Applying Fuzzy Logic to Admission Control in GPRS/EGPRS Networks

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Abstract: We propose a new admission control algorithm for GPRS/EGPRS cellular data networks, based on fuzzy inference. The admission decision is based on system parameters like the network load and users precedence, being expressed in the form of fuzzy if-then rules. Simulation results are presented for the fuzzy admission algorithm, using our model for a GPRS/EGPRS cell and a simplified simulation scenario.

Keywords: GPRS, admission control, fuzzy inference

1 Introduction

The mobile communications had gained a large acceptance in the recent years, which constitutes very good premises for introducing new applications and services, among which data services are playing a very important role. The need for data services on mobile communications networks had increased because the users of personal computers wanted to have access to the same services and applications when they are mobile, as they have from their office or from home.

In this paper we focus on GPRS, the General Packet Radio Service [1], [2], [3], [4], a data service developed over the very popular GSM (Global System for Mobile communications) networks. The evolution of GSM and GPRS towards the 3rd generation mobile networks (3G) will be based on the EDGE (Enhanced Data Rates for Global Evolution) technology, which is capable to ensure higher data rates. The resulting combination between GPRS and EDGE is called Enhanced GPRS, or EGPRS [7].

In order to satisfy the different Quality of Service (QoS) requirements of the users in a GPRS/EGPRS network, a crucial problem that has to be solved is the resource allocation, with a focus on the allocation of the radio resources. This problem can be split into two main sub problems: *admission control (AC)*, which is the decision to admit or to reject the request of an user for entering into the system, and *transmission control*, which comprises the algorithms used to share the network (radio) resources among the admitted users. We have addressed the transmission control problem in [18], [19], [5]. In this work, we focus on the admission control problem, proposing a new admission control algorithm based on fuzzy rules.

The paper is organized as follows: next section presents the problem of resource allocation in GPRS/EGPRS, including our simulation model for a (E)GPRS cell, section 3 describes the fuzzy admission control algorithm, an evaluation of our AC algorithm appears in section 4, followed by a section of conclusions.

2. The Problem of Resource Allocation in (E)GPRS

2.1 A Brief Description of GPRS

GPRS is a packet switching service offered over GSM, that is a circuit switching network. The packet switching offers many advantages for data transfer compared with circuit switching, from both the network and the users' perspective [1], [4].

We consider a number of users in a GPRS/EGPRS cell. The users want to send or to receive data, but before transferring data, they have to be admitted in the system (the admission control). The GPRS nodes involved in the admission control process are: the Mobile Station (MS), the Serving GPRS Support Node (SGSN), the Gateway GPRS Support Node (GGSN), the leading role in the negotiation between those nodes being taken by the SGSN. The Base Station of the cell where the user is situated is informed about the decision resulting from the admission process and it will have to provide the radio resources to the admitted user.

The radio resources for a carrier in a GPRS cell are represented by a number of 8 channels, available every 20 milliseconds. The 8 channels are shared between voice and data traffic, usually the voice having priority over data transmissions. When a channel is allocated for data, it is called Packet Data Traffic Channel (PDTCH). A centralised controller, the Packet Control Unit (PCU), part of the Base Station Sub-system, performs the transmission control, i.e., the algorithms that are used to share the radio resources among the connected users from the cell served by the PCU.

2.2 Our Model for Resource Allocations in GPRS/EGPRS

2.2.1 General Aspects

The tool used for our model is the discrete event network simulator OMNeT++ [20]. A simulation model in OMNeT++ consists of a number of modules (nodes), the communication between nodes being realised through messages. The model can be hierarchically structured, the basic building blocks of the hierarchy being the simple modules. Their behaviour is described in C++.

In our model, each *user* is a composed module, the other modules in the system being the *Packet Control Unit*, the *user generator*, the *admission controller* and the *stat node*. The user generator and the stat node have no direct correspondence in a real GPRS or EGPRS network, but they are important for simulation purposes: the user generator is used for creating new users in the system, and the stat node serves for collecting the simulation results.

The user generator creates users at certain time intervals and provides the user with their main characteristics: the QoS profile, the amount of data that the users want to transfer in a session and the pattern of the data generation process (users' data source), their mobility pattern, etc. Related to users mobility, it is important to know if the user comes from another cell (handoff user) or it begins the connection in the current cell, and how long will the user stay in the current cell.

The information about each user created by the user generator is sent to the admission controller, which decides if the user will be admitted in the system or if it will be rejected. If the user is admitted, a "start user" command is sent to a free user node (a node that is not occupied by another user).

2.2.2 The Model for the Users and for the PCU

A user is modelled through a compound module consisting mainly of *a source node*, *a file buffer*, *a data packet buffer* and *a sink*. The source generates a number of *files* according to the specific traffic pattern. A "file" in our model can be a real-life file, like in a FTP or e-mail transfer, a group of files (for example the content of a web page in a www session), or a part of a file (a frame in a streaming session).

The files are stored in the file buffer until the "send file" command coming from the PCU determines the first file in buffer to be split into data blocks (or radio blocks), according to the coding scheme of that user, and the data blocks are moved into the data packet buffer. The data blocks have a fixed length, of 456 bits, consisting of user's information and the code bits. Depending on the coding scheme (CS) used, the number of user's bits in a data block can vary in GPRS from 181 bits for CS1, to 428 bits for CS4. In EGPRS, there are 9 modulation and coding schemes, MCS1 to MCS9.

Depending on the scheduling algorithm used for transmission control, the PCU will inform each user how many data blocks to transfer during the current block cycle of 20ms. In this work the Weighted Round Robin (WRR) algorithm is used for scheduling [18], [19], [5], and the weights are given by the QoS profile of the users: the streaming users are assigned a weight of 8, which means that they are allowed to transfer up to 8 data blocks during a block cycle, the web browsing (www) users can transfer up to 4 data blocks, and the background users (the users that are transferring files through e-mail download or FTP) can transfer only 1 data block (their weight is 1).

More details about the transmission control algorithms are given in [18], [19] and [5], while the simulation model is described in more detail in [16].

3. The Fuzzy Admission Control Algorithm

3.1 Motivation

3.1.1 The Problem of Admission Control in Cellular Data Networks

Admission control (AC) is performed in any type of network that offers certain guarantees on the QoS offered to its users. Admission control has been largely used in ATM (Asynchronous Transfer Mode) networks [13].

User admission plays an important role in mobile cellular networks as well. The first mobile networks were used only for telephony, i.e., they were circuit switching networks. The main problem in that case was to reserve resources for the users that move from one cell to another. It is generally accepted that it is less desirable to drop a call in progress than to reject a new call, and as a consequence, the AC algorithms for cellular networks have two target parameters: the call dropping probability and the call blocking probability. A good AC algorithm tries to minimize the call blocking probability while strictly maintaining the call dropping probability under a certain value. In this way, the research on the AC algorithms had focused very much on mobility prediction and on techniques for resource reservation in the neighbouring cells.

The complexity of the AC problem has increased for mobile data networks (like GPRS and EGPRS), compared to mobile telephony networks. In addition to the call dropping and call blocking probabilities, the network has to ensure the negotiated QoS to the admitted users (in terms of delay, throughput, loss, etc) and to maximize the network utilization. Another important aspect is that the traffic patterns for data users are by far more complex than the statistical behaviour of the voice calls, which can be accurately modelled by Poisson processes.

3.1.2 Research Directions in AC for Cellular Data Networks

This section summarizes some of the most interesting research directions in the problem of admission control algorithms for cellular data networks.

The works in [8], [11], [14] and [15] propose different admission control methods based on thresholds. Different admission policies are applied for different regions, and the regions are separated by thresholds. The regions can be based either on network load, like in [11], [14] and [15], or on the number of users from each traffic class, like in [8]. Determining the values for the thresholds that separate those regions is a difficult problem. The authors of [8] use complex mathematical techniques in order to determine the thresholds, while the authors of [11] simply assign them heuristic values. The AC algorithm proposed by Stuckmann et al ([14], [15]) divide the available bandwidth into regions that can be shared by users from adjacent traffic classes.

The authors of [6] propose a decision-theoretic approach based on Markov Decision Processes (MDP), but for real-life problems, the number of states in the Markov model becomes too large.

We can see that the AC methods proposed in the literature for cellular data networks involve complex mathematical methods, which are difficult to apply for real-life problems due to the computational overhead. Moreover, in order to obtain models that are mathematically tractable, numerous assumptions are made, especially concerning the probability distribution functions (pdfs) of the parameters involved in AC. The pdfs for users' traffic characteristics, call durations, cell residence times, etc, are assumed to be of Poisson type, or that they can be described by Markov Modulated Poisson Processes (MMDPs). While for voice calls, most of those assumptions are realistic and the models obtained have shown good results, the characteristics of data traffic cannot be accurately modelled through the framework of Poisson processes or through their extensions, the MMDPs.

3.1.3 Fuzzy Logic: a Possible Solution to AC for Cellular Data Networks

We believe that a fuzzy logic based admission control can overcome those difficulties because:

1) Fuzzy sets can be a natural extension of the solutions based on thresholds: instead of trying to find an "exact" or "optimum" value for a parameter like network load, or number of users from a certain class, it is much easier to define those parameters as linguistic variables, and to separate their domain in linguistic terms, that are fuzzy sets. In this way, a threshold that separates two different behaviours is transformed into a region that ensures a gradual (smooth) change from one behaviour to another. The solutions presented in [8], [11], [14], [15] can be extended in this manner.

2) A fuzzy based solution does not have to rely on any assumption regarding the probability distribution functions for data traffic, session duration, etc.

3) For real-life problems, the fuzzy logic-based solutions are by far less complex (and hence, less computationally intensive) than the solutions based on Markov models.

4) The expertise of the network operators can be easily and directly transposed into fuzzy if-then rules, without the necessity to use sophisticated mathematical techniques (e.g. queueing or Markov models).

Fuzzy logic, sometimes combined with neural networks, has been applied in ATM networks for policing or for admission control [10]. In [9] fuzzy logic was used for admission control in cellular data networks in order 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 neighbouring cells.

3.2 Implementation of the Fuzzy AC Algorithm

For implementing the AC algorithm, we use the general structure of a fuzzy logic controller (FLC) presented in [12], which was modelled and simulated in [17]. The fuzzy rules have in premise the linguistic variables *network load* and *users' precedence*, and in conclusion the linguistic variable *admission decision* with the terms *strong accept (SA), weak accept (WA), weak reject (WR)* and *strong reject (SR)*. The terms for network load and for users precedence are *high (H)*, *medium (M)* and *low (L)*. The shape of the fuzzy sets describing the linguistic variables in premise and conclusion are shown in Figure 1. The values for the parameters in Figure 1 are: m=63, a1=m/4, a2=m/2, a3=3m/4, b1=8 (SR), b2=24 (WR), b3=40 (WA) and b4=56 (SA).

Since the work is in progress, in this paper we present a simplified simulation scenario that includes a simplified form of the fuzzy rules, where only the network load is taken into account in the premise. The set of rules is:
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.

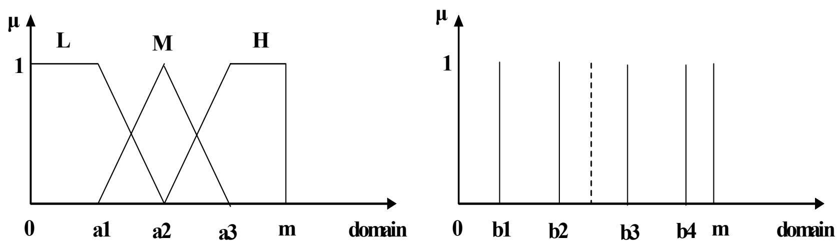

Figure 1. The linguistic variables in premise (left) and conclusion (right)

The FLC will try to keep the network load close to a target value, which is in this case the middle of the interval [0,m]. If the output of the FLC (the admission decision) is below 31 then the user is rejected, while for a value of the admission decision higher than 31, the user is admitted.

4 Evaluation of Our Fuzzy AC Algorithm

4.1 Simulation Results

In this work, we do not consider users mobility and their precedence. The number of channels used for data traffic is always 8. For an easier interpretation of the simulation results, the process of user generation is periodic, not random, as in reality, and we call *a step* a period of the user generator. In order to generate the initial load of the system, all the users created in the firsts 20 steps of the user generation process are admitted.

Figure 2 shows the network load (in the left) and the FLC input and output (in the right) when the target load is 5 and the user generation period is 230ms.

The ***network load*** *is given by the* ***sum of users' weights*** *for all the admitted users,* ***over the average number of channels*** *available for data traffic*. We can see that in the first 20 steps, when the initial load is generated, the network load increases to values higher than 10, but then the fuzzy AC algorithm manages to keep it close to 5. Actually, the network load never exceeds 5.5 after step 40.

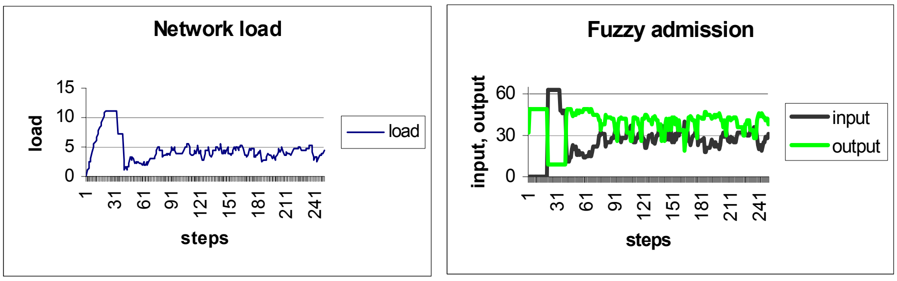

Figure 2. The results of the fuzzy AC algorithm

FLC input includes the existing network load plus the extra load given by the user that attempts to be connected, scaled to the interval [0,63]. The output of the FLC shows that, after the initial period, the majority of the users are admitted, but there are also situations when the FLC output is below 31, which means rejection.

If the user generation period is smaller, then the FLC oscillates around the middle of the interval, more users being rejected.

4.2 Discussion

An AC algorithm compares the bandwidth used by the connected users plus the bandwidth required by the user that attempts to be connected with the bandwidth provided by the network. If the available bandwidth can accommodate the new connection, the new user is admitted, otherwise, it is rejected. In (E)GPRS, the network provides a certain number of channels, but the users' transfer rates depend on their coding schemes, that can change in time (e.g. because of users' mobility), hence a first problem would be how to express the bandwidth (required by users or provided by the network). Our approach is to consider user's assigned weights and, based on them, to determine the network load. A certain network load will determine the delay experienced by the users' files, and hence, the QoS provided by the network. In this work, each QoS class has a certain weight, but it is possible that users' weights change in time, for example, based on their coding schemes. In such a situation, an average weight should be consider for each QoS class. We mention that we do not consider here applications that are very delay sensitive (e.g., those that correspond to the conversational traffic class) and for which the network has to reserve (radio) resources.

Another important aspect is how to determine the average number of PDTCHs (channels available for GPRS) provided by the network, since it depends on the traffic channels allocated for voice calls (in GPRS) or reserved for conversational applications (in EGPRS)? We can compute the average value for a time window, or even combine a long-term value and a short-term value, with different relative weights. A similar problem is how to take into account users activity factor (they do not transfer data all the time when they are connected). For computing the network load, we have considered the weights for all connected users, but we will have to investigate how to combine this approach with considering the weights for the users that are active (that are transferring data in the current block cycle).

The users' precedence will play an important role, especially if we decide to admit the users with high precedence, even if the network load is high. User's precedence is a conventional value, assigned by the network operator, according to user's QoS class (that can be subscription based, traffic based, or both) and to its mobility situation (if it comes from another cell, or if it is a new call). If we decide to admit all users that come from another cell, like in [8], then it is possible to admit too many users and the network can fall in a congested state. To avoid this, we can use a bandwidth adaptation algorithm (similar to [8]), or to block the allocation of physical resources to low precedence users, even if they are admitted.

Conclusions

This work describes a new admission control algorithm for GPRS and EGPRS networks, based on fuzzy if-then rules. We have shown the effectiveness of the algorithm in a simple simulation scenario.

Our future work will use the result from this paper in order to improve and extend the fuzzy admission control algorithm, taking into account more information about the users and the network (e.g. users' precedence, the quality of the radio link, etc). Finally, the algorithm will be tested in more complex simulation scenario, close to real-life situation.

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