Evaluating the Performance of DVB-S2 Over Asymmetric Heterogeneous Optical to Radio Frequency Satellite Links Using the LLGrid

Nancy List, Tommy Royster, and Ryan Shoup
MIT/Lincoln Laboratory
{nlist,troyster,shoup}@ll.mit.edu

Introduction

The DVB-S2 coding standard [3] has seen widespread use in many radio frequency (RF) communications applications. The availability of commercial-off-the-shelf (COTS) intellectual property (IP) that can be used to rapidly prototype and field communications systems makes this well-performing, standards-based approach to forward error correction (FEC) coding extremely attractive. In this paper, we evaluate the application of the DVB-S2 coding standard to an asymmetric satellite communications channel. This evaluation was done using a bit-exact software implementation of a commercial DVB-S2 codec in an extensive series of simulations performed using pMatlab on the LLGrid [1].

The physical system evaluated in this study comprises a fading optical link employing binary differential phase-shift keyed (DPSK) modulation, and a RF link employing 16-ary amplitude and phase shift keyed (16-APSK) modulation. To simplify the payload implementation, hard-decision uplink demodulation is considered with uplink channel state information transmitted on the downlink for soft-decision decoding in the ground-based receiver.

Heterogeneous Optical/RF Satellite Communications System

A diagram of a heterogeneous optical and RF communications system is shown in Figure 1. The system components include an optical transmitter, a space-based optical receiver and RF transmitter, and an RF ground-based receiver. Communication in one direction only (optical uplink, RF downlink) is described in this section, though it is assumed that communication in the opposite direction (RF uplink, optical downlink) is the logical inverse.

The optical transmitter sends an optically modulated DPSK communications signal on the uplink to the satellite. In the system shown in Figure 1, the satellite receiver demodulates the DPSK signal, but does not decode the demodulated signal, and re-transmits the signal using 16-APSK modulation on the RF downlink. We call this configuration "end-to-end decoding."

Channel degradations on the uplink include optical fading and additive white Gaussian noise (AWGN). Only AWGN in the RF channel degrades the signal transmitted on the downlink. Encoding and interleaving mitigate the impact of fading and receiver noise. Framing is used to delineate DVB-S2 codeword boundaries and to reserve data bits for transmission of channel state information. The channel state information includes information on the fading depth experienced by each transmitted uplink frame. If the signal is only demodulated, not decoded, on the satellite, this channel state information is needed to properly bias the log-likelihood ratio (LLR) inputs to the soft-decision decoder on the ground.

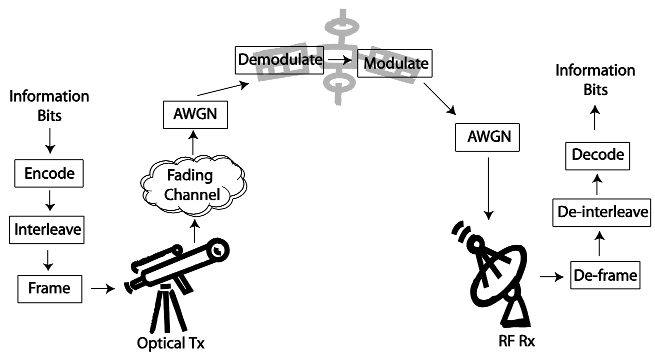

Figure 1: Heterogeneous Optical Uplink / RF Downlink satellite communications system with end-to-end decoding

Communication Channel Models

The uplink channel was modeled using an optical channel fading time series that was obtained via the parallel optical propagation software (POPS) tool described in [2]. Different optical communications channels were modeled for use in simulations. From the POPS tool time series we were also able to measure the channel coherence time. As mentioned above, the convolutional interleaver depth was then set to be ~100 times as long as the coherence time of the channel. In addition to the uplink fading, AWGN further corrupts the optical uplink as well as the RF downlink as illustrated in Figure 1.

The measured coherence time of the channel model was also used to choose the appropriate frame length. It is desirable for the frame length to be short enough that a single fade value accurately approximates the fade level seen by all the bits in the frame. This estimated fade level is used to compute the LLRs provided to the decoder in the ground-based receiver (or in the payload of the satellite in the case of payload decoding).

In addition to the use of a strong rate-1/2 code and channel interleaving, measuring and applying the optical channel state information is a third means to mitigate the effects of fading. The LLRs supplied to the decoder can and should include information regarding the uplink channel state experienced by each bit.

This work was sponsored by the Department of the Air Force under Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

For practical considerations such as payload complexity and downlink channel throughput, we do not consider in our analysis either soft-decision payload decoding or ground based decoding using soft-decisions on payload bits. However, it is feasible to consider using soft information from an A/D in the ground-based receiver along with the uplink channel state information for each bit (i.e., using the cross-over probability, p_{ul}, of the uplink channel experienced by a particular code bit) to calculate a more refined LLR input to the end-to-end decoder.

Simulation Results and Analysis

Rather than approximating the fading channel using a fading distribution and an "infinite" interleaver in our model, we used an actual fading time series [2] and a convolutional interleaver [4] in our simulations. While this increased the fidelity of our simulation, it also increased the computational complexity. In addition, we needed to model an "end-to-end" link in our simulations to capture the effect of both uplink and downlink conditions on overall system performance. This increased computational complexity by essentially squaring the parameter space of each of our simulations.

Because of the computational complexity and low BER requirements for our analysis, we turned to the LLGrid to facilitate our work. Each simulated data point on the red and green curves in Figures 2 and 3 corresponds to a point at which the BER performance of the end-to-end link was measured at ~ 10^{-7}. The asymptotes in Figures 2 and 3 show the RF Es/No and the optical photons per bit required to achieve a BER of ~ 10^{-7} if the signal were decoded and re-encoded onboard the satellite payload. Though these curves were very time-consuming to produce, the resulting data made it very easy to visualize the constraints on the trade space between uplink photons per bit and downlink Es/No levels.

An interesting conclusion that can be drawn from the performance curves in Figures 2 and 3 is that when the downlink signal level is in the asymptotic region of the performance curve, the end-to-end performance is the same as if hard-decision decoding were performed onboard the satellite.

For the rate-1/2 DVB-S2 used in this analysis, there is approximately 1 dB gain in performance on the uplink asymptote using soft-decision versus hard-decision decoding in the asymptotic region of the performance curve. However, the additional hardware complexity that is entailed with soft-decision payload decoding would have to be weighed against this performance gain.

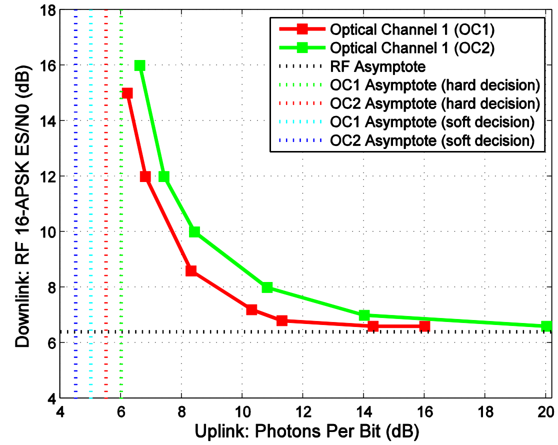

Figure 2: Optical Uplink – RF Downlink

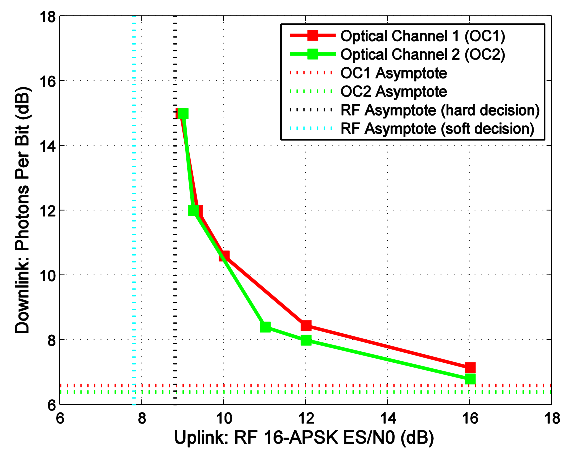

Figure 3: RF Uplink – Optical Downlink

References

[1] N.T. Bliss, R. Bond, J. Kepner, H. Kim, and A. Reuther, "Interactive Grid Computing at Lincoln Laboratory," Lincoln Laboratory Journal, Vol. 16, No. 1, 2006, pp. 165-216.

[2] Scot E. J. Shaw and Jan E. Kansky, "Atmospheric effects on active illumination," Target-in-the-Loop: Atmospheric Tracking, Imaging, and Compensation II, edited by Michael T. Valley, Mikhail A. Vorontsov, Proc. SPIE, vol. 5895, 2005.

[3] "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2), Final draft ETSI EN 302 307," V1.2.1 (2009-04).

[4] B. Moision and A. Biswas, "Memory Requirements to Mitigate Fading Losses on an Optical Channel ," IPN Progress Report, 42-170, August 15, 2007.