PRICING VOWLAN SERVICES THROUGH A MICRO-ECONOMIC FRAMEWORK

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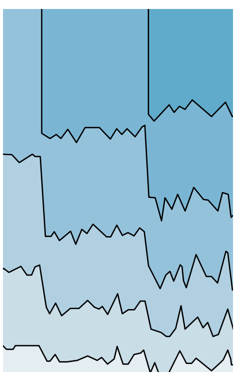

The simplicity of connection and the low cost of Wireless Local Area Network cards have led to a large diffusion of devices provided with WLAN connectivity, especially based on the IEEE 802.11b standard.

ABSTRACT

This article investigates the issue of determining an appropriate pricing strategy for voice over WLAN provisioning. This is performed by first framing the voice services in a tunable QoS scenario. The analysis is then performed with the awareness that in a WLAN system the tariff payment determines price-based access regulation, which implies a different service perception because of the modified network conditions. For this reason, we apply a micro-economic framework that considers the trade-off between perceived QoS and paid price in the users' request (i.e., including in a tunable way both service requirements and willingness to pay). This allows us to investigate the provider's task of having a suitable price policy, both identifying the subsequently involved trade-offs and providing insight on how to efficiently cut them.

INTRODUCTION

The simplicity of connection and the low cost of wireless local area network (WLAN) cards have led to a large diffusion of devices provided with WLAN connectivity, especially based on the IEEE 802.11b standard. In this article we refer interchangeably to WLANs and IEEE 802.11b-based networks, using the distributed coordination function (DCF). WLAN connectivity, at first limited to laptops, is now migrating toward palmtops and even mobile phones. Following such a diffusion of WLAN devices, the number of hotspots is also rapidly increasing, and the services offered are going to cover a broad set of applications.

Although WLAN systems have mainly been designed to carry best effort traffic, it is expected that such systems will soon be required to also carry many types of audio, video, and multimedia traffic. In particular, voice over Internet Protocol (VoIP) [1] is gaining relevance in the wireless environment, opening the way to the appealing voice over WLAN (VoWLAN) scenario.

The analysis of VoWLAN is an important aspect for researchers in both engineering and economics. On one hand, the challenge for engineers is to improve the transmission efficiency for VoWLAN [2] to obtain reliable service. This impacts on the economic aspects, since enhanced quality of service (QoS) might imply higher commercial value of the service and, consequently, larger revenues for the operator in the long run. On the other hand, VoWLAN provisioning can be faced as a distributed allocation, a competitive game, and a constrained optimization problem, which are concepts derived from economics [3]. Finally, another economic aspect concerns the design of appropriate pricing strategies for provisioning such a service that are complicated by the difficulties in capturing the capacity of a WLAN.

The investigation of effective pricing strategies for telecommunication services has been widely studied mainly for Internet-like environments in the wireline case [4]. This has shown, for example, the difficulty of identifying a good tariff function that, besides generating proper revenue, is both easy to understand and appreciate by users, and efficient in terms of regulating access to the service. Indeed, this is also a problem for services like VoWLAN, with the additional limitation of system capacity, which is inherently difficult to treat analytically. Different from other kinds of networks, the medium access control (MAC) strategy adopted in WLANs is based on the carrier sense multiple access with collision avoidance (CSMA/CA) mechanism that does not provide QoS and/or fairness guarantees to users. Also, the capacity is not a well defined quantity, since it depends on many factors related to channel conditions and traffic patterns. Thus, the service provided to users depends on the actual working conditions of the systems and the admission control policies possibly implemented by the system manager.

In our view, such difficulties are probably one of the reasons for the lack of significant contributions concerning VoWLAN pricing. Such an issue, indeed, is generally washed out by relying on the large basic potential of the WLAN, without any consideration of the efficiency of system management, the dimensioning of economic quantities, and the access control capability of price-based regulation. On the contrary, we believe that it is essential to consider these

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aspects as well in order to achieve larger and larger diffusion of VoWLAN services, and obtain economic benefits.

Therefore, we aim here at discussing a design methodology that might be a useful instrument for a provider operating VoWLAN services. In more detail, we capture the allocation problem in a micro-economic framework, where users' QoS perception and willingness to pay are described by means of mathematical instruments. Furthermore, we specifically take into account the CSMA/CA capacity of the WLAN. The whole procedure is aimed not only at investigating certain specific tariff strategies, but more widely at identifying the trade-off between the objectives of users and provider, in order to give an overview of how a network manager might set up pricing for VoWLAN service.

This framework relies on two separate parts. First of all, the specific characteristics of the WLAN capacity must be accounted for. In order to have a better treatable model, we also introduce some assumptions about QoS and fairness among users, which are discussed in the following section. Second, we also need to model the users' perception of the service through a micro-economic framework for wireless systems. This is needed since pricing strategies impact not only the regulation of service demand, as in classic economic models, but also network operating conditions, thus indirectly affecting the QoS perceived by users.

For this latter part, we make use of the model presented in [5], which considers the trade-off between QoS and pricing by defining a probability measure of *user satisfaction*. The allocation is thus evaluated with respect to a specific performance metric, such as generated revenue or number of users provided with satisfactory QoS, which is weighted with the user satisfaction probability. This might be regarded as an implicit admission control mechanism, since we may think of unsatisfied users as rejecting the service conditions and therefore not taking part in the system over the long term.

Finally, these two components might be integrated by means of a micro-economic scheme as follows. Investigation of the pricing policy is possible given that the following preliminary evaluations have been performed:

- QoS requirements of users. This can be done via subjective testing of the VoWLAN service. The result of this estimation will be numerically treated in the following as a *user utility function*. The provider might even store a user's profile that describes the utility parameters specific to each user.
- Sensitivity of users to price and utility variation. This evaluation impacts the satisfaction probability, and might be performed via extensive sampling.
- Expected number of incoming users and duration of calls, in order to evaluate the aggregate performance of multiple connections.

It is important to observe that due to the nature of the VoWLAN service, the whole system is on a feedback loop, where all the values mentioned above impact each other. A scheme to represent this behavior is outlined in Fig. 1.

Several aspects of this figure are worth more emphasis and are discussed in the following sections. In particular, as explained later, our approach in this article is to investigate network capacity by means of simulation, which probably represents an easier and faster way for a network manager to investigate WLAN capacity. Clearly, approaches based on analytical evaluations are possible as well, although the simplifications usually assumed by such models may conceal some of the complex interactions that might arise in reality.

The rest of this article is organized as follows. In the next section we discuss WLAN capacity and explain the way in which soft QoS might be required by VoWLAN users and also perceived, depending on limitations in system capacity. We discuss an economic model in order to describe how this impacts users' choices, also driven by the pricing policy chosen by the operator. Finally, we discuss with a numerical example how this can be useful for the provider of the WLAN in order to identify a suitable tariff plan that both matches users' QoS requirements and generates adequate revenue.

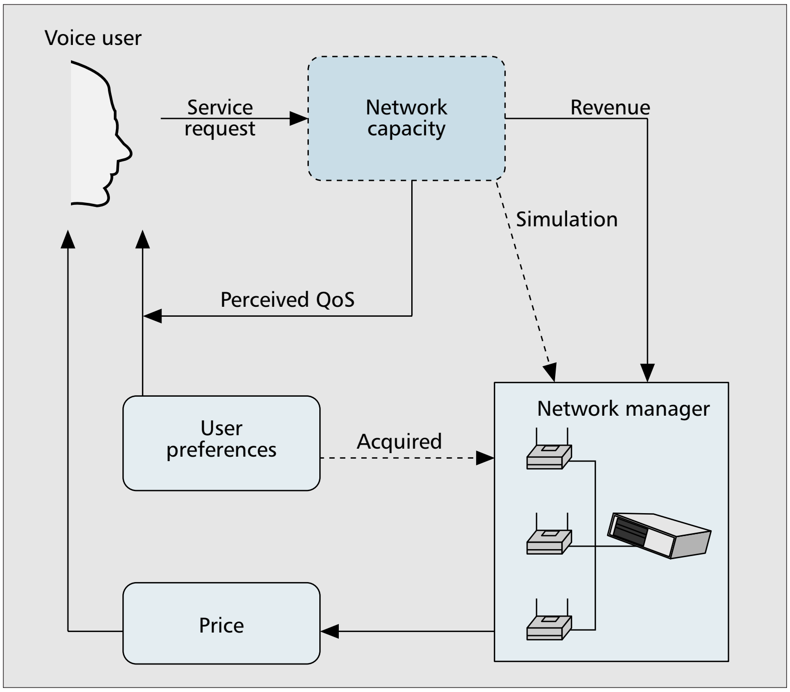

Figure 1. *The estimation scheme and the micro-economic model application to VoWLAN service.*

QoS Provisioning over WLAN

The IEEE 802.11b standard does not encompass any QoS mechanism for supporting transmission of voice or, in general, multimedia contents. The channel access is ruled by a contention-based strategy, DCF, which does not natively provide any service differentiation mechanism. Limited service differentiation might be provided by using the point coordination function (PCF) to rule channel access. However, the PCF functionality is defined as optional in IEEE 802.11b and is typically not implemented in commercialized IEEE 802.11 devices.

Problems arising from distributed sharing of

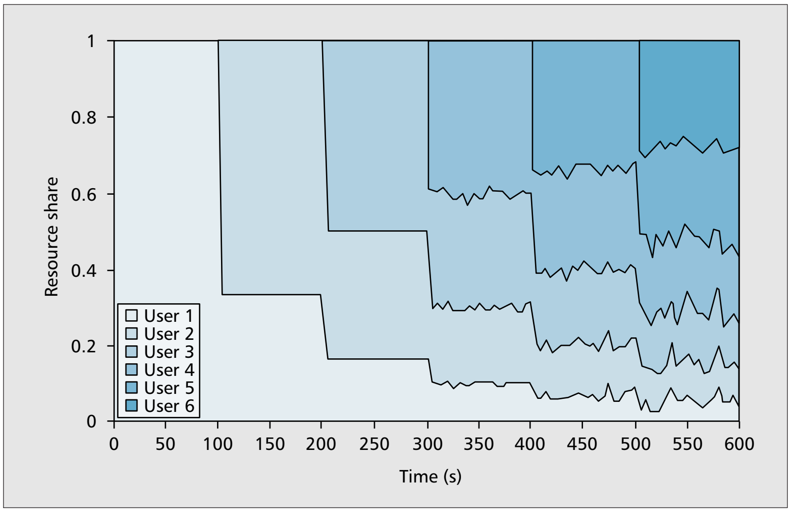

Figure 2. *Proportional share of resource for a WLAN system with six users with increasing priority. This confirms and extends to a larger system the results already obtained by [8].*

available resources are the lack of throughput and maximum access delay guarantees [6]. For light traffic, the DCF mechanism is generally able to satisfy the packet rate and delay requirements for voice applications. However, when the allocated traffic approaches system capacity, the access delay may result in total inadequacy for support of multimedia and voice services. The problem is exacerbated by the coexistence of voice and data traffic, since the transmission of long data packets may worsen the delay and jitter of voice packets.

These impairments have direct effects on the perceived voice quality, which will gradually decrease as the system approaches the saturation condition, with a sensitivity depending on the specific codec adopted.

Nonetheless, different quality levels can be obtained by using adaptable codecs. Such codecs allow for adjusting the service quality and amount of required resources, according to user requests or available resources [7]. Notice that, in general, scaling of service quality is obtained by relaxing the requirements in terms of bandwidth or delay.

We might therefore focus on a VoWLAN scenario, where users require different service levels, according to their personal preferences and the price paid for the service [5]. As long as the total requested rate is below the network capacity, the allocation does not present problems, and all users are entitled to obtain the requested rate (i.e., to experience the desired QoS). However, as the total requests approach the available capacity, the rate experienced by users has to be reduced in order to maintain the packet delay within the limits required for the voice/video service to be acceptable. The policy used for subdividing the available resources among users can greatly impact the QoS perceived by the users, determining their behavior. We will assume a rate scaling policy that assigns to each user a fraction of the available resources proportional to the requested rate (i.e., service level). In this way, the degradation of service experienced by each user is proportional to its original request, thus providing a generalized best effort quality.

Even though a detailed study of a service differentiation mechanism for IEEE 802.11b is beyond the scope of the present article, in the following we consider a specific strategy for the purpose of our investigation. For the sake of simplicity, we refer to the simplest technique of those proposed in [8], which, without substantial modifications to the standard, acts on the length of generated packets . Since DCF provides equal access probability (in the long term) for all the contending nodes (including the access point), under the assumption that all the nodes in the cell served by an access point work with the same physical rate, the resource share gained by each node is thus proportional to the length of the transmitted packets. Note also that more complex and realistic service differentiation mechanisms can be defined, but we stress that our approach can be kept almost unchanged since it simply involves evaluation of the perceived service, and hence does not rely critically on a given differentiation mechanism.

Following this resource sharing strategy, when the network approaches the saturation, the average transmission rate obtained by each user results to be proportional to its packets length. Furthermore, the ratio between the traffic of any two users will be the same both in the non saturated and saturated case. Our evaluation with the *ns2*-simulator [9] confirms the results shown in [8] over a wider population range. Figure 2 shows, for example, the results of the subsequent allocation of up to 6 users in the WLAN scenario, where a new user is added every 100 seconds. The resource requirements of each user are subsequently increasing, so that the rate request of the i-th user, $i > 1$, is i times the request of the first one. In other words, user 2, 3, … requires a rate equal to 2, 3, … times the request of user 1. As shown in the figure, the correctness of the assumption of proportionally fair share of resource holds.

We notice that the AP will get just the same amount of resources as a generic user, even though the AP has to serve all the downlink traffic that is generally much higher than the uplink flow generated by each terminal. In particular, with voice connections the AP has to serve as many inbound flows as the number of active voice sessions, thus rapidly becoming the bottleneck of the system [10]. However, solutions to alleviate this problem and consequently increase the voice capacity of WLANs have recently appeared in the literature [11].

Finally, we remark that in the saturation case the proportionally fair share of resources can determine an unsatisfactory allocation for some users. In order to investigate this point in detail, we introduce a micro-economic model, with the goal of quantifying the wireless resource allocation, which is described in the next section. Under this framework, specific evaluation of VoWLAN service provisioning is performed and useful insights are given, in particular concerning the design of an appropriate pricing strategy, capable of both coordinating users' requests and achieving adequate provider revenue.

MICRO-ECONOMIC RESOURCE ASSIGNMENT MODEL

The offer of a VoWLAN service has a side-effect on the network manager. In order to reach a sustainable business model, the service provider must achieve adequate revenue from the network operation. Hence, the higher the number of connections, and the more resource demanding they are, the higher the potential revenue. However, pricing and allocation strategies heavily influence the behavior of the users. In fact, users who are faced with inadequate QoS or very high price are likely dissatisfied. For these reasons, it is important to also incorporate economic considerations into the analysis.

To describe the allocation of soft QoS, many researchers, even in the telecommunication field, have proposed employing utility functions [3]. These are micro-economic instruments intended to map the welfare of purchasing a good or service. The capability of utility functions to capture the QoS evaluation by users of a wireless network becomes even more important when economic aspects such as service pricing are considered. This is especially needed for WLAN systems, where it has been shown that resource pricing is also a way to implicitly regulate the access of the terminals [12].

Therefore, our investigations about micro-economics of WLANs are made through the adaptation to this particular scenario of the model presented in [5]. The very general idea adopted in this framework is that users' service perception is determined by the trade-off between utility (representing the perceived QoS) and price. Formally, this consists of evaluating a numerical value for each user measuring satisfaction probability, which increases as utility increases and/or price decreases.

This value is then used in order to weigh all performance metrics, since from the economic point of view an efficient resource usage not only aims at satisfying the users as much as possible, but also evaluates the performance mostly on *satisfied* users. Metrics like throughput and even more the provider's revenue obtained from service provisioning are not meaningful if the associated service appreciation is low. If a peak allocation is obtained without respecting users' requests, it is likely that the users will abandon the service on the long run. This is why the economic model we employ considers only satisfied users (or better, it weighs the performance metrics with the satisfaction probability of users) as concurrent with the evaluation of allocation efficiency.

According to the assumptions made, both utility and pricing, and hence users' satisfaction, depend on the allocated resource, which we describe through the average transmission rate r obtained by a user. We remark that according to the differentiation mechanism considered, the rate r is determined by the length of the packets transmitted over the wireless channel, while the actual signaling rate at the physical layer is assumed to be equal for all users and constant over time. Note that it would be possible to extend this approach by also considering other factors such as delay or delivery ratio (which are, however, correlated with the rate). Nevertheless, this would lead to more complex expressions without affecting the method here proposed.

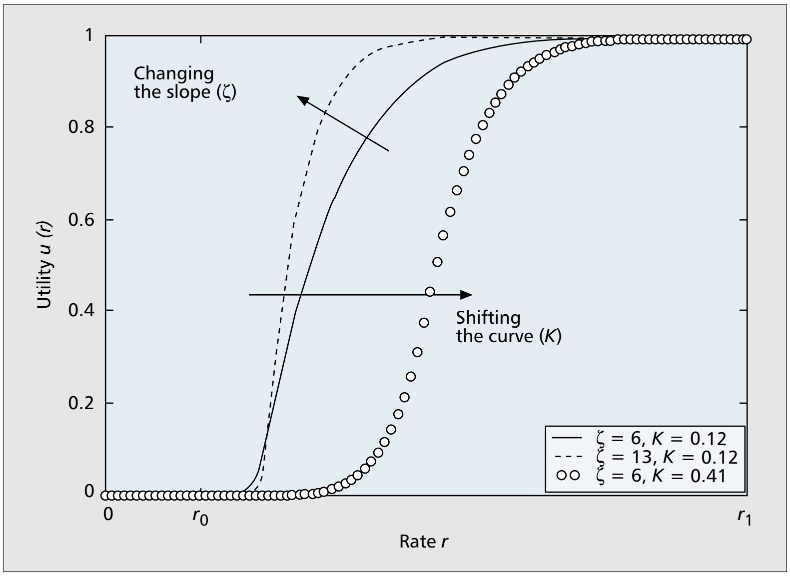

Figure 3. *Sigmoid utilities chosen to represent the QoS perceived by the users as associated with different rates.*

From a mathematical point of view, we adopt the following descriptions, proposed in [5]: both utility and pricing functions ($u(r)$ and $p(r)$, respectively) increase as the allocated resource increases. However, whereas the price might indefinitely increase as the allocation becomes larger, the utility must saturate after a certain point. In particular, we assume that the rates available at the codec span over an interval $[r_0,r_1]$.

The utility $u(r)$ might be obtained, as previously discussed, through subjective testing. This results in a different utility function for each user; also, since the set of rates is discrete, this would determine a stepwise constant function. However, for the mathematical approach, we assume that $u(r)$ can be approximated with a continuous function. This is reasonable if the number of available rates is large enough; and, in any case, the analysis presented in the following might be replaced by taking a quantized version of the utility values. Moreover, utilities are assumed to be normalized between 0 and 1, and for every user we impose that $u(r)$ is always 0 when $r < r_0$ and 1 when $r > r_1$.

Formally, the utilities we consider are sigmoid-shaped functions, where the middle point and curvature are regulated by means of numerical parameters, indicated with K and ζ, respectively. This means we consider $u(r)$ as follows:

$$u(r) = \begin{cases} K^{1-\zeta}\left(\dfrac{r-r_0}{r_1-r_0}\right) & \text{for } r_0 \le r \le r_0 + K(r_1-r_0) \\ 1-(1-K)^{1-\zeta}\left(\dfrac{r-r_0}{r_1-r_0}\right)^{\zeta} & \text{for } r_0 + K(r_1-r_0) \le r \le r_1 \end{cases} \quad (1)$$

where $0 < K < 1$ and $\zeta > 1$ are adjustable parameters. Note that keeping track of specific

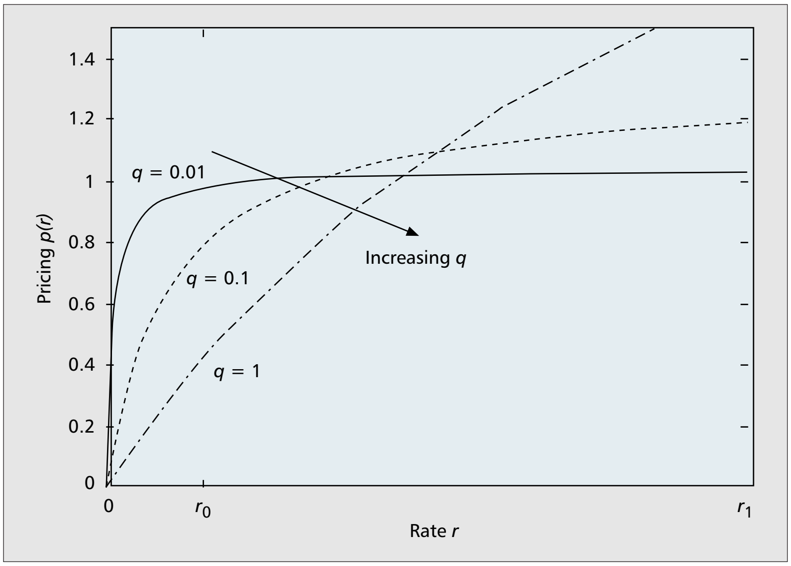

Figure 4. *A model for a (normalized) pricing function. As the parameter* q *goes from low to high values, the pricing changes from flat to approximately linear.*

values of K and ζ might be a way for the provider to synthetically represent the utility for a given user. A sketch of different utilities is plotted in Fig. 3.

The choice of an appropriate pricing function is instead important for correctly managing and regulating the medium access. In order to understand what a suitable pricing function for a VoWLAN service might be and outline a framework to characterize it, we need to take a tunable approach that can describe the existing trade-off between flat and usage-based pricing [4]. Appropriate pricing management is necessary not only for revenue collection, but also to perform access control, which in the end increases revenue even more. Our framework, however, allows us to distinguish between the different needs associated with the pricing function. Flat pricing policies may be more appreciated by users. Nevertheless, they cause more congestion in the WLAN since users do not try to regulate their resource demand according to the price, which is fixed anyway. Usage-based pricing partially amends the congestion due to unnecessary large requests, and therefore leads to larger revenues, but is less satisfying to users. In the following we show a way to quantitatively evaluate this trade-off and find an optimal point to solve it once the ratio between user and provider needs is known.

Thus, the considered pricing functions are intended as a mixture of a flat (asymptotic) value and an initial linearly increasing part. By appropriately tuning the steepness of the pricing via the parameter q it is possible to switch from a fully linear to a fully flat price. In this way we intend to show how it could be possible to find the pricing function, regulated by the provider, which cuts the design trade-offs in the optimal way.

Our choice in this article is to consider the following $p(r)$, also graphically represented in Fig. 4:

$$p(r) = \overline{p}\left(r_1\left(1 - q\ln\left(1 + \frac{1}{q}\right)\right)\right)^{-1} \frac{r}{r_1 q + r}, \tag{2}$$

where $\overline{p}$ and q are adjustable parameters, explained in the sequel.

The choice of this tunable pricing function is motivated by the possibility of investigating, through the parameter $q > 0$, the aforementioned trade-off between linear and flat pricing. The choice of q allows us to turn the pricing from linear (high q) to flat (low q), where the parameter $\overline{p}$ is the average value of the pricing from 0 to r_1, regardless of q. In this way it is possible to regulate the average value or shape of the pricing function independently.

It is important to notice that, whereas the utility variations depend on subjective perceptions of different users, and it is hence reasonable to assume that the curves of Fig. 3 might represent the utilities of different users in the same network, the pricing curve is only *one*, since it has to be known a priori by the users. Thus, the curves in Fig. 4 represent possible choices for the network manager, but only one can be chosen. Of course, this can be extended by considering a class-based approach in which different pricing functions are allowed according to the service subscriptions of users. Even though this point is not directly addressed here, it might be considered with only straightforward modifications.

Finally, the micro-economic model defines a satisfaction probability A for every user, which depends on the trade-off between utility and price. A possible choice is as follows:

$$A = 1 - \exp(-ku^{\psi}p^{-\varepsilon}), \tag{3}$$

where k, ψ, and ε are positive constants, appropriately chosen, that regulate the sensitivity of users' satisfaction to the QoS/price trade-off. For example, increasing ψ makes the users more sensitive to the utility, whereas increasing ε does the same for the price. The last value, k, is simply a normalization constant. This equation is chosen in order to respect the intuitive behavior that the satisfaction of a user increases as the quality increases and/or the price decreases. Note, however, that its functional behavior might easily be adjusted by tuning the parameters, so this is indeed a very general choice. Finally, observe that since both u and p depend on r, A is also in turn a function of r. Possible behaviors for the function $A(r)$ are represented in Fig. 5.

The model can be applied to the VoWLAN scenario in order to dimension the network and identify an appropriate pricing function as follows. First of all, an *econometric* measurement is required in order to characterize all parameters involved in the scenario, that is, the utility behavior of the users, which might be done through qualitative subjective tests, and the acceptance probability parameters. Our approach gives the freedom to change the parameters $\overline{p}$ and q of the pricing function in order to choose a tariff that sets the average price and combines the effects of flat and linear pricing in the most suitable way. Thus, a direct application of the model to a real case might assume the scenario as known, and $\overline{p}$ and q as variables.

The model allows the evaluation of different metrics of interest to the WLAN manager, such as the average satisfaction rate of users or the revenue generated by the allocation. The former simply corresponds to the evaluation of $A(r)$ averaged over all users; the latter is, instead, the sum of the prices paid by the users weighed on their satisfaction probabilities, $\Sigma_i A(r_i) p(r_i)$. As discussed in the introduction, from an economic point of view dissatisfied users are lost customers, and their generated revenue is not significant in the long run.

In practice, a possible application of the model via the evaluation of the two aforementioned quantities is as follows. Due to the complicated relationships that interrelate the QoS achieved by users of a WLAN, it seems reasonable to adopt a simulation approach, at least in order to perform simple and fast performance evaluation. This is also the simplest method to use in a real situation for a WLAN manager. Thus, it is necessary to implement the micro-economic model in a simulator such as *ns2*, where IEEE 802.11b procedures are already available. This is useful to evaluate the impact of CSMA/CA in terms of capacity on the allocation of a variable traffic rate for every user, according to user preferences. In particular, if a different sigmoid-shaped utility function is randomly determined for every user, this user is therefore assumed to ask for the transmission rate r^* that maximizes her satisfaction probability. Note that once the utility is chosen, the behavior of A is also known, since the pricing is known a priori. It is immediately verified that such a value always exists, as visible in Fig. 5.

In this way once the micro-economic parameters of the system are known, an estimate of the most suitable pricing policy might be obtained, and in particular the trade-off between contrasting objectives, such as user satisfaction and revenue maximization, might be investigated.

Model Application

The general idea is that with the model outlined above, it is possible to evaluate and compare different pricing policies for VoWLAN service. As shown in the literature [4], a pricing policy might be analyzed under different aspects. In particular, due to QoS elasticity (i.e., the possibility for users to regulate r), which results in both different QoS and price paid, the average price is not the only factor to consider. In particular, we believe that the difficult part of the investigation resides in the trade-off between flat and usage-based pricing strategies. The former kind of pricing, which corresponds to a constant $p(r)$, independent of QoS, is often adopted in WLAN hotspots, where the payment of a fixed fee guarantees access for a given time (but without quality constraints). The latter, instead, has been shown to be more effective in managing multiple access, as flat pricing does not prevent the system from being abused. Note that this is also captured by our micro-economic framework, since flat pricing implies that the most preferred rate is always r_1 (i.e., the highest value given by the codec).

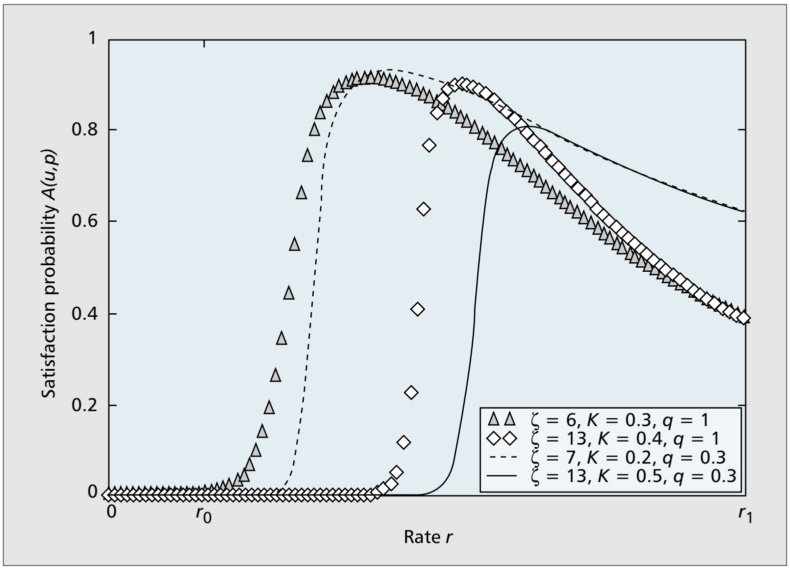

Figure 5. *Examples of satisfaction functions. For all curves it is assumed* $\overline{p} = 0.45$, $\mu = 2$, $\varepsilon = 4$, $k = 0.15$.

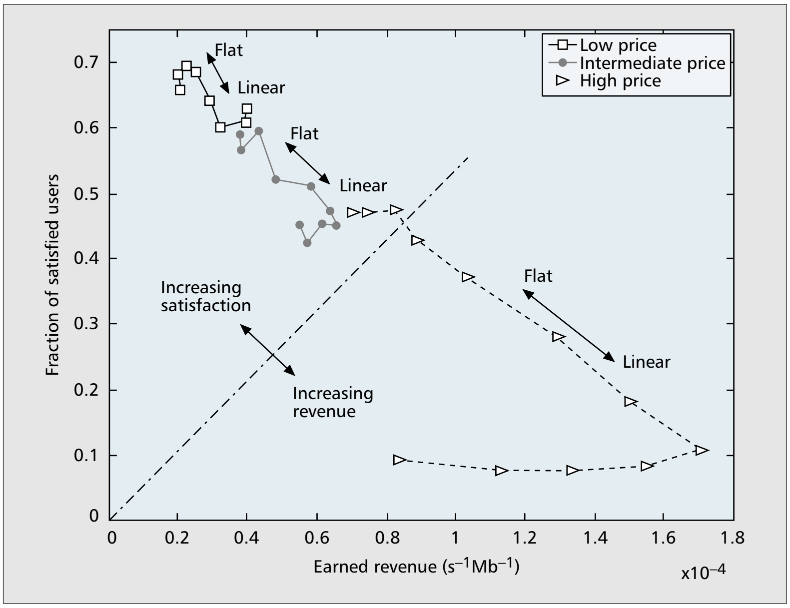

Figure 6. *Example of results of pricing policy evaluation through the micro-economic framework (the value of* $\overline{p}$ *is 0.3 for low price, 0.5 for intermediate price, 1.0 for high price).*

In other words, a flat pricing strategy leads to inefficiency in terms of congestion, since users have no incentive to decrease unnecessarily high rate requirements, and hence network operation is brought toward the low-performance Nash equilibrium point, where all users request the highest rate. On the other hand, with usage-based strategies users are prevented from requesting high rates; this leads to improved cooperation and hence to higher provider revenue.

In order to investigate this point, we present the result shown in Fig. 6. Here, we consider a small network where a single AP is in charge of managing a variable number of users, and we focus on the trade-off between overall user sat-

It is also worth noting that purely flat or purely linear strategies do not offer generally a good tradeoff, since the curves tend to wrap so that a hybrid strategy is often preferable.

isfaction (average value of the $A(r)$ function for all users, including those who refuse the service) vs. provider revenue. A total operation duration of 10,000 s is evaluated. During this time, calls are generated and terminated according to Poisson processes with intensity $\lambda = 1/30$ s^{-1} and $\mu = 1/150$ s^{-1}, respectively. Not all the generated calls actually enter the system: in fact, every user requests the most satisfactory allocation r^* that gives the maximum of her own curve $A(r)$, and also evaluates her satisfaction prior to entering the system, so the probability of system entrance is $A(r^*)$. Moreover, users can become dissatisfied due to degradation in the service and therefore, even though they already are in the system, can prematurely leave before their call is terminated. To this end, every 20 s the perceived rate ρ of every user is evaluated, and thus the satisfaction $A(\rho)$. Should it be lower than $A(r^*)$, the user keeps the service with a conditional probability $A(\rho)/A(r^*)$, and leaves the system otherwise.

The utilities of arriving users are generated with ζ and K randomly distributed in [6,20] and [0,0.85], respectively. The rates provided by the codec range from r_0 to r_1, where $r_1/r_0 = 5$. Due to the small size of the network, the maximum signaling rate (i.e., 11 Mb/s in the IEEE 802.11b standard) is available to all terminals. However, note that we also performed similar evaluations for more complicated scenarios where different signaling rates coexist, and they exhibit similar trends to the ones shown. The user satisfaction parameters are $\psi = 2$, $\varepsilon = 4$, $k = -\ln 0.9$. All these values are given as input to the *ns2*-simulator, and other parameters simply reflect the implementation of the IEEE 802.11b standard in this simulator.

In this scenario we aim to explore the aforementioned trade-off between flat and usage-based pricing (i.e., a purely linear function of r, or a hybrid one as previously discussed) by introducing a parameter q. Three average prices have been considered, $\overline{p} = 0.3,0.5,1.0$. It is emphasized that the choice of a pricing strategy results in a different outcome of network management, where, roughly speaking, user satisfaction might be traded for provider revenue. In fact, Fig. 6 confirms the previously discussed behavior of the pricing policies: usage-based policies (in this case linear pricing) achieve higher revenue with respect to flat pricing but also yield lower user satisfaction. This trade-off between the immediate goal of the provider and the users' welfare can be cut by an appropriate choice of the relative weight between the two contrasting objectives, so in the end the choice of pricing policy might be directly determined by looking at one suitable point in Fig. 6.

It is also worth noting that purely flat or purely linear strategies do not generally offer a good trade-off, since the curves tend to wrap so that a hybrid strategy is often preferable. This emphasizes even more the need for an appropriate investigation of all pricing policies by allowing more factors than the simple average price in order to tune the price not only quantitatively but also qualitatively (i.e., changing the shape itself of the pricing function).

Conclusions

The application of micro-economic models to VoWLAN provisioning might shed some light on the pricing issue for such a system. In fact, to correctly determine the impact of the pricing policy on system performance, it is necessary to investigate the problem from the perspectives of both users and service provider. For this reason, we employ a micro-economic framework, able to describe the choices of the users, in terms of rejection or acceptance of the offered service, as depending on a trade-off between perceived QoS and price.

In the case of WLAN systems no QoS guarantees are supplied to users, since the service depends on system load. Anyway, if we assume a correlation among the QoS levels achieved by different users, a fair degradation of the perceived QoS is provided, and therefore an adjustable QoS degree is supplied. The micro-economic model provides a way to describe users' reactions to this WLAN behavior, which is controlled through an appropriate price setting.

To this end, several pricing strategies can be applied by the service provider ranging from a price proportional to the obtained service to a flat price, all with different effects on the final performance. Within the described micro-economic framework, these possibilities can be identified, and guidelines for provider choices can also be supplied.

Numerical examples, given through *ns2* simulation, confirm the need for the provider to appropriately determine a correct pricing strategy that corresponds to efficient network management. Moreover, the proposed methodology offers both advantages of easy implementation, even in different scenarios, and direct identification of the required pricing strategy.

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The proposed methodology offers advantages of easy implementation, even in different scenarios, and direct identification of the required pricing strategy.