A Call Admission Control Strategy based on Fuzzy Logic for WCDMA Systems

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Abstract— **Call Admission Control (CAC) plays a basic role in multimedia 3G systems, properly accommodating new connection requests while ensuring seamless service provision to the existing connections. CAC is classically based on Signal to Interference Ratio estimates and threshold comparisons. A novel CAC strategy founded on Fuzzy Logic is proposed in this paper for WCDMA systems and, in particular, for UMTS. Starting from cell parameters like congestion state, available load and total interference a *fuzzy set* is defined. A *fuzzy rule base* is then constructed, giving the rules for the admission criterion. An UMTS radio access simulator, fully taking into account both user movement and channel conditions is employed to evaluate the performance of the new CAC algorithm and compare it to classic solutions. Simulation results show the improvements attained by the proposed solution.**

Keywords- UMTS, Quality of Service, Admission Control, Scheduling

I. INTRODUCTION

Resource management is one of the most important engineering issues in modern third-generation (3G) wireless mobile communications systems where the radio spectrum is a very scarce resource. Such systems aim to provide mobile multimedia services like voice, video telephony, high-speed Internet access, mobile computing etc. For this purpose multiple traffic classes are supported, each class being characterized by its required Quality of Service (QoS) parameters (i.e. Eb/No, transfer delay, guaranteed bit rate and delay jitter). Call Admission Control (CAC) is employed to decide whether to accept or not a new service request: the goal is to admit an higher number of service requests while at the same time guaranteeing the required QoS for every already active connection.

In this paper a novel CAC scheme based on the Fuzzy Logic approach is proposed for WCDMA systems and in particular for UMTS, which allows soft capacity management. We refer to the uplink, whose capacity is limited by the interference generated in the same and in the neighboring cells [1], [2]. The performance of the proposed CAC is evaluated and compared with the solutions described in [3] and [4] by using a UMTS terrestrial radio access simulator which takes into account both user mobility and channel conditions.

The paper is organised as follows. In Section II some classic CAC algorithms are described. After introducing some fundamentals of Fuzzy logic, the proposed CAC scheme is presented in Section III. Section IV is completely devoted to the software simulation environment and traffic models. Performance analysis is carried out in Section V by showing simulation results and comparing the proposed CAC with the classic CAC solutions. Some conclusions are finally drawn in Section VI.

II. CLASSIC ADMISSION CONTROL SCHEMES

In WCDMA systems the classic criterion to accept a new connection is based on the Signal to Interference Ratio (SIR) featuring each existing connection after that the new one is activated. SIR depends on the power emitted by mobile users. Power Control (PC) mechanisms attempt to keep the SIR of each connection quite close to its target value [5], which in turn is fixed on the basis of QoS requirements [6].

Referring to the UMTS scenario, from [7] we assume that CAC algorithms are implemented in the RRC (Radio Resource Control) layer of RNS (Radio Network System). Here below two typical CAC algorithms are described.

A. *Interference-based CAC (ICAC)* [3]

ICAC policy foresees that the RNS evaluates the total interference generated by active users in the cell and in surrounding cells. The total cell load (i.e the so-called load factor η, defined in [8]) is then computed and a new request is accepted if it is smaller than a given threshold η_{th}

B. *Arrows CAC (ACAC)* [4]

ACAC is similar to ICAC, with an additional "admission with prioritisation" rule: a request for a conversational call (referred also as real-time or voice traffic) can be accepted at the expense of a data traffic connection (referred also as no real-time traffic). It is assumed that some kind of "soft QoS" is provided for the active data traffic connections.

ACAC can be summarised as follows. The RNS calculates the load factor η. If it is smaller than a given threshold (η_{th}) the new request is accepted. Otherwise, if the new requested refers to a conversational call, the bit rates of active no real-time connections are properly reduced (but always kept larger than the minimum value allowed by their QoS requirements) to let the new call be admitted to the network. If bit rate reduction is not sufficient, the new call is rejected and the bit rates of existing data calls are left unchanged.

III. FUZZY CALL ADMISSION CONTROL

A. *Basic concepts of Fuzzy logic* [9], [10]

In the Aristotelian logic a classical set can be defined as a set with a crisp boundary. For example, a classical set A of real numbers greater than 6 can be expressed as

$$A = \{x | x \geq 6\} \quad (1)$$

There is a clear and unambiguous boundary "6": if x is greater than this number it belongs to the set A, otherwise x does not belong to the set.

On the contrary, in the Fuzzy logic a set is defined without a crisp boundary. The transition from "belong to the set" to "not belong to the set" is gradual, thus representing the truth-grade related to the definition of the concept. This smooth transition is characterized by the so called Membership Functions that give set flexibility in modeling commonly used linguistic expressions, like "the temperature is hot" or the "weather is warm". A Fuzzy System consists of a Fuzzifier, an Inference Engine, a Fuzzy Rule Base and a Defuzzifier. The Fuzzifier transforms the values of the input parameters into the fuzzy linguistic terms through a set of Membership Functions. These fuzzy linguistic terms are the inputs of the Inference Engine which will perform the logic inference according to the Fuzzy Rule Base. The Fuzzy Rule Base is constructed by the expert knowledge of the phenomenon (admission control, in this paper). The Defuzzifier converts the results of the inference into the usable values for admission decisions.

The Fuzzy Reasoning, also known as "approximate reasoning", is an inference procedure that derives conclusions from a set of fuzzy rules and known facts. It can be divided into four steps:

- Degrees of compatibility: compare the known facts with the antecedents of fuzzy rules to find the degrees of compatibility with respect to each antecedent Membership Function;
- Firing strength: combine degrees of compatibility with respect to antecedent Membership Functions in a rule using fuzzy AND or OR operators to form a firing strength that indicates the degree to which the antecedent part of the rule is satisfied;
- Qualified induced consequent Membership Functions: apply the firing strength to the consequent Membership Functions of a rule to generate a qualified consequent Membership Function;
- Overall output Membership Function: aggregate all the qualified consequent Membership Functions to obtain an overall output Membership Function.
- These four steps are employed in the fuzzy inference system shown in the following section.

B. *The proposed Fuzzy Call Admission Control Algorithm*

The novel Fuzzy Call Admission Control technique (hereinafter also referred as FCAC) proposed in this paper is based on the definition and calculation of Fuzzy System and its inputs. Fuzzy System Model, depicted in Figure 2, is able to elaborate inputs from the UTRA (UMTS Terrestrial Radio Access, modelled by means of a software simulator described in the next section) and to give the decision of call rejection or acceptation, whenever a new connection request occurs.

The inputs are:

- C: congestion state within the cell, i.e. C=1 if the cell is congested and C=0 otherwise, as detailed in Section III.C;
- I_{TOT} : total interference in the cell, i.e. the interference measured at the Node B at the moment of the requesting call.
- η_{AV} : available load, i.e. the load supported by the cell without the load assigned to real-time connections at the moment of the request;

The equations involved for η_{AV} and I_{TOT} calculation are well defined and expounded in [8] Sect. 9.4.1.

Fuzzy System is based on the following fuzzy linguistic term set:

- T(C):{Negative, Positive};
- T(η_{AV}): {Small, Medium, Big};
- T(I_{TOT}): {Low, Medium, High}.

The output linguistic variable, denoting the acceptability of the new call (hereinafter referred as D), is defined as:

- T(D):{Rejected, Weakly Rejected, Weakly Accepted, Accepted}.

The relative membership functions are shown in Figure 3, where η_{max} denotes the maximum allowed load by the system and I_{Th} is the threshold for the interference calculated at the Node B. The coefficients a_C , b_C , a_η , b_η , c_η , a_I , b_I , c_I , a_D , b_D , c_D , d_D are the fuzzy set ranges of C , η_{AV} , I_{TOT} and D respectively.

On the basis of the previously introduced fuzzy set, the Fuzzy Rule Base has been constructed; Table I lists the rules settled for the admission criterion. Fuzzy inference algorithm is based on the Mamdani Fuzzy Inference System using max-product composition, while the adopted defuzzification method to obtain the final decision of acceptance or rejection is the Centroid of Area Defuzzification Method [9].

C. *Congestion Control Procedures: the Data Scheduler*

After accepting a new connection, system must assign the appropriate bandwidth (i.e. choose the Spreading Factor in WCDMA systems) to all active connections, so as to provide them with settled QoS parameters while controlling system overload (i.e. maintaining $\eta<\eta_{max}$). For this purpose a frame-by-frame Data Scheduler (DS) algorithm has been designed. It is described here in the following. No real-time services (e.g. web browsing and email) have no requirements in terms of transfer delay, so it is possible to handle their bit rates to control the load produced by data services according to the instantaneous load of real-time services, which is virtually uncontrollable. DS strategy aims to keep load factor (η) as large as possible, close to its maximum value (η_{max}): when the cell is underloaded it allows data connections to increase the bit rates; when the cell is overloaded the same bit rates are decreased or, eventually, fixed equal to zero.

The congestion parameter C is calculated according to the values assumed by the load factor η: when $\eta>\eta_{max}$ system is considered congested (i.e. C=1, otherwise C=0).

IV. THE UMTS TERRESTRIAL RADIO ACCESS SIMULATOR

Traffic is not uniformly distributed within an UMTS cell, mainly due to user movement. This must be inspected to properly take into account variations of the emitted powers, due to different path losses within the cell and to PC mechanisms [5].

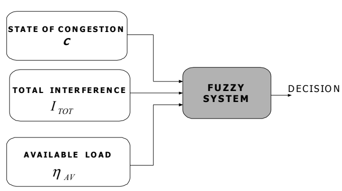

Figure 1. Fuzzy System Model

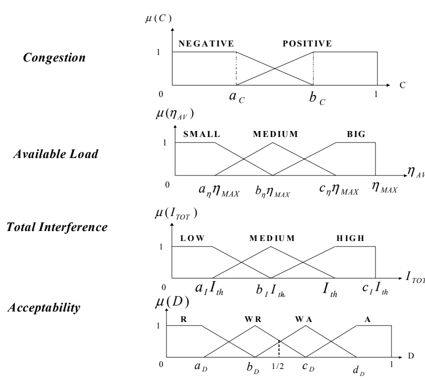

Figure 2. Fuzzy Membership functions definition

TABLE I. FUZZY RULE TABLE

FUZZY RULE	C	η_{AV}	I_{TOT}	D
1	Negative	Small	Low	W.Accepted
2	Negative	Small	Medium	W.Rejected
3	Negative	Small	High	Rejected
4	Negative	Medium	Low	W.Accepted
5	Negative	Medium	Medium	Accepted
6	Negative	Medium	High	Rejected
7	Negative	Big	Low	Accepted
8	Negative	Big	Medium	W.Accepted
9	Negative	Big	High	Rejected
10	Positive	Small	Low	Rejected
11	Positive	Small	Medium	Rejected
12	Positive	Small	High	Rejected
13	Positive	Medium	Low	Rejected
14	Positive	Medium	Medium	Rejected
15	Positive	Medium	High	Rejected
16	Positive	Big	Low	Rejected
17	Positive	Big	Medium	Rejected
18	Positive	Big	High	Rejected

According to this, a realistic radio access simulator for a urban environment, where users randomly move while producing multimedia traffic has been developed. The simulator allows to test performance of UMTS access network protocols such as call blocking probability, call dropping probability, probability of handoff successes, bit rate. Basic features of the simulator, distinguishing it from other simulators based on the classic Manhattan model ([11], [12]), are:

- the whole area is divided in pixels; within pixel all the parameters involved are constant;
- buildings and other obstacles are not necessarily rectangular in shape, as in Manhattan model;
- cells lay upon a torus surface in order to avoid border effects;
- node Bs employ omni-directional antennas with a gain of 11 dB
- mobile user terminals employ omni-directional antennas with a gain of 0 dB

The simulator is basically an event generator which, after an initialization step, manages many different processes like:

- user movement from a pixel to another (also taking into account user speed),
- request of a new connection,
- opening/closing of a connection;
- drop out of a connection;
- run of Power Control algorithms;
- run of Call Admission Control algorithms.

A. Propagation Model

The macro cell propagation model, valid for urban and suburban environment is employed. Path loss L is then expressed according to [13] as follows:

$$L = 128.1 + 37.6 \text{ Log } (R) + \text{Log } (F) \qquad (2)$$

where R is the distance (in meters) between mobile and Node B: Log(F) represents the loss due to fast fading, F being a Gaussian random variable with zero mean and 10 dB standard deviation.

B. Mobility Model

Two user classes “Active” and “Stand-by” have been considered and managed in a different way.

Active user are single entities featured by parameters like position within the cell and emitted power. “Pedestrian” and “Vehicular” users have been considered. The difference is in their speed range. The state machines of Figure 3 has been employed to reproduce variations of user speed and direction. State transitions are controlled by different values of probability: P(M,M), P(M,S), P(S,S), P(S,M) for user speed; P(C), P(T) for user direction. These are properly set on the basis of the supposed environment (urban, suburban, rural, etc.).

On the contrary, Stand-by users are not represented as individual entities, but are globally featured by the number of them standing inside each pixel. The number of Stand-by users then represents the state of the pixel.

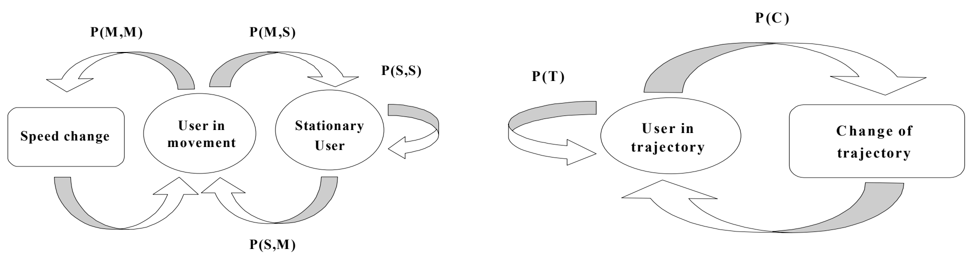

Figure 3. : State machine for user movement: Change of Speed (left side), Change of Trajectory (right side)

Such state can change according to two different events: "connection request" and "user movement". Whenever an event occurs, pixel state is refreshed.

C. Power Control

The transmitted power is adjusted by PC mechanism each step (assumed equal to 20 msec) to keep the SIR at the target value (SIR_{target}). The new power level for each user terminal is evaluated as:

$$P_{Updated} = P_{OLD} \frac{SIR_{target}}{SIR} \tag{4}$$

$P_{Updated}$ cannot be set larger than a maximum value featuring the mobile terminal (assumed equal to 30dBm). Users unable to reach the SIR_{target} at the end of a PC loop are considered in "outage". If quality is equal to (SIR_{target} – 0.5 dB), the user is considered satisfied, otherwise the connection is dropped out.

D. Traffic Source Models

Three different service classes have been implemented simulator.

1) Conversational Service

Voice calls are generated according to a Poisson process and an exponential distribution, assuming the typical mean call duration of 180 seconds. 50% average activity cycle is assumed.

2) Interactive Service

The burstiness of this service is modelled as follows. A packet service session contains one or several packet calls and reading times, depending on the application. During a packet call several packets may be generated, so that the packet call constitutes a bursty sequence of packets. Session opening time is modelled as a Poisson process; the number of packet call request per session and the reading time are two geometrically distributed independent random variables, while the size of a packet call is a random variable which follows a Pareto distribution with cut-off.

3) Background Service

The model simulating file uploading or email service consists of only one packet call, whose size is a random variable with Pareto distribution with 30 Kbytes as mean value.

V. SIMULATION RESULTS

In order to test the performance of the proposed FCAC, several computer simulations have been performed using the traffic simulator described in the previous section. The aim is to compare FCAC with ICAC and ACAC performance in term of blocking probability, dropping probability, and mean transfer delay, while considering different traffic sources so as to test a truly integrated voice-data network. The case of exclusion of any admission control procedure (hereinafter referred as No CAC) has been also evidenced.

The case of conversational services only is analysed at first. From Figure 4 the flexibility of FCAC resource allocation allows to keep both blocking and dropping probability lower than ICAC and ACAC. When interactive and background services are added to generate mixed (voice and data) traffic, ACAC privileges the conversational services and grants a smaller blocking probability than both FCAC and ICAC strategies for those services, as shown by Figure 5. On the contrary, FCAC policy and its data scheduler can obtain a better radio resource allocation in terms of mean bit rate for data traffic and dropping probability for voice traffic (see Figure 6). It can be noticed that increasing voice traffic, ACAC policy lets decrease bit rate for data traffic (and consequently increase mean transfer delay, as showed in Figure 6), while the bit rate does not change significantly in FCAC. Finally, Figure 7 highlights FCAC benefits, showing how the dynamics (in terms of the load factor η) is exploited at higher values than ICAC and ACAC.

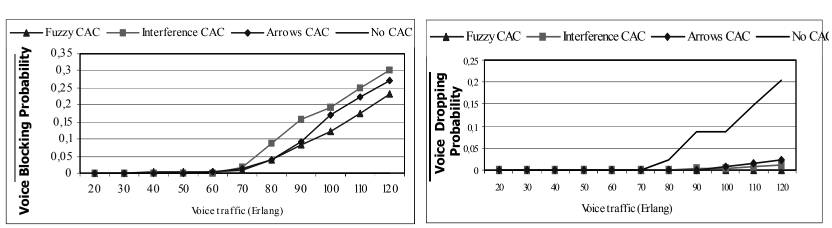

Figure 4. Voice Blocking Probability (right side) and Dropping Probability (left side). Only-Voice traffic case

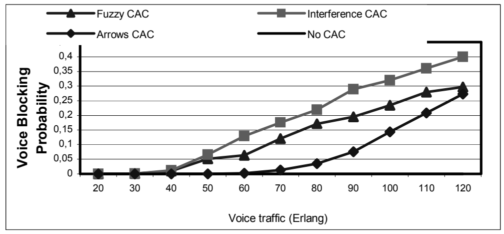

Figure 5. Voice service Blocking Probability. Mixed (Voice and Data) Traffic case

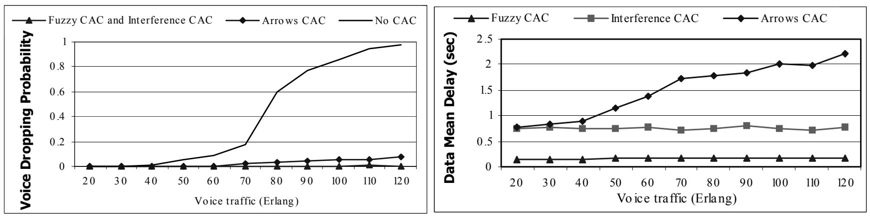

Figure 6. Voice service Dropping Probability (right side) and Data Mean Delay (left side) varying voice traffic. Data traffic is kept constant at 300kbps for background services and 100kbps for interactive services

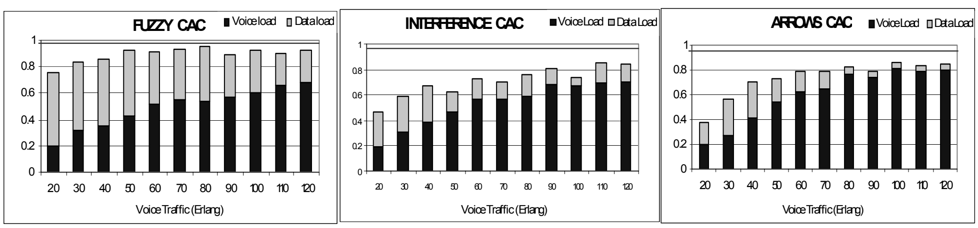

Figure 7. Load Factor (η) comparison varying voice traffic: Fuzzy CAC (top), Interference CAC (bottom left) and Arrows CAC (bottom right). Blue and green diagrams represent load factors for voice and data traffic, respectively.

VI. CONCLUSIONS

An innovative strategy for radio resource management based on Fuzzy logic has been presented for WCDMA systems (mainly, UMTS). Its performance has been analysed and compared with other well-known algorithms by means of a UMTS radio access simulator. Numerical results demonstrate its ability to grant better service provision in term of dropping probability and transfer delay for services accepted by the network.

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