Scheduling for Wireless Networks with Users' Satisfaction and Revenue Management

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ABSTRACT

Several proposals for wireless scheduling algorithms have been presented recently, where models focused on users' subjective perception of the service are used. This has the goal of designing scheduling policies aimed at satisfying more directly the users' preference. In the present paper we extend this approach, by studying Radio Resource Management with particular emphasis to the scheduling task, considering an original model to represent the behavior of multimedia users. We include charging strategies and users' reaction to prices, in order to include qualitative and quantitative economic considerations. After having briefly discussed how to include both perceived QoS and pricing, in order to achieve a user-centric evaluation of the quality, we show how it is possible to apply this model to the scheduler and to obtain a more efficient resource usage, i.e., characterized by both larger users' appreciation, and higher revenue for the provider.

Keywords: Scheduling, Communication system economics, User modeling, Radio Resource Management, QoS.

1. INTRODUCTION

Nowadays, many services are accessible on the wireless channel, thanks to the diffusion of communication systems based on packet transmission in Wideband Code Division Multiple Access (WCDMA) networks. However, to exploit the capacity of a WCDMA system it is necessary to take into account the coexistence of a possibly large number of users, which interfere one to each other, and the intrinsic unreliable nature of the radio channel. Moreover, in a wireless medium the errors are characterized by a considerably higher frequency and burstiness, besides to time and location variability. All these factors have a strong impact on the system performance and the offered Quality of Service (QoS). In particular they prevent the service requests from being satisfied with rigorous guarantees. Thus, it becomes impossible to apply classic scheduling strategies designed for the wireline case.

Hence, it is crucial for the scheduler to be aware of the users' instantaneous link state conditions. It can be shown that the scheduler can obtain an efficient usage of the system capacity by serving in a greedy manner the users with best channel conditions. This leads to the development of Channel-State Dependent Schedulers [1]. The problems of such schedulers are related to unfair resource sharing and QoS provisioning. To have a wide diffusion of the service, it is necessary to provide a balanced resource supply, that implies to serve also users with bad channel conditions. For this reason, several contributions have dealt with the problem of increasing fairness among users [2, 3]. Moreover, we are interested in approaching the problem of increasing fairness not only from the theoretical point of view but also because users' satisfaction is connected with economic aspects, like the provider's task of achieving an adequate revenue. In fact, a real network operator is willing to compensate and overcome the costs of service provisioning.

In general, users' appreciation of the supplied QoS can be investigated with an approach based on utility functions, which is a line of research widely used in the recent literature, in particular for the Radio Resource Management (RRM) operations [4]. Several scheduling strategies can be regarded as applications of a utility-based framework. In fact, it is possible to see the scheduling problem as a prioritization of users in a queue. This can be done by defining appropriate weights, as in the Weighted Fair Queuing (WFQ) [5] or WF^2Q [6] schedulers. A detailed mathematical formalization of the RRM problem, which involves utility functions to represent the QoS requirements, can be found in [7]. By joining these approaches, the scheduling can be seen as a strategy to maximize the total utility of the system. However, the system welfare is still seen only from the users' perspective, without considering the operator's economic counterpart.

Instead, in this paper we aim at considering also the provider's point of view, which means to include also considerations about the earned revenue. To do so, it is necessary to extend the framework and consider the tariff of the service, by introducing a pricing function with properties similar to utility but with a negative impact on users' degree of satisfaction. Thus, we directly investigate the trade-off between utility and price by applying a framework, developed in [8], to the scheduling problem. In this way, we refer to economics in two directions, since the allocation efficiency is eventually related not only to the QoS provisioning but also to the money exchange between user and service provider.

In [8] we preliminarily applied such a model only to dimension the network and to gain insight about the points of trade-off involved. Rather, in this paper we take into account the user-centric model of service appreciation as a pragmatic approach to develop strategies of scheduling on in WCDMA system.

The contribution of the present paper is to discuss how an acceptable QoS for the users and together a satisfactory income for the provider can be obtained, and to compare different scheduling strategies in terms of achievable revenue. We analyze existing techniques to optimize scheduling from the technical point-of-view (i.e., by maximizing throughput), and discuss their performance within the above framework, i.e., by considering at the same time users' satisfaction and provider's revenue. Moreover, we will discuss and quantify possible margins of improvement, and we will present original proposals where QoS and revenue are considered as goal parameters to significantly increases the goodness of the allocation in terms of satisfied users and generated profit.

The remainder of this paper is organized as follows: in Section 2 we present the analytical model for the users' satisfaction, including both pricing and utilities. In Section 3 we discuss different scheduling strategies under the theoretical point-of-view and we outline how they can be modified to take into account the revenue improvement aspect. Section 4 presents simulation results and Section 5 concludes the work.

2. MODEL FOR THE USERS' SATISFACTION

Let us consider a set (network) of N users. In micro-economics [9], utility functions are introduced to describe the assignment among the users of a resource, represented with a generic non-negative parameter r. For the sake of simplicity, we assume that r is a scalar, even though an extended analysis can be easily obtained for a multi-dimensional r by following the same approach presented in the following. The distribution of the resource r generates an allocation vector $\mathbf{r} = (r_1, r_2, \ldots, r_N)$. The outcome of a particular $\mathbf{r}$ can be seen by the perspective of the ith user as mapped through its utility function $u_i(r_i)$, which depends on the ith element of r. In other words, the utility of the ith user is related to the amount of resource received. When RRM is studied, r_i represents the share of network resources allocated to user i and the utility $u_i(r_i)$ describes the "value" of the spectrum allocation received by the user, by considering both the technology of the user's terminal and the subjective perception of the user. Since both these aspects can be subject to great dispersion, it is then reasonable to assume that $u_i(\cdot)$ is a different function for each i.

To investigate the scheduling issue, it is possible to identify r with the assigned data rate. Note that, even though the effective transmission rate is subject to time dispersion, the utilities are evaluated with r_i averaged on the whole transmission, to obtain meaningful results, since subjective perception of the achieved data rate is possible only after a sufficiently large temporal window. A more complicated analysis which re-evaluates the situation every given time interval is possible, even though it is omitted here for the sake of simplicity.

For what concerns the representation of the wireless users' utilities, note that a detailed investigation on how to derive them for different specific systems is out of the scope of this paper. Thus, we limit the analysis to standard assumptions performed in the literature for the utility-based RRM which can be specialized in more detail if necessary. Usually, utilities are assumed for every kind of assignment to be non-decreasing quasi-concave functions. According to the type of systems, it is sensible to consider also that there is a maximum rate $\mathcal{R}$, which is not restrictive to take as equal to 1, allowed to the technological support. We further introduce the assumption of having sigmoid-shaped functions, as in [10]. In particular, we adopt the following expression:

$$\forall i = 1, 2, \ldots, N \qquad u_i(r) \triangleq \frac{(r/K_i)^{\zeta_i}}{1 + (r/K_i)^{\zeta_i}} , \tag{1}$$

where the parameters $0 < K_i < \mathcal{R}$ and $\zeta_i \geq 2$ depend on the index i, so that different users may be characterized by different utility functions. In the simulations, K_i and ζ_i are randomly generated with uniform distribution within a given interval.

These assumptions, besides being common in the literature, are suitable for our purpose. For example, sigmoid functions have also an upper-limit which seems to be reasonably similar to what multimedia services can achieve on wireless networks. It is also realistic to assume that the highest perceived QoS is close to $u(\mathcal{R})$. Thus, it is possible to write:

$$\forall i = 1, 2, \ldots, N \qquad u_i(\mathcal{R}) \approx \lim_{r \to \infty} u_i(r) . \tag{2}$$

Another pleasing aspect of the above assumption for utilities is that, even though it is a specification, it is still general enough for our purpose, since the internal parameters K_i and ζ_i can be tuned so to determine very different behaviors for different users.

We can define an aggregate of the utilities as total network welfare $W(\mathbf{r})$, and consider a possible goal of the RRM to be the welfare maximization. If the utilities are additive, W is simply the sum. This leads to a formulation of RRM task as an optimization problem [7]. A way to formalize it is:

$$\max W(\mathbf{r}), \quad W(\mathbf{r}) = \sum_{i=1}^{N} u_i(r_i) \tag{3}$$

$$\text{s.t.} \quad \mathcal{C}(\mathbf{r}) \leq C_{max} . \tag{4}$$

To have a properly defined optimization problem, one must also take into account a capacity constraint of the network, represented by Equation (4) in the above formulation. Thus, $\mathcal{C}(\mathbf{r})$ is a given function of the allocation vector $\mathbf{r}$ and C_{max} describes the upper limit allowed for $\mathcal{C}$. Also this constraint can be easily extended to a multi-dimensional condition. For wireless systems, the simplest possibility to introduce a capacity constraint is to consider a *hard capacity* system, that is a Time or Frequency Division Multiple Access (TDMA, FDMA) with a fixed maximum total rate C_{max} which can be allocated on aggregate, related to the number of time or frequency slots. Thus, the function $\mathcal{C}(\cdot)$ is simply a sum, and the constraint becomes $\sum_{i=1}^{N} r_i \leq C_{max}$. It is worth noting that, even though this kind of constraint is useful to understand what follows, it is not realistic for WCDMA networks. WCDMA networks have in fact a similar limitations in the maximum number of codewords, but usually this number is assumed to be very large for practical purposes. Another constraint, i.e., the interference limit, is usually more restrictive and will be considered in the following [11]. In more detail, according to the link gain conditions, Signal-to-Interference Ratio (SIR) requirements and allocated rates, an interference condition can be written for every user. Thus, a vector $\mathbf{r}$ is said to be *feasible* if all these constraint are met. The feasibility condition is complicated to investigate with analytical instruments, but is easy to check within a simulator. Besides, note that we adopt in this paper a simulation-based approach, whereas analytical solutions are left for future study. However, it is thanks to the WCDMA capacity constraint that all the factors impacting on system performance, like channel variability or location-dependent errors, can be included in the optimization problem, more precisely in Equation (4).

Now, we extend the above problem description by considering also the pricing [12, 13], which has a negative impact on users' appreciation of the service. This extension allows to understand whether the allocation is not only technically efficient, but also sensible from a micro-economic perspective, i.e., users that do not get both adequate QoS and affordable price are unsatisfied customers. It can be assumed that these users pay only a certain fraction of the tariff due, or alternatively they leave the service with a certain probability. In this way, overassignments, which are a trivial way to allocate a high amount of resource, are refused by users since they imply higher prices.

The model presented in [8] proposes to define the satisfaction A_i of the ith user as a value into the range $[0, 1]$. This satisfaction value can be seen as a weight, or a probability of service acceptance, to evaluate all metrics related to resource assignment, so that only resource coming from satisfactory allocations is efficiently used. For example, the total provider revenue R is evaluated as:

$$R = \sum_{i=1}^{N} A_i p_i , \tag{5}$$

where p_i is the price paid from the ith user. Similar expressions can be used to evaluate other metrics [14], for example the sum of the A_i's represents the fraction of satisfied customers, i.e., the ones who keep paying for the service without abandoning it or being driven to other operators. However, the interesting point is that this framework is not only useful for evaluations, but also indicates a possible approach to scan the solutions of the allocation problem to improve the scheduling strategy, as will be outlined in next Section.

To represent the trade-off between the offered QoS and the price paid, we consider a definition of A_i which depends on u_i and p_i. Hence, we write $A_i = A(u_i, p_i)$ for each i, by assuming that every user in the network adopts the same criterion to decide whether the service conditions are satisfactory or not. A possible expression [8] for $A(\cdot)$ is as follows:

$$A(u_i, p_i) \triangleq 1 - e^{-C\cdot(u_i)^{\mu}\cdot(p_i)^{-\epsilon}}, \qquad (6)$$

where C, μ, ϵ are positive constants. The exponents μ and ϵ tune the sensitivity to utility and price, respectively, whereas C is simply a normalization constant Note that the above Equation is written in this form only to emphasize the trade-off, but actually both u_i and p_i depend on the allocated resource r_i. In fact, in this work we always consider that u_i's follow Equation (1), whereas $p_i = p(r_i)$, with $p(\cdot)$ being a non decreasing function, which is the same for all users [1]. Equation (6) satisfies several properties which are expected to characterize A_i, like monotonicity or boundary conditions (for details see [8]). However, it is adopted here only for the sake of simplicity, but the conclusions drawn in the following are still valid for other choices of $A(u, p)$.

Thus, the total revenue expressed by Equation (5) can be rewritten as $R(\mathbf{r})$. This opens up the possibility of formalize a different optimization problem, in which the goal function is no longer the users' welfare but the revenue. Note that this goal, besides being an alternative which might be interesting for the provider, is not fully disjoint from welfare maximization, since, as will be shown in the results' Section, when the revenue is increased the satisfaction of the users is generally improved. This follows directly from the definition of revenue in Equation (5): note that increasing the price paid p_i *decreases* A_i. With a similar formulation of the problem (3)-(4) we write then:

$$\max R(\mathbf{r}), \quad R(\mathbf{r}) = \sum_{i=1}^{N} A(u_i(r_i), p(r_i))p(r_i) \qquad (7)$$

$$\text{s.t.} \quad \mathcal{C}(\mathbf{r}) < C_{max}\,, \qquad (8)$$

where Equation (8) is still related to the WCDMA interference management. The scheduling strategies derived in the following will be identified as approximate solutions to this problem.

3. SCHEDULING ALGORITHM FRAMEWORK

We now introduce the application of the above framework to scheduling strategies for WCDMA systems. In wireless systems, the choices about scheduling have a major impact on the performance and in particular the scheduler must be aware of the radio conditions, because of the location-dependent and bursty errors. For example, a user in a fading dip may experience a bad channel and may be unable to transmit. In this respect, also time variability, which is determined by fading and users' mobility, has to be considered. For these reasons, we assume in the following to have a wireless system with mechanisms to predict channel conditions. An example is the High Speed Downlink Packet Access (HSDPA) release of UMTS [15]. In HSDPA, the channel conditions might be rapidly tracked to improve the system throughput, thanks to the Medium Access Control features located in the node-B, to evaluate the rapid variations of the wireless channel.

[1] This assumption is done for fairness reasons, since in this paper we consider only one service class for all users. If there are different service classes, then a set of pricing function should be considered. However, it is realistic to assume that this set is small; thus, an extension to this case is straightforward.

Parameter (symbol)	value
cell radius (d)	250 m
gain at 1 m (A)	-30dB
path loss exponent (α)	3.5
shadowing parameter (σ)	4dB
Doppler frequency (f_d)	2Hz
mean SNR at cell border	40dB
max assignable rate ($\mathcal{R}$)	96
utility parameter (ζ)	$5.0 \div 8.0$
utility parameter (K)	$0.2 \div 6.0$
acceptance prob. parameter (C)	0.5
acceptance prob. parameter (μ)	2.0
acceptance prob. parameter (ϵ)	4.0

Table 1
List of Parameters of Simulation Scenario

To directly consider existing policies, we might include in our analysis a traditional SIR-based scheduler, called C/I, with a greedy assignment of the available resources [16]; such a strategy obtains the maximum sector throughput, but with high degree of unfairness. A possible solution to cope with this problem was proposed in [3], where a similar scheme called in the following *Weighted Code Assignment* C/I (WCA C/I) scheduler, was introduced. The WCA C/I scheduler adopts a utility-function-based assignment, with the goal of increasing fairness. The dependance on the utility permits to obtain not only a better degree of fairness, but also a generally better allocation. This happens because the rate is assigned by following the perceived user-utility and not only the channel state. In a utility-based approach it is possible to assign the resources according to more complex metrics compared to a simple C/I policy; user parameters like SIR, buffer state, deadline of the packets can be considered and mixed in a more efficient manner.

Intuitively, a better matching of users' utilities can also determine a higher revenue. However, this is only an indirect consequence. Instead, we want to address the problem of the users' service appreciation and revenue generation more directly. Thus, we propose an original contribution in which the solution presented in [3] is taken as an initial condition, but the assignment is modified iteratively by means of a local-search algorithm, obtaining a local optimum solution. The initial greedy heuristic assignment is modified by giving more resources to the user with the highest marginal utility, in order to improve the total sector utility. Thus, this scheduler subtract resources to users with the lowest marginal utility, to obtain a variation of the total utility as small as possible. The algorithm ends when the goal function reaches a local maximum.

The revenue will also depend on the pricing strategy. Thus, the choice of the function $p(r)$ should be indicated to clarify the above definition of revenue, as given in Equation (5). In the literature [13], different pricing strategies have been proposed, and obviously the pricing strategy choice heavily affects the value of the total revenue. In this work we will consider two kinds of pricing policies, mainly for their conceptual simplicity. The first one is a *flat price* strategy, i.e., the price is fixed for any value of the assigned rate. The second policy represents a simple usage-based pricing with linear price. This means that $p(r) = kr$ is

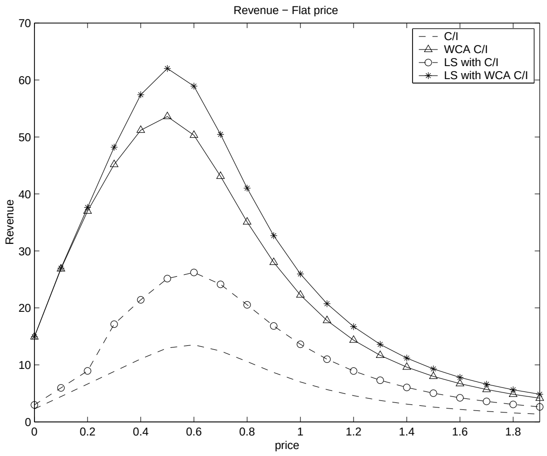

Fig. 1. Revenue for flat price, 120 users, as a function of the price

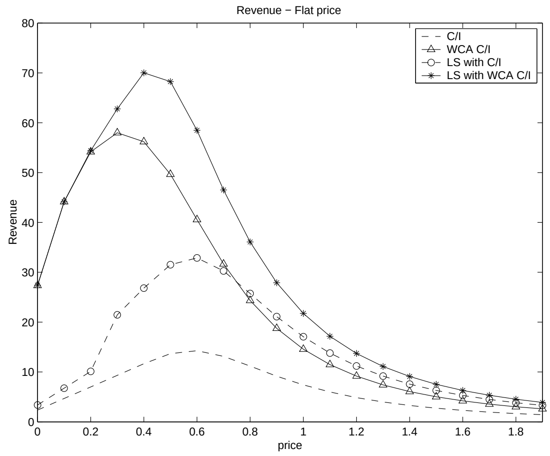

Fig. 2. Revenue for flat price, 180 users, as a function of the price

linearly related to r through a given constant k. It is interesting to observe that in Equation (5) there is expressed a double dependence of the revenue on the pricing, as also A_i is a function of the price. These two metrics are also representative of other values of interest from the technical point of view. Being in fact a flat price policy assigning the same price to all users, the revenue is directly proportional to the number of users accepting the service. Hence, the revenue for the flat price policy can be seen also as a measure of the number of admitted users. Instead, the revenue in the linear pricing case equals the unit price times the throughput; thus, in this case a weighted version of the throughput is considered. In general, it is at the same time true that a real pricing policy is likely to be something hybrid between these two policies [12], but also the interest for the provider in having a satisfactory revenue is connected to having both high throughput and a large fraction of satisfied users.

In the next we will consider the behavior of the C/I scheduling policies in the classic [1,16] and modified [3] version against our proposal introduced to improve the revenue. The policies will be compared by means of simulation in terms of generated revenue in order to highlight the consequences on the provider side.

4. RESULTS

In this Section we will present the results obtained with a HSDPA UMTS simulator developed at the University of Ferrara. A cellular cluster is simulated with a 3×3 hexagonal cell structure and wrapped onto itself in order to avoid the "border effect". In radio channel propagation, path loss, fast fading and shadowing have been included. To consider the environment mobility, a non-zero Doppler frequency is assigned, even though stationary users are considered. All these effects are included in the Power Control module, so that the spreading gain (which determines the rate) and the transmitted power are tuned to allocate a vector $\mathbf{r}$ which is feasible with the interference constraints. This applies Equation (8) to our case. Table 1 reports the parameters for the simulation scenario and the Acceptance-probability model.

In Figures 1–4 we compare different scheduling strategies, by evaluating the earned revenue for the cases of flat and linear price. In particular we compare the classic C/I strategy and its weighted assignment version, indicated with "C/I" and "WCA C/I" respectively. Also, we consider improved versions for both strategies in which the Local Search (LS) procedure introduced in the previous Section is implemented. These strategies will be referred as to "LS with C/I" and "LS with WCA C/I" respectively.

From all the results reported, it is clear that the classic C/I scheduling obtains worse revenue performance with respect to the weighted version. This is reasonable, since the C/I method has the problem of assigning the resource to the best users, without considering their utility. In fact, a given user might be already satisfied and not require a larger assignment, even though his channel conditions are good. Nevertheless, a C/I scheduler will still keep assigning him resource. In other words, the C/I scheduler might introduced overassignments, which are avoided with the WCA version.

Note that we are introducing here two kinds of contributions: first of all, we evaluate the performance of the scheduler in terms of economic quantities, which reflect also efficiency metrics, as discussed before. Moreover, we are able to go further by introducing the LS algorithm, where the micro-economic concepts of users' satisfaction are employed also to drive the scheduler. This strategy is more revenue-aware, and therefore is able to improve the performance, with respect not only to the pure "C/I" scheduler, which is clearly outperformed, but also to the weighted assignment.

There are two types of improvement that the LS solutions present: the first one is a general increase in the curves, which means that the revenue that the provider can achieve is increased. Secondly, the curves are also wider in general, which implies a higher robustness of the system performance. In fact, it is likely that the provider might be interested not only in exactly maximizing the revenue (which may occur for a narrow range of prices or network load values), but also in having robust performance with respect to variations of these parameters. Hence, the curves given by the LS strategy are a step forward in this direction.

Finally, an important comment which distinguishes between the flat and linear pricing is as follows: for the flat pricing a revenue improvement means that resource is better allocated since satisfaction is achieved by a higher number of users. For the linear pricing, things are more complicated. If the number of users is sufficiently larger, a revenue increase can not be achieved only by increasing the number of satisfied users, since if two assignment vector allocates the same global amount of resource C, the revenue is identical (it is equal to the unit price times C). Thus, to improve the revenue in the linear case, the scheduler must also increase the total throughput. This is more difficult to do when the system is saturated, i.e., the rate request is higher than the resources available for allocation, since the total rate allocated is supposed to be high anyway. However, in WCDMA systems it becomes possible thanks to a better interference management, since the total allocated rate is not fixed, but depends on the interference constraints, as discussed in Section 2. A Local Search aimed at improving revenue is therefore able to increase the assignment where it is more efficient, i.e., for users which cause less interference to the system.

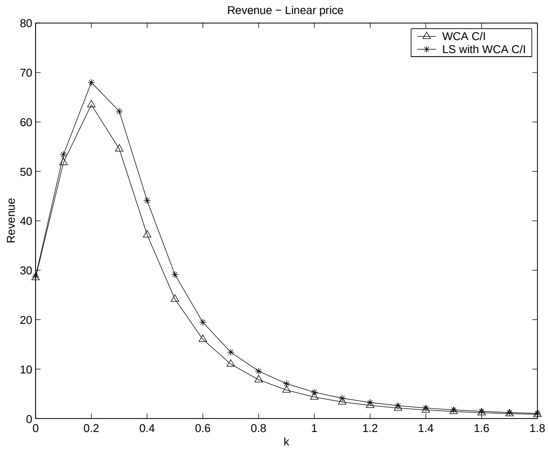

Fig. 3. Revenue for linear price $p(r) = kr$, 120 users, as a function of k

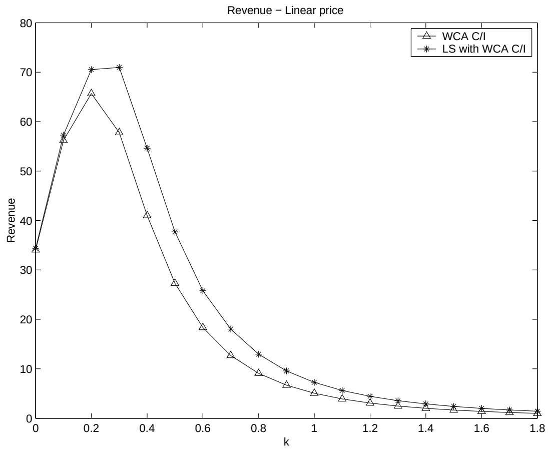

Fig. 4. Revenue for linear price $p(r) = kr$, 180 users, as a function of k

We now discuss the results in more detail. Figures 1–2 refer to the case of flat pricing policy. As discussed before, here the revenue is directly related to the number of admitted users, as the tariff paid by each user is the same, regardless of the quality, as long as the service is satisfactory. In this case it can be shown that there is a margin for increasing the number of satisfied users with respect to the C/I strategies. This happens because the LS allocation scheme avoids unnecessary overassignments, which waste resources without improving users' satisfaction.

For the flat pricing policy, we plotted results also for the original C/I strategy since it is comparable with WCA (even though the general performance is poorer). We considered also the LS with C/I, without weighted code assignment. It is emphasized here that the LS strategy, being only directed toward a local optimum, heavily relies on the first solution. However, there is anyway a significant gain in using the Local Search: the revenue increase achieved by the improved allocation scheme is between 15 and 20 percent.

Similar conclusions can be drawn also for the case of linear pricing policy, analyzed in Figures 3–4. In case of linear pricing, the revenue can be equivalently seen as a measure of the total assigned throughput, i.e., how much the provider succeeds in assigning as much resource as possible to the users. We have a gain of the same order of magnitude as in the previous case, and this shows that even with a completely different pricing strategy our proposal is still able to significantly improve the assignment. However, note the following: first of all, the simple C/I strategy is not reported here (neither in the original nor in the LS version) due to the poor performance exhibited. The reasons for the

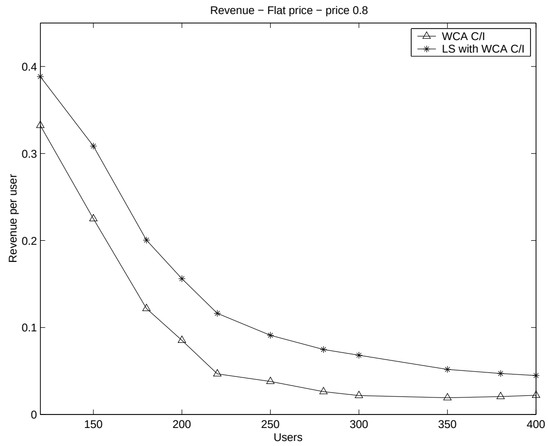

Fig. 5. Normalized revenue for flat price equal to 0.8, as a function of the load

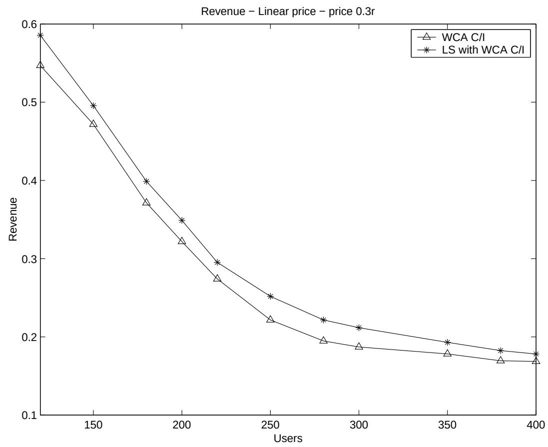

Fig. 6. Normalized revenue for linear price with $k = 0.3$, as a function of the load

failure of the standard C/I policy when we adopt a linear pricing are in the higher inefficiency of overprovisioning. In this case in fact, not only overassignments are a waste, but they also decrease the users' appreciation of the service, since they imply a higher cost.

Another phenomenon that should be observed is that the gain of the LS strategy is slightly lower than with flat pricing (its average is around 10%). However, as previously discussed, this is indeed the result of a strong improvement in the assignment efficiency, since it corresponds to a throughput increase.

To sum up, for all the cases reported in Figures 1–4 the Local Search strategy outperforms significantly the C/I (or WCA C/I) algorithm taken as the initial solution. The price for such improvements is in the increased computational complexity required by the LS procedure. Fortunately, for the examined cases this is not very high, since the number of iterations is usually low (10 iterations at most, but usually 4–5); thus, in this case a simple variation from the initial solution allows to greatly improve the earned revenue. This remark can be extended to make the scheme even more tunable. In fact, it can be observed that if the maximum number of iterations is limited, the final value the local search algorithm converges to is also different. Hence, a possible extension of the proposed strategy might be a conceptually simpler scheduler in which a fixed number of iterations is set a priori, with the goal of improving the revenue. This opens up a trade-off between the number of iterations and the obtained improvement, which is left for further research.

To better study the dependence on the network load (i.e., the number of users), and to gain insight on the price setting issue, we might consider the collection of the revenues achieved by the same scheduler for different load conditions for a given pricing policy setup. For example, in Figures 5 and 6 this is reported for flat (with price $p(r) = 0.8$) and linear ($p(r) = 0.3r$) pricing, respectively. From this Figures, one can see that the gain in using the LS strategy is present for different load conditions.

Finally, we remark that we also tested rather different choices for the local search policy, and the results obtained are more or less equivalent to those shown in this Section. In general, it is emphasized that the real gain comes from the scheduling strategy being driven by a utility- and price-aware model, which makes it capable of better allocating the constrained resource.

5. CONCLUSIONS AND FUTURE WORK

We presented an analysis from the provider's point-of-view of the scheduler, by including also revenue maximization among the goal of the scheduler. This is made possible by the introduction of the *Acceptance-probability* model, which accounts for the joint effect of user utility and price, by allowing to include economic considerations.

The results show interesting possibilities of improving the network management. In particular, the application of a classical efficient strategy, like the C/I scheduler, by neglecting the economic counterpart of the allocation, can lead to unsatisfactory results for the operator, since the maximized throughput provided by the C/I strategy might not be what users want. On the other hand, a simple strategy that locally searches for higher values of the revenue is able to greatly improve the profit and the economic efficiency of the resource management, by keeping the users' satisfaction level almost constant, if not increased. Thus, the usefulness of the economic considerations is highlighted.

Finally, it could be also possible to develop, within the given framework, a theoretical analysis of the scheduling, in which the the optimization problem (7)–(8) for revenue maximization is explored analytically. This study, that can allow better understanding of the RRM issues, is left for future research.

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