

Cross-Layer Optimization of TCP Throughput for DVB-S2 Links

Joan Enric Barceló

Dpt. Telecom. and Syst. Engineering
Universitat Autnoma de Barcelona
Bellaterra 08193 - Barcelona, Spain
joanenric.barcelo@uab.es

Giovanni Giambene

Dpt. of Information Engineering
Universita' degli Studi di Siena
Via Roma, 56 53100 - Siena, Italy
giambene@unisi.it

María Ángeles Vázquez Castro

Dpt. Telecom. and Syst. Engineering
Universitat Autnoma de Barcelona
Bellaterra 08193 - Barcelona, Spain
angeles.vazquez@uab.es

Abstract—This paper presents a methodology to optimize the use of the forward link DVB-S2 capacity. Our interest is optimizing the switching E_b/N_0 thresholds for adaptive coding and modulation selection in DVB-S2 in order to maximize the TCP goodput according to a cross-layer design approach.

Index Terms—Adaptive Coding and Modulation (ACM), Cross-layer design, DVB-RCS, DVB-S2, PER, TCP.

I. INTRODUCTION

Currently, most Internet applications such as file transfer, Web browsing and email services are running over the TCP-IP protocol stack. TCP permits to achieve a reliable end-to-end connection for data delivery. TCP operates in a full-duplex way: all data sent must be acknowledged via a return link.

Satellite communications represent a viable solution for Internet access for wide areas. For a satellite interactive network, the second-generation of DVB-S, DVB-S2 [1], shall be considered with a return link according to DVB-RCS [2]. In this framework, the forward link is referenced as DVB-S2 link and the return link as DVB-RCS link.

DVB-S2 provides an increase in capacity of up to 30% [3] compared to the older first-generation of DVB-S using the same bandwidth and power and under the same channel conditions. This improvement is achieved by applying higher order modulations and by the use of *Low Density Parity Check* (LDPC) codes and *Bose-Chaudhuri-Hochquenghem* (BCH) codes. The main novelty is the possibility of using *Adaptive Coding and Modulation* (ACM). In such a scenario, the selection of the suitable spectral efficiency (η) and the related *Modulation and Coding* (ModCod) level must be carried out considering the state of the channel. If a spectral efficiency higher than appropriate is used, the system will perceive higher capacity than actually available, but with an excessive *Bit Error Rate* (BER). Alternatively, if a too low spectral efficiency is selected, there is a waste of capacity. The DVB-S2 standard allows the choice between different ModCods providing a *Quasi Error Free* (QEF) quality target; this is performed on the basis of suitable E_b/N_0 threshold values. In this work we refer to the QEF definition provided in the DVB-S2 standard as “less than one uncorrected error-event per transmission hour at the level of a 5 Mbit/s single TV service decoder”, approximately corresponding to a transport stream *Packet Error Rate* (PER) equal to 10^{-7} .

The aim of this work is to go one step further in the optimization of the ModCod threshold values to improve the throughput of the DVB-S2 forward link by taking into account the TCP performance in satellite networks and its sensitivity against packet losses and available bandwidth. This optimization is analytically performed by considering *Scalable-TCP* (S-TCP), an improved TCP version suitable for satellite networks, as proven in [4].

II. REFERENCE SCENARIO

A. Overview of DVB-S2

DVB-S was introduced as a standard in 1994 and is still widely used for television and data broadcasting services. It is based on QPSK modulation and convolutional *Forward Error Correction* (FEC), concatenated with Reed-Solomon coding. Using static coding and modulation implies that the system must be designed to operate also in bad channel cases with poor adaptability. Therefore, the system is fully designed on the basis of the worst-case assumptions, thus causing a significant waste of capacity.

DVB-S2 is the second-generation specification for satellite broad-band applications developed in 2003. The necessary bandwidth resources for large throughputs can only be found at *Extremely High Frequency* (EHF) bands, such Ka band and above. At those frequencies, atmospheric effects become very important and can only be faced by overcoming the conservative worst-case design approach in favor of adaptive mode selection. DVB-S2 provides a fade mitigation method by means of ACM. Signaling between every *Satellite Terminal* (ST) to the gateway is employed to notify the ST-perceived channel state. According to this information, a spectral efficiency (ModCod) is selected on a physical layer frame basis in the link from the gateway towards every ST (forward link). DVB-S2 offers a wide range of modulations and coding rates for ACM. The allowed coding rates are $1/4$, $1/3$, $2/5$, $1/2$, $3/5$, $3/4$, $4/5$, $5/6$, $8/9$, $9/10$ and the supported modulation schemes are QPSK, 8-PSK, 16-APSK, 32-APSK. The possibility of selecting both coding rate and modulation allows a more efficient use of system capacity. Using a high order modulation with slight coding rate permits to transmit with a high channel efficiency for clear sky conditions; while, using lower order modulation combined with low coding rates improves the robustness to face

channel losses, but at the cost of lower spectral efficiency. Then, it is possible to select a suitable spectral efficiency for each ST, guaranteeing a BER level according to the QEF requirement.

B. ACM in DVB-S2

The real novelty introduced by DVB-S2 was the possibility to use ACM instead of non-adaptive physical layer systems. Using a powerful FEC system based on LDPC codes concatenated with BCH codes, QEF operation is allowed at about 0.7 dB to 1 dB from the Shannon limit, depending on the transmission mode. Combining the 11 defined coding rates with the 4 supported modulation schemes, different spectral efficiencies are possible; among them, only 28 are considered by the standard with a range of bandwidth efficiencies from 0.5 bits/symbol up to 4.5 bits/symbol. The performance of different spectral efficiencies in AWGN channel is depicted in Fig. 1 under the following assumptions [1]: less than 50 decoding iterations in the receiver, perfect carrier synchronization recovery, and no phase noise. The packet error rate is referred to DVB-S2 packets or frames called normal FEC frames, which consist of 64800 encoded bits (BCH and LDPC encoding). DVB-S2 also provides shorter FEC frames of 16200, used for delay-critical applications, but we will not consider them in this paper. In order to support the spectral efficiency adapta-

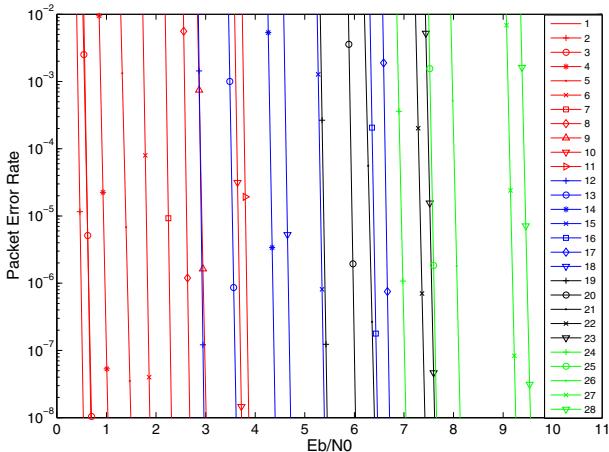


Fig. 1. DVB_S2 performance in the AWGN channel for long FEC frames and 28 ModCods.

tion functionality, periodical channel estimations are required, which are performed at the ST in the case of the forward link; then this information is sent back to the Gateway via signaling. On the basis of this information, the Gateway shall select the most suitable ModCod according to established thresholds that are described in [1] and can be also derived from Fig. 1 by considering the E_b/N_0 values corresponding to $\text{PER} = 10^{-7}$ (QEF requirement).

III. PROPOSED CROSS-LAYER APPROACH FOR TCP THROUGHPUT OPTIMIZATION

A. A survey on Cross-layer Methods

A number of Internet applications require a reliable delivery of data that is guaranteed by the TCP protocol at the transport

layer. TCP is extremely sensitive to lossy channels, and thus to packet errors. To improve TCP performance by optimizing satellite-dependent layers, cross-layer design methods have been proposed [5]. Cross-layer design is particularly important in the satellite scenario where many constraints and costly challenging technical solutions need to be employed to optimize the efficiency of the system. In Reference [5], two basic cross-layer approaches are considered: (i) Implicit cross-layer design, in which there is no exchange of signaling among different layers during operation, but in the design phase all the layer interactions are taken into consideration to perform a joint protocol optimization; (ii) Explicit cross-layer design, in which signaling interactions among non-adjacent protocol levels are employed so that dynamic adaptations can be simultaneously performed at different protocol layers.

Cross-layer design opens a wide fan of new possibilities to enhance the performance of wireless networks. Recently, several research papers have been published on this subject. Authors of Reference [6] analyze the behavior of video transmission (H.264) over UDP-Lite with QoS requirements. They show that changing packet size with respect to the checksum coverage yields less packet drop and improves video quality. Also the approach proposed in [7] provides QoS by introducing a bandwidth allocation fairness parameter, tuned via cross-layer architecture. In [8], enhancements are proposed at the IP layer to manage CRC and FEC codes at layer 1. Moreover, a new resource allocation scheme is proposed in [9] considering the interactions between TCP and MAC layers. The authors use an explicit cross-layer technique to predict the amount of data that will feed the MAC buffer on the basis of the TCP congestion window value.

B. Proposed Cross-layer Optimization

We are interested to a PHY layer optimization on the basis of the behavior of the transport layer (TCP protocol). Our aim is to improve the capacity of the system as seen by higher layers. In particular, our new method implies to redefine the QEF thresholds of ACM according to the following implicit cross-layer design technique: the ModCod selection is performed in order to maximize the TCP goodput [10] rather than guaranteeing $\text{PER} < 10^{-7}$. We propose the optimization based on S-TCP, since it has been proven as an efficient solution for error-prone and high delay-bandwidth-product satellite networks [11].

1) Spectral efficiency modeling: Let us refer to the spectral efficiency performance with LDPC from reference [12] that characterizes the PHY layer of DVB-S2 forward link. It is necessary to convert from symbol to information bit that is from E_s/N_0 to E_b/N_0 by using the following equivalence [1]:

$$\frac{E_s}{N_0} [\text{dB}] = \frac{E_b}{N_0} [\text{dB}] + 10 \log_{10}(\eta) \quad (1)$$

where η is the spectral efficiency that it is computed as $\eta = \log_2(M) \times r$; where M is the size of the modulation constellation and r is the code rate.

We propose an analytical model of the PER behavior of each spectral efficiency of DVB-S2. The exponential model

from [13] is considered with two tunable parameters λ and γ (the first one controls the position of the curve in the E_b/N_0 axis, while the second one determines the slope):

$$\text{PER} \left(\mu, \frac{E_b}{N_0} \right) \approx \lambda(\mu) e^{-\gamma(\mu) \frac{E_b}{N_0}} \quad (2)$$

where μ denotes the ModCod index, $\mu \in \{1, 2, \dots, 28\}$. The mean square error obtained with this modelization is always lower than 0.1 for the PER interval of interest ($10^{-8}, 10^{-2}$). Note that in other PER intervals, the fitting is not guaranteed.

2) Evaluation of PER at transport layer: To compute the PER experienced at the transport layer, PER_{TCP} , we consider a continuous stream of TCP segments for a given ST, so that partially-used FEC frames are filled in with part of the next TCP segment (fragmentation is allowed). We do not consider efficiency losses due to encapsulation. The optimization of the encapsulation efficiency is an independent issue not affecting our cross-layer optimization study. Please refer to [?] for further details on encapsulation efficiency. We consider uncorrelated losses at layer 2 and 3. We follow an approach proposed in [15] to relate PER_{TCP} and PER at the level of FEC frames, in the usual case that the FEC frame length, $l_{\text{FEC_frame}}$, is longer than the length of an IP packet containing a TCP segment, l_{TCP} :

$$\text{PER}_{\text{TCP}} \approx \frac{\lceil r(\mu) l_{\text{FEC_frame}} / l_{\text{TCP}} \rceil + 1}{r(\mu) l_{\text{FEC_frame}} / l_{\text{TCP}}} \text{PER} \left(\mu, \frac{E_b}{N_0} \right) \quad (3)$$

where $\lceil \cdot \rceil$ denotes the *ceiling function*; the $+1$ term that sums to ceiling function is due to the fact that in the worst-case a FEC frame loss has impact on the loss of $\lceil r(\mu) \times l_{\text{FEC_frame}} / l_{\text{TCP}} \rceil + 1$ TCP segments. The values envisaged are the standard ones: $l_{\text{FEC_frame}} = 64800$ bits (normal FEC frame), $l_{\text{TCP}} = 12000$ bits (standard TCP-IP packet length). Then, one FEC frame at level 1 contains $5.4 \times r(\mu)$ TCP segments in this work.

3) TCP throughput optimization: The rate of erroneous packets as well as the available bandwidth at the transport layer are key factors to determine the TCP throughput; then, we are interested in analyzing the impact on TCP throughput that is related to the use of different spectral efficiencies. Note that different TCP versions have different throughput formulas. In what follows we refer to S-TCP, as previously explained. Authors of [4] propose the following analytical expression to describe the single user S-TCP throughput, R_T , in the case of uncorrelated losses:

$$R_T \left(\mu, \frac{E_b}{N_0} \right) = \min \left(\frac{\frac{l_{\text{TCP}} \times \text{rwnd}}{\text{RTT}(\mu, BW)}, \text{IBR}(\mu, BW)}{\frac{\alpha \times l_{\text{TCP}}}{(\alpha + \beta) \times \text{RTT}(\mu, BW) \times \text{PER}_{\text{TCP}}}} \right) \quad (4)$$

where:

- α is the multiplicative increase parameter and β is the multiplicative decrease parameter of the congestion window in S-TCP. A typical choice in the GEO satellite scenario is: $\alpha = 0.075$ and $\beta = 0.125$ [11].
- $\text{IBR} = \text{IBR}(\mu, BW) = BW \times \eta(\mu)$. It is the information bit-rate experienced at the TCP level that depends on

the bandwidth and on the transmission mode. We neglect here the impact of encapsulation.

- $\text{RTT} = d + l_{\text{TCP}} / \text{IBR}(\mu, BW)$. Where d is the network RTT, that is approximated by the round-trip propagation delay of 560 ms (GEO satellite case).
- rwnd is the maximum value of the receiver window. In our case, we assume an infinite value, i.e., an infinite free space at the receiver buffer. Hence, the injection of data into the network by TCP only depends on the perceived network congestion level.

We are interested in maximizing (4) as a function of the spectral efficiency used over different E_b/N_0 channel conditions; therefore, we can obtain the optimal spectral efficiency for each segment of E_b/N_0 axis, establishing new threshold values instead of those proposed in the DVB-S2 standard. These new thresholds represent the cross-layer design of ACM in DVB-S2, considering the S-TCP behavior.

IV. RESULTS

This Section provides the results related to the optimization process. First we focus on the analytical approach to compute the optimum E_b/N_0 thresholds, then we detail the numerical results obtained.

A. Analytical Methodology

Using (4) and considering $\text{rwnd} \rightarrow \infty$; expressing infinite space at the receiver buffer, we can reformulate the S-TCP throughput as:

$$R_T \left(\mu, \frac{E_b}{N_0} \right) = \min \left(\frac{\frac{K_{S-\text{TCP}} \times l_{\text{TCP}}}{\text{RTT}(\mu, BW) \times \text{PER}_{\text{TCP}}}, }{\text{IBR}(\mu, BW)} \right) \quad (5)$$

where $K_{S-\text{TCP}} = \frac{\alpha}{\alpha + \beta}$. Then, the minimum E_b/N_0 value for the use of Modcod μ , on the basis of (5), results to be when it occurs:

$$\frac{K_{S-\text{TCP}} \times l_{\text{TCP}}}{\text{RTT}(\mu, BW) \times \text{PER}_{\text{TCP}} \left(\mu, \frac{E_b}{N_0} \right)} = \text{IBR}(\mu - 1, BW). \quad (6)$$

Since the TCP throughput curves are so sharp (depending on the quasi-ideal error rate performance of DVB-S2 forward link), we can consider that the above condition is fulfilled for the E_b/N_0 values at which the S-TCP throughput curve for ModCod μ saturates (conservative assumption). Hence, we may write:

$$\frac{K_{S-\text{TCP}} \times l_{\text{TCP}}}{\text{RTT}(\mu, BW) \times \text{PER}_{\text{TCP}} \left(\mu, \frac{E_b}{N_0} \right)} \approx \text{IBR}(\mu, BW). \quad (7)$$

In such a way, the computation of each threshold value can be carried out independently of the previous ModCod. Substituting (3) in (7) and solving for E_b/N_0 , we have:

$$\left. \frac{E_b}{N_0} \right|_{\text{opt}} \approx -\frac{1}{\gamma(\mu)} \ln \left(\frac{K_{S-\text{TCP}} \times l_{\text{TCP}}}{\lambda'(\mu) \text{RTT}(\mu, BW) \text{IBR}(\mu, BW)} \right) \quad (8)$$

where

$$\lambda'(\mu) = \frac{\lceil r(\mu) l_{\text{FEC_frame}} / l_{\text{TCP}} \rceil + 1}{r(\mu) l_{\text{FEC_frame}} / l_{\text{TCP}}} \lambda(\mu).$$

Note that in the return link the approximation in (7) would entail a more conservative use of ModCods, since the error rate

| ModCod ID | Bitrate in Mbit/s (25 MHz) | Standard E_b/N_0 thresholds in dB | S-TCP optimal E_b/N_0 thresholds in dB |
|-----------|----------------------------|-------------------------------------|--|
| #1 | 12.25 | 0.75 | Not used |
| #2 | 16.41 | 0.59 | 0.43 |
| #3 | 19.73 | 0.73 | 0.57 |
| #4 | 24.72 | 1.05 | 0.90 |
| #5 | 29.7 | 1.48 | 1.35 |
| #6 | 33.05 | 1.88 | 1.77 |
| #7 | 37.18 | 2.30 | 2.22 |
| #8 | 39.68 | 2.67 | 2.59 |
| #9 | 41.36 | 2.99 (Not used) | Not used |
| #10 | 44.16 | 3.73 (Not used) | Not used |
| #11 | 44.71 | 3.89 (Not used) | Not used |
| #12 | 44.49 | 2.99 | 2.89 |
| #13 | 49.51 | 3.65 | 3.51 |
| #14 | 55.70 | 4.43 | 4.31 |
| #15 | 61.97 | 5.41 (Not used) | Not used |
| #16 | 66.5 | 6.46 (Not used) | Not used |
| #17 | 66.98 | 6.70 (Not used) | Not used |
| #18 | 65.93 | 4.76 | 4.62 |
| #19 | 74.16 | 5.49 | 5.36 |
| #20 | 79.14 | 6.03 | 5.93 |
| #21 | 82.56 | 6.43 | 6.27 |
| #22 | 88.07 | 7.42 (Not used) | Not used |
| #23 | 89.18 | 7.60 (Not used) | Not used |
| #24 | 92.58 | 7.04 | 6.92 |
| #25 | 98.78 | 7.67 | 7.56 |
| #26 | 102.98 | 8.13 | 8.01 |
| #27 | 109.94 | 9.26 | 9.13 |
| #28 | 111.32 | 9.56 | 9.43 |

TABLE I
COMPARISON BETWEEN STANDARD THRESHOLD VALUES AND OPTIMAL ONES FOR DVB-S2 AND S-TCP

performance of DVB-S2 is less ideal. Formula (8) represents the optimal E_b/N_0 thresholds for S-TCP; such values are shown in Table I that also provides the threshold values that are considered in the standard [1]. Note that some spectral efficiencies can be discarded (Not used) since they have an E_b/N_0 threshold higher than others, while they provide lower spectral efficiency.

B. Numerical Results

The TCP goodput (i.e., the TCP throughput at the receiver), R_G , can be obtained by multiplying (4) by a factor that takes into account the probability $1-PER_{TCP}$ that a TCP segment is correctly received. Thus, equation (9) represents the general goodput expression.

$$R_G \left(\mu, \frac{E_b}{N_0} \right) = (1 - PER_{TCP}) \times R_T \left(\mu, \frac{E_b}{N_0} \right). \quad (9)$$

In Fig. 2, a graphical representation is shown of the behavior of the TCP goodput for each spectral efficiency as a function of the channel status, E_b/N_0 , according to (9). Taking the envelope of the curves in Fig. 2, we obtain the optimal S-TCP goodput curve $R_{G,opt}$ in Fig. 3, where the optimal E_b/N_0 thresholds have been used. It can be observed that using the improved selection method, some capacity gains appear in several segments of the E_b/N_0 axis (see Fig. 4). Finally, we can define the goodput gain ΔR_G obtained with standard and optimized E_b/N_0 threshold values as:

$$\Delta R_G \left(\mu, \frac{E_b}{N_0} \right) = R_{G,opt} \left(\mu, \frac{E_b}{N_0} \right) - R_{G,QEF} \left(\mu, \frac{E_b}{N_0} \right) \quad (10)$$

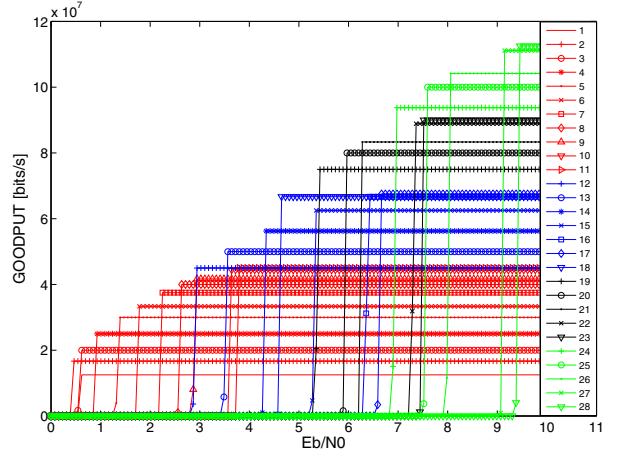


Fig. 2. S-TCP goodput for the 28 Modcods of DVB-S2 for BW = 25 MHz

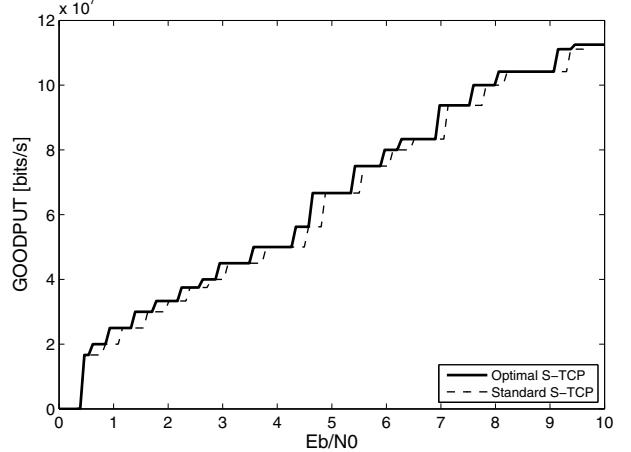


Fig. 3. S-TCP envelope goodput curve for DVB-S2, using both threshold schemes for BW = 25 MHz

where $R_{G,QEF}$ denotes the goodput envelope curve using the different ModCods on the basis of the QEF criterion. The goodput gain for S-TCP between optimal and standard threshold schemes is shown in Fig. 4, according to (10). We can note that we obtain a goodput enhancement up to 25 % for lower spectral efficiencies (i.e., lower E_b/N_0 values). For higher spectral efficiencies we achieve a moderate improvement of 18% around $E_b/N_0 = 4.75$ dB. If we add these results to the fact that DVB-S2 has a high level of optimization, where even small improvements have to be considered, a proposed methodology like ours might be appropriate for defining future systems. This gain would be practically better obtained for a real system when E_b/N_0 may vary so that at different E_b/N_0 values it can found very fortunate conditions. This could be the case of mobile users, when anyway other problems are caused by channel fluctuations. Even better impact is expected for the optimization of the return channel.

Using (7) we obtain the optimal PER_{TCP} requirements for S-TCP links showed in Fig. 5. We observe that the higher the spectral efficiency the stronger are PER requirements. With such PER_{TCP} values on the order of 10^{-4} there is no significant goodput difference between S-TCP and NewReno, because, according to [11], differences (in favor of S-TCP)

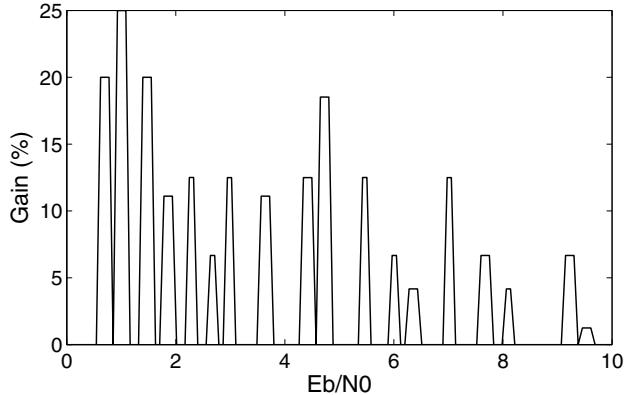


Fig. 4. S-TCP goodput gain with our cross-layer threshold selection method with respect to the classical approach.

can be obtained for $\text{PER}_{\text{TCP}} \geq 10^{-3}$. We believe that S-TCP can represent a good choice especially in dynamic channel conditions (e.g. mobile users) when temporarily there are misalignments between ModCod value selected for transmission and channel at the receiver so that heavy PER_{TCP} values may occur.

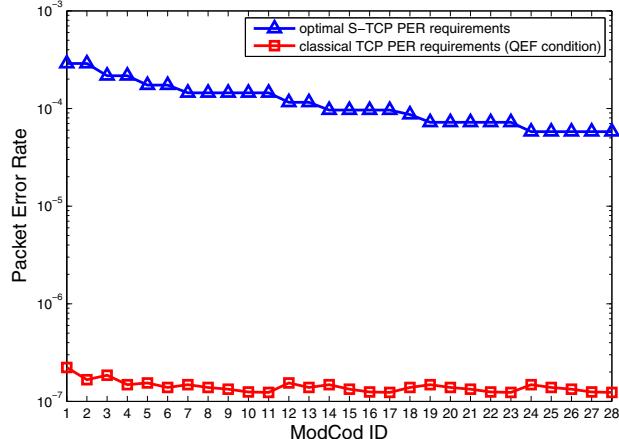


Fig. 5. Optimal (from TCP standpoint) PER requested for the selection of a ModCod with S-TCP.

V. CONCLUSIONS

In this paper, we propose an analytical methodology to optimize E_b/N_0 ACM thresholds for improving transmissions over DVB-S2. In particular, we refer to TCP transmissions for which we obtain a closed formula for the optimal E_b/N_0 thresholds. The analysis of the results show that up to a 25% of TCP goodput gain can be achieved especially for low and medium spectral efficiencies, i.e., when channel conditions are bad. Furthermore, the optimal TCP PER requirements for S-TCP reveal that considering a single PER target for all spectral efficiencies is not the best option and optimized threshold should be used instead. The optimization methodology proposed in this paper can be used for the optimal design of more services to exploit better the capabilities of the adaptive physical layer.

VI. FUTURE WORK

Further work in the TCP context include evaluating the throughput gain in a dynamic channel scenario (using channel

traces) and the impact of channel misalignment (caused by the round-trip propagation delay) on the PER of FEC frames and, hence, at the TCP level. Also the proposed methodology can be applied for different TCP versions or using more refined theoretical approaches [16] and in a non-TCP framework. Finally, it could be interesting the study of scenarios with multiple TCP users having mixed E_b/N_0 values. This should be an interesting and realistic case requiring some appropriate solutions in order to achieve fairness among different competing TCP flows.

ACKNOWLEDGEMENTS

This work was supported in part by the European Commission through SatNEx II Network of Excellence IST-027393 (ja2230 activity) and by the Spanish Ministry of Science and Education MEC through project ESP2005-03403.

REFERENCES

- [1] *Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications*, ETSI EN 302 307 v1.1.2, June 2006.
- [2] *Digital Video Broadcasting (DVB); Interaction channel for satellite distribution systems*, ETSI EN 301 790 v1.4.1, September 2005.
- [3] A. Morello and V. Mignone, "DVB-S2: The second generation standard for satellite broad-band services," *Proceedings of the IEEE*, Vol. 94, pp. 210-227, January 2006.
- [4] G. Giambene and D. Miorandi, "Scalable-TCP over satellite links: Performance issues and cross-layer design," *In Proc. of the ISWCS*, September 2005.
- [5] G. Giambene and S. Kota, "Cross-layer protocol optimization for satellite communication networks," *Int. J. Satell. Commun. Network*, Vol. 24, pp. 323-341, 2006.
- [6] W. Stanislaus, G. Fairhurst and J. Radzik, "Cross-layer techniques for flexible transport protocol using UDP-lite over a satellite network," *Wireless Communication Systems*, pp. 706-710, September 2005.
- [7] F. Vieira, M. A. Vazquez and G. Seco, "A tunable-fairness cross-layer scheduler for DVB-S2," *Int. J. Satell. Commun. Network*, Vol. 24, pp. 437-450, 2006.
- [8] J. Cantillo, J. Lacan and I. Buret, "Cross-layer enhancement of error control techniques for adaptation layers of DVB satellites," *Int. J. Satell. Commun. Network*, Vol. 24, pp. 579-590, 2006.
- [9] P. Chini, G. Giambene, D. Bartolini, M. Luglio and C. Roseti, "Dynamic resource allocation based on a TCP-MAC cross-layer approach for DVB-RCS satellite networks," *Int. J. Satell. Commun. Network*, Vol. 24, pp. 367-385, 2006.
- [10] N. Celadroni, "Comparison of FEC types with regard to the efficiency of TCP connections over AWGN satellite channels," *IEEE Transactions on Wireless Communications*, Vol. 5, no. 7, pp. 1735-1745, July 2007.
- [11] G. Giambene and D. Miorandi, "A simulation study of Scalable-TCP and highspeed TCP in geostationary satellite networks," *Telecommunication Systems Journal*, Vol. 30, no. 4, pp. 297-320, 2005.
- [12] M. Eroz, F. Sun, and L. Lee, "DVB-S2 low density parity check codes with near shannon limit performance," *Int. J. Satell. Commun. Network*, Vol. 22, pp. 269-279, 2004.
- [13] J. E. Barcelo, "Cross-layer optimization of channel capacity in DVB-S2 forward link," *Master Thesis in Telecommunications Engineering*, 2007.
- [14] A. Mayer, B. Collini-Nocker, F. vieira, J. Lei and M. A. Vazquez, "Analytical and experimental IP encapsulation efficiency comparison of GSE, MPE and ULE over DVB-S2," *Sat. and Space Commun.*, pp. 114-118, September 2007.
- [15] G. Giambene, S. Giannetti, C. P. Niebla, M. ries, and A. Sali, "Traffic management in HSDPA via GEO satellite," *Space Communications Journal*, Vol. 21, no. 1-2, pp. 37-54, 2007/2008.
- [16] J. Payde, V. Firoiu, D. Towsley and J. Kurose, "Modeling TCP throughput: A simple model and its empirical validation," *in Proc. of ACM SIGCOMM'98*, May 1998.