

# Programmable active emulation of wireless systems - A DVB-RCS Example

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**Abstract**—This paper presents a DVB-RCS satellite emulation system built using the NPBox programmable network emulation system. NPBox allows system components to be modeled both at a higher abstraction level using a finite-state-machine like abstraction, and also at a lower level using customized event guards and actions. Comparison experiments show that the emulated performance is similar to that of a complex low-level emulator.

## I. INTRODUCTION

Experimental characterization of wireless networks is an important complement to theoretical analysis and simulations. Experiments can be performed in live networks or in more controllable testbeds. In testbeds it is common to emulate aspects of the network in order to decrease the need for expensive and complex physical equipment. The emulation can be performed at varying levels of abstraction, providing different trade-offs between emulation accuracy, complexity and cost. In this paper we present a system for programmable active emulation that can recreate the essential lower layer behavior while reducing costs and complexity in comparison to regular low level emulators. While the presented emulator can be used in many wireless scenarios, this paper focus on a satellite scenario.

Satellite emulation systems can be realized using various degrees of abstraction. There are low-level satellite emulation systems based on actual lower layer protocol implementations (e.g., ATM, MPEG2, DVB access scheme, etc). These emulation systems use a wireless channel model to avoid the use of a real air interface. The physical link is emulated to introduce geostationary end-to-end delay, and possibly various loss models. While

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these kind of systems can provide accurate emulation, they are also complex and expensive to develop and maintain as all the lower level protocols must be implemented and verified.

An alternative approach to satellite emulation is to use a higher level of abstraction and only emulate the effects of the lower layers on the data to be transmitted. This network level emulation models the link layer using a higher level of abstraction that do not require a detailed implementation of the various link-level protocols and signaling mechanisms. The link layer model is instead focused on recreating the net effect of the link layer delay behavior on the upper layers.

Many performance evaluation studies of satellite systems such as [9], [10], [12] are related to the transport layer (typically TCP), or application layer performance. In these cases, the complexity and low-level details of a detailed low-level emulator is typically not necessary as long as the effects visible to the upper layers are similar. In this paper we present a satellite emulation approach based on a high-level representation of the relevant satellite mechanisms. The satellite emulation systems is realized using the general programmable emulator NPBox, which can be used for other wireless scenarios. Thus, by focusing on recreating the link layer impact on the data transfer instead of a heavy implementation of all low-level behavior, a simple, easily extended and high performance satellite emulation system can be realized.

In this paper we show that the dynamic low level behavior of a DVB-RCS DAMA system can be successfully recreated using the NPBox system. Experiments show that the NPBox programmable emulation system is capable of recreating the relevant emulation behavior, but at a significantly reduced complexity. The rest of the paper is structured as follows. Section II provides some background on emulation and satellite communication.

Section III describes the implementation of the DVB-RCS emulation systems, and Section IV reports on the experimental results obtained. Finally, Section V provides the conclusions.

## II. BACKGROUND

### A. Emulation

In the general sense, emulation refers to an evaluation approach where parts of the artifacts are real, and parts of them are simulated. When employing emulation for data communications, the cut-off point between real artifacts and simulated artifacts can vary quite widely.

Network emulation systems have been much used in computer communications research and provide the ability to emulate various delays, available bandwidths and packet loss ratios. Dummynet [11] and NISTnet [1] are well-known network emulation systems that can be used to emulate both the effects of a single link, or the concatenation of multiple links. However, these emulators are hard to employ when the conditions that are to be emulated can vary dynamically over time, for example if a Bandwidth-on-Demand allocation scheme is used. When it is necessary to emulate systems that have these dynamic changes, regular network emulation systems cannot be used, and purpose built emulators need to be developed.

The aim of the NPBox system is to allow purpose-built emulation systems to be constructed in a simple and efficient way. NPBox build on the Dummynet functionality, and enhances this with two programmability possibilities, state-events graphs and programmable custom actions as described in Section III-A.

### B. DVB Satellite Communication Basics

DVB-S and DVB-RCS [2], [3], [4] are used to carry out IP-based applications over geostationary satellites: The DVB-S (Digital Video Broadcasting - Satellite) standard is used to transport data over the forward link (from the Gateway Earth Station to numerous Satellite Terminals). The DVB-RCS (DVB - Return Channel System via Satellite) standard is used to transport data over the return link and specify the access scheme to the return link. This standard enables the efficient sharing of resources between a great numbers of Satellite Terminals (ST) accessing the return link. The ST receives a standard DVB-S transmission generated by the Gateway.

An ST receives general network information from the DVB-RCS Network Control Center (NCC), sent over the forward link, to get control and timing messages. All data transmissions by the ST over the return link are

controlled by the NCC. This dynamic resource admission control assures an optimal use of the costly resources of the satellite. The dynamic resource control consists of the assignment of resources (slots) to STs based on their requests to the NCC and the limit values negotiated during connection establishment. The assignments are conditioned by the availability of resources within defined return channels. The assignment is the responsibility of the MAC Scheduler (in the NCC), which implements a Demand-Assignment Multiple Access (DAMA) protocol.

So, each ST calculates the capacity request required for its current traffic and sends it to the NCC. The NCC then calculates and broadcasts the overall assignment to the STs taking into account the current load of the system as well as the requests and limitations of specific STs.

The DAMA implementation of DVB-RCS uses a combination of static and dynamic allocation techniques in order to ensure a set of Quality of Service (QoS) guarantees as well as high bandwidth efficiency. The return link scheduler supports three main capacity assignment types to reach this objective, described in a simplified manner below:

**Fixed rate (Constant Rate Assignment - CRA).** The CRA assignment type is a guaranteed rate capacity, fully provided for the duration of the connection between a ST and a Satellite System, without any DAMA request. The delay associated to this capacity assignment is fairly constant and reduced to the propagation delay of the satellite link.

**Variable Rate (Rate Based Dynamic Capacity - RBDC).** This assignment type is based on requests depending on the average rate of incoming data to the ST. It has two components: a guaranteed part and a non guaranteed part, both on demand. The rate assignment is valid for a certain period of time: after the timer has expired, capacity is not assigned anymore except if a request was done in the meantime.

**Best effort (Volume Based Dynamic Capacity - VBDC).** This assignment type is based on requests indicating the volume of data standing in the ST buffers. The capacity is assigned when available in response to a request, without any guarantee on assignment. The delay for traffic using this capacity assignment type can be long (if capacity is not available) and may vary much.

Table 1 summarizes the characteristics of the traffic assignment types described above. We notice that this complex access scheme is used by DVB-RCS to assure a high utilization of the satellite resource as well as

Table I  
DVB-RCS TRAFFIC ASSIGNMENT TYPES CHARACTERISTICS

Traffic Assignment Type	Guaranteed	On Demand
CRA	Yes	No <i>Permanently Allocated</i>
RBDC	Yes <i>Up to a maximum</i>	Yes <i>Rate Based and Timer</i>
VBDC	No	Yes <i>Volume Based</i>

catering for different QoS guarantees.

### III. EMULATION OF DVB-RCS DAMA

#### A. The NPBox emulation system

The NPBox emulation system [5] is a flexible emulation system that allows for “active” emulation in the sense that the emulated conditions can adapt to dynamic effects such as incoming traffic. The NPBox derives its considerable flexibility from its programmability that allows the user to control exactly how this active emulation should react. It is thus possible to create active emulation for a wide variety of different systems, not just the DVB-RCS DAMA system discussed in this paper. The NPBox system is programmable on two levels. One level utilizes a finite-state-machine like representation that uses the notions of states, state transitions, evaluation points, event guards and actions. Transitions can be triggered either by packets arriving at different positions in the emulation pipeline or by timers<sup>1</sup>. Further, there can be zero, one or many event guards that must be true to allow a particular transition. If a transition is performed, there can also be a number of actions associated to the transition. Typically, the event guards and actions are parametrized to behave differently depending on the particular position in the state machine where they are located.

The second level of programmability is based on the concept of *custom* event guards and actions. In the NPBox system there are already a considerable number of generic event guards and actions implemented. In addition to these, it is also possible to create custom event guards and actions. These custom event guards and actions are created using C code and are used to model behavior that is more readily expressed at this level of abstraction.

<sup>1</sup>There are five evaluation points: Reception of packet (RP), Dequeuing of packet (DP), Forwarding of packet (FP), Emission of packet (EP), and Timed event (TE)

These two levels of programmability provides a simple system that allows a large degree of expressibility. In terms of processing overhead the C code is the most efficient, but the design of the in-kernel finite state execution engine also ensures high performance. The NPBox system is designed to handle state machines of at least 50000 states and 100000 transitions.

The FSM model can be constructed using an user-friendly GUI application. An XML-based interchange format is used to represent the state machine before it is inserted into the kernel by a modified version of the firewall configuration tool ipfw.

#### B. An alternative to low-level DVB satellite emulation

We propose a new type of satellite system emulation that has the objectives to be simple to design and implement, requiring low resources to deploy, and that can easily evolve to take into account the evolution of low level protocols. The emulator should produce the various effects on the traffic that result from the signaling protocols and the return link access behavior without completely implementing these protocols.

The emulation of the DVB-S forward link is pretty straightforward, as the access to this link is centralized on the gateway. For this direction, no complex access scheme is required to access the resource; thus, the emulation system, for this direction, acts as a normal router and adds the propagation delay of the air link as well as the loss model corresponding to link losses.

However, the emulation of the DVB-RCS Return Link is much more complex in the sense that it must take into account all the effects of the access scheme on the traffic: This means the protocol scheduling and signaling of the different access classes depending on the actual traffic arriving on the emulation system, as well as the constant propagation delay of the traffic and the loss model. In particular, the scheduling and signaling of the various DVB-RCS classes introduce varying delay and bandwidth restrictions, depending on the incoming traffic. These must be applied on the traffic crossing the emulated return link. The capacity requests and scheduling taking place in the Satellite Terminal and in the NCC scheduler are not going to be as fully implemented as it is in low level emulation system, but are taken into account to apply the emulated parameters. The delay corresponding to calculation and propagation time of capacity requests is emulated while the same NCC scheduling algorithm is implemented in order to take the same decision as a real scheduler depending on the rate of incoming traffic measured upon arrival.

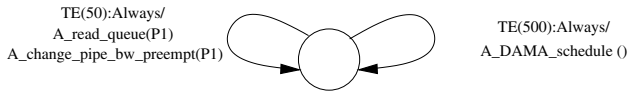


Figure 1. Finite state machine for DAMA active emulation

### C. DVB-RCS emulation in NPBox

Emulating the DVB-RCS system is challenging since it requires active emulation to allocate the available bandwidth according to the DAMA scheduling performed in the NCC. Further, the application of the scheduled bandwidth should be done in a delayed manner to emulate the signaling propagation delay in the satellite network. With NPBox, this can be realized by creating a very simple state machine and a single custom action.

The finite state machine is shown in Figure 1. The state machine defines two transitions that lead back to the same state. The transitions are triggered by a timed event (TE), i.e a timer. The right transition is triggered every 500ms, which corresponds to the frequency of the periodic scheduling requests in the DVB-RCS system. This transition performs a custom action called `A_DAMA_schedule`. This action performs the scheduling calculations based on the amount of incoming traffic since the last scheduling. What assignment class and what bandwidth assignments to use are provided as parameters to this action. Based on its parameters and the amount of incoming traffic the action calculates ten slot assignments, and puts these in the generic queue data-structure provided in the NPBox system.

The left transition occurs every 50ms, which corresponds to the slot time. At each slot time a bandwidth value is read from the queue and applied to reflect the earlier scheduling calculations done by the `A_DAMA_schedule` action. The queue is preloaded with the appropriate number of slots, to emulate the signaling propagation delay. The use of the NPBox queue thus emulates the fact that the bandwidth is scheduled at the NCC, but should be applied at the ST.

The `A_DAMA_schedule` custom action models the DAMA scheduler for the relevant assignment classes. It should be noted that this custom action does not require any large amount of complexity. The current version implements three different assignment types and requires less than 150 lines of C code.

## IV. EVALUATION

To evaluate our approach we will compare experimental results obtained on the emulation platform with the

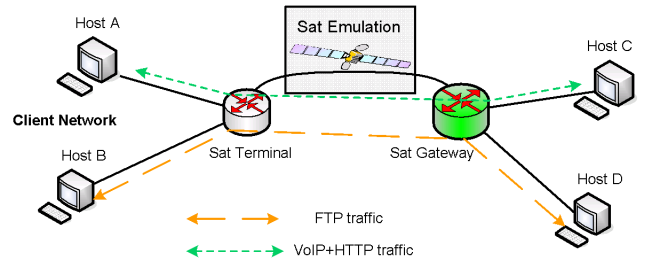


Figure 2. Topology for trials on the Alcatel Platform

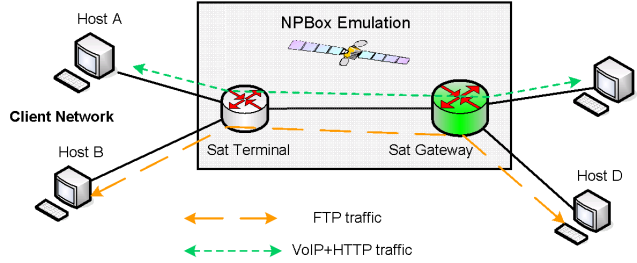


Figure 3. Topology for trials on the NPBox Platform

ones obtained on a low-level emulation platform developed by Alcatel. The Alcatel platform was developed in a European project [6] and completely implements the Satellite Terminal, the Network Control Center and the Gateway hardware and software of Alcatel 9780 system architecture; the only emulated part corresponds to the air link. Reference results obtained on this platform were published in [7]. We reproduced the same trials to make the comparison with the Alcatel platform. The comparison of the two approaches (the NPBox kernel space emulation compared to the low-level emulation developed by Alcatel) is divided into two parts:

- 1) A simple scenario with a single flow using one DVB-RCS access class, in order to compare the basic behavior of our emulation platform.
- 2) A more complex scenario including three concurrent flows using two DVB-RCS access classes to compare the behavior of the emulation platform in a more realistic case.

Both scenarios were realized in the same conditions with same traffic profiles and scenarios and using similar TCP configuration (TCP newReno with window scaling). Figure 2 shows the network topology for the tests on the Alcatel Platform while Figure 3 shows the topology when using the NPBox kernel space emulation platform. The only difference between those topologies corresponds to the emulated part of the satellite system.

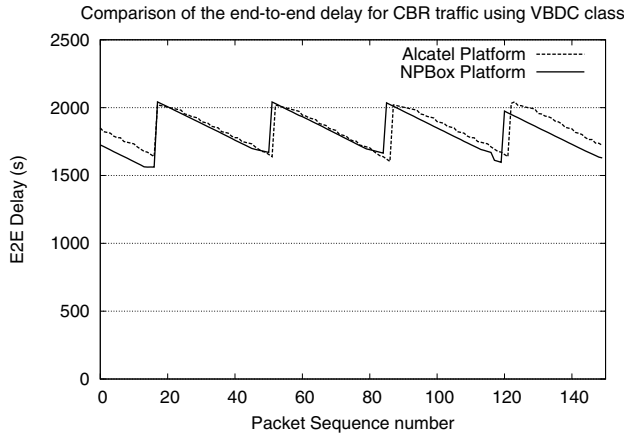


Figure 4. End-to-end delay of CBR traffic on VBDC class

### A. Simple Scenario

In order to evaluate the basic behavior of the satellite emulation system, a single flow is sent using the VBDC access class on the return link of the satellite system. The rate of the CBR flow sent on the return link is 128kbps and the Minimum guaranteed rate for the VBDC access class is 512kbps. Figure 4 shows the comparison of the results for the end-to-end delay of the flow obtained on the low level Alcatel platform and on the kernel-space NPBox platform. We can observe on this figure only a very slight difference in the behavior of the end to end delay between the two emulation platforms. The cyclic phenomenon observed for the delay of packets can be explained as follows: 1) packets are buffered until the first VBDC allocation is received from the NCC. Earlier packet will be buffered for longer time, which produces the sloping delay, 2) when packets arrive just after a request to the NCC has been sent these packets will have to wait for the next request, which causes an abrupt increase in delay. This result shows that the NPBox platform performs a good emulation of the VBDC access class in these conditions, as the behavior is practically identical to the Alcatel platform.

### B. Scenario with concurrent traffic

The scenario with concurrent traffic evaluates the behavior of NPBox for a more realistic case. For this, three concurrent flows are sent using mixed CRA and VBDC access classes on the return link of the satellite system. The three flows are an FTP file upload, a flow of HTTP requests<sup>2</sup> and a VoIP flow. Table II summarizes

<sup>2</sup>These are the request messages (GET etc.) sent to web servers. This low rate flow is modeled as a Poisson process which is typical for WWW session arrivals [8].

the configuration of the satellite link (Service Level Agreement, SLA, set between the Satellite Terminal and the gateway) and the traffic profile used for the trials. The VoIP flow is modeled by a CBR flow periodically sending packets of constant size with a rate of 20kbps. Figure 5 shows the relative starting and ending times

Table II  
EXPERIMENTAL TRAFFIC FLOW

Satellite SLA		VoIP flow		HTTP requests		FTP
CRA	VBDC	type	rate	type	rate	File size
64kbps	64kbps	Periodic	40kbps	Poisson	20kbps	1 MByte

for the different flows. Five phases can be differentiated, each with different combinations of flows concurrently running over the satellite return link. Figure 6 shows the

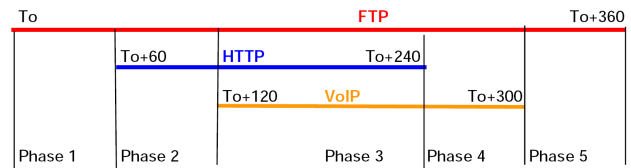


Figure 5. Traffic flow timings

comparison of FTP throughput obtained on the satellite return link for NPBox and for the Alcatel Platform.

The results show an evolution of the TCP throughput that corresponds to the starting and ending of the HTTP and VoIP concurrent flows during the 5 phases. During the first phase, the TCP flow completely fills the capacity of the satellite return link as it is alone on the channel. In the second and third phases, a decrease of TCP throughput is noticeable. This corresponds to the entrance of the

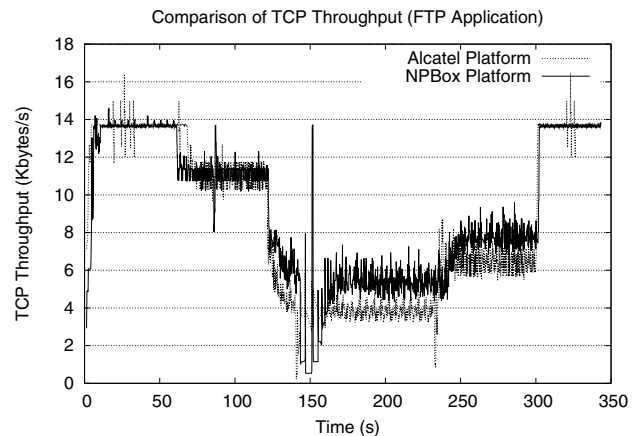


Figure 6. Comparison of TCP throughput

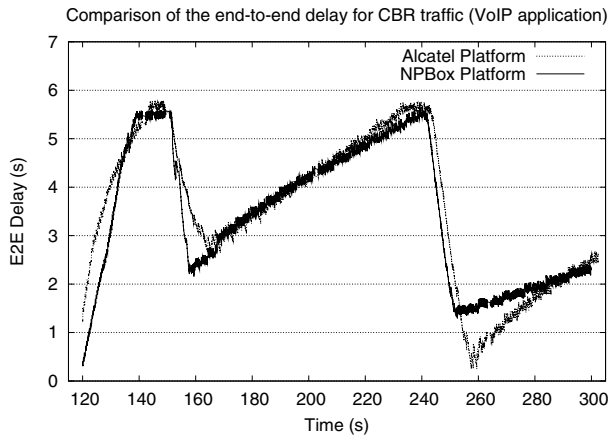


Figure 7. Comparison of CBR end-to-end delay

HTTP and VoIP flows. Then, when the HTTP and VoIP flows stop, in phase 4 and 5 respectively, TCP again increases its sending rate, which is observed on both curves. The evolution of the throughput is similar and the mean values are very close. Some minor difference may be due to the evolution of the transport protocol stack implementation in the time between both tests. However, we can conclude from this graph, that concerning the TCP throughput in a complex scenario, NPBox reproduces very similar impairments on the traffic as the Alcatel Platform.

Figure 7 shows the end to end delay experienced by the VoIP packets. The general shape of both delay curves is very similar for NPBox and the Alcatel Platform. The evolution of the VoIP delay in phase 3 and 4 can be explained as follows: First the delay of packets starts to increase very quickly due to the new entering VoIP flow. When the buffer length is reached, the delay is stabilized and packets are lost. VoIP delay decreases again due to the decrease of the TCP sending rate following the packet losses. Then it increases again as TCP increases its rate again. Next, packets losses are experienced simultaneously to the end of HTTP flow at 240 seconds which explain the brutal decrease of VoIP packet delay. The behavior of NPBox is again very close to the one of the Alcatel Platform.

We underline here that the scenario and architecture used for these experiments correspond to a reference case without any QoS support. This is why no guarantee is given for the delay of VoIP packets; this was not the aim of this study.

## V. CONCLUSIONS

Evaluation of wireless network performance is a challenging task. Testbeds using emulation techniques is one approach to obtain more controllable and repeatable results. This paper introduces the NPBox flexible and programmable network emulation platform, and employs it to a satellite system evaluation task. By modeling the relevant characteristics at a relatively high level of abstraction it has been possible to emulate the characteristics of the non-trivial DVB-RCS DAMA channel. It should be noted that the amount of time needed to model and implement the DAMA emulation scenario is very short due to the flexible approach of the NPBox system. NPBox allows system components to be modeled both at a higher abstraction level using a finite-state-machine like abstraction, and also at a lower level using customized event guards and actions. Comparison experiments performed against a complex low-level emulator have shown that the fidelity of this active emulation approach is very good both with regards to throughput and delay characteristics.

For future work we intend to continue to extend the NPBox platform and prepare a freely available distribution, and also to create active emulation for other wireless environments such as WLAN.

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