded by both public and private organizations. In particular, she participated in the research project RAINBOW in the ACTS program founded by the European Commission. In the context of the 5th European Framework Program she participated in the IST projects WINEGLAS, CAUTION++, and ARROWS. Currently she is participating in the STREP-IST project EVEREST and the Network of Excellence NEWCOM.

XAVIER REVÉS BALLESTÉ [M'99] (xavier.reves@tsc.upc.edu) received an Engineer of Telecommunication degree from UPC in 1998. He is currently applying for a Ph.D. degree in the Department of Signal Theory and Communications at UPC. In 2001 he joined UPC as an assistant professor, which is its current status. His research is focused in radio communications, with special emphasis in digital processing platforms including hardware and software architectures, software radio technologies, and analog/digital transceiver front-end architectures. Since 1999 he has participated in several projects of technological transfer to industry, including the European FUSE program. He has also been and is currently involved in European Framework Program projects such as ARROWS and EVEREST.

JORDI PÉREZ-ROMERO [M'98] (jorperez@tsc.upc.edu) is an associate professor in the field of radio communications at UPC, in the Radio Communications Group of the Signal Theory and Communications Department. His research interests are currently in the field of heterogeneous mobile communications networks, involving radio resource and QoS management as well as packet radio techniques for future mobile systems. He has published different papers on these topics in IEEE journals and conferences, and has participated in different European Projects as well as in projects for private companies.

FERNANDO J. CASADEVALL (ferranc@tsc.upc.edu) received an Engineer of Telecommunication and Dr.Eng. degrees from UPC in 1977 and 1983, respectively. In 1978 he joined UPC, where he was an associate professor from 1983 to 1991. He is currently a full professor in the Signal Theory and Communications Department. After graduation he was concerned with equalization techniques for digital fiber optic systems. He has also been working in the field of digital communications with particular emphasis on digital radio and its performance under multipath propagation conditions. In the last 10 years he has mainly been concerned with the performance analysis and development of digital mobile radio systems. In particular, his research interests include cellular and personal communication systems, multipath transceiver design (including software radio techniques), mobility and radio resources management, and end-to-end QoS issues. During the last 15 years he has participated in more than 20 research-projects founded by both public and private organizations. In particular, he participated in the research projects CODIT and ATDMA in RACEII and RAINBOW in ACTS, all founded by the European Commission. In the context of the 5th European Framework Program he participated in the IST projects WINEGLAS, CAUTION++, and ARROWS, being project manager of the last one. He is currently project manager of the STREP-IST project EVEREST and is also participating in the Network of Excellence NEWCOM. He has published around 100 technical papers in international conferences and magazines, most of them IEEE publications. He has also been a Technical Program Committee member of different international IEEE supported conferences as well as a reviewer for several IEEE magazines. From October 1992 to January 1996 he was responsible for the Information Technology Area in the National Agency for Evaluation and Forecasting (Spanish Nation Research Council).