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Fiber-like Aircraft Satellite Communications: FAST, an Aerospace Valley project. System architecture and protocol stack design

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Aeronautical communications systems are experiencing a fast evolution due to digital migration which demands new perspectives and solutions in order to define a reliable data link communication. This paper presents a project called FAST: Fiber-like Aircraft Satellite communications. The project is funded by Aerospace Valley (a competitiveness cluster for aeronautics, space and embedded systems) in France and gathers industrial and academic partners. The objective is to design a versatile satellite communication system and to develop and demonstrate key technologies (active antenna, proxies' software ...). A focus will be placed in this paper on the global system design, the definition of supported services and the network and protocols structure. The main challenge is to converge heterogeneous traffics on the same satellite link with high reliability and availability. The proposed services cover classical aeronautical communications ATC/AOC along with "new generation" services such as telemedicine and On-board Security surveillance.

I. Introduction

Air traffic forecasts project an important increase of aeronautical communications in a mid-long term. In fact, aviation is undergoing major changes in its telecommunications infrastructure with modernization efforts underway to convert from the current analogue, primarily voice-based system to a digital voice and data link system for both Air Traffic Management (ATM) as well as airline operational (AOC)-type communications.

The increasing demand for making air traveling more pleasant, secure and productive for passengers is one of the key factors for airlines and aircraft industry to be pushing in the ATM digital migration direction, which will provide, to their clients and crew, from In-Flight Entertainment (IFE) to a variety of new services such as On-board Video surveillance or real time graphical weather forecast, among many others. Indeed, the European Organization for the Safety of Air Navigation (EUROCONTROL) and the Federal Aviation Administration (FAA) have both produced a technical document titled "*Communications Operating Concept and Requirements for the Future Radio System"* (COCR [1]), as a kind of roadmap up to 2020, where new data-based Air Traffic Services (ATS) and AOC are identified and meant to be deployed in this time period.

The actual communication infrastructure which supports ATM is conformed by heterogeneous and disparate communication systems resulting in a low cost efficiency and low system efficiency. In that context, satellite communications systems are well suited to bring global coverage (essential in aeronautical scenario) and to cope with the ever increasing data rate requirements of all new services, ATS/AOC and Air passenger communications (APC), integrating all traffic flows coming from/to the aircraft in one single satellite data link. Thus, it is a cost-effective solution which can provide enough capacity and bandwidth to cope with the next generation ATM requirements.

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However, several issues rise up when it comes to converge, in the same satellite link, ATN traffic (*Air Traffic Network*), which requires high priority and full availability, with other services on-board like telemedicine, Security Video surveillance and APC which also may have restricting QoS requirements to be satisfied. Thus, adding the aircraft manufacturer's restrictions, issues involving system architecture definition, Security, QoS management, transmission efficiency must be considered.

Considering this scenario, an industrial project entitled FAST (explained in section II in more detail) aims to design, test and validate an aeronautical satellite communications data link from the antenna design to high layers performance. Specifically, this paper is focused on the system architecture definition in order to provide broadband Internet access to passengers and a high-reliability channel for aeronautical traffic, including new pre-operational services such as telemedicine and Security Video surveillance.

Section II introduces and defines briefly the FAST project and its objectives. In section III, a system description is carried out defining the reference scenario for the architecture definition. In section IV, system architecture and protocol specifications are introduced, as well as, the simulation scenario used for terminal performance evaluation in section V. Finally, section VI concludes this paper and presents a few prospective works about this research area.

II. FAST project overview

FAST (Fibre-like Aircraft Satellite Telecommunications) is an industrial project co-funded by the Aerospace Valley pole and the French government (*Direction Générale de la Compétitivité, de l'Industrie et des Services - DGCIS, Fonds Unique Interministériel - FUI*). The FAST consortium is composed by enterprises, research institutes and universities in order to develop infrastructure technologies for aeronautical dedicated satellite networks. From the industrial side, the enterprises involved are Axess Europe (www.axesseurope.aero, project leader, antenna design and demonstration), EADS Astrium (www.astrium.eads.net, system design, satellite links emulation and validation), Vodéa (www.vodea.com, embedded video surveillance high resolution codec and stanag 4609 wrapper) and Medes (www.medes.fr, telemedicine station) and from the academic/institutional side are CNRS/LAAS (www.laas.fr, antenna RF circuits design, development and validation), ISAE (www.isae.fr, protocol stack design and system simulation), ENAC (www.enac.fr, protocol stack design, security architecture, system emulation) and Telecom Bretagne (www.telecom-bretagne.eu, telemedicine station characterization, TCP performance enhancement).

The project federates research efforts from all partners aiming to study the feasibility and reliability of a high-capacity airborne satellite infrastructure by means of laboratory validation and simulation of all the key components of this infrastructure. The target markets of FAST project involve commercial aircrafts and business planes. Nowadays, this two categories use Immarsat-type satellite links in a 10% of the fleet. This low percentage of equipment installed is related to the high cost of the satellite link access and its poor data rate performance which is not economically competitive. Indeed, Immarsat system must be completed to increase available capacity in order to provide high rate services and follow the growth of the world fleet in a mid-long term.

Hence, the system foreseen must allow data rates from 20 up to 100 Mbps in aircraft reception and between 5-10 Mbps in aircraft transmission, following the plane position. The antenna system design is then a key factor in the success of the project and consists of a new generation low-cost extra-flat satellite antenna technology with electronic pointing, tested and evaluated by Axess Europe.

III. System description

A. System description

The FAST satellite system aims at providing bi-directional satellite communications services on commercial and business aircrafts worldwide. The envisaged service targets to cover the main air routes to provide a worldwide coverage, meaning to cover some high density traffic routes like over Europe, the North Atlantic and North Pacific, the United States of America and the East of Asia.

The system comprises three main parts: an aircrafts on-board segment, a satellite/space segment and a ground segment. Each of these three parts involves the following:

- **On the aircraft side**, Fast Broadband Aircraft Terminal (developed by Axess Europe) which comprises the antenna and the modem responsible for the transmission/reception of communications data from the aircraft to the ground via the satellite system and vice versa.
- **On the ground side**, the Ground Earth Station (GES) transmit and receive subsystems, which incorporate all the required baseband and RF functions to receive/transmit the communications from/to the satellite.
- **On the space side**, the Ku and Ka band satellites. It is assumed that the system takes advantage of existing satellites which currently provides satellite capacity for BSS and FSS services over the world. Commercial agreement with commercial satellite operators would be concluded for leasing satellite resources on both forward and return paths.

The selected air interface is based on the powerful and flexible DVB-S2 standard [2] on the Forward link and on the well-adapted for mobile applications DVB-RCS+m standard [3] [4] on the Return link. The assessment addressed in this paper (see section IV), is mainly focused on the return link terminal performance.

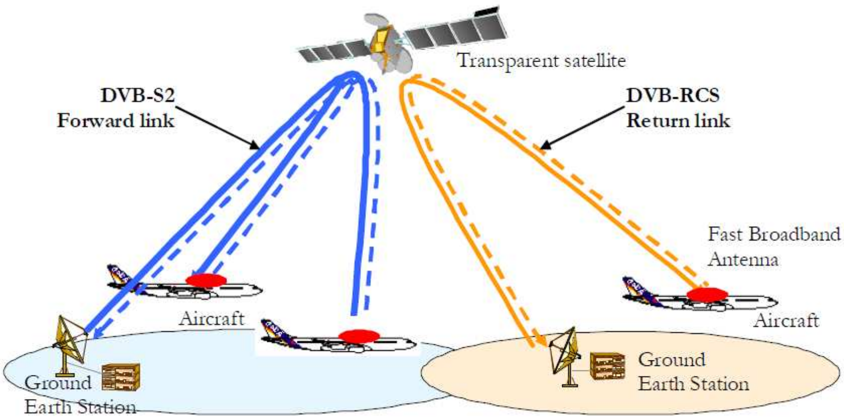

Figure 1. FAST transmission system architecture overview.

B. Targeted Applications

In this section, the aim is to describe which kind of applications the FAST terminal has to support describing its nature and particularities. The main targeted applications are:

- **ATC/AOC cockpit communications:** less demanding in terms of data rate than APC applications but much more stringent in terms of availability and reliability as they are dealing with flight security and safety.
- **Telemedicine:** Medical station on-board which deals with bi-directional communications in case of emergency. It supports typically voice/video and data communications. This application has QoS requirements since, in case of emergency, should be given priority in front of less critical applications.
- **Security Video Surveillance:** A set of MPEG4 video cameras which deal with asymmetric bi-directional communications. The video system is active during all flight duration in a low-medium quality performance. In case of emergency, hijacking and/or attack on-board the aircraft, the HD video surveillance is activated and should be given priority in front of less critical applications.
- **Air passenger Communications APC:** Communications which deal with passenger entertainment during flights. The typical applications are Internet access such as web browsing, email, VoIP…

Taking into account all the applications described above, Quality of Service (QoS) management and system security architecture will play a key role in order to ensure the system reliability and availability. Within the FAST frame, ENAC [5] has carried out the security architecture design for the satellite data link, closely related to the overall system architecture definition addressed here.

IV. FAST Architecture and Protocol Stack pile

In this section, the aircraft network architecture will be described as well as the terminal protocol stack design and the QoS policy and resource management.

A. Aircraft network architecture

The proposed architecture for the complete system is presented in Figure 3. The most significant aspect is the design of the network in the aircraft. The access to the satellite link is handled by a DVB-S2/DVB-RCS+m terminal. Two separate routers are used in order to collect or distribute the different traffic flows. The first one is dedicated to ATN (Aeronautical Telecommunication Network) services (so-called cockpit services), the second to the other services (standard AOC – Aeronautical Operation Communication – and new generation AOC including telemedicine and video surveillance, cabin network for passenger Internet access). Within the cabin, the access network uses WiFi technology.

The first router for ATN uses an IP technology (IPS). It is not expected that the satellite network in KU band will be used as a primary data link for ATN, however this satellite link can efficiently complement the other data links (L-band satellite, VDL Mode 2, LDACS ...). The second router called NG router handles all other traffics. Three ports are defined. A first one is connected to a Wireless LAN for cabin services, including passengers Internet access and telemedicine. Of course, the WLAN can use several WiFi access points in order to provide good signal conditions anywhere in the cabin. The telemedicine station connects through the WiFi network so that any problem can be treated in the aircraft. A second port on the NG router is dedicated to video surveillance. The third port is used by AOC standard services (mainly messages used by airline companies for flight management). The NG router is in charge of all traffic tagging, priority management and security operations. A detailed discussion on security aspects is presented in a companion paper [5].

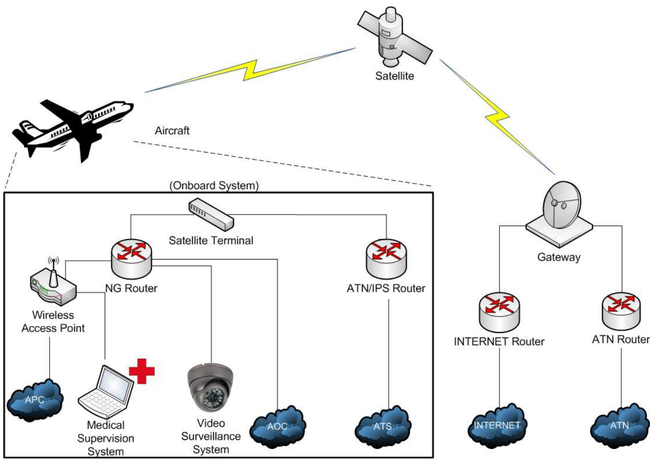

Figure 3.FAST Aircraft network architecture

B. FAST terminal architecture

The satellite terminal architecture is compliant with the BSM (Broadband System Multimedia) standard [6] corpus defined by ETSI. Mainly, the access layer relies on the DVB-S2 and DVB-RCS+m standards [2, 3, 4]. MPEG packet format has been chosen, as ATM related switching capabilities are not used in our system. The related segmentation/reassembly protocol is MPE (MultiProtocol Encapsulation). The network layer uses the IP protocol.

BSM has been designed for Internet services only with a clear frontier between satellite dependant layers (physical and access) and satellite independent layers (network and above). However the flexible definition of the SI-SAP (Satellite Independent-Service Access Point) allows an easy integration of all services, including video surveillance and ATC/AOC. The protocol stack is presented in Figure 4.

<table>
<tr><td colspan="3">IP</td></tr>
<tr><td>AAL5</td><td>MPE</td><td>LLC</td></tr>
<tr><td>ATM</td><td>MPEG 2-TS</td><td>MAC</td></tr>
<tr><td colspan="2">Air interface</td><td>Physical</td></tr>
</table>

Figure 4. FAST terminal Protocol stack

C. FAST terminal. QoS policy and Resource Management

The satellite terminal architecture based on BSM standard is shown in figure 6. It is based on a service differentiation scheme which is supported by means of two internal sets of queues: one at IP level and the other in a MAC level.

As illustrated, the first functional block within the terminal is the "IP classifier" which is in charge of the IP traffic differentiation and the assignation of every traffic flow in its correspondent *DiffServ* queue. A mapping between the output traffic from NG router and the terminal input traffic is then necessary in order to manage the different traffic flows arriving to the FAST terminal. The IP traffic is segregated in several queues, each one with a *DiffServ* service class associated, and they are identified internally by *QID* (Queuing identifiers) identifiers which is a DVB-RSC logical identification mechanism for each IP buffer. The next block corresponds to the IP_MPEG conversion which is in charge of the IP traffic segmentation, by means of MPE, and the encapsulation into MPEG packets and its transfer directly to the MAC server block.

A bi-directional Cross-layer signalization flow is established between the MAC layer and the adaptation layer in order to carry out capacity requests. This capacity requests are calculated not only in function of traffic characterization but also taking into account the control policy set up on higher layers, using several parameters information obtained on the adaptation layer input such as data rates estimations, IP queues sizes, etc. Thus, the adaptation layer carry out an estimation of the real capacity needed which is transferred to the MAC server block in order to generate capacity requests. On the other sense, the TBTP table (Terminal Burst Time Plan table), sent by the Gateway/NCC, is received by the MAC layer and the available capacity is then inferred in order to inform the control policy set up on the access layer which will proceed accordingly.

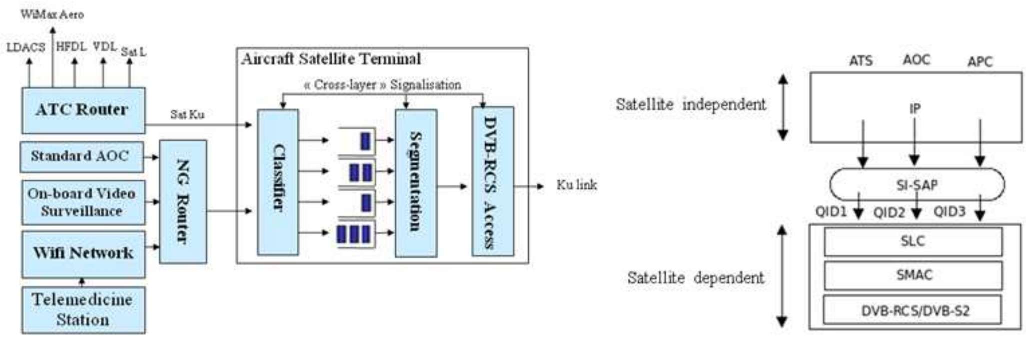

Figure 6. FAST terminal architecture

A QoS policy driven by the Gateway (NCC) is also applied by means of the *ChID* identifier within SAC (Satellite Access Control) MPEG field. *ChID* identifiers allow the definition of different priority levels that can be assigned to the terminal capacity requests in order to settle a supplementary QoS policy level which is managed by the NCC. *ChID* identifiers (*ChID* 0, *ChID* 1…) are defined within every SAC field and they are associated with the *QID* identifiers (several *QID* can be associated with the same *ChID*).

The MAC layer computes periodically the capacity requests in function of the IP queues status, provided by the cross-layer signalization. These capacity requests are sent to the DAMA controller (Gateway/NCC) which will carry out the resource allocation for each satellite terminal following the next *ChID* priority levels policy:

RBDC [*ChID 0*] > (A) VBDC [*ChID 0*]> RBDC [*ChID 1*] > (A) VBDC [*ChID 1*] > …

Even if, generally, the RBDC (Rate-Based Dynamic Capacity) request is given more priority than VBDC (Volume-Based Dynamic Capacity) request, the later can have a higher priority associating a *ChID* to the correspondent request and thus, being attended before by the NCC.

Taking into account the different input traffic flows, the capacity requests and *ChIDs* logical assignation is carried out as it follows:

- *ChID 0*, which has the highest priority, is assigned to the ATS traffic capacity request and it will be the first traffic flow considered by the IP classifier. A VBDC request is assigned to this traffic flow as it is adequate for sporadic traffic profiles with low rates. However, the maximum level of priority is assigned to this service by means of *ChID 0* in order to assure its reliability and availability.
- *ChID 1* is assigned to the AOC standard capacity request which is also VDBC as airline operational traffic has nearly the same characteristics as ATS traffic. Besides, they share the same condition in terms of availability and reliability.
- *ChID 2* is a reserved channel identifier and it is only assigned when a medical urgency (need for a telemedicine station) or a hijacking situation (need for a High Quality video surveillance recording) is produced on any aircraft in the system. In those cases, this two NG AOC services need to be given more priority than any APC service request coming from any plane in the coverage area in order to be able to treat these emergency requests before serving the other demands. This *ChID* has the "reserved" status because if there is no emergency situation within any aircraft of the fleet, it will not be assigned by any terminal.
- *ChID 3* is assigned to capacity requests related to the "NG" AOC services in a normal situation. Thus, it is assigned when no situation of emergency or dangerous circumstances are perturbing the flight. Consequently, almost all the flight duration, the telemedicine station will be inactive. Hence, this *ChID* will be almost exclusively dedicated to the Video surveillance system which will be operating in a low/medium quality definition. When a medical urgency or a hijacking situation is produced, one or both services (depending on the scenario) capacity requests will be assigned to the reserved identifier ChID 2. Table 5 summarizes all possible scenarios addressed above.

AOC « NG »	**Scenario**	***ChID***	**CR**
On-board Video Surveillance system	*Normal situation (5 cameras with standard resolution)*	*ChID 3*	RBDC
	Hijacking On-board *(5 cameras in HD resolution)*	*ChID 2 (reserved)*	RBDC
Telemedicine Station System	*Normal situation*	*ChID 3*	VBDC
	Medical urgency	*ChID 2 (reserved)*	RBDC/VBDC

- *ChID 4*, the lowest priority level, is assigned to the APC capacity requests. A RBDC request will be assigned to applications like video or VoIP and VBDC requests will be associated to more sporadic traffic profile like Web browsing, e-mail, …

V. FAST architecture Performance

In this section, a FAST network architecture simulation model and the satellite terminal is presented and an assessment of the global performance is carried out by means of OPNET modeler, a well-known discrete-event simulator used by researchers and developers to model and simulate telecommunication networks.

A. FAST network architecture simulation model

The network simulation model used in the performance assessment addressed in this section is illustrated in figure 7. As it can be observed, all three segments (aircraft, space and ground) are represented in the model. The aircraft sub network is conformed by traffic sources, the routing system described in section IV and the DVB-RCS FAST terminal. Within the ground segment, a Gateway (being composed by the NCC and the gateway itself) and several servers symbolizing the terrestrial networks (being ISP, Video surveillance controller…) are implemented.

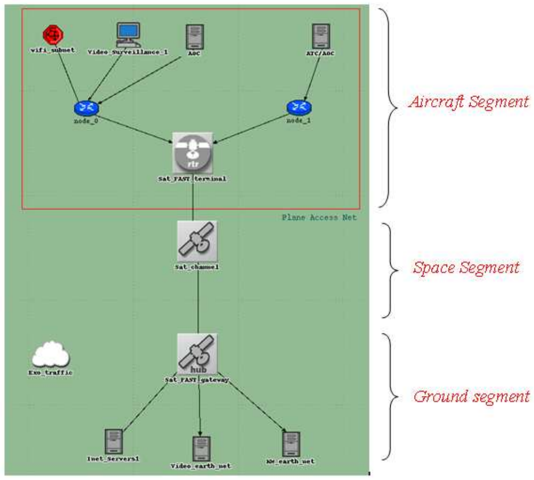

Figure7. FAST network architecture model

This study has been focused on the aircraft-ground communication path and that is why there is only the return link characterized in detail. Note that only one terminal is described in the scenario. However, any number of terminals sharing the same radio electric resource than the analyzed terminal, can be taken into account in our simulation by means of an exogenous traffic generator (the cloud in figure 7)

The FAST applications presented in section III have been modeled as a realistic traffic sources in order to assess the performance of the architecture proposed. A source model provided by ENAC has been used in order to model ATS/AOC standard traffic which is characterized by a sporadic behavior and low intensity in charge. Wifi network and APC traffic have been modeled by means of OPNET libraries, defining traffic and application profiles in order to emulate realistic passenger usage (web browsing, ftp, email, VoIP…). The Telemedicine station, being within the Wifi network, is still in process by Telecom Bretagne and aims to test TCP enhancements for its traffic flows in a transport layer level. Finally, the security video surveillance system has been implemented by an ISAE mpeg4 video source model, based on Markov chain random processes. The transition matrixes have been obtained from a real mpeg 4 video trace [7], which has been the root in order to generate statistically valid traces for our performance study.

The DVB-RCS terminal and the Gateway have been modeled by ISAE after several years of expertise in DVB-RCS return link characterization and modeling.

B. FAST architecture performance

So far, in terms of terminal performance, the simulation work addressed here pretends to assess the cross-layer signalization flows behavior between the MAC layer and the adaptation layer as well as analyzing the allocation and congestion of the terminal MAC queue system.

The curves illustrated in figure 8 present the capacity requests of ATS/AOC standard and those from the Wifi output traffic (APC). These capacity requests are based on VBDC demands computed from IP queues, as the nature of both traffic profiles is "bursty" and sporadic even if the requests have assigned a totally different priority level. Note that the volume handled by both traffic profiles is relatively low, from the order of kbits.

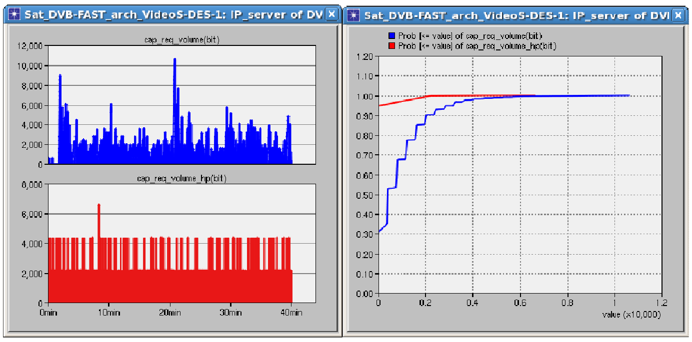

Figure 8. VBDC request of Internet traffic (top) and ATS (bottom). CDF on the left.

A RBDC request is assigned to video surveillance traffic. In figure 9, the MP4 video traces flow (bits/s) is represented overlapped with the rate estimator implemented in order to send capacity demands to MAC layer. For the moment, estimation is still not optimized and further work is on-going to be able to follow the sharp rate changes of the video traffic flow.

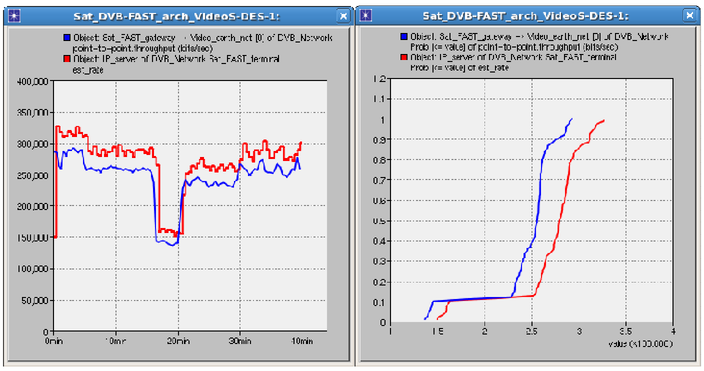

Figure 9. Video Surveillance rate estimation and real trace representation (left). CDF (right)

Two traces are represented in figure 10. The one on the top represents TRF traffic bursts allocation which is sent by the gateway as an answer of the capacity requests sent by the terminal. The second curve shows the evolution of the MAC queue in terms of number of packets stored. As we can observe, there are several congestion peaks mainly due to the video estimator which is incapable, in some periods, of following the rate progression and thus, an insufficient capacity request is carried out provoking MAC's buffer overflow.

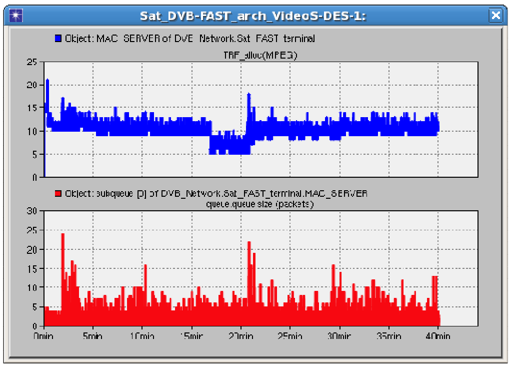

Figure 10. TRF burst allocation (top) and MAC queue size (bottom)

Observing the Video transmission behavior in terms of delay and jitter and without applying priority levels over the different video flows, we notice a reasonable quality of service video transmission performance with a delay a little bit under 1 second and a jitter of approximately 300ms.

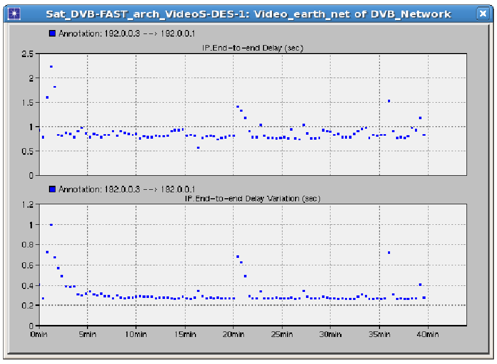

Figure 11. Video surveillance delay and jitter performance

VI. Conclusion

The FAST project is scheduled to end in December 2010. This paper has presented the system design, the global architecture and has discussed the protocol stack performances. It should be emphasized that the proposed system is able to handle heterogeneous traffic flows with a reliable QoS management. Hence, the offered services can improve greatly the airline companies' offer with security related equipments (cabin video surveillance and telemedicine station) and a performing Internet access for passengers. Important achievements will be obtained by the project team in the next few months with a finalized antenna demonstrator and a system emulation platform. The objective is to validate technology choices and to provide customers a complete performance assessment.

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