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Conventional and Unconventional Cellular Admission Control Mechanisms

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1. Introduction

The wide range of services offered by third generation (3G) networks made them more popular around the world. Examples of these services are web browsing, video streaming, image transmission, downloads, videoconference, voice over IP (VoIP), voice calls and Short Message Service (SMS). When an user requests a particular service, a new call is requested. The greater the diversity of services required, the greater is the network resources management difficulty. Availability, reliability and performance are the major goals of its management.

Quality of Service (QoS) is related to the users' satisfaction (Steinmetz & Wolf, 1997). Quality is not measured only by the resources availability, but also by the performance. For example, when an user wants to start a videoconference, it is important, for him or her, low delay, low jitter and high throughput. If these requirements are not met, then the QoS may not be honored. As the number of calls in the network increases, higher will be the difficulty in deciding which requests should be accepted or not. The absence of an admission control mechanism does not guarantee that the network resources will be well distributed, leading to bad resources utilization and a consequent interference in the network availability and QoS assurance.

A Call Admission Control (CAC) is a QoS mechanism. This mechanism decides witch requests should be accepted according to the resource availability, to maintain QoS guarantee. A research challenge is the development of a CAC that solves the following problem: how to decide which application to accept in accordance with the network status. For instance, if a call is requested and the network is free, or a little bit congested, or even very congested, this new call can be accepted or not. This decision influences the QoS of the new call and the QoS of the already established calls. If the network can be guarantee the QoS, the CAC can accept the new call. Otherwise, the call must be blocked.

Another challenge is the CAC's precise knowledge in accept or reject a new call in accordance to its priority. Blocked calls can cause poor network resources utilization, which is unacceptable to cellular operators. Therefore, CAC needs to know which call should be accepted while it faces multiple calls requests in congestion times. Besides, CAC's decision should be taken in the shortest time with the lowest complexity. In summary, CAC's three main requirements are: (1) decides a new call's acceptance (or not), (2) selects which call to accept according to the pre-established services priorities, (3) the decision should be taken in the shortest time.

This chapter is organized as it follows. Section 2 presents how services are admitted through 3G networks, describing the services classes, the network architecture and the basic CAC concepts. Section 3 introduces references of conventional CACs. Section 4 presents a case study of two conventional CACs. Section 5 explains unconventional CAC's concepts. Section 6 presents a case study of two unconventional CACs. Section 7 describes how a CAC evaluation can be made while section 8 demonstrate some of this evaluations in a case study. Section 9 concludes this chapter and section 10 presents references.

2. How services are admitted through 3G networks

3rd Generation Partnership Project (3GPP) group has conceived the 3G cellular networks to meet three requirements: (1) at least 2 Mbps peak throughput, (2) multimedia transmission with QoS and (3) international roaming. To make this guarantee, the services were divided into four classes. These classes are used to conduct services prioritization in CACs.

2.1 Types of services

Applications and voice have specific QoS requirements. For example, the requirements are different for web browsing, video streaming, image transmission and SMS. The 3G network services are classified in four QoS classes for each traffic type (3GPP, 2010):

Conversational. This class of service represents real time (RT) applications, such as voice or telnet. The main QoS requirement is low delay. Low jitter and low packet loss are also important.

Streaming. This class of service represents multimedia and data transfer with continuous and stable stream processing. It's main QoS requirement is low jitter. Low delay and low packet loss should also be considered.

Interactive. This class of service is characterized by client/server requests with traffic bursts, such as web browsing, interactive games and email server access. Although this class is not sensible to jitter, the main QoS requirement is delay.

Background. This class of service represents not real time (NRT) applications, such as email (server to server), fax and transactions services, as SMS. This class is the most tolerant to delay. The main QoS requirement is a high throughput.

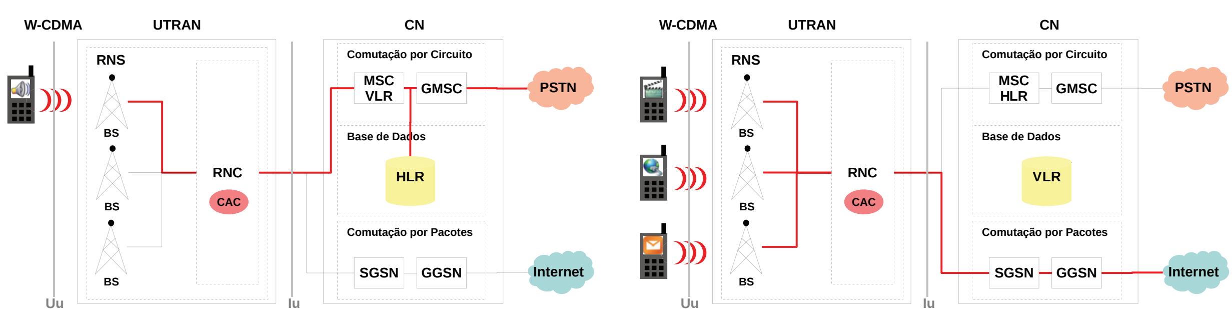
The difference between the classes of services is related to their sensibility to QoS parameters such as delay, jitter and throughput. Delay is the time interval in which the packet traverses the network until it reaches its destination. This interval corresponds to the time to send a package from a sender to a receiver. Jitter is the variation of consecutive delays. Mathematically, it consists in the difference between consecutive packets delay (Kurose & Ross, 2009). For example, multimedia and VoIP applications do not support jitter, so it should tends to zero. Throughput is the effective rate of transmission for an application, in bits per second. Some interactive applications like WEB browsing require high throughput. Some RT applications, like VoIP, require low delay.
In summary, table 1 shows the QoS parameters requirements for the higher-sensitive services of each class, specified by 3GPP (2010). For voice calls (1), the maximum of delay achieved must be less then 400ms. For video (2), jitter must be at most 2s. For web browsing (3), delay can be between 2 and 4s, or less. For SMS (4), the minimum throughput should be 2.8 kbps.

Class	Application	Demand	Delay		Jitter	Throughput
Conversational	Voice call	Higher	Best	< 150ms	< 1 ms	4–13 kbps
			Limit	< 400ms		
Streaming	One-way video	Low	Limit	< 10s	< 2s	32–384 kbps
Interactive	Web browsing	Higher	Limit	< 4s	–	> 20 kbps
Background	SMS	Medium	Limit	< 30s	–	2.8 kbps

Table 1. QoS requirements for 3G UMTS classes of service

2.2 3G infrastructure

Specified by 3GPP, the Universal Mobile Telecommunications System (UMTS) is the most popular 3G cellular networks. As it is shown by figure 1, UMTS architecture is composed by three interacting domains (3GPP, 2009; Kaaranen et al., 2005): (1) the call requested by a user equipment; (2) the air interface UTMS Terrestrial Radio Access Network (UTRAN); and (3) the Core Network (CN). When a call is requested, a solicitation is sent to the UTRAN. The responsible module for the communications with mobile users, over a coverage area (cell), is the Base Station (BS). The Radio Network Controller (RNC) controls the management of the BSs and it is also responsible for the soft handover (the user process of changing BS without loss of connection). Thereafter, the call request is sent to the CN, which is responsible for providing access to Internet and to other networks through the Public Switched Telephone Network (PSTN). Internet is accessed through the elements of Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). The circuit switched domain through the Mobile Switching Centre (MSC), the Home Location Register (HLR), the Visitor Location Register (VLR) and the Gateway MSC (GMSC) achieves PSTN.



(a) Voice calls traffic (b) Video, web-browsing and e-mail traffic

Fig. 1. Tracing different service calls in 3G UMTS network architecture

Figures 1(a) and 1(b) present respectively the voice call traffic and the data traffic in 3G UMTS architecture. Independent of service type, the call request passes through UTRAN in the BS of its coverage area, managed by the RNC. In the CN, while the voice calls traffic passes through MSC and GMSC to access the PSTN, the data traffic passes through SGSN and GGSN to achieve Internet access.

2.3 Admission control

A Call Admission Control (CAC) is an algorithm of decision-making that provides QoS in the network by restricting access to the network resources (Ghaderi & Boutaba, 2006). Figure 2 explains the CAC's functionally. According to the requested call type, CAC decides to accept or block the new call according to the network resources availability. When there are not sufficient resources to ensure the call's quality or to keep the active calls' QoS (services already accepted – established), CAC blocks the new call. Otherwise, the call is accepted.

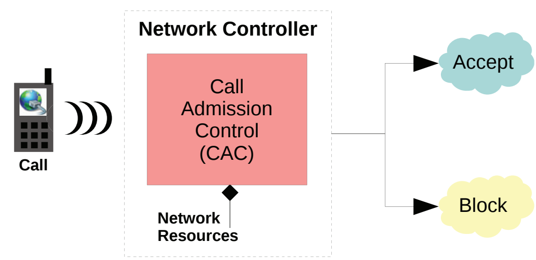


Fig. 2. Call admission control functionality

The literature presents several CAC techniques. Figure 3 shows a taxonomic tree of the CAC techniques used, adapted from (Ghaderi & Boutaba, 2006). The difference for Ghaderi & Boutaba (2006) tree is that they does not present a single tree. Ghaderi & Boutaba (2006) do not describe the thresholds technique, the homogeneous or the heterogeneous services and the application of computational intelligence in admission control as is presented in this work.

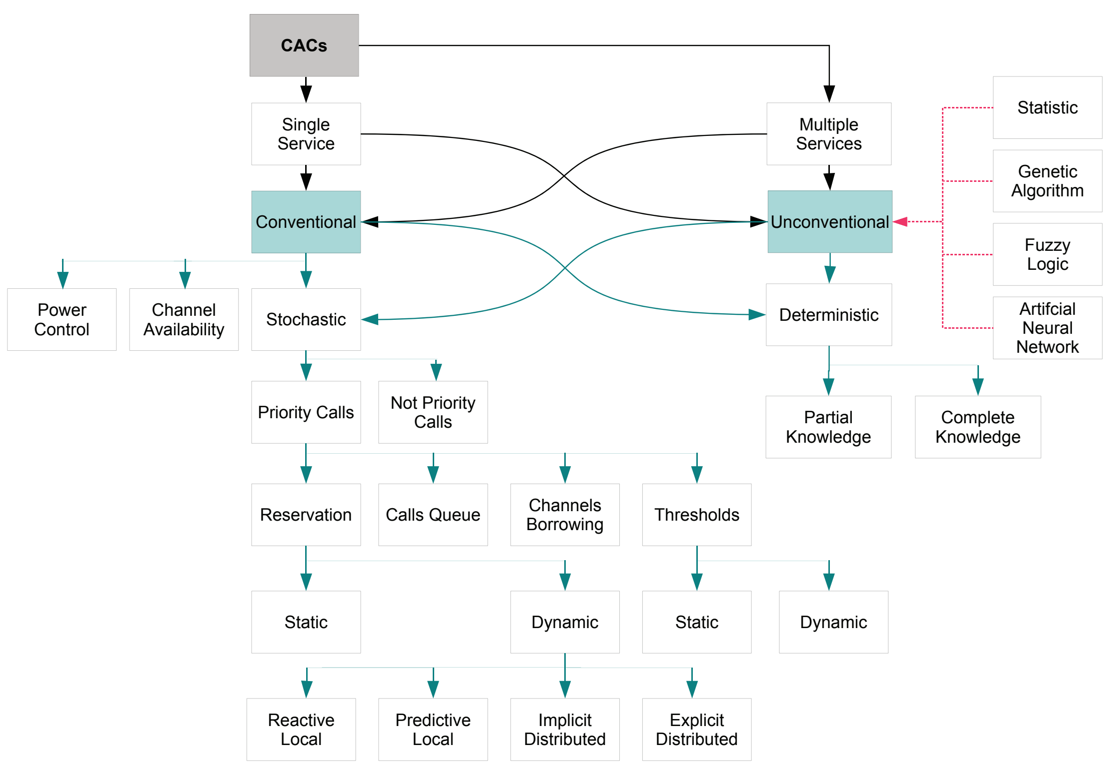


Fig. 3. Taxonomic tree of admission control techniques
Font. Adapted from Ghaderi & Boutaba (2006)

A CAC can work with a single service (voice, for example) or with several types of service (as 3G applications – multimedia, Internet access, email, voice or telnet). Admission control techniques are classified as conventional or unconventional. The conventional CACs use prioritization of calls, resources reservation and borrowing of channels. The CACs that apply computational intelligence methods associated with the traditional techniques are classified

as unconventional CACs. Among the methods used, there are the artificial neural networks, fuzzy logic, genetic algorithms and statistical methods.
CACs can also be classified according to the confidence interval assured to QoS parameters. They can be deterministic, guaranteeing 100% of confidence, or stochastic, which are those that guarantee a probability of confidence (for example, 95% of confidence). The two main basic techniques are the power control, which analyze the uplink and downlink levels, and the channel availability, which tries to allocate an available channel for the call request.
The stochastic techniques can not use services, channels, resources or calls prioritization methods. CACs with services prioritization can use techniques of resource reservation, borrowing of channels, calls queue and acceptance thresholds. Acceptance thresholds technique set limits in some network parameter (for example, the network utilization) to decide, based on the call priority and the parameter level, if the request can be accepted or not. These limits may be static as defined by Service Level Agreement (SLA) or dynamic, updated according to the network status. In the calls queue technique, a queue for soft handover (SHO) is created. If a SHO attempt is blocked, the request can be kept in the priority queue. When there are channels available, the process allocates the channel to the first SHO waiting in the queue. On borrowing channels technique, a cell uses borrowed channels from their neighbors to SHO processes. A channel can only be borrowed if it does not interfere with existing calls. Importantly, when a channel is borrowed, other cells are prohibited from using it.
The last prioritization technique is the resource reservation, which can be static or dynamic. In the static reservation, there is a fixed amount of resources reserved for priority calls. In dynamic reservation, the amount of resource reserved varies according to external factors, such as network performance, availability and congestion level. The dynamic reservation can be a reactive or a predictive local approach. The reactive local approach consists in the use of channels thresholds for priority services. If the channels threshold is reached for a particular application type, no more channels can be allocated. In the predictive approach, the network global state is estimated through prediction models based on local information. The dynamic reservation can also be an implicit or a explicit distributed approach. When the reservation is implicitly distributed, the processing is local, but neighboring cells information are needed. The difference for explicit approach is that the processing is not local and the neighboring cells information are involved in the decision-making.
In addition to stochastic CACs, there are deterministic techniques. They can use partial or complete knowledge. The partial knowledge of CACs reserves resources in several cells to maintain a deterministic guarantee. The complete knowledge of CACs consists in an imaginary CAC of perfect knowledge that use all the user mobility information to make the best acceptance decision. In general, they are used for benchmarking and prediction purposes.

3. Conventional admission controls

This section describes some conventional CACs presented in the literature. The most basic CAC uses just the power control and channel availability. Stochastic techniques are the most common scheme used in admission controls. As we have said, it allows the ensuring of a probability of a confidence interval, generally of 95%–99%. The following techniques are generally used: services prioritization, borrowing and reservation of channels, queue calls and acceptance thresholds.
Deterministic schemes are only possible with partial knowledge. This is because the perfectionism of a complete knowledge is not tangible in admission controls, even in indoor environments (Lu & Bharghavan, 1996). Perfection is just theoretical, for benchmarks

purposes. Talukdar et al. (1999) and Lu & Bharghavan (1996) propose deterministic CACs with a partial knowledge model. They are called worse case schemes because they must reserve resources in several cells to provide deterministic guarantees.

Katzela & Naghshineh (1996) presents a survey of channels borrowing schemes. In accordance with this study, the better borrowing technique for heavy loads is the hybrid one. The hybrid scheme combines two techniques: (1) a channels subset for nominally assigned in each cell, and (2) another channels subset to be borrowed to neighboring cells. In the hybrid technique, CAC can also reallocate calls from borrowed to nominal channels in order to minimize future calls from borrowing channels, which is the most common way in heavy loads.

In static reservation technique, we can reference (Hong & Rappaport, 1986). The authors make static reservation of permanent channels for SHO (called the guard channels), which are priority applications over new calls. They have shown that this reservation reduces the SHO blocking in comparison to CACs without priority calls. When the number of guard channels increase, the probability of dropping calls (forced termination of calls) decreases significantly, even when compared with the increase of new calls blocking.

In general, dynamic reservation technique is better than the static scheme, but it provide high overhead. Box & Jenkins (1990); Talukdar et al. (1999); Zhang et al. (2001) use dynamic predictive local reservation. In general, they assume that the control mechanism periodically measures the arrival rate and then compute the expected arrival rate from such online measurements through a simple exponentially weighted moving average. The channel reservation is calculated based on these parameters, which try to estimate the global network state.

Distributed dynamic reservation was introduced by Naghshineh & Schwartz (1996). The idea was that CACs should collaborate to make the acceptance decision in the combination of adjacent cells information with the local cell information. Although this paper technique was not stable and had violated the required dropping probability as the load increases, Levine et al. (1997) have evolved this technique including the shadow cluster concept. The idea is to use dynamic clusters for each user based on its mobility pattern instead of restricting itself to direct neighbors only. This technique is expensive and sometimes useless in practice (Ghaderi & Boutaba, 2006). Furthermore, it requires a precise knowledge of the mobile trajectory. In distributed dynamic reservation technique, it is also used analytical approaches, which involve huge matrix exponentiations (not acceptable for sequential computer architectures).

Chang et al. (1994) use a finite priority queue of waiting calls to gain access to available channels. In their model, Soft Handover (SHO) calls have priority over new calls. In contrast, Hong & Rappaport (1986) use an infinite queue of SHO attempts despite the channel reservation scheme. This queue can be used if, and only if, the SHO call is inside a handover area between cells. Results showed that using the queue improves the pure guard channel scheme performance, diminishing the dropping probability and maintaining the blocking probability.

Thereby, we perceive that CAC is a collection of techniques to improve the acceptance of new call in the network. The major goal is the better utilization of network resources, maintaining the commitment between performance and availability of the service's quality. Conventional CACs present techniques that can ensure a high efficiency, a low complexity and a low overhead. Nevertheless they are not adaptable, not stable and do not ensure 100% of confidence.

4. Case study: 3G conventional CACs

This section presents two conventional CACs: CAC-J (Antoniou et al., 2003) and CAC-RD (Tostes et al., 2010). CAC-J (Call Admission Control of Josephine Antoniou) is the most basic admission control, because it only does power control and channels availability. Differently, CAC-RD uses several CAC techniques.

In (Storck et al., 2008a;b; Tostes et al., 2010), the authors present CAC-RD: an UMTS call admission control based on resource reservation and a network diagnosis. It has the following modules: static blocking thresholds; channel reservation, network diagnosis and power control. CAC-RD uses a static threshold scheme for blocking lower-priority calls when the network utilization reaches certain limits. If the network utilization is up to 40%, all calls are accepted. If the utilization is between 40%–50%, non-real time (background class of service) is blocked. Between 50%–65% of utilization, background and interactive calls are blocked. Between 65%–75%, background, interactive and streaming calls are blocked. Above 75%, all new calls are blocked, including conversational calls. Results show that CAC-RD decrease 40% of SHO blocking and 11% of voice calls blocking.

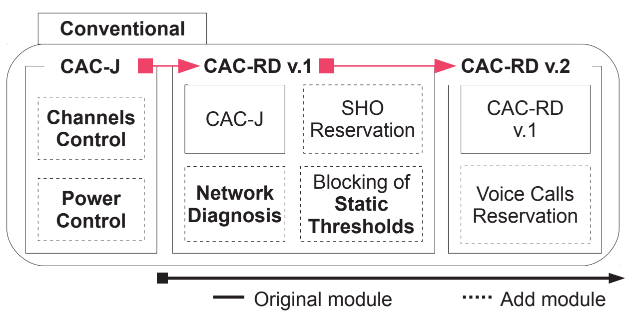


Fig. 4. Evolution line of CAC-RD

As figure 4 shows, two versions of CAC-RD were proposed. CAC-RD's first version (Storck et al., 2008a) reserves dynamically channels for SHO calls, which is the only priority call type. As the probability of conversational calls blocking attained unacceptable high levels, the second version of CAC-RD (Tostes & Duarte-Figueiredo, 2009) reserves dynamically channels for both SHO and conversational calls. Thereby, results presented a gain of 66.65% for conversational calls and of 82.70% for SHO processes.

5. Unconventional admission controls

In addition to the conventional CAC schemes, the academic community has proposed the unconventional CACs. In this category, computational intelligence is applied to conventional methods in order to attain better decision-making. As we have said, the most used methods are statistical approaches, genetic algorithms, Artificial Neural Networks (ANN) and fuzzy logic.

Deterministic algorithms are the most common traditional technique in unconventional CACs. Shen et al. (2000) developed a distributed deterministic CAC with intelligent techniques addressing the probabilistic estimation and prediction of mobility information.

Within genetic algorithms, Karabudak et al. (2004) propose the Genetic Admission Control (GAC) for next generation wireless systems. GAC aims high network utilization with the minimum cost, SHO latency and required QoS levels. Still, it incorporates the Markov decision model. Its main contribution is the provision of an efficient CAC with an intelligent approach to minimize the financial cost.

The self-learning ANN capacity is being applied in CACs to characterize the relationship between the traffic inputs and the system performance. Among ANN-based CACs, there are several approaches as (Hiramatsu, 1989), (S. A. Youssef, 1996) and (Cheng & Chang, 1997). Hiramatsu (1989) proposed a CAC with an ANN multilayer perceptron. The declared traffic parameters were used only for split connections into several services classes. The trained ANN has learned the relationship between the number of connections in each class and the required QoS, in accordance with the class' statistical characteristics.

S. A. Youssef (1996) developed a CAC with a trained ANN to compute the effective requested bandwidth rate. This is done so that CAC supports connections with different QoS requests. This CAC was proposed for Asynchronous Transfer Mode (ATM) networks. Results have shown that the CAC's adaptability to new traffic situations has been hit.

Cheng & Chang (1997) proposed the Neural Network-based Connection Admission Control (NNCAC) for ATM networks. The ANN was modeled with three pre-processed input parameters in order to simplify the training process and to increase the CAC's performance. According to Cheng & Chang (1997), ANN-based CACs provide learning and adaptability capacity, in general, to reduce the estimation error of conventional CACs and to achieve a similar performance of fuzzy logic-based CACs.

Several works with fuzzy logic are also presented in the literature. Ascia et al. (1997) present a fuzzy logic-based CAC for ATM networks. Fuzzy logic-based CAC was designed to know which decisions must be taken in case of traffic load level variations. Its fuzzy logic model consisted in three network parameters: (1) congestion, (2) quality and (3) network capacity. Ascia et al. (1997) analyzed the CAC's behavior in comparison with conventional CACs and the hardware implementation. Results have indicated that the fuzzy logic-based CAC is the most closer to the ideal behavior. Stability is one of the most important features in this CAC.

According to (Pedrycz & Vasilakos, 2000, p.67), fuzzy logic-based CACs have demonstrated the ability to make smart decisions for soft thresholds schemes, developing inaccurate quantity-based calculations and modeling linguistic rules. This technique emulates the decision-making of experts. Fuzzy logic-based CACs can model the acceptance decision as a linguistic variable, allowing a soft decision (accept, weakly accept, weakly blocked and blocked). This technique is particularly useful when precise mathematical models are impractical or unavailable.

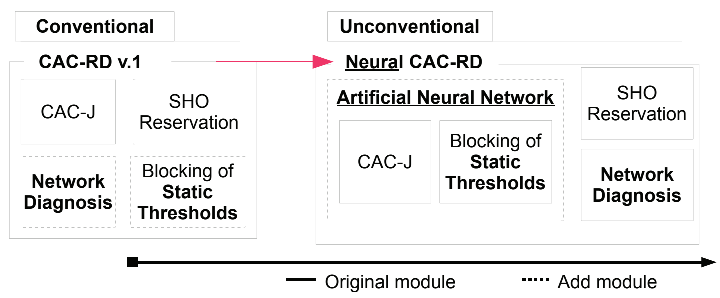
Fuzzy Logic Connection Admission Control (FLCAC) was proposed in (Pedrycz & Vasilakos, 2000, chapter 3). Simulations compared FLCAC to conventional CACs. Results demonstrated an improvement in the network utilization and the better consumption of network resources while keeping the QoS contract. This has happened because FLCAC employs input variables with much more information than conventional models. Still, the fuzzy logic linguistic capabilities can handle the traffic complexity, providing a smooth control. For real applications, authors suggest the utilization of fuzzy-chips.

Another intelligent applied technique is neuro-fuzzy systems. In addition to the fuzzy logic-base CACs, Raad (2005)'s work has been extended with the neuro-fuzzy CAC proposal. Its distinguishing characteristic is the ANN adaptability. Cheng et al. (1999) had also used this approach, but in the context of high-speed multimedia networks.

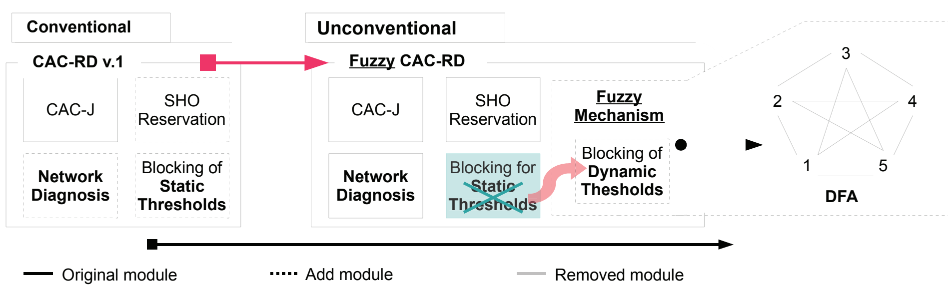
Although there are different proposed unconventional CACs, the embodied knowledge in conventional methods is difficult to be incorporated into ANN or fuzzy logic design. To facilitate the representation of knowledge personified in conventional methods, two procedures for creating a ANN and fuzzy logic-based CACs were presented in Tostes (2010).

6. Case study: 3G unconventional CACs

In section 3, we have explained CAC-RD (Tostes & Duarte-Figueiredo, 2009), which is a conventional CAC. In order to improve CAC-RD, we have proposed two unconventional CACs as figure 5 shows: (1) Neural CAC-RD (CAC-RDN) (Tostes et al., 2008) and (2) Fuzzy CAC-RD (CAC-RDF) (Tostes et al., 2011). CAC-RDN represents CAC-RD's knowledge in an ANN while CAC-RDF makes a dynamic blocking of lower-priority calls.



(a) Neural CAC-RD



(b) Fuzzy CAC-RD

Fig. 5. Unconventional schemes of CAC-RD through neural network and fuzzy logic

The development of CAC-RDN has followed a CAC Neural Representation procedure. This procedure consisted in the creation of an ANN that replace the following CAC-RD modules, as figure 5(a) shows: static blocking thresholds, channel and power controls.

This neural procedure explains the ANN creation process in 10 steps. In step 1, ANN inputs (for instance, the network utilization or costs) and output (for instance, the decision of a new call acceptance) variables were chosen as well as the main CAC classifier attribute (in CAC-RD, it is the BS utilization). In step 2, a database of these variables was established. Each dataset sequence corresponded to the input values that result in a specific output. In step 3, a numerical coding was chosen for ANN variables. For example, each service class code – 1: conversational, 2: streaming, 3: interactive 4: background. Then, in step 4, we have calculated the size (x) of the training set. Step 5 consisted in balancing the database. In step 6, the database was reduced to the size of the training set (x) by removing outliers and selecting the best sequences. In step 7, we have selected which data sequence will go to the ANN training or to the ANN validation. Step 8 consisted in the ANN training, establishing a stopping criterion, and the ANN validation. The ninth step was the implementation of the trained ANN into CAC-RD. In step 10, we made the ANN-based CAC validation through simulations. Results have demonstrated that CAC-RDN reproduces CAC-RD with less complexity. CAC-RDN's major gain is the scalability: it is possible to simulate much more users and cells in less time.

In CAC-RDF, the dynamic blocking of calls occurs in accordance with the network congestion level. If the network is not congested, any new call is accepted. If the network is pre-congested, lower-priority calls are blocked in accordance with the QoS level met for established applications. In case of big network congestion, CAC-RDF does not accept any new call until some resource is released. In case of a soft congestion, some of the new calls are blocked. To represent these situations, we have used the fuzzy logic concepts, allowing the creation of a qualitative mechanism through natural rules based on linguistic descriptions.

CAC-RDF's architecture is divided into modules, as figure 5(b) presents. All CAC-RD modules were retained except the static blocking module. This module has been replaced by dynamic blocking module, which is a fuzzy logic mechanism. This fuzzy mechanism is represented in the figure by the deterministic finite automaton (DFA), which analyzes the network resources and decides which classes should be blocked. From the QoS level guaranteed, by class, the fuzzy engine defines the network state (output), which is one of the following five states of the DFA: (1) accept all calls (AA), (2) blocks background calls (BB), (3) blocks background and interactive incoming calls (BI), (4) blocks background, interactive and streaming calls (BS), (5) blocks all calls, including the conversational class (BC).

The fuzzy-based CAC development has followed seven steps. The first step is the CAC's thresholds definition: in CAC-RD, four thresholds. In step 2 and 3, the input (QoS parameters) and output (network status) variables and their inference functions are defined. Then the fuzzification process is done, transforming the input values (for instance, 100 ms of delay and 2 ms of jitter) in linguistic values (respectively low and high) from its inference function specified in step 3 ($f(x)$ with x variable). In step 4, a specialist defines the system linguistic rules, used by the inference mechanism to deduce the resulting output from the linguistic inputs. In the CAC-RDF, 27 rules were defined. The fifth step consists in selection of the defuzzification algorithm, which translates the output linguistic value to the corresponding discrete value from its inference function. The chosen algorithm was the gravity center, the most common in fuzzy literature. In steps 6 and 7, the fuzzy mechanism implementation and validation is made. Results have shown that CAC-RDF achieved two goals: greater acceptance of priority calls than CAC-RD and better distribution of available network resources. CAC-RDF also provides greater adaptability and stability in its decision-making.

Thereby, there are several CACs techniques reported in the literature: conventional and unconventional. We believe that unconventional CACs proposed for ATM networks may be adapted to 3G UMTS networks. Among the advantages of unconventional schemes are a high adaptability, a high stability, a high flexibility and a low complexity. The challenge of these new approaches is how to model and design an unconventional solution to ensure the availability and performance of networks. It is important to highlight that if the computational intelligence modeling is not well done, the CAC may not work correctly as it should. Notwithstanding, the problem of how to guarantee QoS and better network resources management is still opened.

7. Evaluation of admission controls

As it was previously explained, there are many parameters involved in the CAC's decision-making evaluation. Some parameters differ from CAC architecture. It is difficult to develop a CAC evaluation framework. Although there are several forms of CAC assessment, we present eight evaluation criteria (Ghaderi & Boutaba, 2006), as it follows:

Blocked calls. It refers to the number of services not accepted. This may happens due to the network congestion (scarce available resources or insufficient power).

Dropping calls. It measures the forced termination of calls in progress, after the CAC's acceptance decision. This evaluation has a more negative impact from the user's perspective, in general.

Soft handover failures. It measures the number of hard handover calls. A soft handover (SHO) failure occurs when the call path forces the network to discontinue the user call.

Efficiency. It refers to the achieved utilization level according to the network capacity requirement given a pre-defined QoS.

Complexity. It is related to the CAC's algorithm complexity in relation to its decision-making. A very complex CAC algorithm tends to be less efficient in time then a simple one.

Overhead. It refers to CAC's induced overhead. The CAC's processing time must be the minimum possible.

Adaptability. It measures the CAC's ability to react to the network conditions. For example, if the network has some performance problem, the CAC may reject more new requests.

Stability: It is the CAC's sensibility to traffic load fluctuations.

QoS performance parameters: The major network operator goal must be high availability with excellent performance. Though the CAC must look at the performance every time to avoid performance degradation when it accepts many new calls. Delay, jitter and throughput are the main important parameters to be seen.

8. Case study: Evaluation of the presented CACs

8.1 Blocked calls

Figure 6 shows a bar graph of CAC-RDN denied blocking calls in a 3G UMTS network with 10000 users and 100 cells. We can see that CAC-RDN can simulate more users than CAC-RD (1100 users in 3 cells), but it still blocks a lot of conversational calls. This happens because CAC-RDN was based on CAC-RD version 1, which has only resources reservation for SHO.

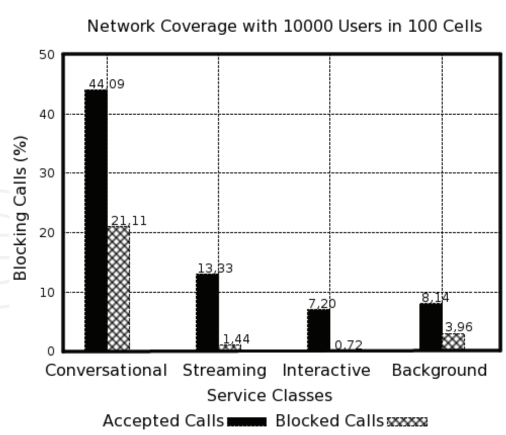
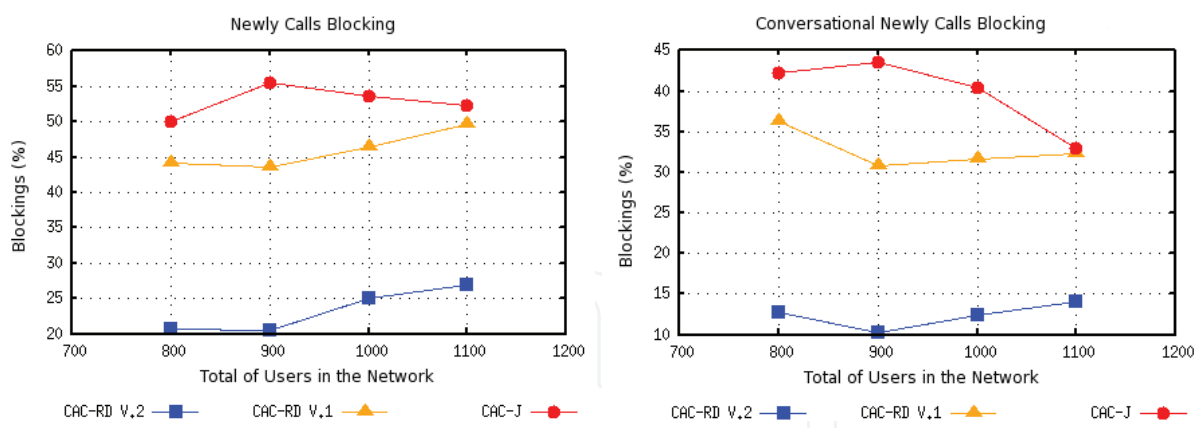


Fig. 6. Newly calls blocking evaluation in CAC-RDN

Figure 7 presents a different type of blocking calls graphics: the line point graphic. In this graphics, we can compare the performance of three different conventional CACs: CAC-J, CAC-RD version 1 and CAC-RD version 2. We can see that the high conversational blocking percentage, presented in CAC-J and CAC-RD, was reduced by CAC-RD version 2.



(a) Line points graphics

Fig. 7. Newly calls blocking evaluation by comparing different CAC schemes

8.2 Soft handover failures

Figure 8 presents SHO failures for three conventional CACs: CAC-J, CAC-RD version 1 and CAC-RD version 2. We can see that the new reservation scheme for conversational calls does not impact in the SHO failures. It only decreases the number of SHO failures to almost zero, in general, despite the total number of users in the network.

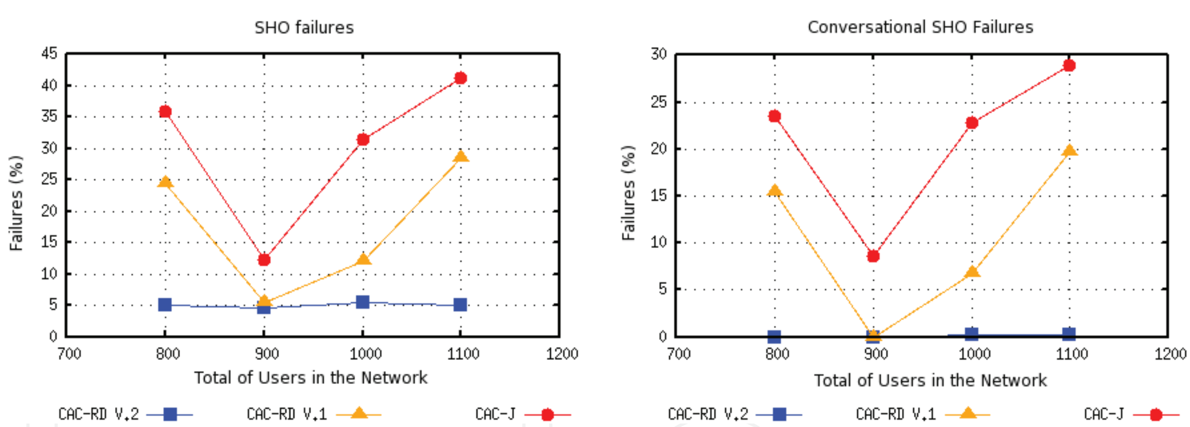


Fig. 8. SHO failures evaluation by comparing conventional CACs schemes

8.3 Efficiency

Figure 9 shows the network utilization comparison between CAC-RD and CAC-RDF. As the simulation time increases, the network moves toward a congestion state, but with a better utilization by CAC-RDF. The network utilization difference between CAC-RD and CAC-RDF is small in comparison to the network state. But as Tostes et al. (2011) analyzed, this difference is highly significant when evaluated the performance of each service class.

8.4 Complexity

Figure 10 shows the asymptotical analysis of CAC-RD and CAC-RDN. We perceive that CAC-RDN is better than CAC-RD in this aspect since it involves less computational operations.

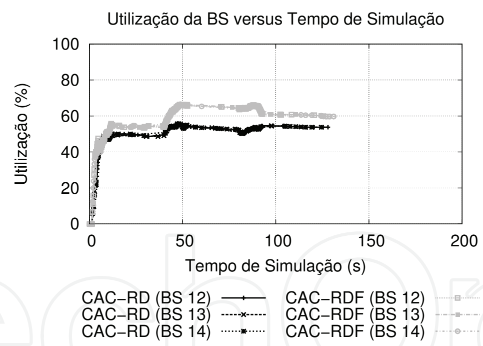


Fig. 9. Efficiency analysis of CAC-RD and CAC-RDF

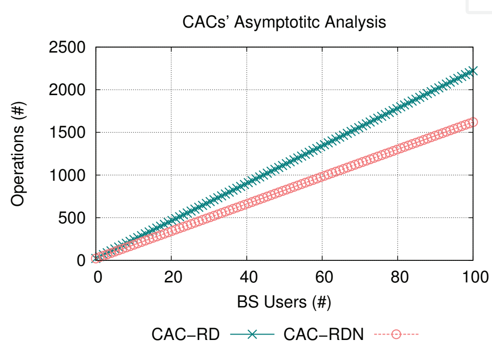


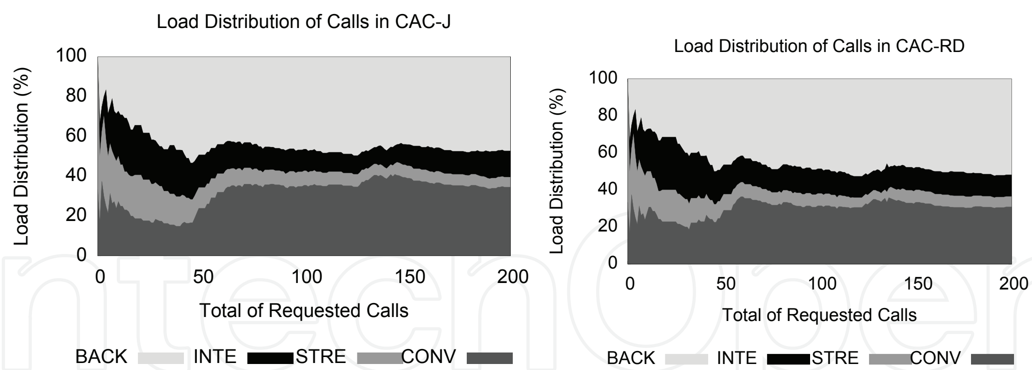
Fig. 10. Complexity analysis of CAC-RD and CAC-RDN

8.5 Adaptability

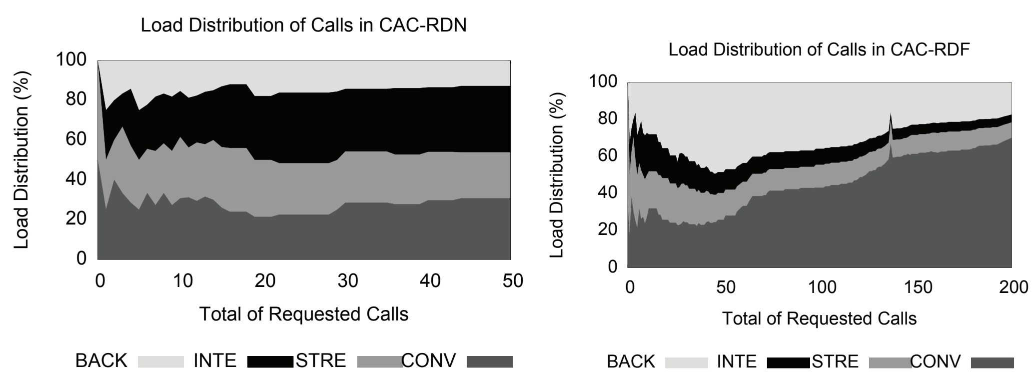
Figure 11 allows the evaluation of CAC's capacity to adapt while the network presents different load peaks. The graphics shows the load distribution as total number of calls increases.
Figure 11(a) presents conventional CACs assessment (CAC-J and CAC-RD) while figure 11(b) presents unconventional CACs assessment (CAC-RDN and CAC-RDF). When the total of requested calls increases, the amount of priority calls (conversational, streaming and interactive) also increases but until a certain extent. This happens due to the use of fixed thresholds and the scarce network resources availability. In the unconventional CACs, we can see that CAC-RDN is fairer due to the balanced calls load of priority classes. But CAC-RDF demonstrates adaptation and adjustment capabilities. It accepts more priority calls while the network tends to congestion (the greater number of required calls).

8.6 QoS performance parameters

Figure 12 shows two graphs, one that measures the jitter and another that measures the flow of the conversational class. The SHO process has been initiated in instance 120 s. In relation to jitter, before the SHO, the call failed to ensure QoS. However, after the SHO, jitter exceeded the limit of 1 ms for this class. This also happened with the throughput per user. After the SHO, the call could not get the minimum to have 4 kbps, which is specified by 3GPP. Therefore, it is clear that there is no QoS guarantee in the SHO process for conversational calls.
As it was shown in table 1, 3GPP has specified some QoS requirements for each class of service. For conversational class, 3GPP has specified a maximum 400 ms delay while for streaming class the delay limit was 10 s. As can be seen in figure 13, CAC-RD and CAC-RDF can guarantee both these requirements. For interactive class, 3GPP has specified a delay limit

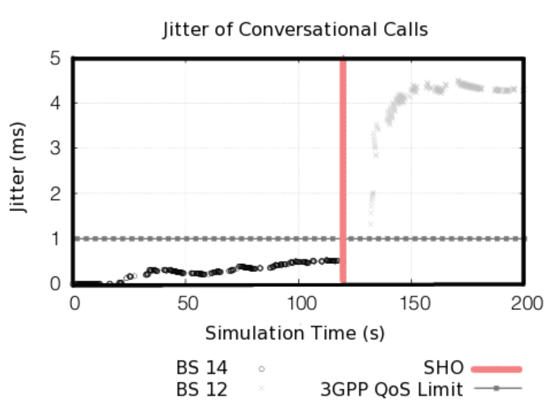


(a) Conventional CACs

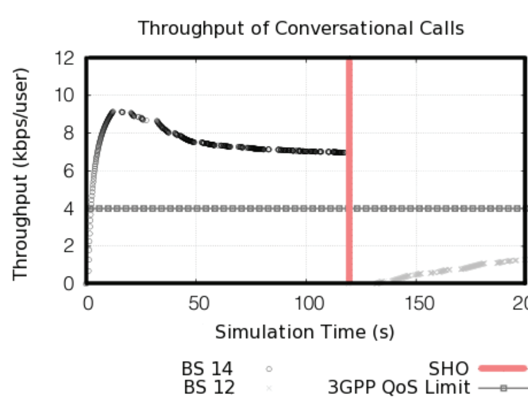


(b) Unconventional CACs

Fig. 11. Adaptability evaluation by comparing different CACs schemes



(a) Jitter



(b) Throughput

Fig. 12. QoS analysis of a call during soft handover process

of 4 s. Figure 13 shows that both CAC-RD and CAC-RDF do not guarantee this requirement all the simulation time. But CAC-RDF has a major advantage: it blocks new interactive calls when it perceives this network degradation. Although both CACs, CAC-RD and CAC-RDF, guarantee the minimum of 2.8 kbps throughput, CAC-RDF stops accepting this low priority class when it detects network degradation.

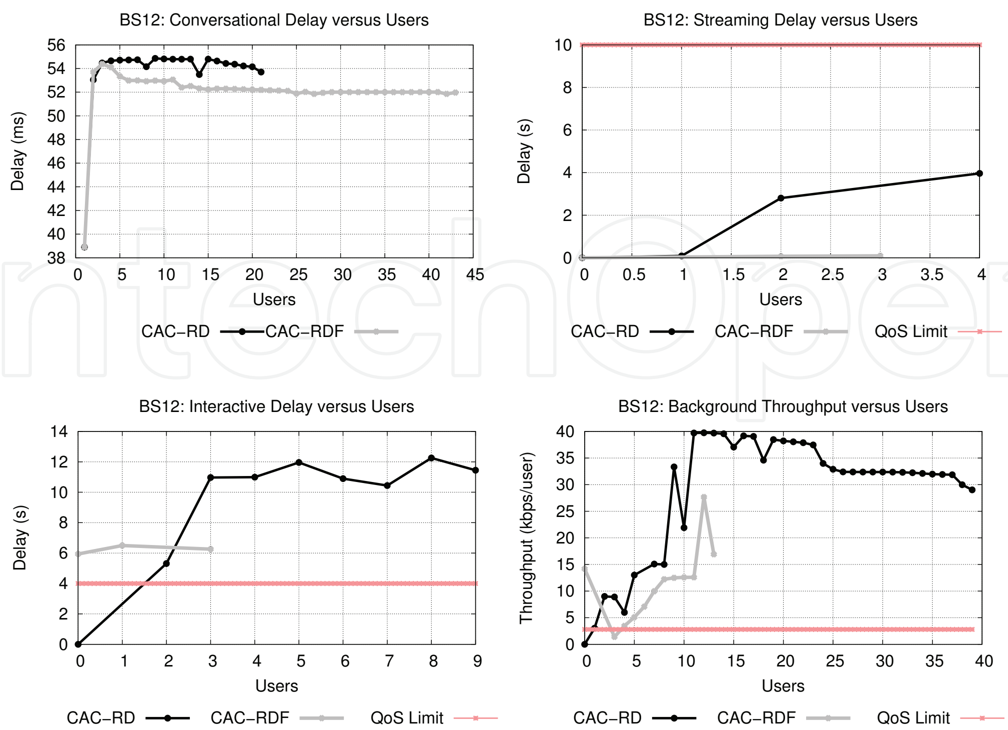


Fig. 13. QoS analysis of a call during soft handover process

9. Conclusion

Cellular networks of third generation (3G) allow us to be connected to the Internet anytime, anywhere, through smartphones, laptops and netbooks. Voice calls, video streaming, email, access to social networks and WEB browsing are some examples of 3G services. When an user accesses a specific service, a new call is requested. It is the responsibility of the cellular operators to ensure the quality of the requested services. As we have seen, the greater the diversity of the services required, the greater is the network resources management difficulty. Call Admission Control (CAC) is a very important system to a cellular network. It decides to accept or not of a new call depending on network conditions, regarding availability of channels, signal power and quality of service. Its greatest difficulty is the knowledge of which required calls have to be accepted and which have to be blocked, due to numerous parameters involved in the CAC's decision. When a new call is accepted, it increases the load over the network resources. The CAC's main challenge is to accept as much as it can, maintaining the network performance acceptable.

CAC mechanisms can be conventional or unconventional. The conventional ones use deterministic or stochastic techniques. The deterministic technique ensures a confidence interval of 100%, while the stochastic ones ensure a probability. The most common techniques are the stochastic ones, such as signal power control, borrowing and reservation of channels, queues and thresholds prioritization techniques. Although they can assure high efficiency, low complexity and low overhead, conventional CACs are not adaptable neither stable. To overcome these needs, the academic community has introduced the unconventional CACs. In this category, CACs use intelligent methods associated with the traditional techniques. Genetic algorithms, statistical methods, artificial neural networks and fuzzy logic are some of the intelligent methods used. The self-learning capacity of neural networks and the fuzzy

logic ability of modeling uncertainties are most often used in the unconventional literature, providing adaptive and stable CACs.
This paper presented some CAC's case studies in both categories: CAC-RD as a conventional control; Neural CAC-RD (CAC-RDN) and Fuzzy CAC-RD (CAC-RDF) as unconventional ones. CAC-RD is an admission control based on resource reservation, blocking of calls according to static network utilization thresholds, and a network diagnosis. But CAC-RD has the low scalability and the static blocking characteristics as a disadvantage. To overcome CAC-RD's scalability issue, we have presented CAC-RDN, which have learned CAC-RD's behavior through neural network training. On the other hand, CAC-RDF has been presented in response to CAC-RD's waste of resources. Its main contribution is CAC-RD's thresholds dynamization, with fuzzy logic (FL), in accordance with the quality of service (QoS) for the blocking of lower-priority calls.
As mentioned earlier, the assessment of CACs can be made through eight evaluation criteria: blocked calls, dropping calls, soft handover failures, efficiency, complexity, overhead, adaptability, stability and quality of service performance. We have presented the evaluation of CAC-RD, CAC-RDN and CAC-RDF. CAC-RD's main contribution is the commitment between performance and availability. With CAC-RDN, it was possible to simulate scenarios up to 10000 users and 100 cells. Furthermore, CAC-RDF had the following advantages over CAC-RD: (1) better utilization of network resources, (2) higher acceptance of priority calls, and (3) CACs' stability. Although it is not possible to say which CAC is the best, because it depends on the users and the cellular operator demands, we have seen that the intelligent techniques can improve the CAC scalability and stability, providing a better network utilization.
Some recommendations may be followed: (1) CAC must ensure not just high network availability, but also high performance; (2) the quality of service requirements must be guaranteed for each class of service; (3) one of the most important CAC evaluation parameter is the number of blocked calls; (4) computational intelligence techniques can offer high scalability and high efficiency characteristics for CACs; (5) the proposed CACs' performance must be analyzed in new scenarios and networks, such as Long Term Evolution (LTE) and next generation networks.

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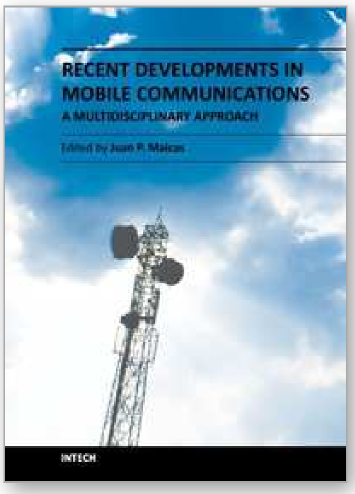

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