A Tool for Satellite Communications

Advanced DVB-RCS / DVB-S2 System and Protocol Simulator

Vincent Boussemart and Hartmut Brandt

Institute for Communications and Navigation
German Aerospace Center (DLR e.V.)
Oberpfaffenhofen, 82234 Wessling (Germany)
vincent.boussemart@dlr.de - hartmut.brandt@dlr.de

Abstract— **A tool has been designed to simulate broadband satellite communication systems and techniques: a system and protocol simulator based on advanced DVB-RCS and DVB-S2 standards. As a powerful and flexible tool, it can be used to investigate and optimize current and future satellite communication systems, mainly to develop resource management algorithms and assess system performances. It is capable of simulating a satellite system using Ka-Band with multi-beam European coverage. It integrates rain attenuation and interference models and respects the complete DVB-RCS/DVB-S2 protocol stack and an evolution of DVB-RCS with Adaptive Coding and Modulation (ACM). The simulator supports different Quality of Services (QoS)/Service Level Agreements (SLA), ACM, several encapsulation schemes, congestion control mechanisms, call admission control and resource management. This paper gives an overview of the possibilities offered by the tool and presents some results.**

Satellite communications; system and protocol simulator; OMNeT++; advanced DVB-RCS; DVB-S2; resource management; fade mitigation techniques; adaptive coding and modulation; congestion control; call admission control; quality of service;

I. INTRODUCTION

The DVB-S2/RCS simulator was developed in the framework of the ESA-Artes 1 project "Resources Management using Adaptive Fade Mitigation Techniques (FMT) in DVB-S2/RCS Multi-Beam Systems" (refer to the note below). This simulator is based upon the second generation Digital Video Broadcasting for Satellite standard ETSI EN 302307 (DVB-S2, [1]) and on research on adaptive techniques to optimize the Return Channel over Satellite (RCS) link capacity ([2]). Both the forward- and the return-links, respectively DVB-S2 and DVB-RCS links, support Fade Mitigation Techniques (FMT) via Adaptive Coding and Modulation (ACM) schemes ([3]). The simulator exploits the K/Ka-frequency bands (roughly 18-27/27-40GHz) and multi-beam antenna patterns over Europe.

Such a tool can be used to develop resource management algorithms, burst formats, encapsulation protocols and to assess system performances. For instance the utilization of ACM in the forward-link aims at increasing the system capacity by a factor of about 2.5 in comparison to the non-adaptive Time Division Multiplex (TDM) system ([4], [5]). The simulator incorporates many features such as rain and attenuation models for FMT, the support of Quality of Service (QoS) and different Service Level Agreements (SLA), different encapsulations schemes, congestion control mechanisms, call admission control and resource management.

This paper presents this broadband satellite communication system tool and gives an overview of its capabilities. The paper is organized as follows: section II presents the simulator architecture and concept and section III shows some results.

II. DESCRIPTION

A. Satellite and Terminals

The tool simulates a transparent satellite system with multi-beam European coverage, high-speed forward- and low to medium datarate return-link. The overall system is composed of gateways, each gateway supporting the users for a given number of beams, to which Internet terminals (INET) are directly connected. The satellite is connected to the gateways and to the satellite terminals (Figure 1.). This results in a multi-star network configuration.

The tool can also simulate regenerative satellite systems. In that case the satellite terminals are connected to each other via a regenerative satellite. Two satellite terminals can communicate within the same beam or within two different beams. The packets are processed on-board (OBP) so that traffic is routed to the correct beam. A Network Control Center (NCC) which is located on the ground takes care of the resources (Figure 2.). The OBP offers mesh connectivity to the user beams at Ka-band. The OBP only interfaces to user uplink and downlinks; there is no gateway anymore.
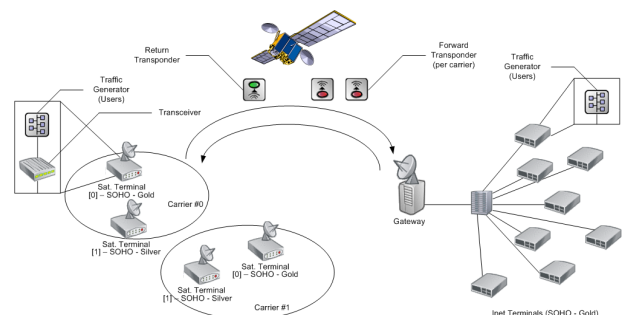

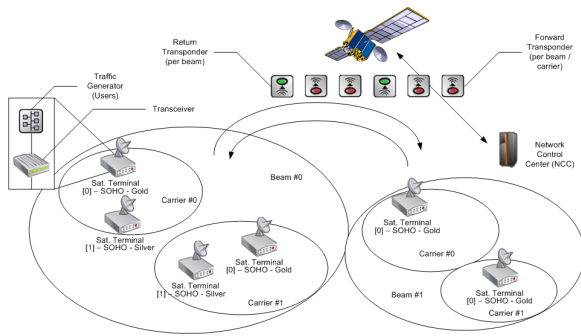Figure 1.   Overall Transparent System Architecture.

Figure 2. Overall Regenerative System Architecture.

In both scenarios (transparent and regenerative) a geostationary orbit at 33° east is assumed for the satellite. The antenna has 72 spot beams and covers Europe including parts of the Middle East. The antenna gain varies between 51 – 55 dBi within a spot beam.

Different terminals types are available within the simulator: Small Office / Home Office (SOHO), Small and Medium-sized Enterprise 1 (SME1) and SME2 terminals; two service level agreements (SLA) are available: gold or silver. The number of users connected to a terminal directly depends on that terminal type. The users generate traffic for the following applications: web browsing, emails, Voice over IP (VoIP), audio / video streaming and video conferencing by means of application layer models. This traffic exhibits the typical burstiness seen in the Internet.

B. Features

The support of the three QoS classes: Best Effort (BE), Expedited Forwarding (EF) and Assured Forwarding (AF), is realized through the implementation of the Internet Protocol (IP). The simulator provides many features such as the classification of the traffic and its regulation via Policy Enforcement Points (PEP), a so-called "Group-Efficient" scheduling algorithm for the forward-link (FL) which is QoS-, SLA- and ModCod-dependant [6], different encapsulation and fragmentation schemes: Multi-Protocol Encapsulation (MPE), Unidirectional Lightweight Encapsulation (ULE) and Generic Stream Encapsulation (GSE), congestion control mechanisms (detection and resolution), Call Admission Control (CAC, for VoIP), signaling (Terminal Burst Time Plan (TBTP), channel measurements, etc.), a return-link (RL) resource management (RRM) allowing resource allocation via the TBTP, optimizing delay-jitter and distributing excess capacity, and fade mitigation techniques (FMT) with Modulation and Coding (ModCod) adaptation.

1) Return-Link
The return-link is based on the DVB-RCS standard and is organized in superframes (SF) which are structured in a Multi Frequency Time Division Multiple Access (MF-TDMA) scheme (Figure 3.).
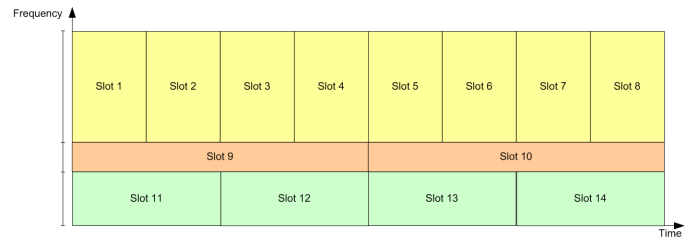

Figure 3. Example of Return-Link Superframe.

Each terminal requests capacity to the gateway or NCC in order to receive resources in one or several slots. The RRM module is responsible for processing such requests and for assigning time slots to terminals. As ACM is used, it is also necessary to attribute a ModCod for each time slot. There are two different scenarios: one in which a ModCod is dynamically assigned to each time slot (dynamic scenario) and another one in which each time slot uses always a specific ModCod. In the second scenario there is the possibility of providing a set of SFs and to select the most appropriate one during an allocation round (semi-dynamic scenario). Different algorithms within the RRM take care of the QoS (e.g. minimization of delay and delay jitter), of resolving conflicts in case more capacity than available is requested and of maximizing the spectral efficiency (ModCod selection).

2) Congestion Control and Call Admission Control
Congestion control mechanisms are implemented in order to detect the presence of congestion and to recover the stability of the system. Congestion can be detected by analyzing the states of the queues / pools in the schedulers. Some thresholds can be set, for instance according to the number of packets dropped because of timeout. Several mechanisms are started in order to resolve congestion: the Call Admission Control (CAC) functionality can be disabled, dropping rates can be set in the pools and backup SLA can be enabled. This last strategy aims at setting more restrictive parameters in the PEP modules. Once there is no more congestion each mechanism is switched back to its default state.

The Call Admission Control feature is utilized in the simulator for VoIP. This mechanism permits to verify that enough resources are available before starting the transmission. The entity performing the call sends a CAC request to the CAC module which will be responsible for evaluating the capacity available on the links (computation based on the load of each link) and for deciding if the system can support the call or not. If not a CAC reject is transmitted and the call stops immediately, otherwise a CAC accept is sent and the call is initiated.

3) Forward-Link
The scheduler present in the forward-link takes care of sorting the packets according to their QoS and SLA. There are two techniques implemented in the simulator: a simple scheduler and a "group-efficient" scheduler. The simple scheduler assigns hard priorities to the different QoS classes whereas the "group-efficient" tries to meet specific QoS requirements (loss and delay) without starving low-priority queues. Both schedulers ensure that the ModCod information related to each packet is kept up to date. The incoming packets are sorted

according to their DiffServ QoS class and their SLA class in different packet pools. An additional pool with the highest priority holds the MPEG packets containing signaling information. The purpose of the scheduler is to maximize the transmission efficiency and to make efficient capacity utilization.

4) Overall

The whole simulator architecture is organized in three large blocks: the pre-processing, the system simulation and the post-processing. The pre-processing step generates Signal-to-Noise-and-Interference Ratio (SNIR) time series and the ModCod selection thresholds. The pre-processing is implemented in Matlab. These time series and thresholds are then used as input for the system simulation. This simulation step is implemented in OMNeT++ (Object Modular Network Tesbed in C++, Figure 4.), a discrete event simulation environment [7]. It simulates the entire system from the upper part of the physical layer to the application layer, including all encapsulation, IP, resource management and so on algorithms and protocols. The system simulation produces vector files which store measurements from the various modules. These vector files are then post-processed (post-processing step) by other Matlab scripts in order to produce results and graphs that can be easily analyzed. The whole simulator configuration is based on the eXtended Markup Language (XML) which is particularly flexible and easy to use.
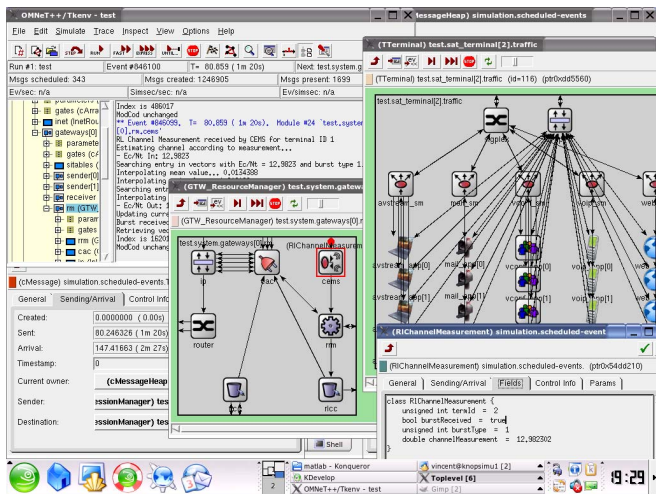

Figure 4. Simulator Screenshot.

III. RESULTS

Since the simulator is completely configurable, it is possible to set independently the number of satellite terminals, the number of beams and the corresponding coverage-pattern, the number of Internet terminals, the algorithms to be used, the mechanisms to be switched on or off, the duration of the simulation, etc. This configuration information together with the measurements from the system simulation results in a large number of graphs and numbers that characterize the system. In the following we will provide some results for the forward-link.

A. Configuration

A baseline scenario, based on a transparent satellite, was designed in order to run the simulations. The following main assumptions were realized. First, the system availability was considered to be equal to 99.7%. This means that the distribution of the received signal-to-noise ratio is chosen in such a way that there is 99.7% of total link availability over all grid points (geographical location) in the coverage area. Second, the coverage is set to 95% meaning that 95% of the geographical satellite system coverage is assumed. Third, the return-link coding and modulation is set, when not using adaptive coding and modulation, according to the standard, to Quadrature Phase-Shift Keying (QPSK) with code rate 2/3. Fourth, the forward-link coding and modulation is fixed, when not using adaptive coding and modulation too, according to the standard, to eight PSK (8PSK) with code rate 3/4.

The forward link capacity is set to 22.5 Msps in order to limit the number of terminals needed to reach a congestion state. Knowing the traffic generation properties for both forward- and return-links, it is possible to determine how many terminals of each type are needed to attain a particular load. In order to mix the different terminal types together during the simulations, i.e. to have SOHO, SME1 and SME2 terminals in the simulator architecture, assumptions had to be done concerning the terminal repartition. 50% of SOHO terminals, 30% of SME1 and 20% of SME2 with 1/3 gold and 2/3 silver were selected.

For different targeted FL loads the number of satellite terminals was computed and the return-link was dimensioned (100% load is expected on the RL). Knowing that three types of RL carriers are considered (4, 2 and 1 Msps) and that:

- SME2 terminals use the 4 Msps carriers but if more capacity is needed, they can use the 2 and the 1 Msps carriers,

- SME1 terminals use the 2 Msps carriers but if more capacity is needed, they can use the 1 Msps carriers,

- SOHO terminals use the 1 Msps carriers only,

it is possible to estimate the number of carriers needed for each carrier type. Three sub-scenarios are based on the targeted FL load: 90, 95 and 110%. This results in about 1000 simulated-satellite terminals.

B. Fade Mitigation Techniques

Figure 5. illustrates the FMT capabilities of the simulator using ACM. The upper graph shows the output from the channel estimator which is the carrier-to-noise ratio (C/No) in decibels (dB) over the time (x-axis, curve in blue). The straight lines on this graph indicate the ModCod thresholds (green and red lines, respectively the upper and lower thresholds) in order to decide either to upgrade or downgrade the ModCod according to the current channel state. The lower graph represents the output of the ModCod selector module in terms of ModCod ID (ModCod [#]) over the time (x-axis). The presence of a fade event (rain) involves a modification of both modulation and coding rate (ModCod): a more robust ModCod but providing less effective bandwidth is selected accordingly.
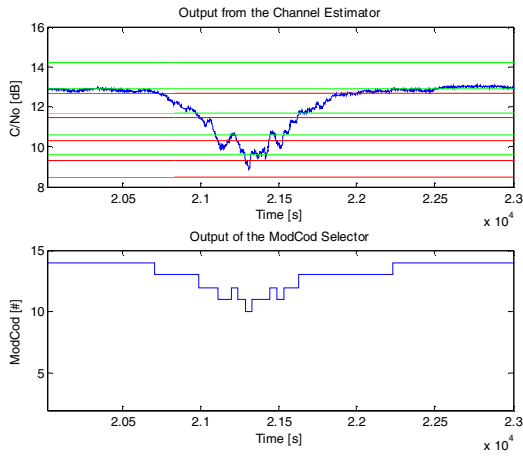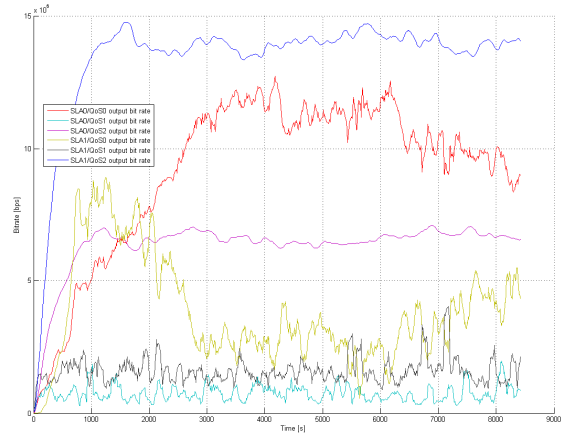
Figure 5. Simulator Result: FMT with ACM.

Figure 7. Simulator Result: Output of the FL Scheduler – 110% Load.

C. Resource Management

Figure 6. shows input bitrates for the different QoS classes and SLAs at the forward-link scheduler. QoS0 corresponds to BE (web, audio / video streaming and video conferencing), QoS1 to EF (email), QoS2 to AF (VoIP), SLA0 to gold terminals and SLA1 to silver terminals. The next figure (Figure 7.) shows how the FL scheduler allocates the resources. Actually the traffic is classified into six different pools (one per QoS per SLA plus one additional for signaling, not shown here) and the scheduler selects the pools according to the level of priority. One can observe that the BE traffic for silver terminals goes down when the overall traffic pattern goes up. It shows that mainly only SLA0/QoS0 packets (silver/BE) are dropped because at the same time the input rates for the other queues go up and they have higher priority. The datarates achieved at the output of the FL scheduler also demonstrates the limitation in terms of capacity of the FL: about 55Mbps at the input and 38Mbps at the output. Actually the number of terminals was selected in order to load the FL above 100%.
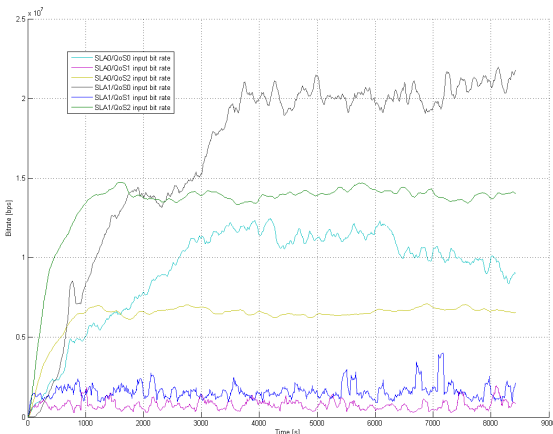
D. Encapsulation

The baseline scenarios are based upon the simple scheduler for the FL which makes "hard decisions". The three scenarios (three loads) were compared to the same scenarios (mainly same parameters) but using the "group-efficient" scheduler and different encapsulation schemes. Whereas the FL modem (S2-modem) uses exclusively long frames in the baseline scenarios, in the other scenarios they can be short and / or long. The ModCod optimization feature was switched off while using the "group-efficient" scheduling algorithm. The ModCod optimization feature aims at allowing a terminal to downgrade its current ModCod in order to get better capacity (in order to better fit the modem frames).

The first simulations were realized while using the three baseline scenarios, the next three simulations while using the Multi-Protocol Encapsulation (MPE) scheme, the next three simulations while using the Generic Stream Encapsulation (GSE) and the last three while using the same scheme but without short frames.

Figure 8. shows the input bit rates in the FL scheduler. The input is classified by the Policy Enforcement Point (PEP) according to the three QoS classes (BE, AF and EF) and to the two SLAs (gold and silver). This results into seven input queues/pools which may be limited in length (number of bytes / number of packets) and / or time. One can see the repartition of the traffic among the three QoS classes and the two SLAs. The proportion of signaling bit rate is not negligible (about 10%).

There are different kinds of losses: queue length limitation (in bytes or packets), timeout and requested drops from congestion management. The bit loss ratio per QoS/SLA was controlled and accounted for all six IP queues. The signaling queue has always highest priority, is unlimited and has no timeout. The bit loss ratio is computed as the number of lost bits over the number of inputs bits. One can observe that with the current algorithm the dropping decision between silver and gold is hard: first all silver packets are dropped before gold packets are dropped (Figure 9.).

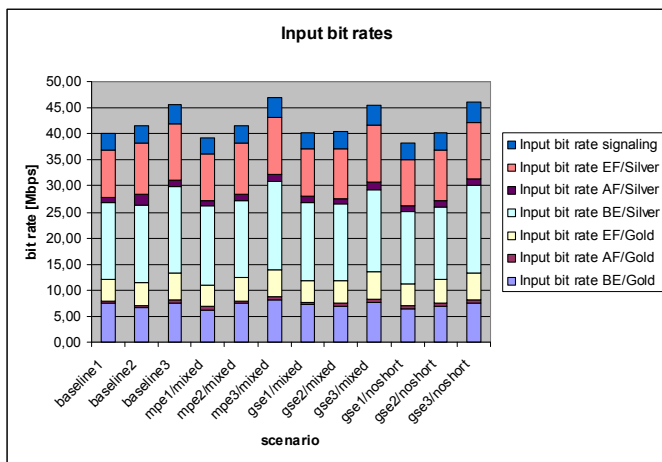Figure 6. Simulator Result: Input of the FL Scheduler – 110% Load.

Figure 8. Simulator Result: Input Bit Rates for different Scenarios.
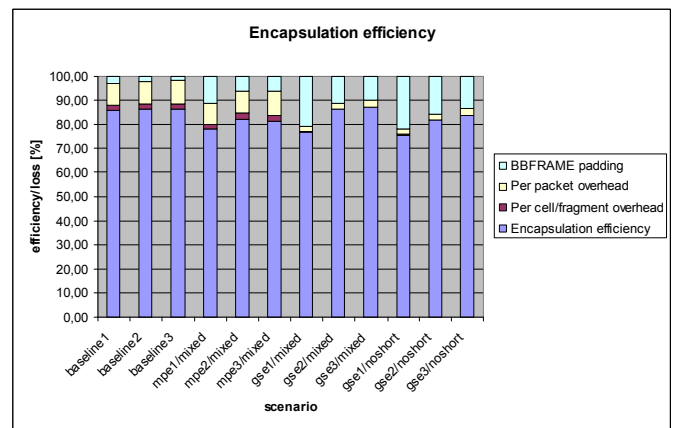

Figure 10. Simulator Result: Encapsulation Efficiency for different Scenarios.

The next figure (Figure 10.) illustrates the encapsulation efficiency, the overhead per cell/fragment, the overhead per packet and the padding of the modem frames (Base-Band Frames, BBFRAMEs). During the encapsulation overhead is added for each packet, for each fragment or cell and padding at the end of the BBFRAME may occur. This can happen because either there is no more traffic or the space is too short for a new fragment/cell. The overhead for the "group-efficient" scheduler is larger because all scenarios are configured without ModCod optimization so padding is not only for one encapsulator but for many (one encapsulator per ModCod). One can summarize that GSE gets better than MPE for higher loads (less overhead, better efficiency).
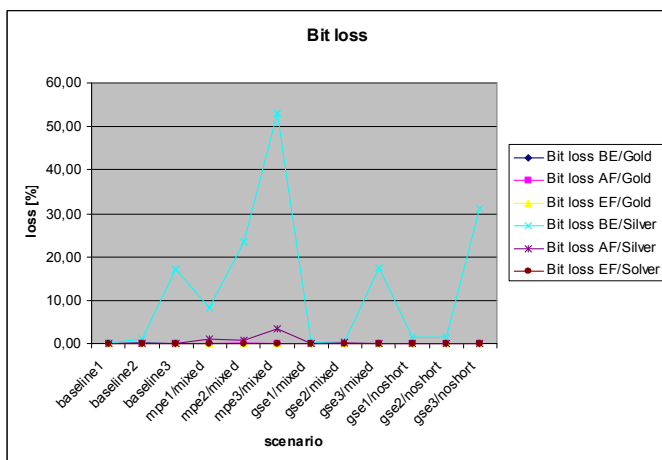

Figure 9. Simulator Result: Bit Loss Ratio for different Scenarios.

IV. CONCLUSION

A DVB-S2/RCS system and protocol simulator has been presented which can be utilized to investigate and optimize current and future satellite communication systems using standards such as DVB-S2 and advanced DVB-RCS. It can be used to develop new resource management algorithms and protocols for better performance and efficiency and to evaluate state of the art satellite communication systems.

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