Admission Control Policies for WCDMA Satellite Return Link in an Avionic Environment

Paolo Dini(1), **Marco Massaroni**(2)

(1) ***INFO.COM department***
University of Rome "La Sapienza"
Rome, Italy
paodini@infocom.uniroma1.it

(2) ***DIS department,***
University of Rome "La Sapienza"
Rome, Italy
apollonio001@libero.it

INTRODUCTION

During the last years, *In-Flight Entertainment* (IFE) has become one of the hot topics in the communications world. This is mainly due to the fact that aircraft seems to be one of the last remaining islands where personal communications, Internet access and real-time communications are not available [1]. Therefore, airlines are increasingly requiring in-flight services to offer similar entertainment or business experience to passengers as their terrestrial counterparts. To make this possible, broadband communications with high bit rate have to be provided to aircraft.

European project NATACHA (Network Architecture and Technologies for Airborne Communication of Internet High Bandwidth Applications) will provide a new generation mobile real-time Internet connection up to the aircraft through bi-directional high bandwidth satellites, thus realizing the concepts of *"office and entertainment in the sky"*. The project basically focuses on the embedded airborne systems part of the communication system and its interface to the satellite link. In particular, system architecture foresees three sub-networks (also referred as *segments*): Aircraft, Satellite and Ground. The Aircraft segment is composed by a router, called Network Control Router (NCR) that interfaces the on board LAN with the Satellite Broadband Terminal. It is a special terminal, developed in the framework of the project, in charge of transmitting/receiving IP traffic through the satellite link. Satellite segment is composed by a constellation of geostationary (GEO) satellites working in Ku-band. Finally, Ground segment consists of an on ground Satellite Broadband Terminal entity and a gateway to external networks.

This paper is focused on the resource management for the return link via satellite; in particular the aim is to introduce different admission control protocols to allow the network to provide passengers with QoS guarantee services. The radio interface chosen is based on Wideband Code Division Multiple Access (WCDMA) [2] which let the system have an asynchronous way of working, more suitable for an high mobility environment with respect to Multi Frequency Time Division Multiple Access (MF-TDMA) typically adopted in satellite systems (like DVB-RCS standard).

The rest of paper is organized as follows. First, services with their requirements are described and several classes of services to support a fair QoS management are introduced, then two different approaches to admission control are described, namely Fixed Threshold and Effective Bandwidth admission control. Finally, some numerical results, derived from software simulations are discussed and analysed.

SERVICE PROVISION

The EU NATACHA project goal is to provide passengers with typical IP based services, like voice over IP, web access, file transfer, email, etc [3]. To support QoS for such different services three Classes of Services (COS) are introduced, taking into account the different requirements and characteristics of traffic sources. Table 1 describes in detail the three above mentioned COS.

During connection set-up phase, each service has to declare its traffic class and QoS requirements, i.e. the so-called *QoS Profile*. It is a set of parameters, that are: traffic class, maximum bit rate, delivery of erroneous packet, residual bit error rate (BER), packet error ratio, transfer delay, guaranteed bit rate. These information are needed by the Satellite Broadband Terminal on ground to control connection accesses to the network and reserve them the right resources, thus a centralized control is foreseen.

Table 1. Classes of Services Definition

Class of Service:	Requirements	Typical application
Real-time	Strict transfer delay and jitter Circuit Switched behaviour	Voice over IP, video conference
Interactive	Round trip delay and packet loss sensitive	web browsing, chat, Telnet
Background	Packet loss sensitive (best effort services)	e-mail, file transfer

ADMISSION CONTROL POLICIES

As mentioned above the selected radio interface for the return link is WCDMA [2], so the main problem for the admission controller is to keep interference low enough to save QoS of the already accepted connections.

The Connection Admission Control (CAC) rules are applied only to guaranteed bit rate connections (i.e. Real-Time and Interactive services), while Background services are treated as a best effort.

In the following two approaches are introduced. In the first strategy (Fixed Threshold CAC, FT-CAC) when a Real-Time or Interactive connection request occurs a "not-manageable load factor" (η_{nm}) is calculated and compared to a fixed threshold value η_{TH} : the request is accepted if the value of η_{nm} does not exceed the value of η_{TH} . The not manageable load factor takes into account an activity factor that is depending on the service class.

In the second strategy (Effective Bandwidth CAC, EB-CAC) we use a more analytical approach to the problem basing on Effective Bandwidth strategy typically adopted in terrestrial networks (see [4]). In this context the effectiveness of Gaussian approximation for the Real-Time and Interactive services, used to get the admission region, is discussed.

Both techniques foresees the same packet scheduler algorithm to assign the right spreading factor to each connection. It will be described at the end of this section.

Fixed Threshold-CAC Algorithm

We consider as "not manageable connections" services belonging to Real-Time and Interactive class, since they have strict delay requirements thus needing a guaranteed bandwidth.

Basically, in the current algorithm, the expression for η_{nm} (not manageable load) is used a formula very similar to the well known one used in the terrestrial environment for the load estimation based on throughput, but some parameters have been changed :

$$\eta_{nm} = (1+f)\sum_{j=1}^{N} \frac{1}{1+\dfrac{SF\_MAX_j}{\left(\dfrac{\hat{E}_b}{I_0}\right)_j AF_j}} \tag{1}$$

where: N is the number of connections, AF is the source activity factor, SF_MAX is the maximum allowed spreading factor, f is the other-to-own spot interference ratio, $\frac{\hat{E}_b}{I_0}$ is the required bit energy to interference ratio.

A not manageable connection is admitted in the system if the next equality is verified :

$$\overline{\eta_{nm}} < \eta_{TH} \tag{2}$$

The admission criterion is based on an average value for the not manageable load factor, thus taking into account a short term fluctuation in the network load has a weak weight on the behavior of the admission controller. In other words, we consider an average load factor in which the already activated sources are considered with a minimum (then guaranteed) bit rate. Moreover in (1) we assumed a bit energy to interference ratio equal to the ideal value because we are assuming an ideal power control.

The threshold value has to be a bit smaller of the maximum load factor expected in the network :

- to take into account the not ideality for the power control;
- to give to Background services the possibility to transmit not too rarely;
- to take in account the bursty nature of the web sources.

Effective Bandwidth-CAC Algorithm

This approach is based on a Minimum Power Allocation Algorithm (MPA), described here in the following.
The goal of MPA is, given a number of dedicated channels (DCHs) with heterogeneous BER requirements, to find the minimum received power level of each code channel such that the QoS constraints are satisfied.
The set of DCHs allocated to user i is represented by a vector $C^i = \left[C_1^i, \cdots, C_M^i\right]$, which must be chosen from an OVSF tree. Such a OVSF tree has M levels of orthogonal codes and the spreading factor of the m-th level is assumed to be $G_m = 512/2^{m-1}$, m = 1,….,M (in our case we consider eight levels, related to spreading factors that go from 512 to 4). In this way the transmission rate of the DCH using code at the m-th level is $r_m = W/G_m$, where W is the chip rate of the WCDMA NATACHA system.
Still considering the i-th user ,one of its DCHs at the ν-th level of the OVSF code tree experiences an interference I_ν^i at the receiver on the base station. I_ν^i consists of two terms: $\mathrm{I}_{\mathrm{TOT}}^i$ that is the interference from DCHs of other users[*] in the same system (including the contribution due to the other spots); N_0, that is the thermal noise.
The SINR of one of the ν-th level DCHs, denoted by , can be described as :

$$\left.\frac{E_b}{I_0}\right|_\nu^i = \frac{P_\nu^i \cdot G_\nu}{I_{TOT}^i + N_0} > \left.\frac{\hat{E}_b}{I_0}\right|_i \tag{3}$$

where $\nu \in \{1,....,M\}$ and $i \in \{1,....,N\}$ are respectively the DCH level and the user of interest, N_0 is the thermal noise Interference $\mathrm{I}_{\mathrm{TOT}}^i$ is contributed by the power levels of DCHs of all users except those of the aircraft in which the user i is located, so :

$$I_{TOT}^i = \underbrace{(1+f)\cdot\left(\sum_{h=1}^{N}\sum_{m=1}^{M} C_m^h \cdot P_m^h\right)}_{\text{power level of all users}} \quad - \quad \underbrace{\sum_{j\in AC_i}\sum_{l=1}^{M} C_l^j \cdot P_l^j}_{\text{power level of aircraft to which user i belongs}} \tag{4}$$

To minimize the power levels of each DCH, the equality in (3) must hold. In this way, we can define the optimal received power of the ν-th level DCH relatively to the user i :

$$P_\nu^i = \frac{N_0 \cdot \left.\frac{\hat{E}_b}{I_0}\right|_i}{G_\nu \cdot [1+A_i] \cdot \left[1-(1+f)\cdot \sum_{q=1}^{\mathrm{N\_AC}}\left(\frac{A_q}{1+A_q}\right)\right]} \tag{5}$$

where N_AC is the number of present aircraft in the spot and

$$\Gamma_j = \sum_{l=1}^{M} \frac{C_l^j}{G_l},$$

$$A_i = \sum_{j\in AC_i}\left(\Gamma_j \cdot \left.\frac{\hat{E}_b}{I_0}\right|_j\right).$$

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[*] users belonging to the same A/C are not interfering

Since each DCH has power constraints (thus allowing load factor not exceeding its maximum value), it is required that the received power level of one of the m-th level DCHs be less than $P_{\max}^{m}$. Thus must be $P_m^i \le P_{m,\max}$ and this inequality must be verified any is the consumer in the spot. Then we define :

$$\Delta = \max_{\substack{v=1\ldots M\\ i=1\ldots N}} \left[\frac{N_0 \cdot \left.\dfrac{\hat{E}_b}{I_0}\right|_i}{G_v\left[1+A_i\right]\cdot P_{v,\max}} \right] = \max_{\substack{v=1\ldots M\\ i=1\ldots N}} \left[\frac{\dfrac{N_0}{G_v \cdot P_{v,\max}} \cdot \left.\dfrac{\hat{E}_b}{I_0}\right|_i}{1+A_i} \right] \tag{6}$$

so we can introduce the following inequality :

$$\sum_{h=1}^{N} \left(\frac{\Gamma_h \cdot \dfrac{\hat{E}_b}{I_0}}{1+A_h} \right) = \sum_{q=1}^{\mathrm{N\_AC}} \left(\frac{A_q}{1+A_q} \right) \le \frac{1-\Delta}{1+f} \tag{7}$$

which must be satisfied in order to have minimum power allocation for each DCH and satisfy BER of each user in a WCDMA system.

$$\frac{\Gamma_h \cdot \left.\dfrac{\hat{E}_b}{I_0}\right|_h}{1+A_h} = R_h \tag{8}$$

can be viewed as the normalized transmission rate of user h, whose transmission rate in a frame is r_h and the required SINR is $\left.\dfrac{\hat{E}_b}{I_0}\right|_h$. Thus, (7) means that the overall transmission rate of all users in a frame cannot exceed $\dfrac{1-\Delta}{1+f}$, which is called normalized system capacity (NSC).

In order to take into account the contribution of non-real-time traffic to the overall normalized transmission rates, a minimum normalized transmission rate, denoted by R_{nrt} is reserved for non-real-time traffic itself.

R_{nk} is a random variable ($E\left[R_{nk}\right] = \mu_k$ and $Var\left[R_{nk}\right] = \sigma_k^2$) because the assigned bit rate varies frame by frame.

Dividing the total users in the various classes of service, from (7), the following constraint must be satisfied :

$$\sum_{h=1}^{N} R_h = \sum_{k=1}^{K} \sum_{n_k=1}^{N_k} R_{n_k} \le \frac{1-\Delta}{1+f} - R_{nrt} \tag{9}$$

where k is the service class and N_k is the number of real-time connections in the system relatively to the class k.

Thus we introduce a satisfaction factor α to evaluate the probability that the inequality is verified. Established $0 \le \alpha < 1$, if

$$\Pr\left(\sum_{k=1}^{K} \sum_{n_k=1}^{N_k} R_{n_k} \le \frac{1-\Delta}{1+f} - R_{nrt} \right) \ge \alpha \tag{10}$$

then (9) is satisfied with probability α.

Given a satisfaction factor α, the admission region can be characterized based on (9). In what follows the Gaussian approximation is used to derive the admission region.

According to the central limit theorem, when N_k is large , $\sum_{n_k=1}^{N_k} R_{n_k}$ can be approximated by a Gaussian random variable G_k with mean and variance equal to $N_k \mu_k$ and $N_k \sigma_k^2$,respectively. Moreover the sum of normally distributed random variables still gives out a normal r.v., so (9) becomes :

$$\Pr\left(G \leq \frac{1-\Delta}{1+f} - R_{nrt} \right) \geq \alpha \,. \tag{11}$$

If we take into account the characteristics of Gaussian random variables the previous equation yields :

$$\sum_{k=1}^{K} N_k \mu_k + \beta \sqrt{\sum_{k=1}^{K} N_k \sigma_k^2} \leq \frac{1-\Delta}{1+f} - R_{nrt} \tag{12}$$

which determines the admission region $\left(N_1, \ldots, N_k\right)$. When a connection of service k arrives, N_k is increased by one. This new connection can be accepted if the new value of N_k respects the inequality (12), otherwise , it is rejected.

Remarks on the applicability of the algorithm

Of course the Effective Bandwidth CAC (EB-CAC) described previously, is applicable only if the hypothesis on the traffic sources are satisfied. This fact means that the sources total bit rate as seen at the scheduler output , as much as possible a Gaussian-like behavior: R_{nk} mean and variance values (μ_k and σ_k^2, respectively), that is related to Normalized Transmission Rate of a generic source n_k belonging to the k service class, are measured on air, i.e. after the SF allocation by the scheduler. Therefore they deeply depend on the scheduler algorithm properties, i.e. as the bit rate (hence the spreading factors) are continuously allocated in the long run.

In the Fig. 1 it is compared the probability density function (PDF) of G_k random variable for the Real-Time and Interactive cases with the one of a Gaussian random variable having the same expected value and variance. In the Interactive case, the two graphs are clearly much different: it can be noticed the absolutely non-Gaussian course of the web connections aggregate .Thus EB-CAC could not be applied as in the analytical study if we include the Interactive class contribution in the equations (10)-(12).

The Effective Bandwidth CAC with Gaussian approximation has to be modified to be really useful.

The Admission Controller accepts the communication requests of the various sources only if the following condition remains true:

$$\left(N_1 \mu_1 + \beta \sqrt{N_1 \sigma_1^2} \right) + \left(R_{WEB} \right) \leq \frac{1-\Delta}{1+f} - R_{nrt} \tag{13}$$

Really the R_{WEB} expression can be calculated as the sum of the NTR (Normalized Transmission Rates) of the web sources, when the assigned spreading factor is the maximum one and introducing an activity factor that estimates the time percentage in which each source gives out data.

$$R_{WEB} = \sum_{h=1}^{N_2} \overline{R}_h = \sum_{h=1}^{N_2} \left(\frac{\Gamma_h \cdot \frac{\hat{E}_b}{I_0}}{1+\overline{A}} \cdot AF_{WEB} \Big|_{SF\_MAX} \right) \tag{14}$$

Packet Scheduler Algorithm

A packet scheduler is foreseen within the Satellite Broadband Terminal on board, to assign the right spreading factor to the active connections, basing on a chosen scheduling discipline, i.e. Earliest Deadline First (EDF) in our case [5].

It is applied only to Interactive and Background classes, since a maximum spreading factor is always allocated to Real-Time connection due to their strict delay requirements (e.g. about 300 msec)

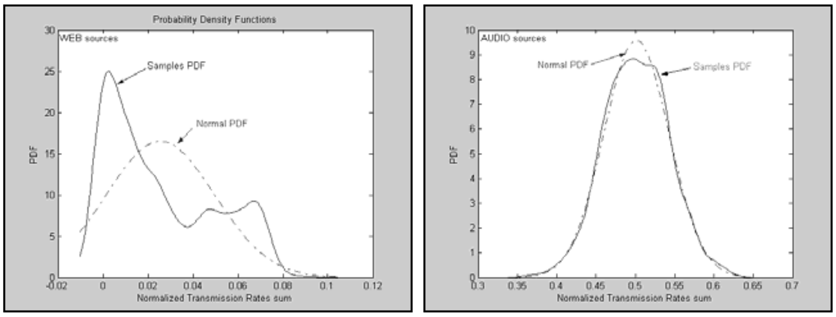

Fig. 1. G_k Probability Density Function, relative to the VOICE and WEB service classes (Samples PDF), compared to Gaussian ones.

First, each transmission buffer is assigned a different priority, according to the EDF discipline. Then, from the higher priority buffer a spreading factor (i.e. a Dedicated Channel, DCH) is assigned so as to empty the buffer during a frame. All the available resources (codes on the OVSF tree, one per aircraft) are assigned until the normalized system capacity is not exceeded.

SIMULATION RESULTS

In order to compare the two introduced admission control algorithms, a software simulator based on OPNET Modeler has been designed. To characterize the three classes of services we have implemented three different traffic sources, whose characteristics are summarized in Table 2.

We have performed two sets of simulations.

In the former (Figure 2 and 3) the measurements are got varying the Voice connection requests per minute (from 70 to 120) and keeping the other service types with a fixed request arrival rate (90 and 80 reqs/min for the Web and Email respectively). EB-CAC accepts much more Web connections, so also web aggregate throughput is quite larger than FT-CAC. The Voice and Email aggregates show a similar throughput for the two algorithms, whereas the End-To-End (ETE) delay are slightly better in the FT-CAC.

In the second set of simulations (Figure 4 and 5) the measurements are got varying the Web connection requests per minute (from 80 to 130) and keeping the other service types with a fixed request arrival rate (90 and 80 reqs/min for the Web and Email respectively). It can be noticed how even in this case EB-CAC behaviour is better than FT-CAC in Blocking probability. The strange shape of the curve in fig. 4 can be explained as follows. Logically if the connection arrival rate augments then there are more connections that compete for the same shared resource (i.e. the Normalized System Capacity). When the Web arrival rate is high (e.g 130 connection req/min) then the Web sources have however an higher probability to obtain the resource as regards the Voice sources (having a smaller arrival rate i.e. 90 reqs/min). Considering that a Voice contribution to the network load is much higher than the Web one, when a Voice call terminates, the Interactive service requests have a larger probability to obtain the released resource. An arriving Voice call then sees most probably an insufficient free system capacity (the released resource is now in part already assigned to some Web source), afterwards it is rejected by the admission control.

Fig.5 shows how ETE delay for web sources and web throughput is higher in the case of EB-CAC.

Tab. 2 Traffic Source Parameters

VOICE source	AMR codec (12.2 kbps) UDP/IP	Average (IP) bit rate : 31.6 kbps	VBR ON-OFF
WEB source	TCP/IPv6	Average (IP) bit rate : 1 kbps	VBR bursty
EMAIL source	TCP/IPv6	Average (IP) bit rate : 3.72 kbps Average Email size : 80kbit	VBR bursty

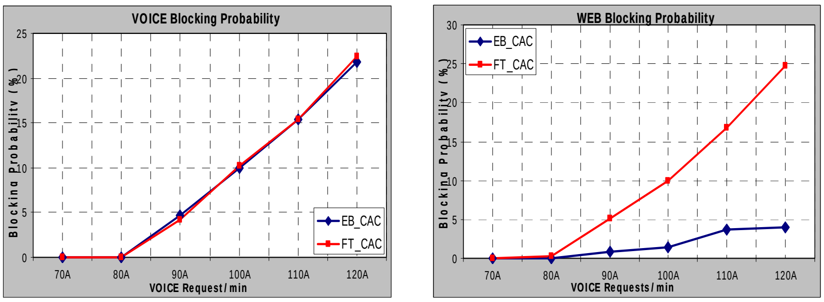

Fig. 2. First set of simulations : connection blocking probability versus VOICE connection arrival rate.

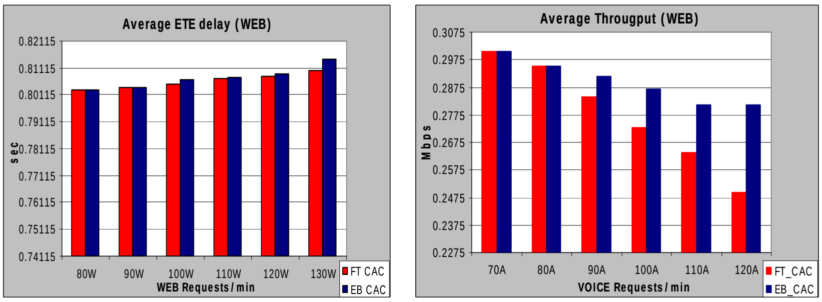

Fig. 3. First set of simulations: ETE delay and (aggregate) and Web throughput versus Voice call arrival rate for the Web class.

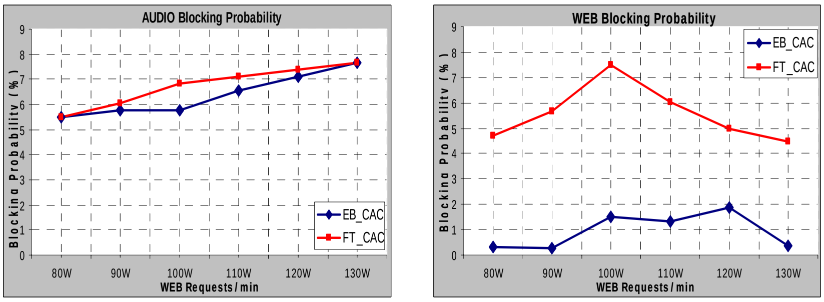

Fig. 4. Second set of simulations : connection blocking probability versus Web connection arrival rate.

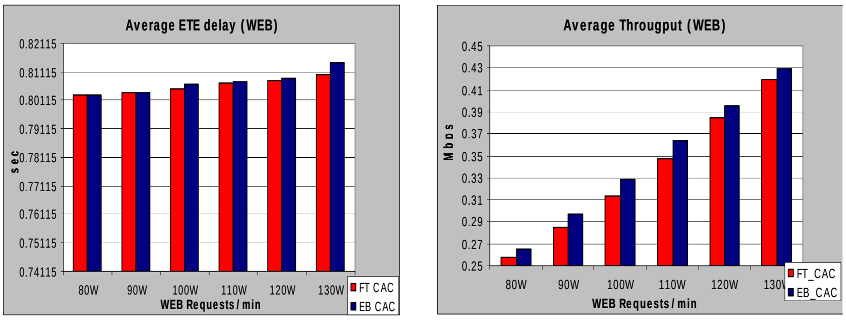

Fig. 5. Second set of simulations: ETE delay and (aggregate) and web throughput versus web call arrival rate for the Web class.

Finally, from simulation results analysis appears how the EB-CAC analytical approach is able to give a better evaluation of available radio resource, thus allowing high capacity in term of number of accepted connection and throughput.

CONCLUSIONS

In this paper we have described two different algorithms to solve admission control issues related to guaranteed bit rate connections. In the former (FT-CAC) the sources are characterized by activity factors that take into account the statistic properties of the generated traffic.In the latter algorithm (EB-CAC) we have used the effective bandwidth concept applied to the guaranteed bit rate connections, also analysing the Gaussian approximation for the aggregate traffic, concluding that it is valid only for the Real-Time class. Then we have introduced an hybrid solution in which the Gaussian approximated is used only for the Voice sources whereas the web connections are characterized again by activity factors.

The results we have obtained point out a better behavior of the EB-CAC to manage radio resource, especially in terms of blocking probability and Interactive service throughput.

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