Demand and Pricing Effects on the Radio Resource Allocation of Multimedia Communication Systems

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***Abstract*— Over the years, Radio Resource Management has been benchmarked mostly by its technical merits. For a service provider, however, also economics must be reckoned with. When the financial needs of the provider and the satisfaction of the users are considered, common objectives in radio resource management like maximising throughput or meeting various quality constraints, may no longer be sufficient. We analyse next generation communication systems by including models of economics, presented in the literature, and reasonable considerations to depict the users/provider relationship in a generalised multimedia environment. In particular, we develop a model of users' satisfaction, in which both requested Quality of Service and price paid are taken into account. The model enables us to investigate how resource allocation dynamics affect operator revenues and to derive some useful insights. The Radio Resource Management can be shown to highly depend on economic considerations. The provider's task to determine the best usage of the network capacity is heavily affected by the users' service demand and their reactions to the pricing policy. Thus, the economic scenario needs to be taken into account to efficiently exploit the constrained radio resource.**

I. INTRODUCTION

The use of multimedia services is expected to increase rapidly. With new devices and applications appearing every so often, the introduction of more flexible applications and forms of information exchange seems inevitable. Soft or adaptive applications adjust their information exchange according to their ability to conform data transmission to current link conditions so that radio resources can be conserved. However, the added flexibility also increases the complexity of determining the best usage of the radio resources.

In the recent literature, various researchers have studied the possibility to include micro-economic concepts in the Radio Resource Management (RRM) of wireless networks [1] [2] [3]. The objective of this approach is to maximise the user welfare, according to some model of the perceived Quality of Service (QoS). By means of game theory and utility functions the radio resource is divided among the users to find the greatest overall user satisfaction. With this approach, only the users have, until now, been considered in the game. The provider has merely been an arbitrator (or mediator).

For the provider to have a sustainable business model, the network operation must generate adequate revenue. The operator provides a data delivery service. Hence, the more data that can be delivered, the higher the potential revenue. The pricing and allocation strategies of the provider heavily influence the behaviour of the users. Users who are faced with inadequate QoS or with (unjustifiably) high QoS at a very high price are likely dissatisfied. Conversely, the provider is not likely to want to sell too cheaply. The total revenue depends on both allocation and pricing policies. Nevertheless, most studies neglect the pricing strategy's effect on user satisfaction. We believe, however, that it is important to also incorporate the economic considerations of the provider in the analysis.

As a first contribution, we introduce in this paper a framework, preliminarily presented in [4], that we call here Microeconomic Elastic Decentralised User's Service Acceptance (MEDUSA). This model enables us to represent the satisfaction of the users by means of a function describing the user's probability of entering an offered service. The trade-off between paid price and perceived quality is included and this allows a direct evaluation of the revenue. The soft degradation of the users' perceived QoS is described by means of a simple utility function. The tariff for each user can be described as a continuous function in a similar way [5]. The price is an independent parameter set by the provider [1].

In particular, in this work we focus on the rate allocation issue for a CDMA network. Besides, the achievable revenues for two pricing strategies and the performance of a class of allocation policies are evaluated and compared. We also study the pricing and the resource allocation by highlighting some interdependencies between these two aspects. Finally, we study the network load as a factor which dramatically affects the behaviour of the allocation algorithms.

The introduction of the MEDUSA model allows us to consider that the RRM techniques are impacted by the economic scenario and vice versa. In particular the revenue depends on the way in which the QoS is assigned to the users, and the system dimensioning is also affected, whereas price and demand determine different behaviours of the RRM. Moreover, the proposed model is emphasised as a possibility of studying the effects of economic factors on the RRM from a theoretical point-of-view.

The work is organised as follows: in Section II we present the model of users' behaviour, by involving the trade-off between perceived quality and paid price. In Section III we analyse an

[1] Note that the pricing strategy in this work relates to the money exchange between user and service provider and, thus, should not be confused with strategies where virtual prices are used in conjunction with power control to improve the assignment of the radio resource [6]. On the other hand, we see the pricing as an operation performed a priori. For reasons of fairness and realism, the price can not be changed, only its correct setup can be investigated under a statistical point-of-view. In this sense, even though some similar ideas can also be found in [7], the aim of the pricing in our work is completely different.

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explanatory allocation scheme, in which the provider assigns the rate to users by exploiting knowledge of their utilities. In Section IV we present the results of this RRM policy, by highlighting points of trade-off and possible improvements. Finally, Section V concludes the paper.

II. Model for the Behaviour of Network Users

The concept of utility function has been widely used in the recent literature [8] to depict the QoS perceived by the users of a wireless network. The idea is to employ this concept derived from micro-economics [9] to mathematically depict the QoS degree perceived by the users. There are several possibilities to define a QoS evaluation with a numerical value: one example is the 5-level mean-opinion-score (MOS) [10], that directly considers the perception of the service and numerically grades the QoS via subjective testing.

The investigation of strategies to derive utility functions is however out of the scope of this work. Here, we simply assume that a utility function $u(r)$ is available, which maps some quality-related parameter r, onto an interval of real numbers, discrete or continuous. In the case of RRM, r represents the network resource given to the users, and could be one- or multi-dimensional.

In general, utilities are assumed to satisfy various mathematical properties. E.g., it has to be assumed that the greater the resource allocated to a user, the higher its satisfaction. This implies the following requirements on the derivative of the function $u(r)$:

$$\frac{\mathrm{d}u(r)}{\mathrm{d}r} \geq 0\,, \qquad \lim_{r\to\infty}\frac{\mathrm{d}u(r)}{\mathrm{d}r} = 0\,, \tag{1}$$

The right part of Equation (1), known in economics as the law of diminishing marginal utilities, reflects the phenomenon according to which the improvement of the QoS is vanishing when an already high grade of satisfaction has been reached. These general assumptions hold for any kind of assigned resources. As we are considering Radio Resource Management in Wireless Networks, we can add more hypotheses. In particular we will focus on the rate assignment, thus in the following we will identify r with the rate. The developed considerations can be extended to other kinds of RRM in a straightforward way, though. In the case of rate assignment it is reasonable to assume that there are intrinsic limitations which prevent the users from exploiting QoS over a certain limit. Thus, there is an upper bound to the appreciation of the service, which can be mathematically expressed by a value l, so that:

$$\lim_{r\to\infty} u(r) = l \tag{2}$$

Note that Equation (2) implies that $u(r)$ is concave for r greater than a given value, i.e.:

$$\exists r_c \,:\, u''(r) < 0\,. \quad \forall r \geq r_c \tag{3}$$

We also assume that there is a maximum value for r, called r_{max}, due to technological constraints. Henceforth, we will consider assignment of the resource only in the range $0 \leq r \leq r_{max}$ and we assume that in practical cases r_{max} supplies a utility close to l. Let the minimum achievable utility

$$u_0 \triangleq \min_{r\in[0,r_{max}]} u(r) \tag{4}$$

be the utility of not receiving service, i.e., $u_0 = u(0)$. In the following we will assume $u_0 = 0$. This holds if an ideal Admission Control (AC) is performed, as in this case the utility value can not go below zero, even for users without service [2].

When $u(r)$ has a continuous derivative for every value of r and r is identified with the rate in a RRM problem we speak of *elastic traffic* [11]. In general, it is not necessary to introduce this property for all kinds of service: e.g., for the simplest services, like GSM voice calls, it is commonly assumed that the quality degree of the service is on/off. In other words, $u(r)$ is bound to have only two values, which mean complete satisfaction or dissatisfaction for the user. However, next-generation services like data transfer or audio/video streaming are usually considered elastic traffic.

The RRM is often seen as the search for a high users' welfare, defined in some way as an aggregate of the utilities and subject to feasibility constraints. For example, in the case of rate allocation, the main constraint is the limited bandwidth. On the other hand, it seems unrealistic to measure only the welfare without taking into account the role of pricing. What we want here is to explicitly consider this effect.

In [4] we presented a model for this purpose. We call this approach Micro-economic Elastic Decentralised User's Service Acceptance (MEDUSA). The model is micro-economic, since it involves the trade-off between the micro-economic concepts of utility and price, and elastic, as their relationship can be tuned by means of users' sensitivity to these parameters (called elasticity in economics). The MEDUSA model defines an *acceptance probability* for every user that requests service, which integrates the impact of perceived quality and paid price. The decentralisation is in the fact that the decision of service appreciation is taken by each user independently, based only on the perceived quality and paid price. The introduction of a concept like an "acceptance probability" was not strictly necessary for the GSM-like services, in which the QoS can be assumed equal for each admitted user and the price fixed a priori (so that the QoS metrics are usually assumed to be the probability of not achieving the desired Signal-to-Interference Ratio or to have the connection refused by the Admission Controller).

In this work, we exploit the MEDUSA model to investigate how economic factors like price changes or load variations affect the RRM. We consider a utility function $u(r)$, as previously defined, that represent the QoS. Also the price is represented by a function $p(r)$ (in general, dependent on the rate) for which no particular assumptions are made, even though it seems reasonable to require that $p'(r) \geq 0$. Thus, from the above discussion we assign to each user an acceptance probability $A(u,p)$, for which we emphasise the dependence on the QoS (through the utility u) and the paid price p. This probability increases for

[2] Rather, in case of erroneous admission control, the welfare can even decrease, i.e., certain users can have negative utilities. This is the case, for example, when an active call is dropped: this event is usually considered more annoying than a block in admission.

increasing utility and decreasing price. That is,

$$\frac{\partial A}{\partial u} \geq 0 \qquad \frac{\partial A}{\partial p} \leq 0 \tag{5}$$

Moreover, there are also asymptotic conditions for the probability A, which has to be between 0 and 1. In more detail, let us consider $A(u,p)$ when the price is fixed to a finite non-zero value. In this case, by varying u, we can say that:

$$\lim_{u \to 0} A(u,p) = 0 \tag{6}$$

$$\lim_{u \to \infty} A(u,p) = 1, \tag{7}$$

where Equation (7) does not represent a real case, because an infinite utility is not reachable. However, it is useful to introduce it to have a more suitable mathematical expression. For a given finite value of the utility greater than zero, it is possible to write the dual relationships for the price, i.e.:

$$\lim_{p \to 0} A(u,p) = 1 \tag{8}$$

$$\lim_{p \to \infty} A(u,p) = 0. \tag{9}$$

A suitable expression for the MEDUSA model, which assures the validity of conditions (6)–(9) is:

$$A(u,p) \triangleq 1 - e^{-C \cdot u^{\mu} \cdot p^{-\epsilon}} \tag{10}$$

where C, μ, ϵ, are appropriate positive constants. The value of C can be determined as follows: if it is estimated that the best rate assignment (giving utility l) with a certain price p has probability q of being *refused*, then

$$C = -\frac{p^{\epsilon} \log q}{l^{\mu}}. \tag{11}$$

The strong point of this model is the tunability, which makes it similar to the Cobb-Douglas demand curves [9], that are widely used in economics. Roughly speaking, the parameter ϵ and μ represent the sensitivities to the price and the utility [3]. Thus, the parameter can be easily adapted to different kinds of markets, in particular ϵ and μ can be changed (possibly through realistic measurements) if the users become more or less sensitive to price or quality variation, respectively.

This analogy between our model and the Cobb-Douglas functions is not only formal. In fact, if we consider a large number of users in the system, each of them with a very low probability to have access to the system (the exponent in the above formula is usually close to 0), it is then true that A tends to the demand d (which also depends on p and/or u) for the access, and the following holds:

$$A(p) \sim d(p) \propto p^{-\epsilon} \quad \text{for given } u,$$
$$A(u) \sim d(u) \propto u^{\mu} \quad \text{for given } p.$$

In spite of this, one should note that the analysis only marginally depends on this definition of $A(u,p)$, as the conclusions we draw in the following are still valid for every function $A(u,p)$ that simply satisfies Equations (5)-(9).

[3] Note that the economic term should be "elasticity" (also for the Cobb-Douglas exponent). However, in the following we will call these parameters "sensitivities" to avoid the confusion with the characteristic of the traffic of being elastic.

In this work, we use the probability A to model the behaviour of users in a *centralised* resource assignment scheme in which the only choice left to the users is whether they want to accept the service or not. In this case the revenue is determined as:

$$R = \sum_{i=1}^{N} R_i = \sum_{i=1}^{N} p_i \, A(u_i, p_i), \tag{12}$$

where the users are considered to be numbered from 1 to N and their relative utility and price to be u_i and p_i respectively.

The MEDUSA model can be explored analytically to give useful insights. For example, Equation (12) can be used for a maximisation problem. In this case, two scenarios are possible: the capacity is either larger than the demand or not. In the former case, the users which accept the service can always be accommodated in the constrained capacity. If the network is conservatively dimensioned, it is likely that this situation occurs for every case of low load. In this case, we can consider the RRM as an unconstrained optimisation problem. Thus, our model can be used to derive properties of a suitable pricing policy that at least gives a satisfactory revenue for the case of no congestion. For a congested system, these results have to be modified according to the capacity constraint; however, simple procedures of constrained optimisation can be tried in order to evaluate the revenue, by achieving useful estimations of the correct price setting.

III. Strategies of Rate Allocation and Pricing

In this Section we present possible pricing schemes and a rate allocation algorithm for the purpose of evaluating the MEDUSA model. We refer in particular to a cellular CDMA system, with an interference-limited soft capacity.

We assume that the provider adopts a centralised and greedy rate assignment strategy. Further, we assume that the provider and, consequently, the resource manager, know the relationship between the assigned rate r and the utility $u_i(r)$ for every user i. This information is exploited by the provider to choose a value for the rate r that might satisfy the user, being at the same time respectful of the limited amount of bandwidth that can be allocated. After the decision, the user can decide whether or not to accept the assigned value, according to the acceptance probability previously defined.

To model the utilities, we employ sigmoid curves, which are well-known functions often used to describe QoS perception [2] [11]. The following expression will be employed to represent these curves:

$$u(r) \triangleq \frac{(r/K)^{\zeta}}{1 + (r/K)^{\zeta}}. \tag{13}$$

The parameters $\zeta \geq 2$ and $K > 0$ tune the utilities, so that they might be different for every user. Utilities are normalised to their upper limit, i.e., the asymptotic value l in Eq. (2) is equal to 1.

The assignment is performed with the following greedy algorithm: first of all, the provider determines the assignment proposed to user i, with i going from 1 to N in increasing order. This means that the allocated value for user i can be determined only when the rates for all users j, $1 \leq j < i$, have been determined. The assignment procedure for user i does not modify the allocations for users with lower identifier, i.e., once assigned, the value is not decreased. For each assignment, an initial value $r_i = r_{i0}$ is tried. However, if r_i violates the capacity constraint, it must be decreased until the constraint is met. Moreover, if the assigned value at the end of this procedure is r_i, the final rate will be evaluated according to the Acceptance probability $A(u, p)$, so that the expected value of the rate allocated to user i will be $A(u_i, p_i)r_i$, giving an expected revenue equal to $A(u_i, p_i)p_i$.

The procedure has still a degree of freedom in determining the initial value for the allocation r_{i0}. To identify a simple and tunable strategy, we consider the marginal utility, i.e., $u'(r)$. This quantity describes the subjective perception of changes in the rate assignment. If $u'_i(r)$ is close to 0 for $r \geq r_0$, there is no point in giving more resource than r_0 to user i. The improvements due to increasing the assignment beyond r_0 can be neglected. Thus, it is possible to define a class of rate allocation strategies, each of them with a different selection of the point r_0.

For this reason, we consider that a value ϑ is determined a priori by the provider. Let us define the set $\mathcal{B}$ as follows:

$$\mathcal{B} = \{r : u'(r) = \vartheta\} \cap [0, r_{max}] \ , \tag{14}$$

so that the initial rate is determined as:

$$r_{i0} \triangleq \begin{cases} \max \mathcal{B} & \text{if } \mathcal{B} \neq \emptyset \, . \\ 0 & \text{otherwise.} \end{cases} \tag{15}$$

Note that, due to Equation (3), if $r_{i0} \neq 0$ and $r_{i0} < r_{max}$, then $u'(r) < u'(r_{i0}) = \vartheta$ for all $r \in]r_{i0}, r_{max}]$. Hence, r_{i0} is the edge point after which a larger assignment is considered wasteful, as the utility is improved by less than ϑ times. In this way, the value of the threshold ϑ can be used to represent the general approach of the provider to the RRM. As the utilities are sigmoid-shaped, the greater the value of ϑ, the lower the initial rate r_{i0} proposed to user i. This implies that the provider has a trade-off in choosing ϑ. With a small threshold, users are generally supplied with very high utility. However, the number of served users is in general low, as a low number of assignments is sufficient to saturate the capacity. On the other hand, when ϑ is high, the rate assigned to each user is in general lower, which means a potential higher number of customer, but also a lower quality and hence also a lower acceptance probability.

The soft capacity of a CDMA system is taken into account by considering the feasibility of the rate assignment in an interference-limited system. We translate the rate to signal-to-interference ratio (SIR) by means of the well-known Shannon's capacity formula:

$$\gamma_{t,i} = 2^{r_i/W} - 1 \, , \tag{16}$$

where $\gamma_{t,i}$ is the target SIR for user i. As the assignment is greedy, this condition can be used, starting from the assignment given by Equation (15), to check if the set of the target SIRs for all users is feasible. In this case, this rate assignment is kept. Else, the new user's SIR is decreased as specified above, by using steps of 1dB.

Finally, we still need to specify the pricing strategy: in this field, several proposals [13] [14] have been presented, and it is not clear whether it is possible to consider all of them to be realistic. For the sake of simplicity, in this work we compare the two following policies: a *flat price* strategy and a linear usage-based pricing. The former implies that each user pays the same tariff p, regardless of the achieved rate. This may appear over-simplified, yet it can also be appreciated by the users for this reason. Note that the MEDUSA model allows to gain insight also for this situation, as the price p needs to be set anyway. In the the usage-based strategy instead, each user is subject to a different pricing $p(r_i) = kr_i$, which depends on the rate r_i. In this way, the price changes according to the network usage. These strategies express contrasting tendencies for more general and complicated pricing policies of future communication networks. It is also possible that realistic pricing is a mixture of these two strategies. However, the point here is not to discuss pricing policies in detail, but to present how the MEDUSA model can be applied. Moreover, note that the model can be applied to every fixed pricing strategy, given that the relationship $p(r)$ is defined a priori.

TABLE I

LIST OF PARAMETERS OF SIMULATION SCENARIO

Parameter (symbol)	value
number of cells	19
bandwidth (W)	20 rate units
max assignable rate (r_{max})	8 rate units
cell radius (d)	500 m
gain at 1 m (A)	-28dB
path loss exponent (α)	3.5
shadowing parameter (σ)	8dB
log-normal correlation downlink	0.5
log-normal correlation distance	75m
mean SNR at cell border	20dB
utility parameter ζ	$2 \div 20$
utility parameter K	$0.2 \div 4.2$
acceptance prob. parameter C	0.05
acceptance prob. parameter μ	2
acceptance prob. parameter ϵ	4

IV. RESULTS

In the following, we consider rate assignment in a CDMA system. A given number N of users is placed in a cellular scenario with uniform spatial distribution. Cells are hexagonal and "wrapped around" to avoid border effects. Table I shows the parameters of the simulation scenario.

The first results presented investigate the relationship between price and total revenue. Figure 1 shows the behaviour of the flat price strategy, whereas in Figure 2 the revenue for the usage-based pricing is plotted. Here 160 users have been considered. As discussed in Section II, there is a price that maximises the revenue; more in general, a price variation causes a non trivial revenue change, as the relationship through the acceptance probability has also to be considered.

One should also note that the price is not the only factor which determines revenue variation. In fact, the revenue varies even if the price is kept constant but a different threshold ϑ is considered. This happens because the average quality is better for lower ϑ, hence a higher price can be applied, and vice versa. Thus, even though the corresponding curves all show the same general behaviour, for different values of ϑ both the maximum revenue and the price for which the maximum revenue is achieved are different. As a general comment, it is shown that the pricing and the management strategy heavily affect each other. A good choice of the price for one RRM approach may no longer be suitable when another RRM approach is employed. Hence, it is appropriate to plan both of them accurately and possibly jointly.

Besides the revenue, another interesting metric for cellular systems is the admission rate, i.e., the fraction of users which are admitted into the network. Users can be not admitted if they do not agree with the proposed assignment and/or price. Moreover, a user can be blocked, and then considered as not admitted, due to scarce network capacity. In Figures 3 and 4 the admission rate is shown, for both pricing policies. Obviously the value decreases for increasing price. For example, when the price is low, the admission rate tends to a constant value, as the acceptance probability tends to 1. In this case, the users are blocked only due to the network capacity, which is saturated, and this constraint does not depend on the price. However, there are different behaviours according to the value of ϑ. First of all, a lower ϑ (i.e., a higher quality) implies that the saturation value is lower, as there are fewer users that can be admitted. At higher price the curves cross each other and this phenomenon can be reverted. In fact, what happens is that the average quality becomes more relevant, and the trade-off between utility and price determines interesting behaviours. For example, in Figure 3, there are more users for low values of ϑ, i.e., the decrease in the number of users is higher when the average quality is poorer. In Figure 4 this does not happen, as the usage-based price strategy implies that the price for lower quality is also lower. Finally, note that the revenue maximisation is achieved approximately where the number of users starts decreasing, i.e., for the highest price for which the network capacity is fully utilised. In fact, this is the point where the effect of decreasing the admission rate outweighs the revenue increase due to higher price.

The curves presented in Figures 1–4 can be shown to be highly sensitive to the number of users. Thus, the effect of the demand on the revenue and pricing has to be stressed. In fact, the revenue that can be earned, and also its maximising price, heavily depend on the number of users that are requesting the service. Figures 5 and 6 show how the system performance depends on the load. In these Figures the different pricing policies and rate allocation strategies have been fixed, and the number of users is the independent variable. In particular, Figure 5 shows different scenarios for flat price, whereas Figure 6 considers linear pricing.

In each case, it is highlighted that the revenue saturates for high demand, due to the constrained capacity. When the load is high, the resource is fully allocated and the fraction of users admitted decreases linearly with the load from this point on (there is an almost constant number of users admitted, whereas the demand is increasing). On the other hand, if the resource is sufficient for the users demanding service, the admission rate is approximately constant, being it the fraction of users that consider the price acceptable for the perceived QoS. Note that in this range the revenue is approximately directly proportional to

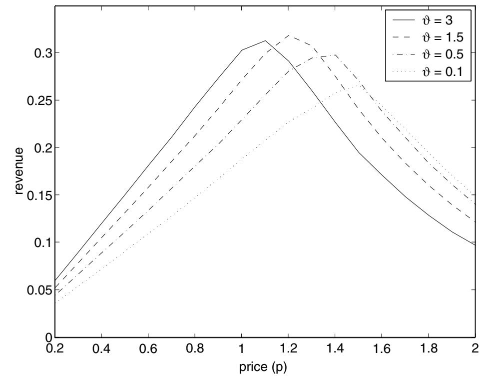

Fig. 1. Provider revenue for flat price, 160 users, as a function of the price

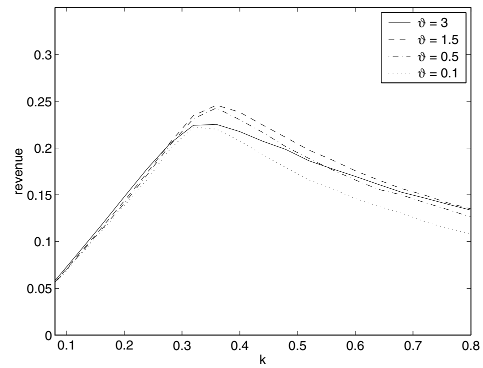

Fig. 2. Provider revenue for price $p(r) = kr$, 160 users, as a function of k

the demand, as the fraction of the used capacity increases (until it saturates). This difference implies that two different states for the system can be identified, i.e., high and low demand, that correspond to complete or partial usage of the resource. The behaviour of the RRM and the values of the economic quantities are very different in these two cases, and also the load value in which the separation occurs is floating with respect to the price and ϑ. For example, in Figure 5 the assignment with solid lines is suitable when the load is around 100 users. A lower value decreases the revenue, whereas a higher value does not guarantee the same admission rate. This is true also for the other sets of curves, but there is a high variability in the point in which this happens. Therefore, an operator has to carefully plan the network by taking into account these aspects.

V. Conclusions

The provider's task of determining the best usage of the network resources, so as to maximise its profit, does not have a trivial solution. The revenue depends on how users respond to both radio resource management and pricing. To better take this into account, we introduced the MEDUSA model, which defines an *acceptance probability* considering the joint effect of user utility and price. The model framework enables us to include economic considerations in the study of communications systems.

In this work the model was applied to a CDMA cellular system. It was shown that similar RRM strategies behave differently when economic parameters like pricing strategies and user

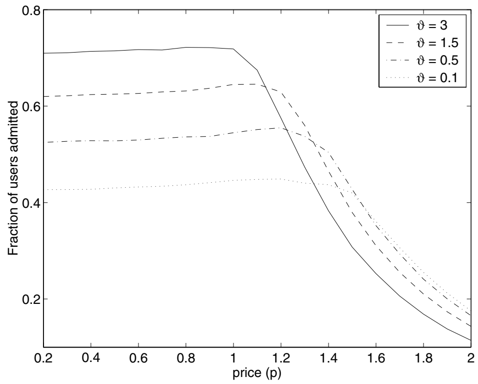

Fig. 3. Admission rate for flat price, 160 users, as a function of the price

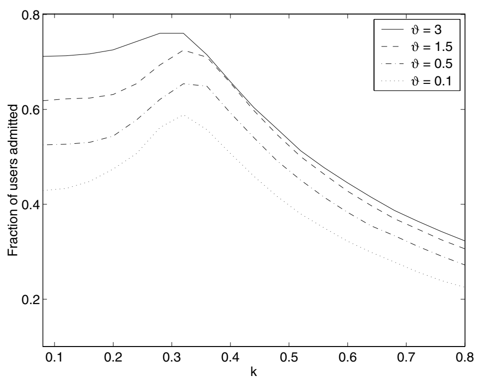

Fig. 4. Admission rate for price $p(r) = kr$, 160 users, as a function of k

demand are taken into account. Thus, a joint study of RRM tuning and pricing policies is indicated as necessary to have a good general performance. Appropriately setting the pricing strategy is crucial for the provider to have a satisfactory revenue. Too high prices drive customers away (in the long run, likely to competitors), with low or no revenue as a result. Too low prices can easily be afforded by the users, but also yield very little revenue. Price variations also affect the expected number of users in the system; hence, they have to be considered in system dimensioning. Future research on self-tunable prices, obtained through negotiations [15] between the users and the provider, can give further insight on this matter. Finally, results indicated that the system performance setup can be addressed better if good estimates of the load are available.

To sum up, the MEDUSA model allows useful insights to be gained about the RRM strategy. The economic aspects of RRM should not be neglected, for they not only affect performance, but also require several strategic choices to be made. It is imperative for the provider to take into account these aspects; thus, our model can be useful to gain understanding of them and improve the RRM in real systems.

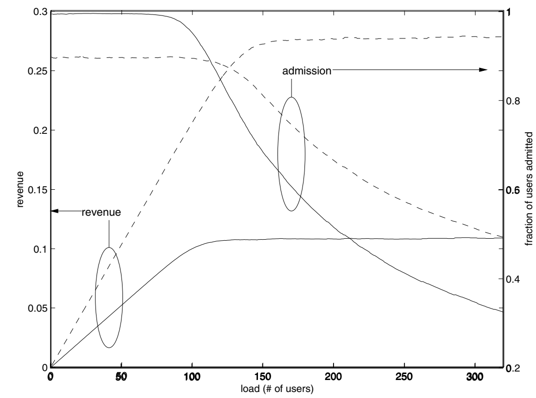

Fig. 5. Provider revenue and admission rate for flat price p, with $p = 0.4$, $\vartheta = 1.5$ (solid) and $p = 0.9$, $\vartheta = 3$ (dashed), as a function of the load.

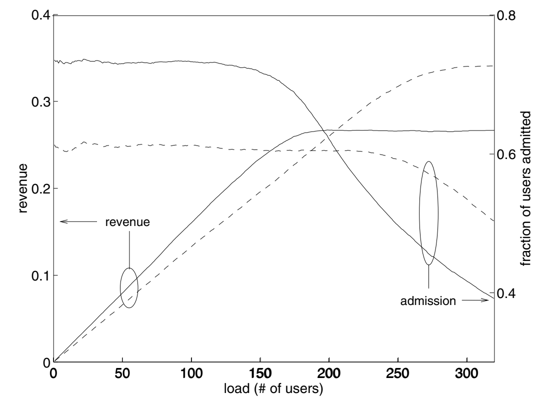

Fig. 6. Provider revenue and admission rate for price $p(r) = kr$, with $k = 0.36$, $\vartheta = 1.5$ (solid) and $k = 0.44$, $\vartheta = 3$ (dashed), as a function of the load.

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