End to End Quality of Service Management for Multimedia Service Provision in the Aeronautical Broadband Communication System

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Abstract— **One of the hot topics in the communication world is to realize a network able to offer a mix of services complying with different requirements, like real-time communications, broadband Internet access, email services, in every place of the world, thus achieving the concept of ”entertainment everywhere”. In such a context a key role is played by aeronautical world that seems one of the last remaining islands in which broadband communications are not available.**

The present paper aims at proposing an architecture able to provide broadband services to aircraft passengers, by describing the main aspects of aeronautical satellite communications, focusing on quality of service support and satellite network resource management.

First a comparison between standard satellite systems and aeronautical satellite communications is performed. Then, a structure to support quality of service is presented, by defining a CDMA-based return link and its resource management.

I. Introduction

In the last years, one of the main purposes in the communication world has been that of achieving the concept of ”entertainment everywhere”, i.e. implementing an architecture able to offer broadband services granting a global coverage. For that reason in-flight entertainment has become one of the hot topics in the communications world. This is mainly due to the fact that aircrafts seems to be one of the last remaining islands where personal communications, Internet access and real-time communications are not available [1].

The goal of research activities carried out in this sector is to offer similar entertainment or business experience to aircraft passengers as their terrestrial counterparts. For that purpose, broadband communications with high bit rate have to be provided to such vehicles. A network having the above mentioned characteristics is called Aeronautical Broadband Communication System (hereinafter also referred to as AirCom).

Some changes to standard satellite systems are needed in a high mobility environment (i.e. AirCom system) so as to comply its different requirements due to mobility.

DVB [2] is a broadband communication system designed to provide different types of services to fixed users. For example, it does not consider handover procedures, because there is no need to make an handover in a fixed environment. Another issue is represented by the return channel access protocol, where DVB-RCS should supply services to mobile vehicles. A precise carrier and burst synchronization between SITs and the ground station are required to obtain an efficient TDMA system with minimum interference between users and maximum throughput. Doppler shift generated by the movement of the vehicle directly affects the synchronization.

The emerging CDMA technique seems to have many useful characteristics for solving return channel issue in a high mobility environment, as reported in [3].

The present paper introduces a possible architecture to support Quality of Service (QoS) in an avionic environment when the satellite return link is based on CDMA . The article is organized as follows. In Section II system architecture and constraints are introduced in aircraft communications and the differences with respect to a fixed DVB-RCS scenario and the standard satellite UMTS surroundings are analyzed. Once the system characterization has been identified, a possible QoS support architecture is introduced in Section III, where a bandwidth on demand (BoD) protocol based on CDMA is proposed for the satellite link. All the functional entities and procedures are described in that section. Finally, some conclusions are drawn in Section IV.

II. Aeronautical Broadband Communication System

The purpose of this section is to describe the overall system architecture of the AirCom, its major components and functions likewise the constraints by the particular environment, basically focusing on the differences with respect to the classical satellite systems.

A. AirCom System Architecture

System architecture is characterized by three segments illustrated in Figure 1.

Airborne segment is composed of:

- the broadband satellite terminal (BST), including the modem and satellite resource management entity (i.e. BoD agent);
- the on-board network, composed of the avionic network for airborne control and LAN/WLAN for consumer entertainment (also referred to as In-Flight Entertainment or IFE network) and an on-board router called Network Communication Router (NCR). It includes server housing applications for security, mobility and quality of service support (i.e. the NCR) and user terminals connecting final users (crew and passengers).

Satellite Data Link segment is composed of a constellation of several satellites, providing the data links both in forward and return directions over several regions of the world.

Ground segment is composed of different ground stations, allowing access to the satellite segment, and providing connectivity between the system and terrestrial networks. The Network Operation Center (NOC) includes the control centers used to manage the system and its components described below:

- A Regional Network Operation Center (R-NOC), which co-ordinates the activities within a region,
- A Primary NOC (P-NOC), which co-ordinates the activities at system level (such as system planning, hand-over, etc.),
- The ground backbone provides communication links between every terrestrial elements (gateways, operation centers) and also between them and final customers (airline, service and content providers). It is composed of an on ground BST and a router gateway (within the ground station) and the IP Core Network.

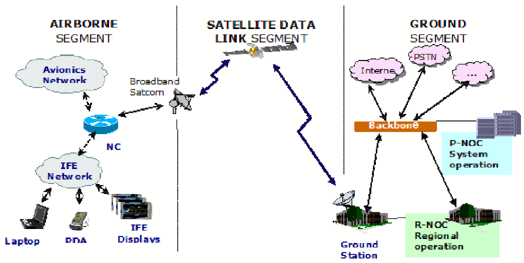

Fig. 1. Overall System Architecture

B. AirCom System Constraints

The comparison between AirCom and the reference satellite scenarios (i.e. DVB and S-UMTS) evidences that there are two main differences between the three scenarios. They can be classified as (i) terminal characterization and (ii) satellite radio channel.

Terminal characterization means the difference in portraying user terminals by the three systems, whereas satellite radio channel indicates the different behavior of air interface, especially the return channel.

It can be noticed that in the DVB scenario, terminals are considered as fixed in a precise place and in S-UMTS scenario mobile terminals are represented by one user driving hand-held device; on the contrary in the AirCom system, terminals have high mobility (i.e. high speed) and are composed of several users (i.e. a LAN) generating traffic.

The terminal characterization has an impact both on traffic management and the satellite radio channel.

Satellite radio channel characterization means the difference in defining a reference model for the AirCom air interface with respect to the classic satellite radio link, as also reported in [4] and [5]. In particular, losses due to rainfall and hydrometeors do not affect aircraft environment during flight. Path blockage losses are not induced by obstacles like hills or trees but they are caused by tail and wings mainly during manoeuvres. AirCom air interface is also affected by Doppler spread and propagation delay variation due to aircraft speed. Those issues can be compensated through pre-compensation techniques based on the precise knowledge of mobile speed. An estimate of said speed may be based on the integration of a navigation receiver (e.g. GPS) on the aircraft providing speed and position information.

III. Quality of Service Support

One of the most challenging objectives of broadband communication systems, like AirCom, is to support Internet QoS-sensitive services providing the user with End-to-End (E2E) QoS guarantees.

Since Integrated Service ([6]) and Differentiated Service ([7]) architectures can be considered as complementary technologies, the solution adopted in our system is based on an hybrid IntServ-DiffServ approach ([8]).

The rationale is to exploit, on one side, the possibility for hosts to request quantifiable resources along E2E data paths, possibly provided by the IntServ architecture, and on the other hand the scalability provided by the DiffServ architecture. According to the hybrid IntServ-DiffServ approach, wireless segments (WLAN and satellite link in the AirCom), acting as access networks, provide QoS guarantees by adopting the IntServ solution, while as far as the core network is concerned, it is envisaged that it adopts the DiffServ solution.

In an access network to support information transfer between mobile users and the terrestrial Internet network with a required QoS, the status of resources occupancy of the core network has to be taken into account while performing the bandwidth assignment within the wireless segments. This resource management co-ordination is required not only at connection set-up but also while the connection is in progress. Rationale is to avoid that access segment resources are redundantly allocated whenever the core network is not able to ensure the requested QoS (due to current load or congestion status). This procedure is mainly required for the satellite systems whose resources could be more critical than those of the terrestrial wireless systems.

According to the hybrid IntServ-DiffServ scenario, four sets of activities need to be performed:

- IntServ operations;
- DiffServ operations;
- Coordination of the resource management between wireless networks and DiffServ domain and interface among different domain, i.e. the definition and enforcement of Service Level Agreements (SLA);
- Fair and adaptive distribution of resources among competing sources.

AirCom E2E QoS Service can be split in three different QoS Services:

- *LAN QoS Service*: i.e. the QoS management performed by the NCR and LAN/WLAN networks for the traffic on board aircrafts.
- *Satellite QoS Service*: i.e. the QoS management performed by the BSTs and the P-NOC for traffic within a satellite spot.
- *Core Network QoS Service*: i.e. the QoS management performed by the ground gateway router and the

backbone routers (edge and core) to complete the path till the wired host/server.

LAN and Satellite QoS Services are based on IntServ approach, whereas Core Network QoS Service is based on DiffServ approach.

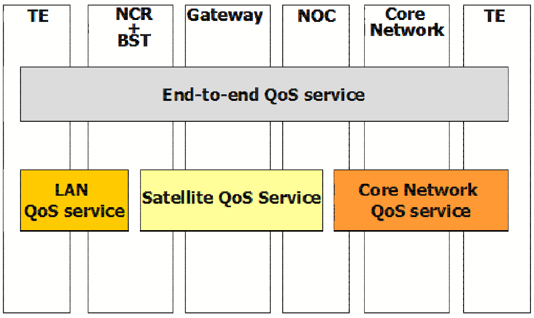

Fig. 2. AirCom QoS Services

Coordination and inter-domain interface functions are implemented within special entities called Bandwidth Brokers (BBs). They act as network resource managers controlling all hosts and router of a given domain. Their main task is to set, change and renegotiate SLA dynamically as a result of variation of offered traffic load or from changes in pricing offered by the provider. Those changes are controlled by automated agents and protocols within the BBs.

Figure 3 shows the architecture for QoS provision, underlining role and location of BBs within the end-to-end path.

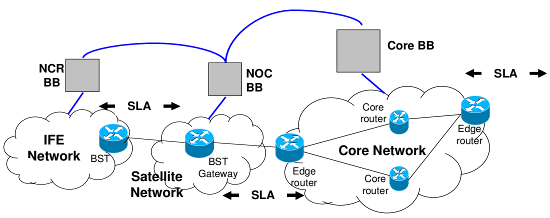

Fig. 3. Architecture for QoS Support in the AirCom

Each AirCom system domain has its own BB in charge of managing domain QoS Service. In particular:

- the BB for the IFE network is within the NCR that is in charge of managing LAN QoS Service and interfacing with the satellite network BB.
- the BB for the satellite network is within the NOC. It is in charge of managing Satellite QoS Service and interfacing with the core network.
- the BB for the core network is a special entity to be designed. It shall be able to interface with NOC and managing edge and core routers (in the following referred to as ER and CR, respectively) within DiffServ domain.

When a passenger intends to transfer traffic with desired QoS, he requests the service to the NCR BB that forward the request to the NOC BB and the core BB, communicating a set of parameters that describe the traffic that will be generated (i.e. traffic descriptors). The three BBs exert admission control algorithms nearby their domain to check whether they can allocate new resources to match the request and eventually accept the requested connection.

During the information transfer, the NCR also execute usage parameter control function so as to monitor the information stream to ensure that the user emits traffic in conformity with the traffic characteristics specified at the connection set-up. In this way, the major complexity is located at the edge of the network.

The ER and CRs implement the DiffServ mechanism by means of suitable PHBs or scheduling discipline. The NCR , the ground gateway router and ER have also the specified task of guaranteeing the respect of the agreed traffic descriptors and user perceived performance between different domains (i.e. SLAs). The BB exchanges signalling information with peer BBs and configures the routers accordingly to achieve such a goal.

It is worth noting that the proposed hybrid IntServ-DiffServ Internet architecture provides the opportunity to establish a fully IntServ compatible E2E communication path, e.g. from the passenger terminal to a wired host, by-passing the core netwrok and thus providing per-flow hard QoS performance.

Regarding the three QoS Service foreseen in the AirCom system, LAN QoS Service is based on the classical approch to provide QoS over a LAN/WLAN (e.g. IEEE 802.11e QoS support when a WLAN is involved [9]), whereas Core Network QoS Service can be based on DiffServ/MPLS approach [10]. On the contrary, Satellite QoS Service can be considered as a new issue to guarantee E2E QoS services in the AirCom.

In the following sub-sections a possible resource management solution for the Satellite QoS Service is presented by introducing a service classification, a BoD protocol with its relative signalling messages and a data link layer architecture when a code division multiple access is applied.

A. *Service Classification*

In order to support a big variety of broadband services with different QoS profiles, three Classes of Service are introduced in order to have a per-flow resource management together with a major network performance.

Conversational is the real-time application class, where delay constraints are very pressing. Services belonging to this class are typically constant bandwidth allocation sources, like VoIP or video-conference service.

Interactive is the time-elastic application class, where delay constraints are more relaxed than conversational but BER requirements have to be complied with. Services belonging to this class are typically bursty sources that allow a dynamic bandwidth allocation.

Background is the best effort class, in which BER requirements are in compliance with. Services are typically bursty sources and a volume-based allocation, when bandwidth is available, is required.

Service classification functions are implemented within the NCR by means of proper mapping procedures between LAN QoS Service and Satellite QoS Service parameters.

B. BoD Protocol Definition

A dynamic radio resource management protocol is required in the AirCom so as to adapt the data link throughput of the aircraft to the satellite real-time capacity, i.e. to adapt physical satellite resources usage in terms of bandwidth, in order to respect regulatory constraints (e.g. power spectral density limit in the relevant bandwidth) guaranteeing at the same time the desired QoS to every active connection.

Centralized resource management functions are performed within the primary NOC. P-NOC controls an on ground BoD agent within the ground BST. Information on resource management is then transmitted by the on ground BoD agent to the aircraft BoD agent within the on board BST, which is able to update the QoS parameters of the NCR. The on-board network IP throughput is thus maintained coherent with the satellite data link performance.

Resource management functions have an impact on several parts of the relevant communication link. First, the NCR receives the request from a user to transmit data. The NCR then applies the QoS rules in order to aggregate and prioritize this data flow in respect of other passengers data flows. The NCR also interacts with the aircraft BoD agent contained in the BST so that the aircraft data link is adapted to support the aircraft communication needs. The aircraft BoD agent then asks the on-ground BoD agent to request a resource allocation. The answer is then forwarded back up to the user terminal.

The whole sequence is described in the chart within Figure 4.

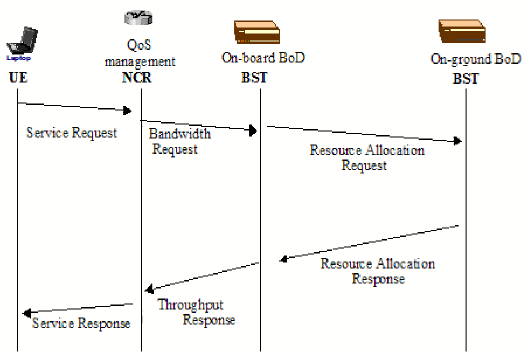

Fig. 4. BoD Protocol diagram

When a new request occurs, the BoD agent on board forwards the request together with its traffic descriptors (i.e. Eb/I_0 and the QoS parameters) to the BoD agent on ground.

Then, an *admission control phase* starts to ascertain whether the new connection can be accepted by the network without damaging the QoS of the already accepted connections. Only if the admission control phase is positive the *resource allocation phase* begins in order to assign the right bandwidth (i.e. DCHs) to the active connections. As in every packet switched network the resource allocation phase is dynamic, i.e. the number of DCHs assigned to active connections is not fixed but it can be changed at every TTI. BoD agent on ground assigns the right DCH to the connection on the basis of a precise scheduling policy and considering that only one OVSF tree per aircraft is foreseen: all connections belonging to the same aircraft have to share the same code tree.

Figure 5 shows the on board and the on ground BoD agent structure.

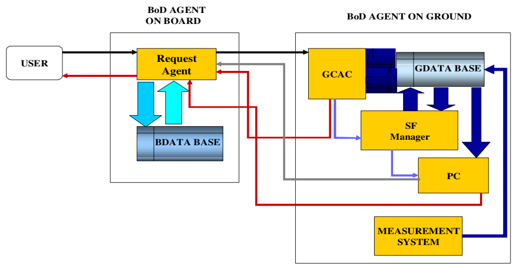

Fig. 5. Architecture for QoS Support in the AirCom

BoD agent on ground is composed of the following entities:

- *On Ground Call Admission Controller (GCAC)*: which receives the connection request and its traffic descriptors from the Request Agent entity within the aircraft BoD agent. Its task is to establish whether the request can be accepted or not according to the call admission control strategy.
- *SF Manager (SFM)*: which is activated when the request has been accepted by GCAC. The task of this entity is to assign the Spreading Factor to each connection according to the scheduling discipline, following which transmits to the PC block a vector composed of the SFs assigned to each application for the next frame.
- *Power Controller (PC)*: which makes the power control working. First it checks the value of Eb/Io for each connection. Then it sends a vector to each aircraft composed of the increasing or decreasing value of the single connection power (ΔP_{jt}). It decides MAC PDU (also referred as Transport Block in CDMA systems) retransmissions and also connection drop, whenever the value of Eb/I_0 is under the target value for a certain number of TTI.
- *On Ground Database (GDB)* in which QoS profiles and current allocated resources of each active connection are stored.

BoD agent on board is composed of the following entities:

- *Request Agent (RA):* which forwards the service request to GCAC with its QoS profile. Said entity is in charge of recording in the on Board Data Base the vector of ΔP_{jt}, sent by the PC and comparing the total amount of requested power with the maximum limit of the aircraft.

- *On Board Database (BDB)* in which transmission power of each active connection is stored.

C. Data Link Layer Architecture

The data link layer architecture able to support data transfer, according to the BoD protocol described above, is depicted in Figure 6.

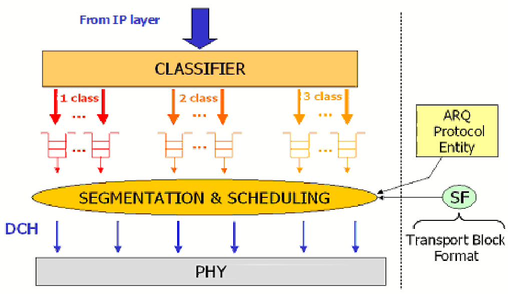

Fig. 6. On board BST data link layer architecture

On board BST data link layer is composed of:

- a Classifier able to divide IP datagrams in several flows according to the datagram class of service defined by the NCR.
- a set of buffers.
- a segmentation and scheduling entity able to form Transport Blocks according to the SF assigned by the adopted scheduler discipline. This entity is commanded by the SFM entity on ground, in which scheduling algorithm runs on every TTI.
- an ARQ entity able to set retransmissions for that kind of traffic in which delay constraints are not so pressing. It interfaces with segmentation and scheduling entity and it commanded by PC entity on ground.

IV. Conclusions

In the present paper an architecture to provide broadband communications with a high bit rate to aircrafts has been construed.

Differences between the relevant scenario and classical satellite systems (i.e. DVB and S-UMTS) are underlined and classified.

An End-to-end QoS management scheme is proposed by introducing different QoS Services and their interworking. This paper has been mainly on satellite data link, and on the definition of a BoD protocol based on IntServ approach and CDMA technique, able to support user applications with QoS guarantees.

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