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Fuzzy Logic Based Admission Control for GPRS/EGPRS Networks

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***Abstract* – This work proposes a new admission control algorithm for GPRS/EGPRS networks. The cellular networks are evolving from the 2nd generation voice systems to 3rd generation data and voice systems, and the classical admission control methods used for voice systems cannot efficiently cope with the new problems posed by the complex nature of data traffic and by the diversity of the quality of service requirements of data users. We use the flexibility and power of fuzzy if-then rules in order to provide an efficient solution for admission control in GPRS/EGPRS.**

***Keywords:* GPRS, admission control, fuzzy inference, fuzzy logic controller.**

I. INTRODUCTION

The evolution of mobile telephone systems from voice only systems to 3rd generation (3G) mobile systems, capable to deal with both voice and data transfer, will begin with General Packet Radio Service (GPRS) [1], [2], [3], [4], and will be continued with Enhanced GPRS (EGPRS) [7], which is using the EDGE (Enhanced Data Rates for Global Evolution) technology in order to ensure higher data rates.

The users in a GPRS/EGPRS network have different Quality of Service (QoS) requirements, and the network aims to satisfy their demands, maximizing in the same time the utilization of the existing resources.

These opposite goals make the problem of resource allocation in GPRS/EGPRS networks to be very complex, implying admission control, transmission control, mobility management, and link adaptation techniques.

Our goal is to investigate the efficiency of different algorithms used for resource allocation in data transfer over (E)GPRS networks. We consider a number of users in a cell that want either to send or to receive data. First, a user requests to be admitted in the system and, if successful, it can start a data transfer session. The resource allocation problem can be then split into two subproblems: the admission control, and the transmission control (the algorithms used to allocate the network resources between the admitted users). While we have focused on the second problem in [18],[19], this work addresses the admission control problem.

An admission control algorithm decides whether to admit or to reject a user. The decision can be based on different criteria: network load, the QoS (Quality of Service) requirements of the user, the quality of the radio link between the user and the Base station, etc.

Several GPRS nodes are invloved in the admission control process, which is a negotiation between the Mobile Station (MS), the Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN), the final admission decision being taken by the SGSN.

The paper is organized as follows: the next section presents the fuzzy logic-based admission control, section III describes our model for the (E)GPRS network, the simulation results are shown in section IV, and the final section contains the conclusions.

II. FUZZY LOGIC BASED ADMISSION CONROL

A. *Related work*

The admission control (AC) techniques have been widely used in ATM (Asynchronous Transfer Mode) networks. A comprehensive survey on AC techniques can be found in [13].

In mobile and cellular networks AC was initially used for voice calls only, and as a result, many works focus only on a subset of design issues, while ignoring others, for example the purpose of AC algorithms is to keep the call dropping and maybe call blocking probabilities under certain levels, but the problem of QoS in packet data transfer remains largely unaddressed.

The admission control problem is more complex when the cellular network is used for data transfer than in the case of networks used only for voice, because the users have different QoS requirements (in terms of delay, loss, precedence levels, etc) and different traffic characteristics: conversational (voice), streaming, interactive (e.g. web browsing) and background traffic (for example e-mail, FTP).

Based on [11], the main requirements for the AC algorithms are to maximize the channel utilization in a fair manner, while minimizing the call dropping and call blocking probabilities; also, to avoid or minimize the reduction in service for connected calls. The authors propose a method called “threshold access sharing”, that uses different admission control policies depending on the network load. The network load can be “small”, “medium”, or “large”, but the authors had difficulties in finding the thresholds for low, medium, and high network load.

Stuckmann et al [14], [15] have developed an AC scheme where the available bandwidth is divided into three regions, each region being shared by two adjacent traffic classes if necessary. When the network is very loaded, the flows with higher priority (more demanding QoS requirements) are allowed to displace flows with lower priority, but only up to a certain limit, each traffic class being confined by its limits.

Kim et al [8] describe a threshold-type admission control algorithm. Each user belongs to a multimedia traffic class and a threshold value is assigned to the number of users from each traffic class that can be admitted. Again, the difficult problem is to find the values for the thresholds, and the authors of [8] use a Nonlinear Programming model in order to solve this problem.

Another interesting approach for the AC problem in data cellular networks is shown in [6], where the authors propose a decision-theoretic approach based on Markov Decision Processes (MDP). The main difficulty is that the number of states of the Markov model becomes very large for real-life problems, which implies unacceptably high values for the time necessary to find a solution for the MDP problem.

B. Fuzzy logic for AC: motivation

Many of the AC algorithms proposed in the literature for cellular data networks encounter a series of problems that can be summarized as follows:

1) In order to express the AC problem in a mathematically tractable form, the probability distribution functions for traffic characteristics, call durations, handover probability, etc are assumed to be of Poisson type or to be accurately described by a Markov Modulated Poisson Process (MMPP), which is not always realistic for data users.

2) For real-life problems, the computational complexity of the AC algorithms becomes very high, mainly due to the number of states that describe the system.

3) For the AC algorithms based on thresholds, it is very difficult to assign or to determine the proper values for the thresholds.

We believe that fuzzy logic can help to overcome these problems because the fuzzy if-then rules are based on linguistic variables, that incorporate human-like knowledge representation of information, and do not rely on any mathematical assumptions concerning the probability distribution functions for traffic characteristics, call durations, etc. Also, the use of linguistic variables and fuzzy if-then rules can reduce the computational complexity compared to Markov models.

The threshold-based AC algorithms can be easily extended through the framework of fuzzy logic. For example, the replacement of a sharp border (a threshold) in [11] with a region will ensure a very smooth transition from one admission policy to another.

Another important advantage is the capability of fuzzy logic to accept rules expressed in a natural language, formulated for example by an expert, and to combine the rules with facts through the fuzzy inference, obtaining the conclusions. In this way the expertise acquired by a network operator can be directly used, without the necessity to use complex mathematical models (e.g. queueing models, MDPs, etc).

Fuzzy logic has been applied to admission control mostly in ATM networks (see for example [10]). In cellular data networks, fuzzy logic is used for admission control in [9], but only in relation with users’ mobility (i.e. to adjust the amount of resources that have to be reserved in a cell for the users that can move onto this cell from the neighboring cells).

C. Fuzzy inference

Given a fact A’ and a rule $R_{A \to B}$, fuzzy inference means the composition A’$\circ$ $R_{A \to B}$ in order to obtain the conclusion B’= A’$\circ$ $R_{A \to B}$.

In this work (similar to that of [17]), we use the computation procedure proposed by Zadeh [21] for the fuzzy inference. According to this procedure, the membership function of B’ is:

$$\mu_{B'}(y) = \max_{x \in U} \min(\mu_{A'}(x), \mu_{R:A \to B}(x, y)) \quad (1)$$

where:

$$\mu_{R:A\to B}(x,y)=\min(\mu_A(x),\mu_B(y)) \qquad (2)$$

After transformations (1) results in:

$$\mu_{B'}(y)=\min(a,\mu_B(y)) \qquad (3)$$

where $a=\max_{x\in U}\min(\mu_{A'}(x),\mu_A(x))$.

In the equations (1) – (3) we have used the following notations: $\mu_A(x)$, $\mu_{A'}(x)$, $\mu_B(y)$, $\mu_{B'}(y)$ are the membership functions of the fuzzy sets A (a term in premise), A' (the fact), B (a term in conclusion), B' (the consequent of the rule) , defined over the universe of discourse of the fuzzy sets, and taking values in the closed real interval [0,1]. The universe of discourse, or the domain, for the sets A and A' (the linguistic variables in premise and the facts) is U, and for the fuzzy sets B and B' is V.

If the premises are composed, the degrees of activation of each premise (a in (3)) are combined using the corresponding logical operators (AND, OR, NOT). We use only the AND operator, which is implemented by *minimum* in fuzzy logic.

When more than one rule is active, the consequents of all active rules are combined through the union operator, which is implemented as a maximum between the membership functions of the partial conclusions. Most often, the result of the fuzzy inference has to be a crisp value, obtained by an averaging procedure applied on the partial conclusions, process that is called defuzzification. A widely used defuzzification method is the center of gravity.

D. The fuzzy logic controller

The fuzzy inference is performed by a fuzzy logic controller (FLC) that can be implemented in either hardware or software.

A linguistic term is a fuzzy set, which is a set characterized by a membership function that can take values in the closed interval [0,1], while the membership function for a non-fuzzy (crisp) set can take only the discrete values 1 or 0 (an element either belongs to the set, or it doesn't belong to that set). In many cases, the "shapes" chosen for the membership functions are linear (triangles or trapezes). We adopt such linear shapes for the fuzzy terms in premises, while the fuzzy terms in conclusions are singletons. They are represented in Fig 1 and Fig 2, where a1, a2, a3, b1, b2, b3, b4 are parameters that can be adjusted. The domains U and V of the linguistic variables in premises and conclusion respectively are mapped in our FLC to the closed interval [0,m].

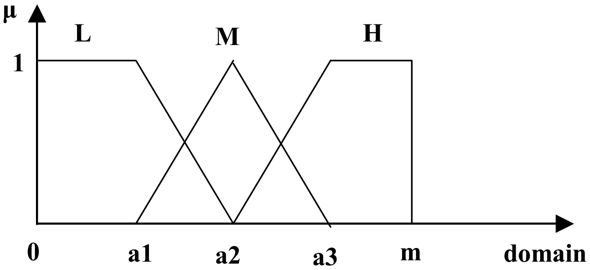

Fig. 1. The fuzzy terms in premises

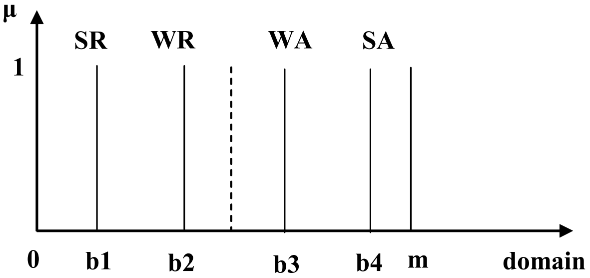

Fig. 2. The fuzzy terms in conclusions

The FLC used to implement the fuzzy AC algorithm was presented in [17] and is based on the description from [12]. The set of rules used are in the form: "**if** network load is *high* **and** user's precedence is *low* **then** admission decision is *strongly reject*", where the part between **if** and **then** is the (composed) premise of the rule, and the rule conclusion follows after **then**. In this example, the linguistic variables are "network load", "user's precedence" and "admission decision", each linguistic variable having a number of *terms*. For example, the terms for network load and for users precedence are *high (H)*, *medium (M)* and *low (L)*. The terms for the linguistic variable "admission decision" in conclusion are *strong accept (SA), weak accept (WA), weak reject (WR)* and *strong reject (SR)*. The rules are completely described in Table 1:

TABLE 1. The fuzzy rules

		Users precedence		
		L	**M**	**H**
Network Load	**L**	WA	SA	SA
	M	WR	WA	SA
	H	SR	WR	WA

III. A MODEL FOR RESOURCE ALLOCATION IN GPRS/EGPRS

In [16] we have presented a detailed description of the model that we have created for simulating GPRS/EGPRS networks. Here we will discuss only the parts of the model involved in the admission control algorithms.

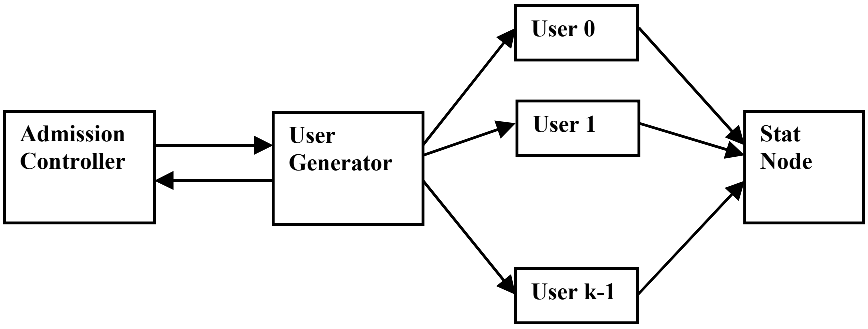

Fig. 3. The simulation model

For modeling our system, we have used OMNeT++, a discrete event network simulator [20]. The model consists of a number of nodes, or modules that can be either simple or compound nodes. The nodes communicate by exchanging messages.

Each user is modelled by an Omnet++ module, the other nodes in the system being the Packet Control Unit (PCU), which is in charge with transmission control, the user generator and the admission controller. There are also nodes that model the radio link quality and the sharing of traffic channels between voice and data.

Fig. 3 presents the simulation model. The *user generator* node generates users during the simulation, according to some probability distribution functions, each user having a Quality of Service (QoS) profile.

When a user is created, it wants to be admitted into the system and sends a request to the *admission controller* node, which decides whether to admit it or not. If the user is admitted in the current cell, the user generator sends the "start user" command to a free user node. Then the user begins a data transfer session, the network resources being allocated to the admitted users by the Packet Control Unit. The PCU is not represented in Fig 3. The *stat node* is used to collect statistics during the simulation.

There are other nodes, not shown in this figure. The radio link quality can be modelled like in [5], where we have used a radio link model based on users mobility in a cell, for different types of cells in urban or rural areas and for different user speeds. The sharing of traffic channels between voice and data traffic is modelled in a very simple manner: the number of channels allocated for voice is given by a certain probability distribution function (e.g. truncated exponential), and the remaining channels are used for data.

IV. SIMULATION RESULTS

Our current work aims at tuning the fuzzy algorithms in order to obtain an efficient admission control. To do the tuning, we want to reduce the complexity of the simulation compared to a real-life situation, which will permit an easier understanding and interpretation of the simulation results.

In our simulation, the users are static (which means that they use the same coding scheme all the time) and the network resources are not influenced by the voice traffic (all the 8 channels are available for data traffic). The users precedence is not considered in these simulations, which means that the fuzzy rules in Table 1 are changed to:

1) If network load is H then admission decision is SR.
2) If network load is M then admission decision is WA.
3) If network load is L then admission decision is SA.

The user generation process is not random, as in a real situation, but periodic, and we call such a user generation period *a step*. The first 20 steps take place at the initial moment of the simulation, in order to provide an initial offered load for the network, each of the remaining 230 steps having a fixed duration. Each user generates the same amount of data: 5 files, the file length being 3620 bits for all files. The users can have three traffic classes: streaming (10% of the users), interactive or web browsing (80%) and background traffic (10%). The users weights are: 8 for the streaming users, 4 for www users and 1 for background users. In the weighted round robin algorithm that we have used for transmission control, the weight is the number of channels assigned to each user in the transmission control algorithm during a block period of 20ms (the period of the transmission control algorithm, see for example [18], [5]).

We consider the network load to be the sum of users' weights, for all admitted users, divided by the average number of channels assigned for data traffic (8 channels in our simulations). The network load has a direct influence on the QoS (mainly on the transmission delay) received by the admitted users. The input of the FLC is the existing network load plus the contribution of the user that request admission (its weight divided by the number of available channels).

The values for the parameters in Fig. 1 and 2 are: m=63, a1=m/4, a2=m/2, a3=3m/4, b1=8, b2=24, b2=40 and b3=56. We chose a target value for the network load and assign it to the middle of the interval [0,m] (the value a2 in Fig 1) using the function that scales the real values of the network load to the interval [0,m]. The FLC will try to keep the network load close to this value, which means that the network load will not be higher than the target value in most of the cases or it will be only slightly higher. If the output of the FLC (the admission decision) is below 31 it means user rejection, while a value above 31 means that the user is admitted. During the first 20 steps, when the initial load is generated, the FLC input is kept to zero, so that all the users are admitted, no matter how high the initial load will be. If the period of the user generation process is very large, the network load can be much below the target.

Fig. 4 shows the input and output of the FLC versus the number of steps when the target network load is 10 and the user generation period is 230ms. After the generation of the initial load (of 20 users), the network load increases and the users that attempt to connect during this period will be rejected. When some of the initial 20 users end their sessions, the network load decreases and most of the new users will be admitted into the network.

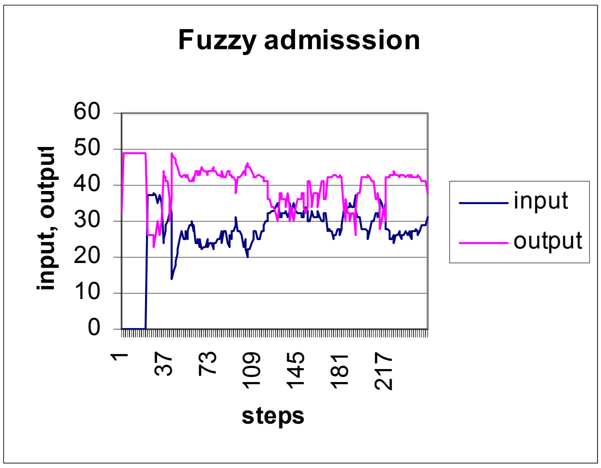

Fig. 4. The input and outputs of the FLC for a target network load of 10 and a user generation period of 230ms.

We can see in Fig 5 that the network load is maintained most of the time close to 10 and it is not above 11, except in the first 20 steps, which means that the admission control algorithm implemented by the FLC is very succesfull.

Fig 6 shows a more demanding situation for the FLC, when the target network load is only 5, and the user generation period is reduced to 130ms.

After the initial load is released, the FLC output has an oscillating behaviour around the value in the middle of the interval, which means that the users attempts to connect are too frequent compared to session duration, and the network has to reject approximately half of the connection attempts.

We can see that in this case the initial network load is higher than 10, which means that it is more than double compared to the target, but the FLC manages to keep the load close to 5 even in this very difficult situation. Actually, the network load never exceeds 5.5 after the step 55, when the initial load was reduced.

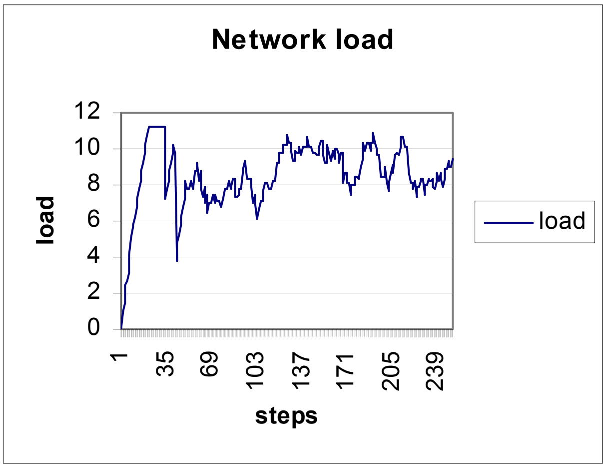

Fig. 5 The network load for a target load of 10 and user generation period of 230ms.

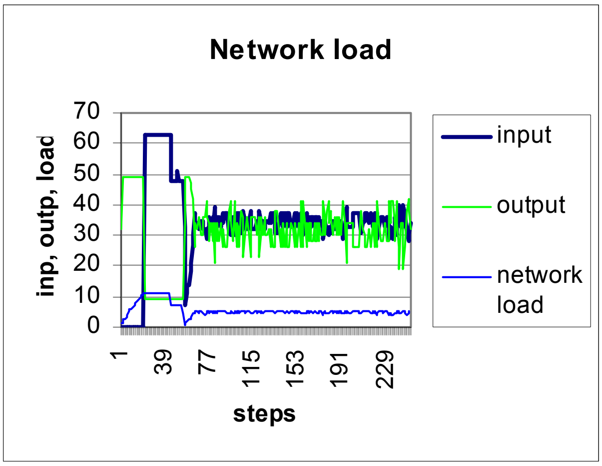

Fig. 6. The FLC input and output, and the network load for a target load of 5 and a user generation period of 130ms.

V. CONCLUSIONS AND FUTURE WORK

This work shows the feasibility of using fuzzy if-then rules for admission control in data cellular networks, where the traditional admission control methods, successfully used for voice-only mobile networks, are difficult or too complex to implement. We focus our simulations on the process that occurs in a single cell and aim to maintain the network load close to a certain target value, such that the quality of service requirements can be met for the connected users.

Our future work will use the results obtained here for tuning the fuzzy admission control algorithms in order to apply the algorithms in more complex simulation scenarios, close to a real-life situation. One possible next step would be to include users precedence in the fuzzy rules, according to the rules shown in Table 1. Related to this aspect, different scenarios will be performed to study how to determine users precedence based on their QoS requirements and on their mobility pattern (for example, a user that comes from another cell has a higher priority that a user that begins the session in the current cell).

We believe that the flexibility of fuzzy logic and their capability to accept the information in a form close to a natural language will permit network operators to use their expertise in a direct manner, without the burden of sophisticated mathematical models.

Combining admission control and transmission control, we aim to provide an efficient and flexible manner of using the scarce radio resources and to ensure the desired quality of service for the users.

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