

# An Access Protocol for Multimedia Services Provision in an Avionic Environment

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**Abstract**—In this paper an innovative architecture to support multimedia service over an avionic environment is described. The focus is on the access protocol definition towards the satellite link. In particular, two different techniques are proposed for the return link: Per Aircraft Technique and Per Connection Technique. Functional architecture for both the techniques is described. Merits and drawbacks of the two protocols are highlighted by means of software simulations.

*Keywords:* In Flight Entertainment, GEO satellite, Quality of Service, Wideband CDMA

## I. 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 NATACHA Broadband Aircraft Terminal (NABAT). NABAT 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 NABAT entity and a gateway to external networks.

This paper is focused on data link via the satellite between Aircraft and Ground segment; in particular the aim is to

describe the access protocol and bandwidth allocation strategy in the return link. The medium access technique used in such system is based on Wideband Code Division Multiple Access (WCDMA) which let the system have an asynchronous way of working. The rest of paper is organized as follows. Section II describes system architecture and constraints. In Section III two different access protocols are described: Per Aircraft Technique and Per Connection Technique. Section IV is dedicated to simulations and result analysis. Finally some conclusions are drawn in Section V.

## II. SYSTEM ARCHITECTURE AND CONSTRAINTS

It is known that the capacity of WCDMA networks depends on the return link rather than the forward link so only that link is treated in this paper. Reference scenario is shown in Figure 1: several aircrafts (A/Cs) compete for the bandwidth according to the service requests they have on board. The satellite is considered as a simple mirror (only the gain of antenna is considered) that is no particular data processing takes place on it.

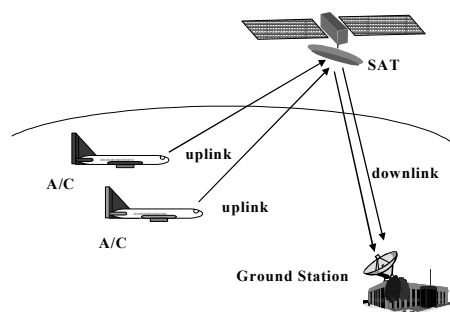


Figure 1 – Return link scenario

On the basis of what described in [2], Figure 2 depicts satellite data link segment architecture. The system is basically composed by several entities and in particular for the A/C side:

- *NCR*: it is in charge of interfacing the on board LAN with satellite segment, of Quality of Service (QoS) at IP level, mobility and security management.
- *NABAT*: it is in charge of interfacing the NCR with satellite radio interface. It can manage radio resources

in term of bandwidth allocation, power control, error correction,...

For the ground side:

- *NABAT*: it is the peer entity to the on board one;
- *Gateway Router*: it is in charge of interfacing with external networks (IP, ISDN, PSTN, ATM,...)

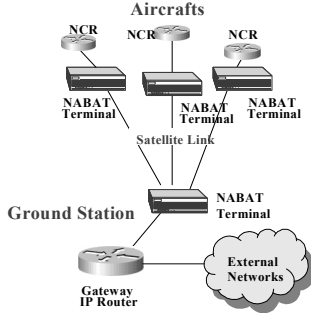


Figure 2 – Satellite Data Link Segment system architecture

#### A. Service Classes and Data Link Layer Design

NATACHA services (voice over IP, web access, file transfer, email,...) [3] has been divided into three classes taking different service QoS requirements into account, as shown in Figure 3.

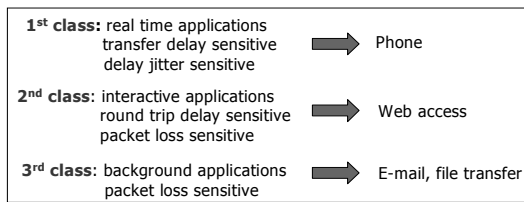


Figure 3 – Service Classes Definition

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.

After the connection set-up phase, data link layer is in charge of encapsulating IP datagrams from the NCR into satellite frame structure (SatCom interface), i.e. to segment and schedule IP datagrams. NABAT SatCom interface both on aircraft and on ground is described in Figure 4.

A/C NABAT is composed by a classifier that selects IP flow, a set of transmission buffers, one for each connection, a segmentation/scheduling entity. Retransmission buffers are also foreseen for Class 2 and 3 (less delay sensitive classes). They are controlled by the *ARQ Entity*, in which Selective Repeat algorithm is implemented.

Ground NABAT is made by a set of receiving buffers, a reassembling entity and the peer *ARQ Entity*.

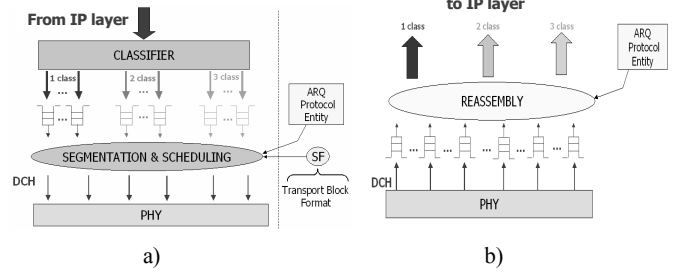


Figure 4 – NABAT SatCom interface. a) on aircraft; b) on ground

#### B. System requirements and constraints: [4], [5]

- *Bit Energy-to-interference ratio ( $E_b/N_o$ )*: it is requested to be upper than a certain value established for each service thus guaranteeing its QoS. The formula we used is shown below where  $P_j$  is the j-th power received on ground,  $SF_j$  is the j-th spreading factor,  $I_{tot}$  the total interference and  $v_j$  the j-th activity factor.

$$\left(\frac{E_b}{N_o}\right) = \frac{SF_j}{v_j} \frac{P_j}{I_{tot} - P_j}$$

- *Load factor  $\eta$* : it indicates how much the system has been loaded by the traffic. It is calculated by this formula where  $W$  is the chip rate,  $i$  the inter-spot interference,  $N$  is the number of users, and  $R_j$  the j-th bit rate:

$$\eta = (1+i) \sum_{j=1}^N \frac{1}{1 + \frac{\left(\frac{E_b}{N_o}\right) R_j v_j}{W}} = (1+i) \sum_{j=1}^N \frac{1}{1 + \frac{\left(\frac{E_b}{N_o}\right) v_j}{SF_j}}$$

- *Maximum load factor  $\eta_{MAX}$* : it represents the upper bound the load factor ( $\eta$ ) can assume. It is fixed by the Power Spectral Density (PSD) constraint.

### III. ACCESS PROTOCOLS

In the following two different approaches are presented: Per Aircraft Technique (PAT) and Per Connection Technique (PCT). The NABAT architecture, depicted in the previous section, is the same for both the approaches: the only difference is in the scheduling discipline that is implemented on board in PAT, and on ground in PCT.

#### A. Per Aircraft Technique (PAT)

In the PAT case each A/C is considered as a single entity that generates traffic. The appropriate SF is assigned to each aircraft (see Figure 5) according to its  $E_b/N_o$  requirement in order to satisfy the load factor upper bound ( $\eta < \eta_{max}$ ). In this way each A/C has a set of available codes the on board NABAT can allocate to the different user applications.

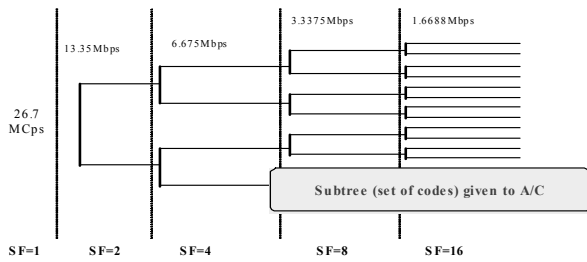


Figure 5 – Spreading code assignment within the A/C. (PAT case)

It is worth highlighting that the PAT foresees an asynchronous access among aircrafts and synchronous among connections within the aircraft. In particular, the interference produced by A/Cs is controlled so as to manage load factor not to exceed the maximum allowed value (asynchronous access), and the bit rate is assigned to a single connection according to its own QoS requirements (synchronous access). This procedure works every Transmission Time Interval (TTI).

The PAT functional architecture (Figure 6) is made by two main blocks within the NABAT terminals: the *Bandwidth Manager (BM) block on board* and the *BM block on ground*.

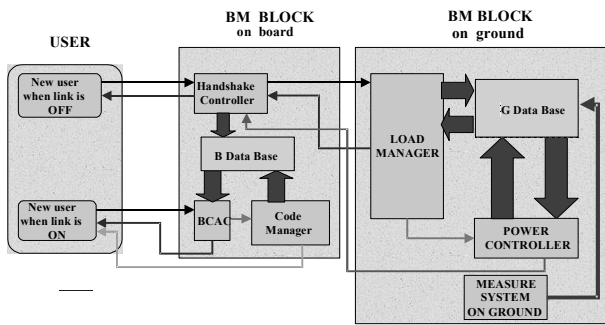


Figure 6 – PAT Functional Architecture

BM block on board is composed by the following sub-blocks:

- *Handshake Controller (HC)*: it receives service requests from user (when the A/C have not the link on yet), the request is then forwarded to the Ground Station (GS). If the request is accepted, the SF is received by the HC together with the information about transmission power: these two parameters are written in the *on Board Data Base (BDB)*. If the request is rejected, HC informs the user about this refuse.
- *On board Call admission Control (BCAC)*: it receives service requests from user (when the A/C has already the link on). The BCAC reads from the BDB the available codes and decides whether the request can be accepted or not. If accepted the request is forwarded to the Code Manager.
- *Code Manager (CM)*: it is in charge of giving each accepted request the available code on the basis of a scheduling strategy which is inspired by the Earliest Deadline First (EDF) strategy.

BM block on ground is composed by the following sub-blocks:

- *Load Manager (LM)*: it calculates the current value of the load factor (with or without modifying the SF) then activates Power Controller.
- *Power Controller (PC)*: it calculates the new value of A/C received power and then starts the power control loop thus satisfying  $E_b/N_0$  requirement.
- *Measure System on Ground (MSG)*: it measures received power for each A/C and writes these values in the *on Ground Data Base (GDB)*.

### B. Per Connection Technique (PCT)

In the PCT case each connection is considered as a single entity. The appropriate SF is assigned to each connection (see Figure 7) in order to satisfy its own  $E_b/N_0$  requirement and load factor ( $\eta < \eta_{max}$ ) constraint. In this case each connection receives the code directly from the Ground Station (i.e. from the NABAT on ground): the NABAT on board is a simple agent in charge of reading signaling messages and consequently set Data Link and Physical layer.

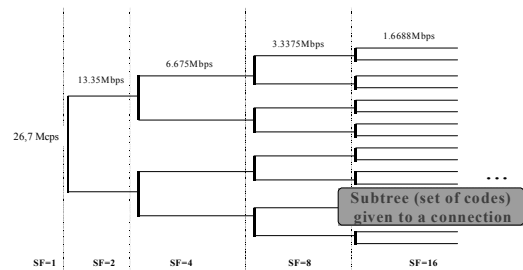


Figure 7 - Code tree and SF assigned to a connection. (PCT case)

The  $E_b/N_0$  is not the same for each connection because of the different class of service the connections belong to. It is worth highlighting that access and load control is completely centralized within the Ground Station. Even in this case only one code tree is for an A/C, thus several connections belonging to a single A/C have to share a limited set of codes as reported in Figure 7. The functional architecture is shown in Figure 8 where the main blocks of the system are presented. As in PAT, the main blocks involved are BM on ground and on board.

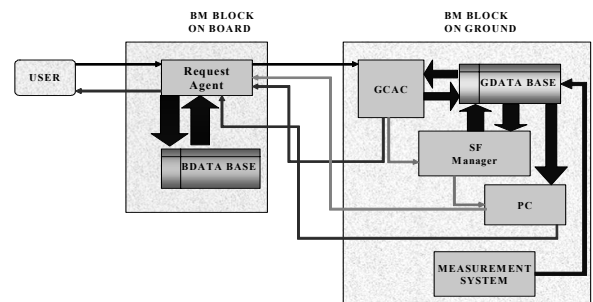


Figure 8 - PCT Functional architecture

BM block on ground is composed by the following sub-blocks:

- *on Ground Call Admission Controller (GCAC)*: it receives the connection requests from the Request Agent. Its task is to decide whether the request can be

accepted or not according to the call admission control strategy. The procedure works as follows: first the value of  $\eta_{nm}$  (not manageable load factor) is calculated and compared with threshold value  $\eta_{th}$  (obtained by simulation):

$$\eta_{nm} = (1+i) \sum_{j=1}^{c_{nm}} \frac{1}{SF_j} \leq \eta_{th}$$

$$1 + \frac{\left(\frac{E_b}{N_o}\right) v_j}{SF_j}$$

The value of  $\eta_{nm}$  is calculated by using the SF<sub>j</sub> associated to the not manageable connections ( $c_{nm}$ ) i.e. connections belonging to service class 1 (video & voice) and 2 (web) taking into account their activity or silence period. As reported in Figure 9, the request is accepted if the value of  $\eta_{nm}$  does not exceed the value of  $\eta_{th}$ .

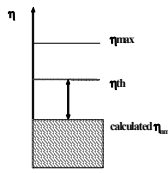


Figure 9 - CAC Algorithm Approach

- **SF Manager (SFM):** It deals the SF to each connection according to the EDF scheduling discipline then, it passes to the PC block a vector composed by the SFs assigned to each application (for the next frame). SF allocation is implemented as follows (as depicted in the flow chart in Figure 10): a parameter called  $\eta_{active}$  is calculated according to the following formula:

$$\eta_{active} = (1+i) \sum_{j=1}^{c_{ns}} \frac{1}{SF_{max}} \frac{1}{1 + \frac{\left(\frac{E_b}{N_o}\right) v_j}{SF_{max}}}$$

where  $c_{ns}$  indicates the number of transmitting connections in the considered TTI,  $SF_{max}$  is the maximum SF associated to a single connection thus guaranteeing a minimum bit rate. Then a loop starts in order to allocate the SF to every active connection till the load factor reach the value  $\eta_{max}$ : a QoS queue is selected according to the priority assigned by EDF algorithm, a spreading factor is assigned so as to empty its transmission buffer during a TTI.

- **Power Controller (PC):** it makes the power control working. First it checks the value of  $E_b/N_o$  for each connection: then sends a vector to each A/C composed by the increasing or decreasing value ( $\Delta P_{jt}$ ) of the single connection power.

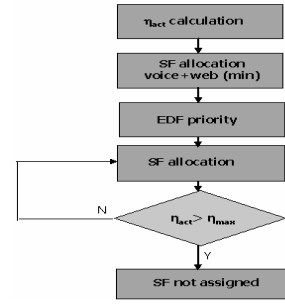


Figure 10 - EDF algorithm flow chart in the PCT

BM block on board is composed by the following sub-block.

- **Request Agent (RA):** it forwards the request to GCAC and the service class it belongs to. Then it records in *on Board Data Base (BDB)* the vector of  $\Delta P_{jt}$  sent by the PC and compares the total amount of requested power to the maximum limit for the A/C power. If the limit is exceeded, the RA does not increase the connection power for a frame waiting for an acceptable power request from PC.

#### IV. SIMULATION RESULTS

In order to make a comparison between the two proposed techniques, a software simulator has been designed using OPNET Modeler. The aim of these simulations is to point out the differences in traffic handling and bit rate allocation by the proposed methods.

##### A. Simulation Scenario

The scenario that have been analyzed is made by 16 A/Cs within the same satellite spot, transmitting to the Ground Station for 5 minutes.

In Table 1 the traffic values for each class of service are shown; both short range (SR) and long range (LR) flights have been considered, even if only short range results are presented in this section. A Rician channel model has been considered for such a scenario.

Table 1 – The traffic values for each service class

| TRAFFIC VALUES   | SERVICE CLASS         |                       |                       |
|------------------|-----------------------|-----------------------|-----------------------|
|                  | 1 <sup>st</sup> Class | 2 <sup>nd</sup> Class | 3 <sup>rd</sup> Class |
| Average (Kbps) * | 15.8                  | 0.9                   | 0.6                   |
| Peak (Kbps)*     | 31.6                  | 6                     | 7                     |
| Max user SR      | 7                     | 5                     | 5                     |
| Max user LR      | 14                    | 20                    | 10                    |

(\*) each value is referred to a single connection

In Table 2 the most significant constraints and the utilized values of received power and  $\eta_{\max}$  are presented.

Table 2- Constraints and parameters

| CONSTRAINTS         | Values          |
|---------------------|-----------------|
| Gain of SAT antenna | 127 db          |
| Max power from A/C  | 51 dbW          |
| $\eta_{\max}$       | 0.80            |
| Received power on   | -121 ÷ -155 dbW |
| Free space loss     | 210 db          |
| Rice factor         | 30 db           |
| Chip rate           | 26.7 Mcps       |
| Bandwidth           | 36 Mhz          |

### B. Results Analysis

Graphs in Figure 11 are referred to a single SR A/C. The comparison between the assigned bit rate and the real traffic transmitted to the satellite is presented for both the techniques. It can be noticed how in the PAT case the system is not able to track the bit rate request; on the other hand the assigned bit rate is able to track the real request of a single A/C for PCT case. This is due to the fact that PAT considers an A/C as an entity which is transmitting traffic with the same Eb/No requirement, while PCT takes into account the different service Eb/No requirements.

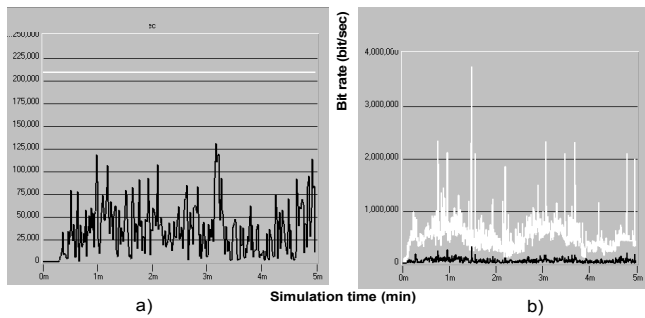


Figure 11- Comparison between bit rate assigned to an A/C (white line) and the real traffic transmitted to the to the satellite (black line) for the short range flight; a) PAT case b) PCT case.

## V. CONCLUSIONS

Two protocols for managing access to a GEO satellite and bit rate allocation have been studied and analyzed for an avionic environment: the so-called PAT (Per Aircraft Technique) and PCT (Per Connection Technique). Both protocols are fully compatible with 3<sup>rd</sup> Generation Partnership Project (3GPP) specifications [6], [7] and [8] for UMTS radio access network.

PAT protocol is basically a static multiple access technique, where the bit rate is assigned on the basis of an aggregated of traffic, i.e. on the basis of a required Eb/No that is the same for all the A/Cs. The required Eb/No is fixed to the strictest values (usually voice Eb/No). It means that a *hard capacity* is assigned to the A/C. It is up to the BM on board to deal this capacity among all user connections.

PCT is a “bandwidth on demand” protocol, i.e. A/C bit rate is assigned on the basis of the effective request by users on board: the QoS parameters requested by a connection are the assigned QoS parameters (Eb/No, Power and SF). It means that a *soft capacity* is assigned to the A/C for the number of services the network is able to manage. System capacity depends on number and type of user service requests. This is a classic 3G WCDMA scenario where the capacity is not previously fixed.

Of course PCT foresees a more complex resource management within the Ground Station and an increasing of signaling messages between the A/C and the Ground Station, but also a more flexible resource allocation and a major network performance in terms of throughput.

It is worth noting that PCT protocol is closely related to the adopted Call Admission Control and Scheduling policies. By means of an optimized network overloaded prevision (CAC) and a smarter SF allocation (scheduling) the system efficiency could get improved in terms of number of accepted connections, QoS provision and throughput.

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