# An Analysis of Multimedia Services in Next Generation Communication Systems with QoS and Revenue Management

Leonardo Badia, Michele Zorzi
Dipartimento di Ingegneria, Università di Ferrara
via Saragat, 1 – 44 100, Ferrara, Italy
{lbadia,zorzi}@ing.unife.it

***Abstract*—In this paper, we present a study that takes into account the models presented in the literature to depict the QoS and the charging strategies in a generalized multimedia environment, with particular regard to 3G Mobile Communication Systems. In particular, we consider different services for CDMA–like systems, and we discuss how it is possible to obtain an efficient allocation for all flows, by considering a mathematical description of the users' satisfaction which integrates the constraints about Quality of Service. At the same time, the provider revenue is analyzed, in order to give both simple results and possibilities of improvement.**

## I. Introduction

The introduction of new services and devices in Mobile Communication Systems is rapidly expanding. For the network operator, it is necessary to allocate the constrained radio resource as efficiently as possible. In particular, the management of the services must be respectful of different constraints in terms of QoS, which might vary significantly according to the type of multimedia users.

Thus, the Radio Resource Management (RRM) must deal with the added complexity introduced by multimedia services. In the literature, several contributions have analyzed the multiplexing of different services for various aspects of the RRM, such as Admission Control (AC) or scheduling [1] [2] [3] [4]. However, here we propose a different approach which is able to generalize already existing procedures, by discussing the RRM from an economic point of view. Due to the growth of the communication market over the years and its increasing impact on the society, other issues beyond the common objectives in RRM have to be considered, such as the economic and social behavior of users in multimedia communication systems.

In the recent literature, several researchers [5] [6] [7] [8] have studied the RRM with a game-theoretical approach. In particular, the QoS requirements are considered as tunable in a soft way and are mathematically represented by means of utility functions, which are concepts derived from micro-economics [9]. Hence, the QoS can be mathematically depicted and RRM is seen as a strategy with the goal of maximizing the system utility, that could be considered as representative of the welfare of the users. In more detail, if $u_i$ is the utility of the $i$th user, and the utilities are additive, the goal of the RRM is the maximization of the welfare $W$, defined as the sum of all $u_i$'s.

Under this perspective, different RRM aspects can be analyzed in the same framework. This offers a better understanding that leads to a simpler study. Possibilities of performance improvement can also be highlighted. At the same time, it is possible to consider directly, like in [10] and [11], charging strategies as challenging ways to generate revenue and to improve the network management. The introduction of economic concepts in the RRM is not trivial; however, they are necessary to have a complete description of the system. In fact, the provider can afford the network business only if the RRM generates an adequate revenue. Moreover, pricing strategies can be used to achieve an efficient sharing of the resource among the users, by avoiding wastes and establishing priorities. On the other hand, the effect of the pricing on the users' satisfaction can not be neglected, as there is a trade-off between the offered quality and the price that the users accept to pay for it.

Hence, it is important to consider, besides the welfare of the management, also the revenue earned by the provider. In a previous work [12] we proposed a model which is able to take into account this trade-off, by defining an *Acceptance value* $A_i$ for each user within $[0, 1]$, which mathematically depicts the degree of satisfaction of the users. This value can also be seen also as the probability of accepting the service, so that only satisfied users generate revenue. Several conclusion can be drawn with such a model, by considering an appropriate parameter setting related to micro-economic quantities.

In this work we focus in particular on multi-service networks, in which different kinds of multimedia applications can be accessed by the users with the same terminal, channel and operator. Since multimedia service is expected to be key in customers' appreciation of next generation systems, a topic of interest is surely how different services can be supplied by sharing the constrained radio resource in a way which is technically efficient and profitable for the operator.

We will draw several insights by analyzing a case study in which resources are shared between two classes of users, with different requirements in terms of QoS and also willingness-to-pay. We will demonstrate that even such a simple scenario is far from allowing a trivial investigation of the optimal pricing and management.

This work has been supported by Ericsson Research

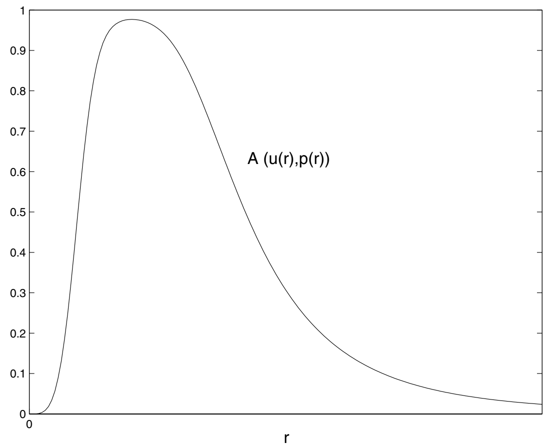

Fig. 1. Behaviour of the acceptance probability $A(u_i, p_i)$ as a function of $r$ for price $p(r_i) = kr_i$ and sigmoid utility

The results for mixed traffic show that our approach provides understanding on how to integrate different services in order to achieve satisfactory welfare and revenue. In particular, we will show that the management of different services becomes complicated, as the superposition dramatically affects the performance. In other words, the performance of each service considered separately differs significantly from the behavior of the system with multiple services combined on the same channel. By means of simulation, we will give both qualitative and quantitative insights of this difference.

This work is organized as follows: in Section II we will briefly discuss the MEDUSA model and how it can be applied to study the management of different services. In Section III the model extension is introduced, in which dynamic multiplexing of the services is considered. In Section IV we present the simulation results for different management strategies and in Section V we conclude the paper.

## II. A MEDUSA Model Overview

Let us give a short summary of the MEDUSA model, which aims at integrating the QoS perceived and the price paid by the users. In the model, both these factors tune the users' satisfaction: the key idea is to define an *Acceptance value*, that depends on the utility $u_i$ and on the paid price $p_i$, assigned to each user $i$. Several expressions are possible an appropriate acceptance function. In [12] we proposed a mathematical expression which will be re-arranged here as:

$$A(u_i, p_i) \triangleq 1 - e^{-k \cdot (u_i/\psi)^{\mu} \cdot (p_i/\phi)^{-\epsilon}}, \tag{1}$$

where $k$, $\mu$, $\epsilon$, $\psi$, $\phi$ are appropriate positive constants. Note that both $u_i$ and $p_i$ depend on the allocated resource $r_i$. Thus, the shape of the acceptance probability as a function of $r_i$ depends on the functions $u_i = u(r_i)$ and $p_i = p(r_i)$. For example, if $u(\cdot)$ is a sigmoid-shaped function (i.e., it increases and then saturates for large values of $r_i$) and $p(\cdot)$ is linearly related to $r_i$, one can obtain the curve shown in Figure 1, which presents many similarities with the utilities involving battery life and perceived error probability presented in [13], for which several theoretical results have been derived. These results are not discussed here in detail; however, they only rely on simple regularity properties for $u_i(\cdot)$ and $p_i(\cdot)$, e.g., being quasi-concave non decreasing functions [1].

By giving $A_i$ a probabilistic meaning, the model allows a simple and direct evaluation of the statistical average revenue coming from each user allocated with utility $u_i$ and paying price $p_i$, which is determined as $p_i A(u_i, p_i)$. Thus, the total revenue is:

$$R = \sum_{i=0}^{N} p_i A(u_i, p_i) \, . \tag{2}$$

In this sense, an alternative goal for the RRM might be the maximization of the total revenue which leads to different conclusions than the welfare maximization, as shown in [14]. Note that in Equation (2) the following intuitive property is implicitly represented: too high prices drive customers away ($A_i$ decreases) and yield very little revenue. Conversely, too low prices can easily be afforded by the users, but also with low revenue as a result. This can be formalized by stating the existence of an optimal price choice, i.e., an expression for $p_i(\cdot)$, which is the one that corresponds to the maximum revenue. Note however that, when the resource to allocate is scarce, as is usually assumed, this optimal pricing is also achieved when the capacity is fully utilized.

In general the problem is very broad, as we should consider $p_i$'s as general as possible (which is not realistic, since $p_i(\cdot)$ is reasonably the same at least within the same service class, and in general similar for all users). Moreover, a realistic pricing function is also often required to be simple, as users usually do not like to deal with complicated tariff plans. For the sake of simplicity, we will consider a linear pricing policy, i.e., each user pays proportionally to the allocated resource. Hence, $p_i = \alpha_i r_i$, and the unit price $\alpha_i$ fully determines the shape of the function $p_i(\cdot)$. Note that for the sake of fairness, $\alpha_i$ will be equal for all users $i$ belonging to the same class of service.

The model can be exploited for different aspects of the Radio Resource Management. In particular in the following we will focus on rate assignment for CDMA–like networks. That is, $r_i$ will be the transmission rate allowed to terminal $i$. Note that technological constraints impose that $r_i$ is between 0 and a maximum value $r_{max}$, which can be assumed equal for all terminals, for the sake of simplicity. Also for the sake of simplicity, we will consider sigmoid-shaped utilities, which are bound in the range $[0, \psi]$. For lack of space we do not discuss analytical expressions of the sigmoid curves, only we assume their central point $x_s$ to be tunable [2]. For the simulations, $x_s$ is a random variable for each user, having a random distribution within ranges which are service-dependent. Even with these hypotheses and specifications, an analytical investigation for a revenue maximization problem is hard, mainly due to the large variable span and the complicated constraints, and left for further research. Our contribution in this paper is to extend the framework to a general multimedia environment, in which services with different utilities and prices are considered together. To do

[1] Usually, technological constraints also impose additional properties, like upper-limits for the utilities, which simplify the problem even further.

[2] The value $x_s$ is the one that satisfy $u(x_s) = \psi/2$.

so, we exploit the simplicity of a direct evaluation of collected tariffs, which allows in fact a simple test of performance by means of simulation. In the next Section we will discuss how multimedia services can be introduced in the above model and formulate the allocation problem.

## III. Model Extension for Multimedia Network

Let us consider a network in which $\sigma$ services coexist. We indicate the services' set as $\mathcal{S} = \{S_1, S_2, \dots S_\sigma\}$. We can also define a function $s(\cdot)$ for every user, indicating that $s(i) = S_j$ means that the $i$th user requests the $j$th service. In this framework, certain parameters of the MEDUSA model needs to be differentiated, so that acceptance probabilities for different services can be identified. The meaning of these variables will not be discussed in detail here, but some brief comments will be given.

The parameters $k$, $\psi$ and $\phi$ are normalization constants. They can be related one to each other, in particular $\psi$ is the maximum utility, $\phi$ is the normalisation price and $k$ is a constant value which can be seen as the inverse logarithm of the probability than a given user does not accept to pay a price $\phi$ for reaching utility $\psi$ [3]. For this reason, $\psi$ and $\phi$ will be defined differently for every service. In other words, there are $\sigma$–dimensional vectors $\psi = (\psi_1, \psi_2 \dots \psi_\sigma)$ and $\phi = (\phi_1, \phi_2 \dots \phi_\sigma)$, containing the maximum utility and the normalization price for every service. The reference value $k$ will be fixed for all users to $-\log 0.9$, which means that on the average $A_0 = 10\%$ of the users of the $i$th service are satisfied with paying $\phi_i$ for utility $\psi_i$, for every $i$. Obviously, another value of $A_0$ can be chosen. These normalization does not affect however the shape of $A(\cdot)$, which is simply re-scaled. On the other hand, the parameters $\epsilon$ and $\mu$ determine how sensitive the users are to price and utility variation, respectively. In general, also these parameters depend on the service, hence they are replaced by two vectors $\epsilon$ and $\mu$ as above.

With these notations, Equation (1) becomes

$$A(u_i, p_i) = 1 - e^{-k\cdot(u_i/\psi_j)^{\mu_j}\cdot(p_i/\phi_j)^{-\epsilon_j}}, \tag{3}$$

where $j = s(i)$.

It is straightforward to show that the goal function $R$ can be separated as follows:

$$\begin{aligned} R \;=\; & \sum_{i,s(i)=1} p_i(A(u_i, p_i)) + \sum_{i,s(i)=2} p_i(A(u_i, p_i)) + \dots \\ & \dots \sum_{i,s(i)=\sigma} p_i(A(u_i, p_i)). \end{aligned} \tag{4}$$

Remember however that the maximization of $R$ is constrained. Hence, even though the optimization problem could be separated in $\sigma$ parts for every different service, the capacity constraint can not be separated in a trivial manner. In particular, we can even think of sharing the CDMA bandwidth in $\sigma$ reserved sub-bandwidth. However, this is inefficient both from the theoretical point-of-view of resource manager (requires a possibly large overprovisioning) and from the practical counterpart of the provider, which is interested in service integration and resource sharing.

[3]Note that here the utility is supposed to be upperlimited, whereas the price is not.

TABLE I
List of Parameters of Simulation Scenario

| Parameter | value |
|---|---|
| number of cells | 19 |
| bandwidth | 3 rate units |
| max assignable rate ($r_{max}$) | 1 rate unit |
| cell radius | 500 m |
| gain at 1 m | $-28$dB |
| path loss exponent | 3.5 |
| shadowing stdev. | 8dB |
| log-normal correlation downlink | 0.5 |
| log-normal correlation distance | 75m |
| mean SNR at cell border | 20dB |

TABLE II
Acceptance Probability Parameters

| Parameter | Silver | Gold |
|---|---|---|
| average $x_s$ | 0.3 | 0.6 |
| $\psi$ | 1.0 | 2.0 |
| $\phi$ | 1.0 | 2.5 |
| $\mu$ | 2.0 | 3.0 |
| $\epsilon$ | 6.0 | 4.0 |

Henceforth, we rather assume to have a shared medium, in which all services are multiplexed. Moreover, we investigate the assignment by means of a greedy solution, which is simple and easily applicable (for details on the algorithm, see [**?**]). The goal in fact is only to gain understanding on how different services will interact. The heuristic assignment is performed as follows: users are allocated sequentially, so that for first assignments the capacity constraint is likely met. When the network is congested and the assignment is no longer feasible, the resource $r_i$ given to the $i$th user, i.e., its allocated rate, is decreased until the greatest feasible value is reached. Assignments are based on the first derivative of the utility, i.e., we assume that the first trial value of the rate $r_i^{(0)}$ is:

$$r_i^{(0)} \triangleq \max(\{0\} \cup \{r \in ]0, r_{max}] \,:\, u_i'(r) \geq \vartheta\}) \tag{5}$$

where a tunable threshold $\vartheta$ on the marginal utility has been introduced to adjust the management policy. It can be seen that $\vartheta$ determines where the trade-off between the number of admitted users and the assigned quality is cut. In fact, on one hand low values of the marginal utility imply asymptotically high assignments, which give high quality but allow to accomodate only few users. On the other hand, the greater $\vartheta$, the higher the number of allocated users but also the lower their assigned quality. The capacity is modelled by translating the allocated rates $r_i$ into SIRs $\gamma_i$ (since CDMA networks have one-to-one correspondence between rate and SIR assignment) and seeing whether the SIR vector $\gamma$ is feasible.

## IV. Results

Let us consider a scenario in which, for the sake of simplicity, two services are considered, which have been called "Silver" and "Gold". The conclusions can be however extended to

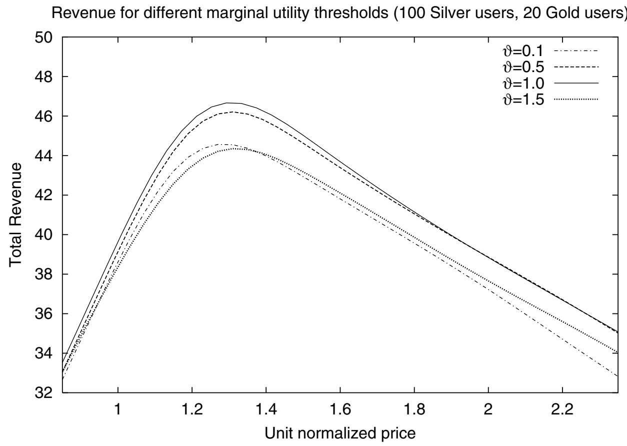


Fig. 2. Revenue for 100 Silver users and 20 Gold users multiplexed in the same channel, as a function of the price

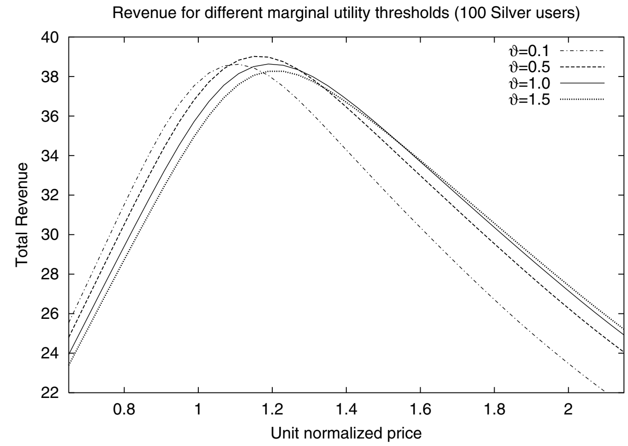


Fig. 4. Revenue for 100 Silver users only, as a function of the price

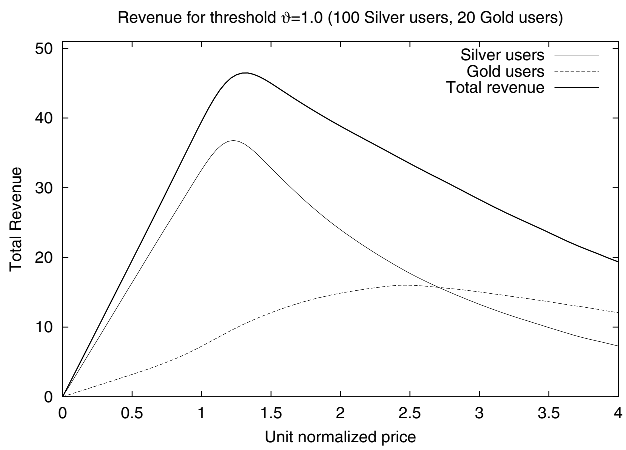


Fig. 3. Partial revenues for 100 Silver users and 20 Gold users multiplexed in the same channel, for $\vartheta = 1.0$, as a function of the price

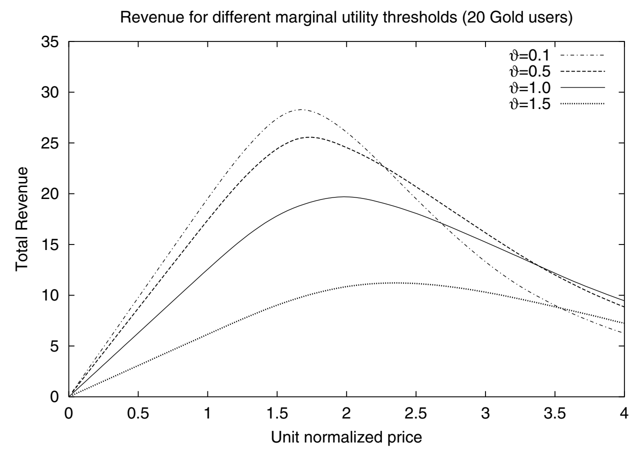


Fig. 5. Revenue for 20 Gold users only, as a function of the price

cases with a larger number of services. Both services are best-effort non-real-time services, with tunable rates. The propagation parameters are given in Table I, whereas the quantities connected to the acceptance probability are reported in Table II for both services. Note that a Gold user has a double maximum utility, but a normalization price more than double, than a Silver user [4]. Moreover, Gold users are more sensitive to the quality and less sensitive to the price variations. In fact Gold users have higher $\mu$, which determines the behavior relatively to $u$ variations, whereas their $\epsilon$ is lower. As practical examples, one might think of having data exchange services with different requirements and also different service perceptions, like for embedded multimedia applications, in which users are very sensitive to the data appearance rather than to their amount (e.g., images can be larger but more appealing than text). In this case, the Gold service shoud be regarded as a more demanding service, which is also considered more expensive in the users' mind.

Let us evaluate the total revenue coming from the assignment, which is plotted in Figure 2 for different values of $\vartheta$. As was to be expected, the revenue has a strong dependence on the price choice. Hence, the determination of the right price is key in the provider's strategy; however, note that the curve has a wide interval of satisfactory choices. In fact, as can be seen from Figure 3, where the single components of the revenue have been separated, the peaks of the two revenues for different services tend to compensate. Hence, the choice of a suitable price is made easier by service multiplexing. On the other hand, this can also be seen with a completely different approach, which is as follows: as the peaks do not overlap, the curve is flatter but the situation is suboptimal since the maxima do not sum. Hence, the multimedia case opens up the problem of combining the services so that the revenue is maximized for both services at the same time. Also the choice of the threshold $\vartheta$ might be discussed. In this case it is easy to show that a suitable $\vartheta$ is somewhere in the middle among the values shown. However, the threshold choice does not dramatically affect the revenue.

Figures 4 and 5 have been introduced instead to highlight that an analysis conducted separately for each service might offer misleading results. Here, the allocation is repeated but for network constituted by 100 Silver users only or 20 Gold users only, respectively. It can be seen that the performance is more variable and price variations affect more heavily the revenue. Moreover, the behavior of the curve with respect to the threshold $\vartheta$ is completely different than before. In particular,

[4]Remember than the normalization price $\phi$ is considered acceptable by $A_0 = 10\%$ of the users for utility equal to $\psi$.

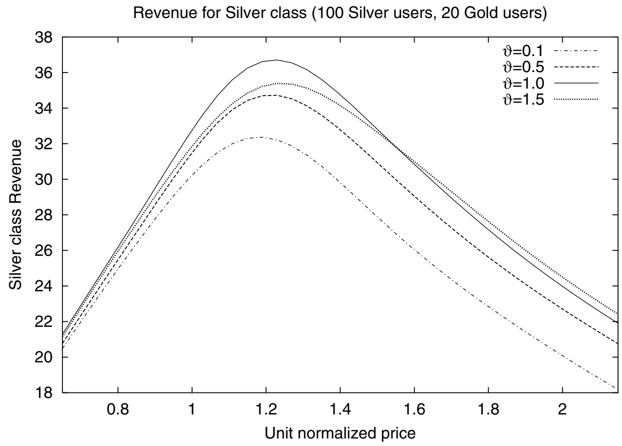


Fig. 6. Revenue from Silver users for the multiplexed case, as a function of the price, for different thresholds

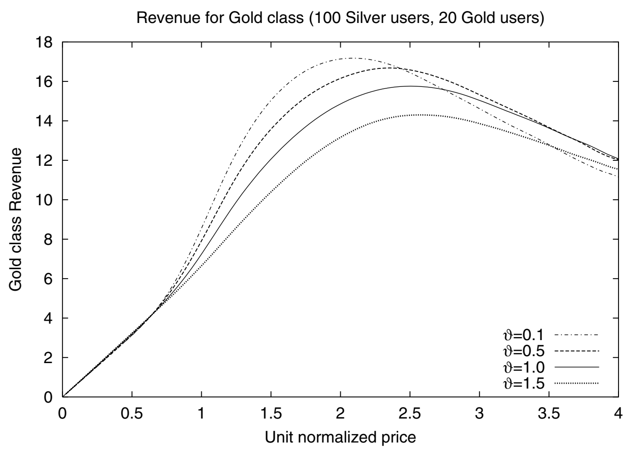


Fig. 7. Revenue from Gold users for the multiplexed case, as a function of the price, for different thresholds

the system with only Silver users is even more insensitive to the threshold choice, but the most suitable threshold is lower than before. On the other hand, the system with only Gold users has a strong dependence of the revenue on $\vartheta$, and the most suitable values are the low ones.

These behaviors are really different than the ones shown by Silver and Gold users in Figures 6 and 7, where again the system with both services at the same time is considered, for different values of the threshold. As a general conclusion, it is emphasized here that the superposition effect does not hold, i.e., it is incorrect and misleading to study a system with multiple services by analyzing each service separately. This not only leads to quantitative errors, but also the qualitative behavior of the revenue is different.

## V. Conclusions and Future Work

In this paper, we have introduced an extended model which takes into account multimedia traffic and integrates it in an probabilistic model of users' service acceptance. In this way, QoS for multimedia services can be integrated with the paid price to determine users' satisfaction.

We also formulated a case study in which we applied the above framework, in order to gain understanding on the integration of different services on the same channel. The results show that it is not easy to efficiently use the constrained radio resource for several services at the same time. For the provider, this might imply that the revenue maximisation is not trivial at all.

More in general, we show that the combination of different services does not mean a combination of the revenues coming from these services. Moreover, a separate analysis of the services which are going to share the same resource can obtain misleading results, since the multiplexed case can have completely different behaviors. The CDMA–like capacity complicates the allocation even more, as it is regulated by non trivial relationships to determine the feasibility of the constrained assignment.

Further research will investigate the role of pricing, and how it can be differentiated to better combine the services (roughly speaking, to sum the peaks of the revenues). Also an interesting issue can be the introduction of different priorities among the users, in order to improve the revenue by guaranteeing access to the more profitable users. Finally, analytical approaches are investigated at the same time to gain more general insight on the matter.

## References


[1] C. Comaniciu, N. Mandayam, D. Famolari, P. Agrawal, "Admission and flow control for multimedia CDMA", *Proc. ICME 2000*, IEEE International Conference on Multimedia and Expo, Volume 3, pp 1265–1268, 2000.

[2] W. Lee, B. Sabata, "Admission control and QoS negotiations for soft-real time applications", *Proceedings of IEEE International Conference on Multimedia Computing and Systems*, Volume 1, pp 147–152, 1999.

[3] A. Campbell, G. Coulson, F. García, D. Hutchison, H. Leopold, "Integrated Quality of Service for Multimedia Communications", *Proceedings of IEEE INFOCOM'93*, pp 732–739, April 1993.

[4] C. Lindemann, M. Lohmann, A. Thmmler, "Adaptive Performance Management for UMTS Networks", *Computer Networks*, Volume 38, pp 477–496, 2002.

[5] C. Saraydar, N. Mandayam, D.J. Goodman, "Efficient Power Control via Pricing in Wireless Data Networks," *IEEE Trans. on Communications*, Volume 50, Issue 2, pp 291–303, February 2002.

[6] T. Heikkinen, "On Congestion Pricing in a Wireless Network," *Wireless Networks*, Volume 8, Issue 4, pp 347–354, 2002.

[7] F.P. Kelly, A. Maulloo, D. Tan, "Rate control in communication networks: shadow prices, proportional fairness and stability", *Journal of the Operational Research Society*, Volume 49, pp 237–252, 1998.

[8] M. Xiao, N.B. Shroff, E.K.-P. Chong, "Utility-Based Power Control in Cellular Wireless Systems," *Proc. INFOCOM 2001*, Joint Conference of the IEEE Computer and Communication Societies, pp 412–421, 2001.

[9] H.R. Varian, "Intermediate Microeconomics: A Modern Approach," *Norton*, New York, March 1999.

[10] E.W. Fulp, M. Ott, D. Reininger, D.S. Reeves, "Paying for QoS: an optimal distributed algorithm for pricing network resources," *Proceedings of IWQoS98*, International Workshop on Quality of Service, pp 75–84, 1998.

[11] C. Lindemann, M. Lohmann, A. Thümmler, "A Unified Approach for Improving QoS and Provider Revenue in 3G Mobile Networks", *ACM Journal on Special Topics in Mobile Networks and Applications (MONET)*, August 2003.

[12] L. Badia, M. Lindström, J. Zander, M. Zorzi, "Demand and Pricing Effects on the Radio Resource Allocation of Multimedia Communication Systems," *Proceedings of Globecom 2003*, December 2003 (to appear).

[13] D. Famolari, N. Mandayam, D. Goodman, V. Shah, "A New Framework for Power Control in Wireless Data Networks: Games, Utility and Pricing", *Wireless Multimedia Network Technologies*, Kluwer Academic Publishers, pp 289–310, 1999.

[14] C. Zhou, M. L. Honig, S. Jordan, and R. Berry, "Forward-Link Resource Allocation for a Two-Cell Voice Network with Multiple Service Classes," *Proceedings of WCNC 2003*, Volume 2, pp 1060–1065, 2003.