Physical Layer Representation for Satellite Network Emulator

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Abstract. In general, emulation of satellite networks has been focused on representing the features of the access network, characterised by large complexity. Physical layer impact has usually been neglected or reduced to static and limited models. The aim of this work is to reformulate a new model of physical layer oriented to network emulation, adapted to multiple satellite systems and configurations. The main achievement of this work is the design of a simple method of analysis of end-to-end communication links, that can rely on separated uplink and downlink attenuation channels generated offline or in runtime. The model has been integrated in the open source platform PLATINE[1], showing an easy integration to distributed machine emulation and reproducing local propagation conditions for each ground terminal.

Keywords: satellite, emulation, network, physical layer, DVB-S2, DVB-RCS, BER, ACM, delay, C/N.

1 Introduction

In the context of networks based on bidirectional satellite systems, gateway stations are connected via satellite links to an important number of terminals, sharing limited bandwidth. The geographic distribution of ground terminals may result in very different atmospheric conditions and interference levels for each satellite link. Also, due to different uplink and downlink frequencies, the propagation conditions may differ slightly in each direction of the communications (forward/return link). Consequently, the resulting network is composed of communication segments whose performances vary throughout space and time (similar to the local conditions of each ground terminal), defining an important aspect of satellite network architectures, as presented in figure 1. Rain especially may strongly affect and collapse a communication link between the satellite and a ground station. Network resources should also implement adaptability to these changing scenarios. For example, in the case of DVB-S2/RCS

[1] The license of this project has recently changed to free software license GPL. Under the new conditions, the name of PLATINE will be abandoned and a new name for the project will be applied in the future.

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architecture, featured with Adaptive Coding and Modulation (ACM) in the forward link, the Network Control Centre (NCC) shall define how to broadcast content with the most efficient MODCOD schemes at all times, and considering the different (C/N_0) reception conditions of each user [1].

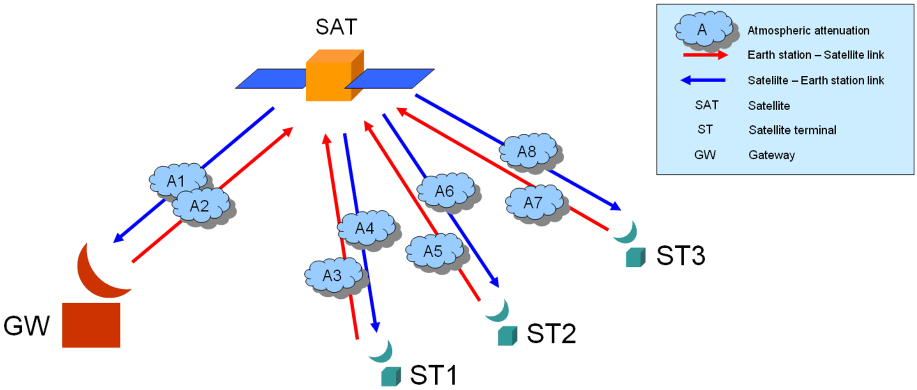

Fig. 1. Attenuation in different links in DVB-S2/RCS based in a unique satellite architecture

In this context, we want to build a model that reflects the main impacts of the physical layer on network communications, such as error introduction and insertion of delays, while still keeping the perspective of network emulation. In other words, the main objective of this paper is to present the base for a physical layer model, simple enough to be efficient in terms of computation, and representative enough to test network performance and capabilities in the context of satellite communications. Additionally, it will be required that the model present a flexible logical structure and several configurations, from extremely simple to more complex models. Network access emulation is already a complex system; the objective is to provide a simple and configurable model to evaluate more realistic results regarding the physical layer impact on satellite networks.

The second section of this paper recalls the principles of analysis of RF communications for both single and multiple links. The third section presents the architecture of PLATINE and the previous context of physical layer representation over satellite networks. The fourth section describes an implementation proposal for the analysis of the Physical Layer impact on bidirectional satellite networks. Final conclusions for this study are presented in section 5.

2 Physical Layer Impact in Communications

The characteristics of satellite RF propagation will determine essential performance parameters for satellite network links: bit error rate, delay or availability, and will affect bit rate adaptation in some satcom systems, such as DVB-S2/RCS. The most representative parameters describing these impacts include: bit error rate (BER), channel capacity and the propagation delay.

2.1 Bit Error Rate and Channel Capacity

In digital satellite communications, the error rate of an incoming data flow is measured by the link BER, which represents the ratio of the number of erroneous received bits over the number of bits transmitted from the communications channel. If the link BER is high, it may exceed the channel coding scheme's capacity of error. For example, in a DVB-S2 system disrupted by heavy rain, the received BBFRAME may have too many erroneous bits, which will be detected by the FEC, and therefore, the frame may be dropped by the receptor. If this situation occurs for successive frames, the channel will be considered blocked or in a state of failure. The calculation of BER in digital communications is directly related to the Carrier power to noise power spectral density ratio (C/N_0) of the link, and the modulation and coding scheme (MODCOD) used for RF communications (where C/N_0 is dependent on the system configuration and the external physical media of transmission, and the MODCOD is only dependent on the system design). The choice of the MODCOD will also determine the effective transmission rate through the communications channel, which is relevant to the whole network performance.

General Link Analysis. C/N_0 shows the ratio of the power of the signal received to the power density of the received noise that interferes in the signal demodulation and is an essential parameter in describing the quality of communications.

To analyse the total C/N_0 (or end-to-end C/N_0 in satellite communications with transparent payloads) [2], there are many parameters to consider, as shown in the following table:

Table 1. Parameters affecting the link budget

Earth station	Satellite	Channel
• Geographical location: Rain fade statistics, Satellite look angle, Satellite EIRP in the direction of the earth station, Earth-Satellite Path loss • Transmit antenna gain G_u + Transmitted EIRP • Receive antenna gain – *related to G/T* • System noise temperature – *related to G/T* • Intermodulation noise - *related to total* C/N_0 • Equipment considerations (cross polar discrimination, filters) – *related to link margins*	• Orbital position • Tx and Rx antennas - *related to EIRP and G/T* • Power - *related to EIRP* • Transponder gain and noise characteristics - *related to EIRP and G/T* • Intermodulation noise - *related to total* C/N_0 • Interference level (C/I) that can be decomposed in inter-system and intra-system interference	• Frequency - related to link margin and path loss • MODCOD - related to required C/N_0 • Intersystem noise / interference

In particular, the main parameter that may dramatically change the C/N_0 throughout time is the attenuation of the channel, which is mostly affected by the weather conditions, i.e. hygrometer absorption due to rain or ice. In mobile systems, shadowing, and multipath propagation also represent important factors, which may eventually decrease the total C/N_0 drastically. Thus, the attenuation of channel due to hygrometers and mobile conditions are key parameters in the representation of a channel model.

Segmented Analysis. In the case of satellite communications, the transmitted signal traverses several segments. It starts from a ground antenna transmission directed to the satellite reception antenna and then crosses the satellite chain, and ends with satellite transmission towards the ground terminal antennas followed by reception in ground (see figure 2). Interference from external noise sources and the intermodulation noise produced in the High Power Amplifier (HPA) in the satellite cannot be neglected for the total C/N_0 calculation.

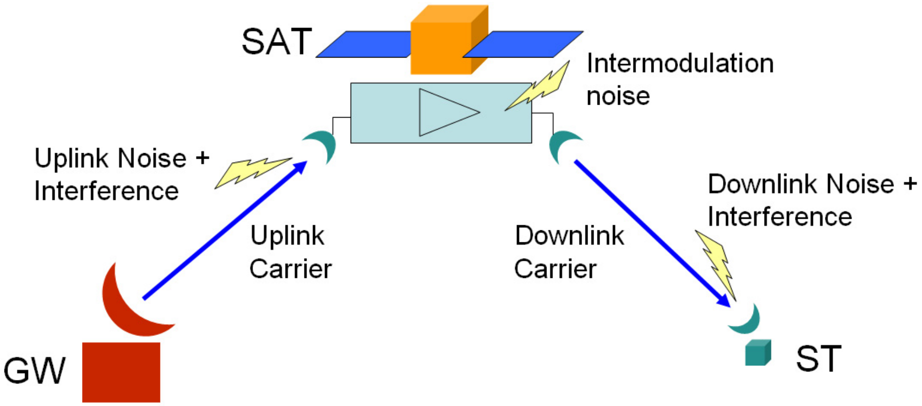

Fig. 2. Segments of satellite communications and noise sources in the global satellite scheme in transparent case

Finally, there is an expression to obtain the total C/N_0 [3], as presented in equation 1, which summarises the end-to-end communications quality:

$$(C/N_0)_T^{-1} = (C/N_0)_U^{-1} + (C/N_0)_D^{-1} + (C/N_0)_{IM}^{-1} + (C/N_0)_I^{-1} . \quad (1)$$

, where $(C/N_0)_U$ is the C/N_0 for the uplink, $(C/N_0)_D$ for the downlink, $(C/N_0)_{IM}$ for the intermodulation, $(C/N_0)_I$ for the interference and $(C/N_0)_T$ for the total Carrier power to noise power spectral density ratio.

Remark: Note that the equation above only applies to transparent satellite-based systems. For the regenerative case, link quality (in terms of BER, for example) is computed independently, per segment. The complete BER consists in, as a first approximation, the addition of BER_U and BER_D, which are independently relative to $(C/N_0)_U$ and $(C/N_0)_D$.

2.2 Delay

In a general data transmission scheme, there exist two sources of delay: transmission delay, which is the time needed in the transmitter to convert a flow of data into a concrete sequence of symbols and push them into the physical medium, and propagation delay, which implies the transportation of those symbols across the physical medium from transmitter to receiver.

In satellite communications, the transmission delay does not present any particular difference compared to regular terrestrial RF systems, however the physical propagation of electromagnetic waves in satellite communications implies a significant delay, due to large distances between the satellite and the earth station antennas. Considering all cases of satellite orbits, a delay model may be seen as a combination of:

- The source ground terminal to source satellite propagation delay (*tup*)
- The Inter-satellite link propagation delays (*ti*)
- The destination satellite to destination ground terminal propagation delay (*tdown*)

The propagation delays t_{up} and t_{down} are dependent on the distance between the ground antennas and the satellite. In case of GEO satellites, this value will be almost fixed. In case of HEO/LEO, t_{up} and t_{down} will vary along the orbit translation and it could be easily computed as an orbital position problem and distances determination. Also, the calculation of t_i in case of satellite constellations requires modelling of inter-satellite links, which may be more complex [4].

3 Satellite Network Emulator - PLATINE

The aim of this study is oriented to integrate a logical structure for physical layer representation over a satcom system emulator. In our case this platform is PLATINE, but the aim is to propose a general structure that could also be valid for other platforms [5][6]. The working modes considered include two main scenarios: a transparent satellite case, implemented in star topology, and the regenerative case, where a mesh structure is used and only a single hop is needed to interconnect two satellite terminals.

In the architecture of PLATINE, each network element, such as Gateway (GW), Satellite Terminal (ST) or Satellite (SAT), is emulated in a dedicated machine and all of them are interconnected with LAN Ethernet. The satellite core network is emulated by the SAT machine as link emulator and the Network control center (NCC)/GW machine as bandwidth manager (Demand Assignment Multiple Access – DAMA).

Concerning the physical layer representation in PLATINE, two different modules have been integrated in the past. The first implementation included the generation of error bursts (a group of consecutive erroneous bits in the data stream), using statistical parameters or loading pre-calculated error files. In addition, MODCOD and Dynamic Rate Adaptation (DRA) scheme profiles of each terminal could also be loaded from an externally generated simulation. This implementation was used to analyse the impact of adaptive capabilities on DVB-S2/RCS systems when affected by rain cells. The second implementation proposed real-time emulation of channel attenuation to determine the C/N_0 of end-to-end links according to theoretical attenuation models.

This approach lacked the segmented analysis (independent analysis of each link from any ground station to the satellite and the satellite chain link), which is essential for a representative evaluation of satellite network performance. It also lacked interaction with the waveform and channel coding chosen for satellite transmission.

This study re-uses this previous work and the principle of channel emulation, while reformulating the logical structure and settling a more flexible analysis of C/N_0 based on link segmentation.

4 Physical Layer Model

The aim of the implementation is to create a common module in all the machines of the emulator to represent the impact of the physical layer on the satellite network. Regarding the architecture of PLATINE divided in blocks, an independent module for Physical Layer functions is introduced between the DVB-RCS block and the Satellite Carrier block. This module is in charge of routing frames through the emulation network. The implementation of Physical emulation in a new block enables easier and cleaner integration, providing independence for external development and remaining open to wider schemes and new implementations of physical layers (figure 3). Internally, the Physical Layer block presents two inner modules referred to as Channels that manage the state of each segment link, e.g. downlink, uplink, or satellite segment. Since PLATINE architecture follows an object-oriented approach, each Channel is represented by a class.

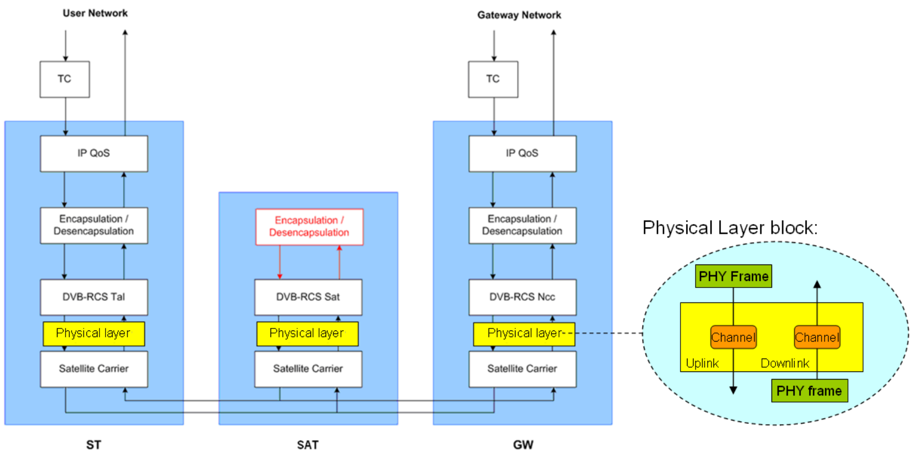

Fig. 3. Block architecture in PLATINE and diagrams of Physical Layer block in different machines

The main function of Channel objects is to manage the flow of incoming or outgoing frames of each machine. Their objective is to reproduce errors and delay when necessary, and provide information about the C/N_0 of the links. In fig.4, the Channel structure presents five associated attribute classes; these are virtual classes. Following this approach, a logical structure has been defined to keep coherent Channel classes among the different machines and to allow the implementation of different models for each attribute class, i.e. Attenuation model may be implemented by Rain model or LMS model or, for example, Delay class may be implemented by a LEO or GEO model of delay.

The five attribute classes for Channels are:

- *Attenuation class* represents the attenuation state of one link, and stores the value in the attribute Attenuation (dB). It is further implemented by different channel models, i.e. Rain model, LMS model or other models.
- *Nominal Condition class* represents the best C/N_0 possible in the link. For example, for Uplink and Downlink, that value corresponds to clear sky C/N_0. In the case of satellite segment channels, C/N_0 corresponds to the best $(C/I)_{IM}$ that can be achieved using the amplification and processing chain.
- *Waveform class* manages and obtains information about the current modulation and coding scheme used for each frame. Therefore, other attribute classes, such as Error Insertion, may use this information to complete their tasks.
- *Error Insertion class* (optional) generates and inserts erroneous bits into incoming frames depending on the $(C/N_0)_T$ obtained and the Waveform. In case of transparent payloads, this class is only present in the receiving channels (Download channels) in the ground stations. Otherwise, it is present in the satellite segment in case of regenerative payload. Two models are initially proposed: Single bit error, which calculates a reference BER and inserts erroneous bits accordingly, and Error Gate, which drops every incoming frame if the $(C/N_0)_T$ is insufficient compared to a given threshold value.
- *Delay class* inserts a time elapse between the reception and reemission of the frame. The duration of this delay will depend on the implementation model chosen.

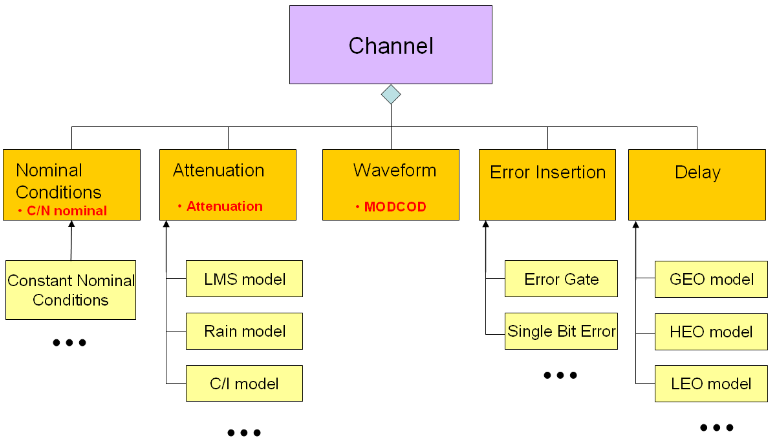

Fig. 4. Class structure for Channel module

4.1 Principles

In each frame transmission from one ground station, such as ST or GW, to another ground station, the “Physical Layer” block will determine how to affect the communications, blocking the frame transmission or inserting erroneous bits if necessary. One main element must be determined for each end-to-end frame transmission: $(C/N_0)_T$, calculated as the combination of all the segments the frame has been through, using equation 1. The C/N_0 of each segment (uplink, downlink or satellite segment) is calculated in each Channel module as:

$$(C/N_0)_X = (C/N_0)_X^{Nominal} - Attenuation . \quad (2)$$

4.2 Execution Steps

In the case of transparent communications, the sequence for the Physical layer function implies three stages, as shown in fig.5. First, the $(C/N_0)_U$ is calculated in the Channel object for uplink in the emitting ground station and this information is inserted in a special header in the frame, obtaining a PHY-frame. The calculation of C/N_0 for the uplink requires the emulation by the Channel object, calculating the attenuation in that given time and subtracting it from its nominal C/N_0 value. Thereafter, the PHY-frame is routed through the SAT machine, where an additional $(C/N_0)_{IM}$ due to intermodulation noise, is optionally added to the PHY-frame. Finally, the frame arrives at the destination machine and $(C/N_0)_D$ is calculated by the downlink Channel object. Then, gathering $(C/N_0)_U$, $(C/N_0)_D$ and $(C/N_0)_{IM}$, the parameter $(C/N_0)_T$ is obtained using equation 1 and it may be used to calculate error effects.

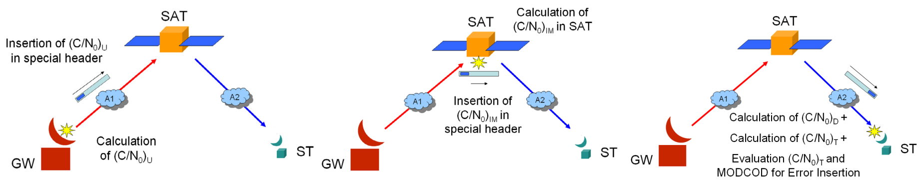

Fig. 5. Distributed calculation of $(C/N_0)_T$ in transparent case

In the case of regenerative communications, the evaluation of $(C/N_0)_T$ is also performed when the frame arrives at the SAT machine and errors effects are also introduced.

4.3 Results

To validate an initial implementation of physical layer over PLATINE, several tests have been developed. Rain and ONOFF models of attenuation over ST links have been applied. Errors have been emulated by frame corruption when the $(C/N_0)_T$ value did not reach a minimal threshold value. For example, Iperf tests have been used to generate UDP traffic at constant bit rate (CBR) and to internally validate the correct calculation of $(C/N_0)_T$ for end-to-end frame transmissions. Results has been compared to an ideal model based on NS-2 simulations. An example of ONOFF channel is shown below, where a loss of bit rate efficiency may be appreciated compared to the ideal model, due to the protocol overhead considered in the Platine emulation. Also, another difference between both platforms is that channel disruption has been implemented as frame loss during physical propagation in the NS-2 simulation whereas frame corruption has been applied at end-user level in our physical layer over Platine.

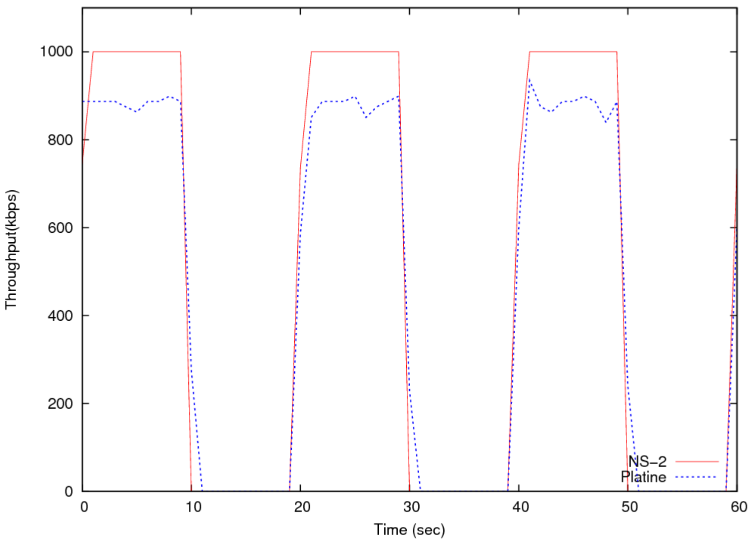

Fig. 6. Performance comparison between Platine and ideal simulation with NS2. Test: UDP traffic received by the GW from ST, with CBR traffic generation of 1 Mbps over a 1Mbps CRA channel in Return link, and affected by periodic disruptions of up/downlink every 10 seconds. DVB-RCS/ATM/AAL5 protocol stack implementation over Platine yields a lower traffic throughput due to the overhead introduced.

5 Conclusion

First, a thorough analysis of RF satellite communications has been schematized and simplified into logical modules adapted to the network emulation case. Here, the insertion of errors based on $(C/N_0)_T$ calculations and delay has been chosen as the most representative impacts of the physical layer on the network emulator.

The definition of a logical and class structure for the physical layer presented some challenges, such as setting up a modular structure capable of providing elementary models of the physical layer, while being sufficiently adequate for future complex models, like new models of attenuation.

The main achievement of the design lies in the establishment of segmented analysis of end-to-end $(C/N_0)_T$, since it distributes the individual link C/N_0 calculation among all the emulator's machines and improves the computation efficiency of the system and avoids overloading certain machines.

At the moment, only basic tests have been performed to demonstrate the correct functioning of the emulator. Errors have been implemented with blocking states, when $(C/N_0)_T$ was below a certain threshold.

The next version of Physical layer implementation will introduce error effects directly translating the $(C/N_0)_T$ into Bit Error Rate (BER), which assures a gradual degradation of communications with the decrease of $(C/N_0)_T$. This feature will ease the QoS evaluation of real-time services such as voice communications over IP or video conferences. Furthermore, the $(C/N_0)_T$ value calculated in end-to-end communications will be used to test the adaptation of upper layers with changes in modulation and coding schemes, to improve robustness against errors and modify the bit rate.

Other future improvements include dynamic changes in execution time, such as the introduction of transition profiles of Channel models, e.g. change from heavy Rain conditions to a clear sky model. Finally, new sources of degradation impacting the total C/N_0 calculation shall be taken into account, such as the intermodulation effect in the satellite segment or the modelling of interference noise.

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