# Fuzzy Admission Control with Similarity Evaluation for VoWLAN with QoS Support

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***Abstract*—In this paper, we make use of a fuzzy approach to determine a soft Admission Control mechanism for Voice-over-Internet-Protocol services over Wireless Local Area Network. In such a system, complicated interactions between service provider and clients take place, since the network capacity constraints must be matched with users' preferences and needs. Most of the difficulties in dealing with these interactions stem from the fact that it is very difficult to define both the load condition of the network and the users' requirements in a crisp manner. To this end, we define a framework in which the provider expresses the network status and the clients describe their preferences by means of an approach based on Fuzzy Set Theory. In this way, we are able to develop an Admission Control strategy, based on Similarity Evaluation techniques, that enforces the soft constraints expressed by the two parties. The obtained framework is numerically evaluated, showing the benefit of employing Fuzzy Set Theory with respect to the traditional crisp approach.**

***Index Terms*—Fuzzy set theory, Admission Control, Voice-over-WLAN, QoS, Wireless Local Area Network.**

## I. Introduction

Wireless Local Area Network (WLAN) connectivity, especially based on the IEEE 802.11 standard, has gained large diffusion and popularity due to its simplicity and cost-effectiveness. Due to the widespread use of IEEE 802.11 networks, using the Distributed Coordination Function (DCF), we will primarily refer in the following to this kind of networks and use "IEEE 802.11" and "WLAN" interchangeably. In particular, there is a large interest in providing multimedia services and applications over WLANs, which is still an open research challenge as IEEE 802.11 lacks of an explicit quality of service (QoS) support. Even though certain standard extensions, such as IEEE 802.11e, provide MAC enhancements aimed at QoS, this is mainly useful to obtain service differentiation under low/medium network load [1]. When the traffic load increases, and network congestion risks to arise, it becomes necessary in practice to employ Admission Control mechanisms [2], [3].

However, due to its intrinsically best effort character, it is very difficult to know the exact condition of an IEEE 802.11 network, and thus make an accurate decision on whether or not to admit a new flow. This is especially true for multimedia systems such as Voice-over-WLAN (VoWLAN), where the user requirements themselves are difficult to define precisely. In fact, it is often unclear which kind of service management is adequate to satisfy the QoS level required by a user, and therefore the intention to avoid users' dissatisfaction might lead to over-provisioning users with service.

Because of these major hurdles, Admission Control for multimedia services with non-trivial QoS requirements, such as VoWLAN, is extremely difficult to realize over an IEEE 802.11 network. For this reason, we propose in this paper to counteract these problems by adopting an approach based on the Fuzzy Set Theory (FST) [4], which is a powerful instrument to deal with human-based interactions in an autonomic manner.

FST is a well-established concept in the field of computational intelligence investigations: in the last three decades, it has proved to be useful in a number of heterogeneous applications, such as data analysis and modeling, pattern recognition, control systems, query languages, image processing, etc. However, it has been rarely used for defining efficient allocation strategies in wireless communications. Remarkable exceptions in this sense are represented by [5] and [6]. In these papers, fuzzy decision making is utilized to perform Admission Control in cellular system employing Wideband Code-Division or Orthogonal Frequency-Division Multiple Access. In both these contributions, FST is adopted in order to overcome the inherent uncertainty in the decision made at the Admission Controller, which has an imperfect knowledge of the network residual capacity.

In this paper, we take a similar approach, i.e., we utilize FST to define a *soft* Admission Control which determines different degrees of service based on user preferences and available capacity. However, we also propose to evaluate by means of FST the decision taken by the Admission Controller itself, and the appreciation of it made both *a priori* and *a posteriori* by the users. Differently from [5] and [6], we are in fact not only interested in the evaluation of the technical correctness of the admission decision, for which FST proves to be a powerful instrument, but also in taking into account QoS considerations. To this end, we put in relationship the users' satisfaction with the cost of the service [7], which determine both service agreement and final satisfaction of the users. To describe this process, we make use of the framework presented in [8], where the interested reader can find further details on how Service Agreements can be obtained through FST in an autonomic and effective way.

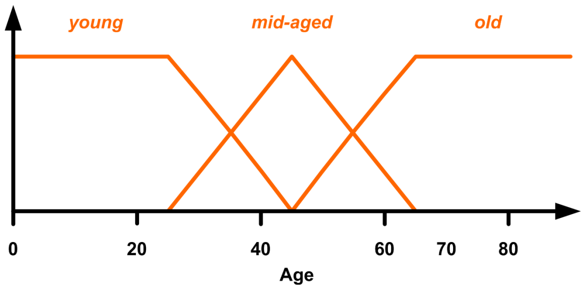


Fig. 1. Sample fuzzy sets representing the concepts *young*, *mid-aged* and *old* in the universe of discourse *Age*.

As another original point of our proposal, we validate this framework for a WLAN scenario, which follows the rationale for service differentiation proposed in [9] in order to provide users with multiple transmission rates and priorities. Within this scenario, we compare our proposed Fuzzy Admission Control with a more traditional Crisp Admission Control which tries to match user requirements to the available service in a fixed manner. Numerical results are shown to assess the goodness of the proposed fuzzy approach with respect to the conventional approach. For this reason, we believe that the introduction of FST in the Admission Control mechanism for VoWLAN systems should not only be regarded as a useful option, but as the most promising way for the system to be capable, at the same time, to capture users' requirements, coordinate their multiple radio access, and efficiently exploit the capacity of the wireless medium.

The rest of this paper is organized as follows. In Section II we review FST, also pointing out the technical tools utilized in our framework. In Section III we define the Fuzzy Agreement Process (FAP) and the Fuzzy Admission Control (FAC) mechanisms. We present some numerical evaluations in Section IV and we finally draw the conclusions in Section V.

## II. Fuzzy Set Theory Background

FST was introduced by Zadeh in [4] to provide mathematical tools that could deal with the vagueness and the uncertainty that are typical of the human perception and reasoning process. Within FST it is possible to exploit tolerance and imprecision in modeling linguistic real-world concepts, such as, for instance, *high speed*, *young person*, and *warm temperature*.

The basic idea of the fuzzy approach is to extend the traditional set theory, allowing elements to belong to sets with real-valued degrees of membership in the interval $[0, 1]$. For instance, three people aged 18, 35, 50 may belong to the fuzzy set of *young people* with degree 1, 0.5 and 0, respectively. Thus, a possible definition of this fuzzy set on the *universe of discourse* of *age* as a piece-wise linear function with constant value 1 in the range $[0, 25]$, linearly decreasing from 1 to 0 in the range $[25, 45]$, and with constant value 0 for ages greater than 45. Similarly, we can define fuzzy sets for other age-related concepts, such as *mid-aged people*, *old people*, or *very young people*, as shown in Fig. 1.

Formally, a fuzzy set $A$ defined on a universe of discourse $X$ is characterized by a *membership function* $A(x) : X \rightarrow [0, 1]$ that computes the degree to which each element $x \in X$ belongs to the fuzzy set $A$. Typically, membership functions have piece-wise linear (such as triangular or trapezoidal), or Gaussian-like shapes.

The traditional set theory operators $\cap$ and $\cup$ can be extended in FST by generalizing them as *triangular norms* (t-norms) and *triangular conorms* (t-conorms), respectively [11]. A t-norm is a function, chosen accordingly so as to enforce some constraints, that can be used to assess the intersection of two fuzzy sets. Similarly, a t-conorm can be exploited for the assessment of the union of fuzzy sets. The most well known t-norm and t-conorm are the $\min$ and the $\max$ functions, respectively. For instance, given two fuzzy sets $A$ and $B$, we can compute the membership function of $C = A \cap B$ as:

$$C(x) = \min_{x \in X}(A(x), B(x)). \tag{1}$$

For a deeper analysis on t-norms and t-conorms, we refer the interested reader to [11], [12].

A key concept of FST is the *similarity* between two fuzzy sets defined on the same universe of discourse [10]. Indeed, the equality of fuzzy sets is based on a very strict definition: roughly speaking, two fuzzy sets are equal if and only if they are described by identical membership functions. Often, a fuzzier evaluation of the degree to which two fuzzy sets match is needed. For instance, we may want to assess that the fuzzy set of *young people* is much more similar to the fuzzy set of *mid-aged people* than to the one of *old people*, although it is different from both of them. Usually, similarity is evaluated by an index whose values range in $[0, 1]$, so that it can be interpreted as a sort of equality rank. Two identical fuzzy sets are similar with degree 1, and two disjoint fuzzy sets are usually similar with degree 0.

Although not unique, the most well-known index of similarity is a fuzzy extension of the set-theoretic Jaccard index [10], whose formula is:

$$Sim_J(A, B) = \frac{|A \cap B|}{|A \cup B|}, \tag{2}$$

where $A$ and $B$ are two sets and $|\cdot|$ is a cardinality operator. The general version of the Jaccard index can be instantiated in FST as $Sim_J(A, B) : \mathcal{F} \times \mathcal{F} \rightarrow [0, 1]$, where $\mathcal{F}$ is the set of fuzzy sets defined on the universe of discourse $X$ and:

$$Sim_J(A, B) = \frac{\int_{x \in X} \min(A(x), B(x))dx}{\int_{x \in X} \max(A(x), B(x))dx}. \tag{3}$$

In many applications, fuzzy sets must at some point be converted into single crisp values. This operation, called *defuzzification*, can be performed, for instance, by the widely employed *center of gravity* technique [12]:

$$cog(A) : \mathcal{F} \rightarrow X = \frac{\int_{x \in X} x \cdot A(x)dx}{\int_{x \in X} A(x)dx}. \tag{4}$$

Indeed, the concept of QoS for wireless networks can be included among the ones without a neat and precise bound.

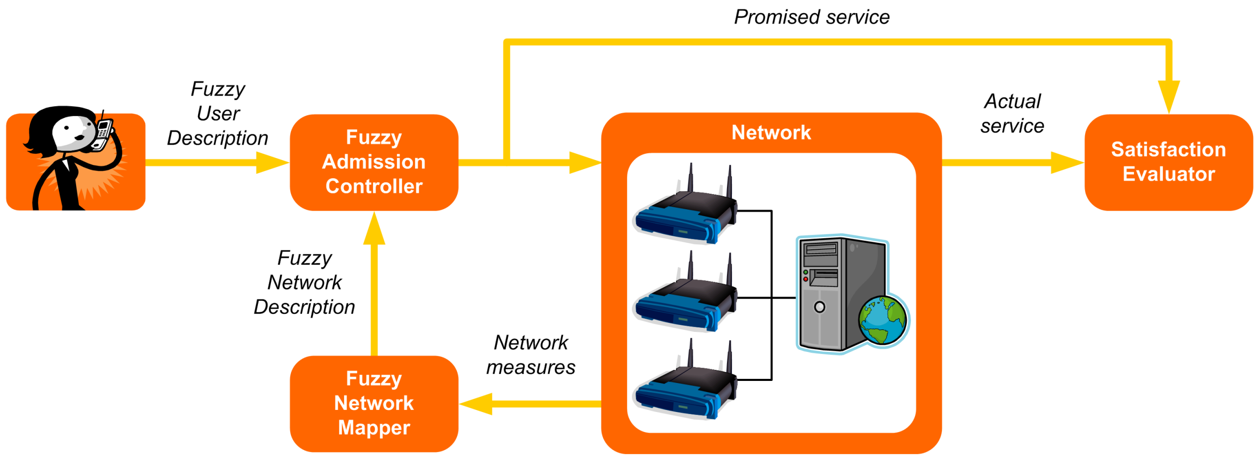


Fig. 2. Overview of the system

Especially for services heavily influenced by human interaction, such as VoWLAN, fuzzy sets can be effectively used to describe both the user-centric aspects of the provisioning and the network-related issues which are difficult to quantify exactly. In particular, a sharp evaluation of the WLAN capacity needs to take into account several related factors, most of which are de facto unpredictable. At the same time, also users do not exactly define their QoS requirements, which express only a vague idea of the actual needs of the users themselves.

The quality requirements of a voice user, which can include certain values of error rate, delay, and delay jitter, depend on technical elements in the Medium Access Control procedure. Following the approach of [9], we can think of differentiating users according to their rate and priority values to determine their transmission opportunity. However, a direct application of this representation has to deal with the fact that the user QoS are blurry and difficult to specify in exact terms. For instance, a voice user with high audio quality requirements might need a rate of *about* 40 kbps, which can be intuitively modeled by a triangular fuzzy set defined on the universe of discourse of *rate*, centered in 40 kbps, and with a spread that depends on the tolerance of the user. Finally, also the analysis of the user appreciation of the VoWLAN service involves subjective and vague concepts and may therefore benefit from exploiting an approach based on FST.

For this reason, we propose to take a fuzzy approach for Admission Control in VoWLAN, which involves not only a fuzzy evaluation of the admission decision, but also the system as a whole. More precisely, FST can be used to represent both the *customers' requirements*, i.e., the constraints on the rate and on the priority given by the specific customer needs, and the *service provider offer*, i.e., the available service levels that differentiate the QoS configurations offered by the provider in terms of different rates and priorities. In light of the fuzzy approach, the users' requirements are interpreted as *soft constraints* on the Service Agreement. Further, the matching process between requests and offers is purposely designed so as to take into account the amount of vagueness and uncertainty modeled in the fuzzy set description, by assessing the soft constraints via the evaluation of fuzzy similarity rather than traditional crisp equality.

## III. Fuzzy Admission Controller for VoWLAN

We propose a framework that exploits well founded tools from FST to deal with certain specific aspects of Admission Control in a VoWLAN system. On the one hand, the ability to handle imprecise service level descriptions is a key issue when dealing with user-centric QoS requests. On the other hand, the intrinsically best effort character of an IEEE 802.11 network hinders the perception of the exact network condition, thus making difficult to provide accurate descriptions of the service availability. In such a scenario, the constraint satisfaction process that matches user requirements with service offers shall tolerate the vagueness of the descriptions, while admitting to trade the similarity between requests and offers for the cost of the proposed solutions.

The *Fuzzy Admission Control* (FAC) model proposed in this paper deals with these vagueness and imprecision aspects in a principled way. The users and service providers are allowed to model their QoS requests and offers, respectively, by means of *Fuzzy Descriptors* (FD), that represent the constraints of the VoWLAN actors in terms of fuzzy sets. The VoWLAN admission control is modeled as a *Fuzzy Agreement Process* (FAP), i.e., an autonomic computation that mimics the complex contract agreement interactions performed by humans [8]. In particular, the key characteristics of a FAP are:

- Tolerance and vagueness are admitted in both request and offer specifications;
- The matching of request and offers is evaluated with respect to the trade-off between similarity and cost metrics.

Admission is determined by applying the FAP to the FD defined by the VoWLAN actors. Beside the admission decision, such a process produces a targeted resource allocation resulting from a trade-off between user requests and available QoS. Furthermore, the FAP automatically determines the cost of the offered solution based on the agreed service configuration.

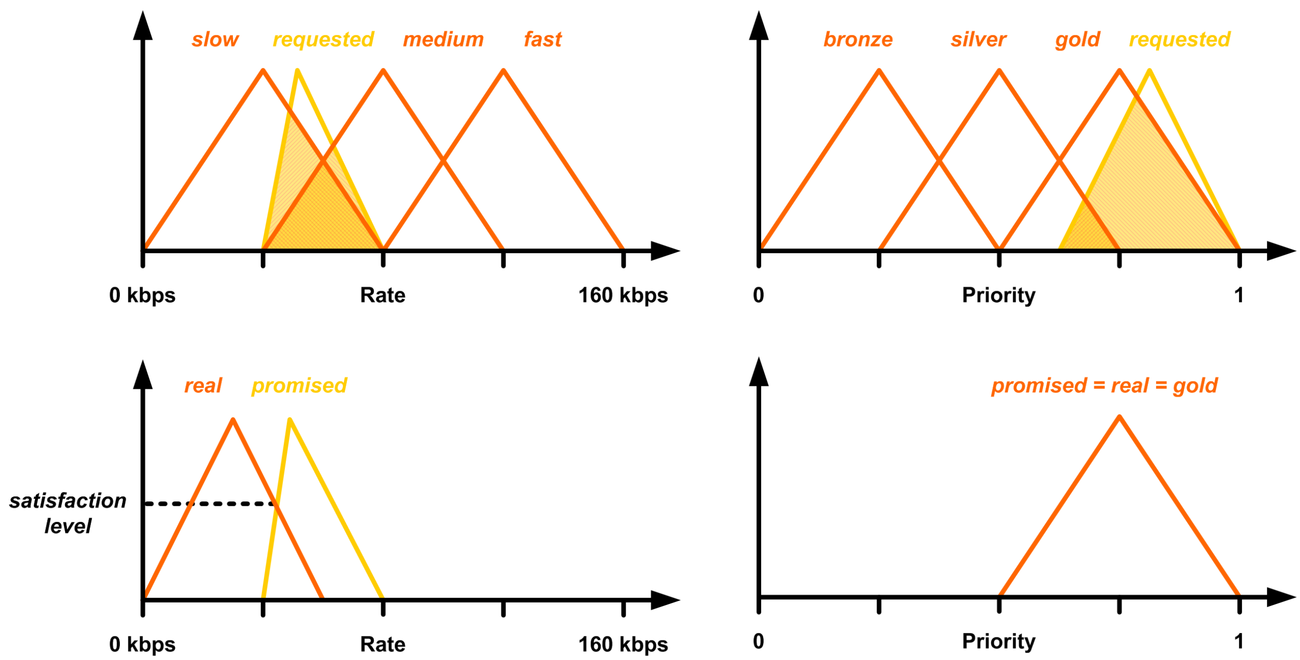


Fig. 3. Fuzzy representation of VoWLAN related concepts: rate and priority (requested, promised, real values).

### A. System Modules

In order to illustrate the main ingredients of the model, let us consider the VoWLAN scenario described in Fig. 2. The key actors of the system are the users $U_1, \ldots, U_n$, that are willing to sign a contract for a VoWLAN service offered by a network provider $N$.

The users describe their QoS requests in terms of some properties that characterize the VoWLAN service. For the sake of clarity, we will restrict the analysis of FAP to the two parameters of the adopted service differentiation mechanism, i.e., *rate* and *priority*. Such requests are modeled as *Fuzzy User Descriptions* (FUD), that are pairs $D_U = (F, \mathcal{A})$ where $F$ is an ordered pair of fuzzy sets $(f_{rate}, f_{prio})$ that describe the customer's profile, and $\mathcal{A}$ is an *acceptance function* describing the user appreciation of the service. More formally, $F$ associates each of the two properties to the desired service level determined by the corresponding fuzzy set. The fuzzy sets labeled as *requested* in Fig. 3 are a possible instance of the rate-priority profile $F$ of a VoWLAN user. Each service configuration proposed to the users by the admission controller is characterized by a cost and an index of similarity with respect to the original request. Users are allowed to determine the acceptability of a service configuration $c$ by means of the function $\mathcal{A}(s_c, r_c) : [0, 1] \times [0, 1] \rightarrow \{0, 1\}$. This function measures the trade-off between the cost $r_c$ and the similarity $s_c$ of the proposed service levels with respect to the original customer request, deciding whether that solution is acceptable or not.

The VoWLAN provider describes the portfolio of its services by means of a *Fuzzy Network Description* (FND), that is a pair $D_N = (V, P)$, where $V$ is an ordered pair of fuzzy descriptions of the service configurations offered by the VoWLAN. Each of the two properties of the VoWLAN service is associated with a fuzzy description in $V$. For the sake of simplicity, we assume that the order of properties in $V$ reflects the order in $F$, i.e., $V = (v_{rate}, v_{prio})$ and that every $v_i$ is a set of *three* fuzzy sets characterizing the three different service levels offered for the specific property. For instance, in Fig. 3, we have the fuzzy sets labeled *slow rate*, *medium rate*, and *fast rate*, and similarly for the priority we have the fuzzy sets labeled *bronze priority*, *silver priority*, and *gold priority*.

Moreover, $P$ is a pair of functions $(P_{rate}(\cdot), P_{prio}(\cdot))$ determining the pricing of the service configuration with respect to the specific property. Costs can be expressed in terms of money, time, risk or any other business-related meaningful measure. Different shapes of cost functions can represent different cost models. For instance, an important contract aspect may be characterized by a steeper cost function than a less critical property. A detailed investigation of pricing issues for VoWLAN services is out of the scope of the present paper, however, this interesting topic has recently received attention and could be explored with an extended version of the framework presented here, along the lines of [7].

The overall configuration of our system is summarized in Fig. 2. The basic blocks are the users $U_1, \ldots, U_n$, the *Fuzzy Admission Controller* (FAC), the *Network*, the *Satisfaction Evaluator*, and the *Fuzzy Network Mapper* (FNM). Users generate service requests in terms of FUDs. The FAC compares incoming FUDs with the current FND and takes decisions about users' admission to the Network with a promised service level corresponding to the FAP output. Periodically, the FND is updated via a feedback loop by the FNM. Indeed, the FND can be dynamically tuned by the FNM, coherently with the current WLAN load. Finally, when an accepted user leaves the Network, her actual obtained service level is compared with the service level that was promised by the FAC, to assess the satisfaction level of each user. We remark that, within the present, the obtained service level is, for simplicity, evaluated only at the end. It would be actually possible to perform a periodical evaluation of the perceived QoS during the connection, also averaging over time-varying channel realizations. Then, with an entirely similar approach, it would be possible to feedback the information about user satisfaction to the FAP, which could lead to re-negotiating the service. In this sense, the mechanisms proposed by [3] can be applied to further improve performance, which is an interesting subject for future research.

### *B. The Fuzzy Agreement Process*

The FAC module performs the FAP to determine if a user can be admitted to the VoWLAN service, eventually producing the service instantiation $c$ that best matches the request $D_U$ with the offers $D_N$. In particular, the FAP can be summarized with the following steps.

*1) Priority Matching:* Calculate the overlap of the user priority request $f_{prio}$ with each of the priority service levels offered by the provider. For instance, the shaded areas in the top right graph in Fig. 3 shows the fuzzy intersection between the fuzzy set $f_{prio} = requested$ and the service classes $silver$ and $gold$ (there is no overlap with $bronze$). Compute the fuzzy set $r^i_{prio}$ that represents the cost of the $i$th service level by applying the pricing function $P_{prio}$ to the fuzzy set resulting by the intersection, for instance:

$$r^2_{prio} = P_{prio}(requested \cap silver). \quad (5)$$

Additionally, compute the similarity $s^i_{prio}$ between $f_{prio}$ and each of the possible priority offers using the function in (3), for instance:

$$s^2_{prio} = Sim_J(f_{prio}, silver). \quad (6)$$

*2) Rate Matching:* Repeat the previous actions for the rate profiles: the top left graph in Fig. 3 shows the overlaps between a sample client request (i.e., $requested$) and three offered rate profiles (i.e., $slow$, $medium$ and $fast$). Fig. 4 shows the cost projected intersection of the client request with the $slow$ rate profile, i.e. $r^1_{rate} = P_{rate}(requested \cap slow)$.

*3) Configuration Generation:* Generate the set $C$ of all VoWLAN configurations $c_i$ by combining the costs of each overlapping priority service level obtained at the first step, with the cost of every overlapping rate service level generated at the second step, e.g., $c_1 = (r^2_{prio}, r^1_{rate})$, $c_2 = (r^2_{prio}, r^2_{rate})$, etc.

*4) Configuration Pricing:* Calculate the aggregated cost $r_c$ for each of the admissible solution $c$ by applying the defuzzyfication operator in (4) to the fuzzy union of the priority cost with the rate cost. Fig. 5, for instance, shows a sample cost $r_{c_1} = cog(r^2_{prio} \cup r^1_{rate})$ for the admissible solution $c_1$. Moreover, compute the aggregated similarity $s_c$ of each configuration $c$ by multiplying the similarity of the priority (e.g., $s^1_{prio}$) to the rate similarity (e.g., $s^1_{rate}$).

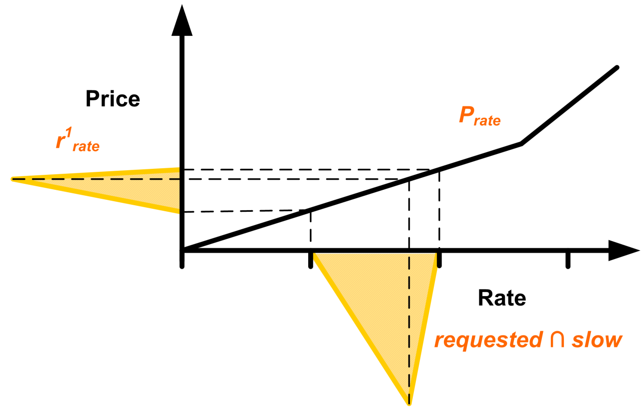


Fig. 4. Fuzzy cost set representing the price of the intersection between the user rate demand $requested$ and the $slow$ rate profile offered by the provider.

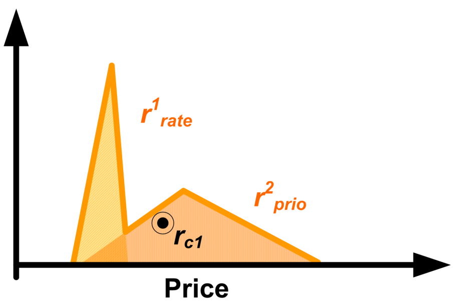


Fig. 5. Aggregated cost of the admissible solution $c_1 = (r^2_{prio}, r^1_{rate})$. The crisp price $r_{c_1} = cog(r^2_{prio} \cup r^1_{rate})$ is determined using the *center of gravity* defuzzification in (4).

*5) Configuration Selection:* Select all admissible configurations $c$ satisfying the user-defined tradeoff between price and similarity, i.e., all $c$ such that $\mathcal{A}(r_c, s_c) = 1$. If there are no admissible configurations the user is blocked. On the other hand, if there are multiple admissible solutions, the tie is broken in favor of the configuration that maximizes the distance from the hyperplane separating the admissible solution region from the rejection region.

*6) Configuration Allocation:* If a user is admitted, then the FAC determines the promised rate (e.g., the $promised$ fuzzy set in the bottom-left graph of Fig. 3) by normalizing the intersection of the $requested$ rate fuzzy set with the most similar offered rate profile (which is the fuzzy set $slow$ in Fig. 3). Moreover, the promised priority is chosen as the most similar offered priority profile (see the bottom right graph of Fig. 3 where $promised$ is the fuzzy set $gold$).

### *C. Remarks About FAP*

Basically, the FAP described above estimates the closeness between the offer and request by calculating the similarity of the fuzzy sets used to model the service properties. Fuzzy intersection and union are used to generate a set of configurations satisfying the local properties specified by the VoWLAN actors. Moreover, each solution $c$ is associated with a personalized cost $r_c$ determined by the pricing functions

$P$. The similarity and the cost are then used to compute the feasibility of the solution from the point of view of the users constraints (modeled by the acceptance function $\mathcal{A}$). Finally, for each admitted user the FAP generates a customized service level configuration that is the result of a bargaining process between the users requests and the provider service portfolio.

We also remark that a similar mechanism for service evaluation is also used in the Satisfaction Evaluator. More specifically, this block determines a final satisfaction value for the user at the end of call, by comparing the actual achieved service and the promised values which were the output of the admission controller. For this comparison, we evaluate the average value and the standard deviation of the rate for the call. If the actual QoS is strictly better than the promised QoS (which means that not only the average rate is better than the promised one, but also that the standard deviation falls within the promised tolerance), the user is surely satisfied. Otherwise, a similarity comparison is performed between promised and actual service and the result is evaluated against the cost on the acceptance function $\mathcal{A}$, which determines if the user is satisfied even in the presence of a lower QoS than the promised one.

## IV. Performance evaluation

We performed a simulation-based investigation to validate our proposed approach. The simulation scenario is a WLAN hot-spot, where a single Access Point serves a variable number of users, which access the voice service. Due to the preliminary character of this investigation, we do not enable multi-hop and we assume that the same signalling rate is available to all terminals: the extensions to these points are left for further research. However, users are differentiated according to their *transmission rate* and *priority* by following the mechanisms reported by [9]. We also assume that voice users can exploit a constant effective bandwidth $B$. This means that for simplicity we assume all other kinds of traffic (e.g., best effort data) in the network as fixed and focus only on voice users. In the simulator, $B$ has been taken equal to 1 Mbps.

Voice users may have a three step priority value, i.e., $gold$ (highest priority), $silver$, or $bronze$ (i.e., best effort), which are ranked on a 0–1 scale as 1, 0.5, and 0, respectively. The allowed data rates are from 0 to 160 kbps. However, the provider tries to assign users to three main classes, namely $low$ (centered around 15 kbps, and corresponding to a GSM-like voice quality), $medium$ (centered around 40 kbps, and corresponding to a high-end audio quality), and $high$ (centered around 100 kbps, for applications including also a small video transmission).

The average requested values of user rate and priority are independently generated according a Gaussian mixture distribution, centered around the aforementioned values and with standard deviation equal to 20% of the average value. The user's profile contains also tolerance values for rate and priority, which are evaluated with a truncated Gaussian distribution with mean and standard deviation equal to 20% of the maximum value. Finally, independently of their rate and priority parameters, all users determine their call duration according to an exponential process with mean equal to 120 seconds. The users' arrivals into the system follow a Poisson process. Two cases have been considered, i.e., the arrival rate has been chosen to obtain an offered load on bandwidth $B$ (expressed in MHz) equal to $1.67B$ and $2.67B$ erlang, which have been found to correspond, for the aforementioned set of parameters, to a moderate and high load condition, respectively. For each simulation run, a total time of 1800 seconds has been simulated.

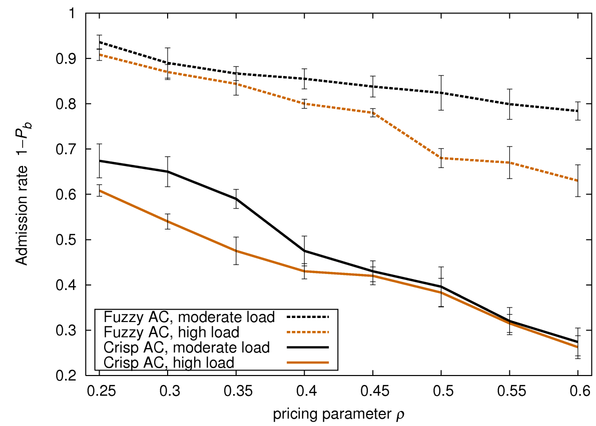


Fig. 6. Comparison of the Fuzzy and Crisp Admission Control procedures, admission rate $1 - P_b$.

When users are generated, their quality requirements are also randomly determined according to the process outlined in the previous section. On average, the requested rate is classified as low, medium, high, for 50%, 40%, 10% of the users, respectively, whereas the requested priority is bronze, silver, gold, for 50%, 30%, 20% of the users, respectively. Finally, the pricing function of the service and the acceptance function of the users have been taken, for simplicity, as linear functions. However, additional results for other kinds of functions show entirely similar results from the qualitative point of view. The acceptance function is taken as equal to 1 if and only if the similarity $s_c$ is greater than a linear function of the cost equal to $(0.08 + 0.02r_c)$. The pricing functions have been taken equal to $P_{rate} = \rho r_{rate}$ and $P_{prio} = 0.2\rho r_{prio}$, where $\rho$ is a tunable parameter which has been taken as the independent variable in our investigations.

We evaluate the performance by considering the following metrics. First of all, we investigate the admission rate of users in the system. This is complementary to the probability of users being blocked by the admission controller $P_b$. Secondly, we take the dissatisfaction rate of admitted users, $P_d$, which addresses the QoS level of ongoing call. To summarize both metrics, in order to capture the overall QoS provided by the Admission Controller, we take into account a weighed version of them, and specifically $P_b + 10P_d$. This is a widely used metric [13], which is motivated by the observation that the annoyance of not being admitted in the system is lower than being admitted but receiving an unsatisfactory service.

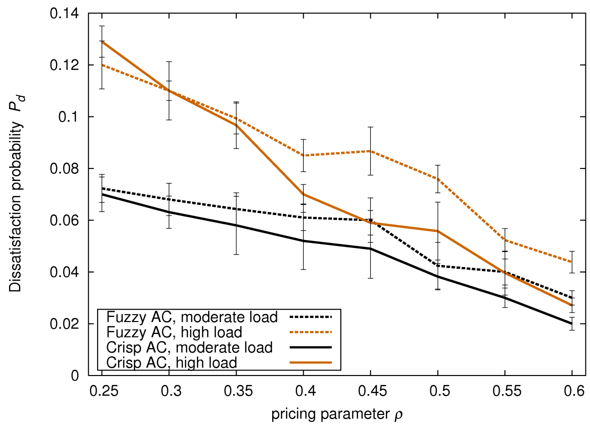


Fig. 7. Comparison of the Fuzzy and Crisp Admission Control procedures, dissatisfaction rate of admitted users $P_d$.

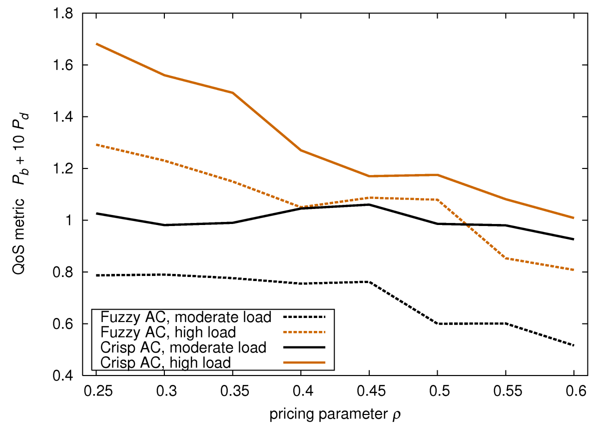


Fig. 8. Comparison of the Fuzzy and Crisp Admission Control procedures, QoS metric equal to $P_b + 10P_d$.

In Fig. 6, it is shown that the proposed FAC mechanism is able to increase the number of admitted users by more than $30\%$, in different load conditions. The traditional crisp admission controller makes instead a more conservative use of resource and does not admit many users. Note also that Fig. 6 shows a decrease of the admission rate into the system when the price is increased. This is a consequence of the price-based self-regulation made by the users: when the service is regarded as expensive, the number of users accepting the FAP decreases.

Fuzzy strategies also cause a slightly higher amount of users to be dissatisfied with the service compared with the more conservative crisp admission control, as visible in Fig. 7. This increase is however limited and perfectly justified by the higher admission rate. These curves have higher variance, since the dissatisfaction is evaluated on a smaller set of users, i.e., the ones which enter the service.

We also observe that the dissatisfaction rate also decreases with the price, which is a consequence of the service being admission controlled. In fact, the AC mechanism benefits from a higher price, since the most critical users whose cost-similarity pair $(r_c, s_c)$ is on the edge of the acceptance curve are more likely to refuse the service agreement during the admission control phase.

Finally, we observe, as reported in Fig. 8, that the QoS of the system is clearly increased by utilizing the Fuzzy Admission Control mechanism. In particular, note that the fuzzy strategy in the high load case and the crisp strategy in the moderate load case obtain about the same QoS performance. This validates our proposed technique as a useful method to perform Admission Control for VoWLAN services. In particular, the advantage of a fuzzy admission control is not only in obtaining a good description of the system, which is particularly difficult to characterize in best effort media such as a WLAN, but also in allowing a better match of user requirements and therefore tailoring the supplied services on the user needs.

## V. Conclusions

Modeling voice applications for wireless networks and design proper management techniques for this kind of services is a challenging and intriguing task. In this paper, we have reviewed Fuzzy Set Theory techniques for Wireless Network Services and envisioned its applicability for Admission Control in VoWLAN services.

In particular, we have proposed a Fuzzy Admission Controller which modifies traditional radio management techniques in two directions. First of all, it considers the QoS requirements of the users in a broader meaning. Instead of guaranteeing hard quality constraints, which dictates for the Admission Control mechanism to be very conservative and therefore to under-utilize the system resources, we propose a soft QoS approach which takes into account the vagueness in the user description of the required service. At the same time, we take into account a fuzzy representation of the network resource occupancy, which is helpful to characterize the uncertainty of network access in WLAN systems. In this way, the Fuzzy Admission Control can be inferred by a fuzzy decision process where the best fit is sought (in fuzzy set terms) between user requirements and available capacity.

Numerical evaluations have been produced to quantify the benefit of such techniques for the VoWLAN service management. To this end, we have compared the Fuzzy Admission Control strategy with a traditional Admission Controller adopting a crisp approach, i.e., where users are admitted only if a strictly better service than their requests is available. The Fuzzy Admission Controller was shown to achieve a significantly better exploitation of the capacity and an overall QoS improvement with respect to the traditional strategy.

We believe that fuzzy techniques emerge as a powerful tool to manage such services, and real network providers should take them into serious consideration for their management techniques. At the same time, fuzzy techniques can also be used to describe inter-users, inter-providers and inter-services relationships. For this reason, further applications of Fuzzy Set Theory to other aspects of radio resource management appear as one very promising topic for future research in wireless service provisioning.

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