A Cross-Layer PEP for DVB-RCS Networks

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Abstract. The aim of this paper is to consider the problems of TCP performance in broadband GEO satellite networks and to propose a cross-layer approach for a transport-layer PEP that makes spoofing actions on ACKs to modify them in case the satellite network is congested. This approach is investigated here from the signaling standpoint with a special attention to the BSM reference model and considering a specific GEO satellite network architecture based on the DVB-S2/-RCS standards. The proposed PEP can prevent congestion in the satellite network, thus allowing a better TCP performance. This work has been carried out within the framework of the EU SatNEx II FP6 Network of Excellence.

Keywords: Satellite Networks, BSM, DVB-RCS, TCP, PEP.

1 Introduction

The ETSI working group *Broadband Satellite Multimedia* (BSM) has defined [1] a reference architecture where the protocol stack is divided into two main blocks connected by the *Satellite Independent-Service Access Point* (SI-SAP): the upper part of protocols is characteristic of the Internet and independent of the satellite implementation (i.e., IP-based protocol suite), while the lower part depends on the satellite system technology. Primitives are used to exchange signaling on the control plane across SI-SAP between these two blocks of protocol layers. The BSM standard envisages a framework for *Quality of Service* (QoS) support, allowing a mapping between layer 3 traffic classes and layer 2 technology-dependent allocation methods.

DVB-S2 is a second-generation standard for forward link communications in broadband satellite networks for broadcast, multicast, and interactive services [2]. Note that 28 *Modulation and Coding* (ModCod) combinations are possible in the standard. The transmission is typically organized in blocks of 25 MHz in Ku or Ka bands. *Adaptive Coding and Modulation* (ACM) is used for interactive traffic and permits to change dynamically the ModCod level, depending on channel conditions by means of E_b/N_0 ModCod thresholds determined to guarantee *Frame Error Rate* (FER) below 10^{-7} in the *Additive White Gaussian Noise* (AWGN) channel case (*Quasi Error-Free*, QEF, operation). The sender dynamically acquires information on the receiver channel conditions by means of a return link. The DVB-RCS specifications have been introduced to allow a return path for satellite networks based on DVB-S/-S2 [3]. The return channel

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can dynamically assign its time-frequency resources (*Multi-Frequency - Time Division Multiple Access*, MF-TDMA, air interface) to the terminals. SatLab recommendations have defined QoS mechanisms for DVB-S2/-RCS on the basis of the BSM framework [4]. A new specification has been recently released to support mobile users. This specification (called DVB-RCS+M) has been issued by the DVB organization in its Blue Book [5]. Some basic features of DVB-RCS+M are the adoption of spread spectrum techniques, the support of different handover scenarios, the adoption of shadow/fading-resilient techniques (Link Layer FEC), and the ACM support also in the return link.

At present, the air interface is based on the separate design of protocols at distinct OSI layers (PHY, MAC, Network, Transport, Application), thus reducing the complexity and allowing the interoperability among equipments of different manufacturers. However, due to the dynamic nature of the radio channel, there exists a tight interdependence between layers in satellite systems that should be better exploited than allowed by the classical OSI stack based on the layer separation principle. This is evident especially in the presence of ACM-based air interfaces, such as DVB-S2 or DVB-RCS+M. As an example, the higher the ModCod is, the greater the available bandwidth, but also the higher the packet error rate for a given channel condition [6]. These two aspects have opposite impacts on TCP goodput, as expressed by the well known *square-root formula* for the TCP NewReno version [7]. Hence, a suitable tradeoff should be found for ModCod selection (i.e., ModCod threshold values in terms of E_b/N_0) depending on channel characteristics and TCP behavior.

Current research interest in wireless as well as in satellite communications is on protocol architectures where the reference OSI stack is enriched with interactions between protocols even at non-adjacent layers, according to a *cross-layer design* [8]. One interesting aspect of cross-layering is the need to allow the direct exchange of control information (signaling) even among non-adjacent layers [9]. In general, different techniques could be used to support the exchange of signaling information. In particular, two relevant and complementary methods are [6],[9]:

- *In-band signaling* with the use of enriched packet headers to notify internal state variables to either other layers within a given host (internal cross-layering) or in a peer-to-peer case with another host or gateway (external cross-layering). This method needs the redefinition of packets headers (e.g., use of spare bits). This method is for signaling going in the same direction of related data.
- *Out-of-band signaling* via the control plane, that is the use of new primitives and suitable SAPs to allow the dialogue between protocol layers.

This paper deals with the study of *Performance Enhancing Proxy* (PEP) techniques [10] and the possibility to apply cross-layer methods to improve transport layer performance for BSM-compliant DVB-S2/-RCS networks. This work derives from a cooperation between the SatNEx II ja2230 activity (entitled "Cross-Layer Protocol Design") [11] and the ETSI BSM working group [12].

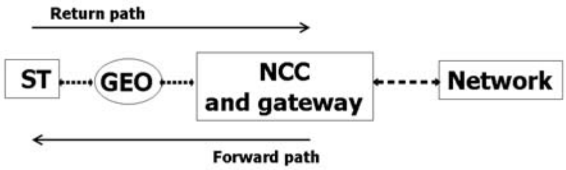

Fig. 1. Reference system architecture

2 BSM-Compliant Reference Scenario

The interest is here for a scenario where DVB-S2 is used for the forward channel with ModCod adaptation and DVB-RCS is used for the return channel with DAMA (*Dynamic Assignment Multiple Access*) controlled by the *Network Control Center* (NCC). The envisaged satellite is of the GEO type and the network is IP-based. We make the assumption that in the satellite network NCC, gateway, and feeder are co-located; the gateway implements a transport-layer PEP. The NCC manages resource allocation in the satellite network, but it is also the network element through which the traffic is exchanged with the Internet. The building blocks of our satellite network scenario are described in Figure 1.

The protocol stack is compliant with the BSM standard at both the *Satellite Terminal* (ST) and the NCC/gateway. Moreover, it is assumed that one layer is in charge of controlling the cross-layer signaling exchange with *primitives*; in our study this is the case of the MAC layer (MAC-centric approach). These new interactions can be used at the ST and/or at the NCC/gateway.

Several layer 2 queues are needed to support different resource allocation methods. The definition of these queues is technology-dependent. In the DVB-RCS case, Satlab work can be considered for the definition of layer 2 allocation techniques with QoS support [4]. The SI-SAP interface allows a general framework for mapping L3 queues on those at MAC layer. This is obtained by means of QIDs (*Queue Identifiers*), abstract queues that represent layer 2 queues in a general way [13].

Cross-layer techniques could be supported by BSM primitives (control plane) used through SI-SAP between MAC and L3([1]). These primitives concern the interactions between the "L3 queue manager" (it manages the queues that are present at the IP level; its functions depend on the IP QoS scheme adopted, that is DiffServ or IntServ) and the layer 2 *Satellite Terminal QID Resource Manager* (STQRM; its functions are: association of QIDs to satellite-dependent queues, translating QIDSPEC into values that are suitable to request satellite-dependent resources, control of resource allocation, translation of primitives arriving at the SI-SAP into lower layer primitives and vice versa) [14]. The simplified layer 2 and 3 protocol architecture of the BSM model is shown in Figure 2.

[1] Even if we consider here adjacent layers, we still have cross-layer interactions in the wide sense that primitives allow the exchange of internal state variables that otherwise would only be used by the related layer.

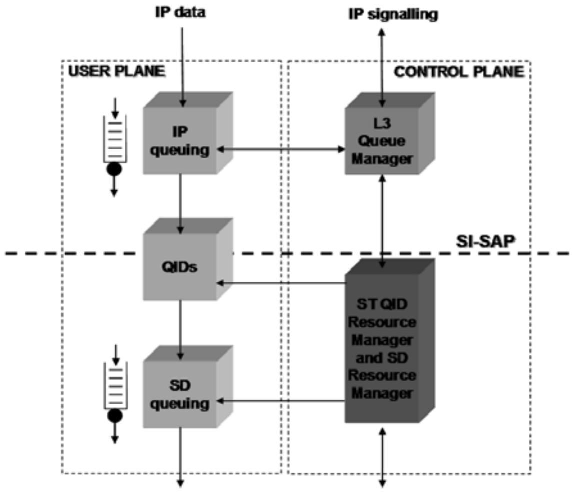

Fig. 2. L3 queuing, QID mapping, and resource management functions at layer 2 according to the BSM model

Cross-layer interactions require an innovative design of the air interface with new primitives among layers. BSM primitives only permit interactions between layer 3 and layer 2 [14]. There is, therefore, the need to include mechanisms to allow the exchange of signaling also among non-adjacent layers. One possibility could be to define some broadcast 'primitives' on the control plane (in upward and downward direction on a 'bus' shared by all the layers, a sort of vertical 'pipe') delivering messages and contents that each layer could simultaneously acquire and use for its purposes. The following study focuses on adopting new combined approaches like PEP and cross-layer design in order to improve the behavior of TCP in DVB-S2/-RCS satellite networks compliant with the BSM model.

3 PEP-Spoofer with Cross-Layer Signalling

Due to the peculiarities of the architecture in Figure 1, congestion control in the satellite network does not need a 'black box' approach, because the bottleneck is the satellite link and the NCC/gateway can have a direct control on it via the resource allocation decided at layer 2. This very special situation can allow the NCC to anticipate congestion events that otherwise could cause packet losses with a possible drop of the TCP congestion window. These additional transport layer functionalities for the NCC require it to operate as a PEP using cross-layer information exchanged with layer 2. Our interest is here for the return link: STs are servers that send TCP flows towards the network through the NCC/gateway. In this study, a DVB-RCS satellite network is considered where the NCC dynamically assigns radio resources to STs for FTP transmissions through a GEO bent-pipe satellite. We adopt a generic DAMA scheme, controlled by the NCC, that allocates resources on a super-frame basis (MF-TDMA air interface). The proposed cross-layer method is described below (see Figure 3):

1. In the ST, the TCP internal state information (i.e., cwnd and TCP phase, that for the classical TCP could be Slow Start or Congestion Avoidance) is propagated from layer 4 to MAC by means of either suitably enriched headers or a periodic primitive reporting about the state of the transport layer protocol (such primitive, not concerned with the BSM work, should be synchronized with the MF-TDMA super-frame structure and the related DAMA resource request made at layer 2). In both cases, a modification to the DVB-RCS standard would be needed. At layer 2, a DAMA capacity request is sent for next super-frame to the NCC on the basis of the current layer 2 buffer occupancy and the prospected TCP injection of data in the next super-frame. Since the allocation of resources arrives at the ST (at least) after a round trip propagation delay from the request, the request must be done considering a forecast on the packets arrived in the meantime; hence, the capacity request has to be based on the expected TCP cwnd increment in the prospected allocation time. The DAMA request to the NCC needs also to convey the cwnd value of TCP and a layer 3 buffer congestion indication for the ST (a threshold scheme is considered here, where the threshold value should be suitably optimized depending on system characteristics).
2. The NCC receives the incoming DAMA requests, assigns the available resources in the super-frame and notifies the allocation through the *Terminal Burst Time Plan* (TBTP) broadcast message. The NCC may reduce the amount of resources assigned to an ST in a super-frame, if the resources the ST requested are not available; then, the NCC defines at MAC layer a corresponding limit, cwnd*, to the congestion window value (cwnd* < cwnd) for the ST. If the ST buffer is congested (threshold method), the cwnd* value is provided back to the transport layer of the ST with external cross-layer signaling, as detailed at the following point #3. The ST cwnd value is thus blocked to the cwnd* one[2]. This procedure is detailed in Figure 4.
3. The NCC at transport layer is a gateway towards the network and operates as a PEP in the forward path where the ACKs of the TCP flow under consideration are intercepted according to a spoofing action. If the cwnd* value is set for a given ST, such value is included in a suitable field of a transport-layer modified ACK*. Moreover, a flag in the ACK* notifies the ST if the cwnd* option is active. A suitably-modified TCP version running on the ST (sender) should be able to manage the modified ACK* with cwnd*

[2] This mechanism to control congestion is effective when there is very low FER (like QEF condition that requires $FER < 10^{-7}$ for fixed users) so that TCP goodput is only affected by timeouts caused by buffer overflows. However, this mechanism could be also useful when there is a higher PER (like in DVB-RCS+M for mobile users, requiring even $PER < 10^{-3}$), but there are many users that cause layer 2 resource congestion.

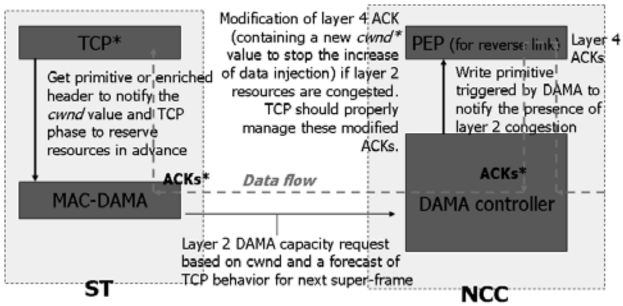

Fig. 3. Case study of cross-layering with in-band and out-of-band signaling. Cross-layer interactions are present at both ST and NCC.

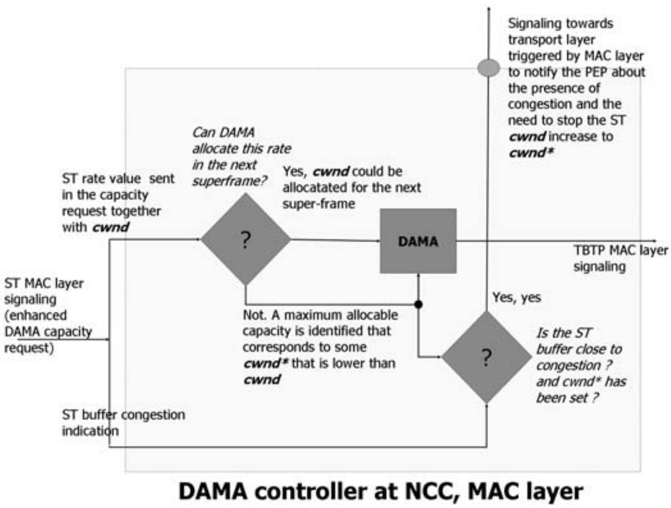

Fig. 4. DAMA controller at the NCC with cross-layer functionality (MAC-centric approach)

so that TCP can set the current cwnd to the cwnd* value to block the normal cwnd increase (non-transparent PEP approach).

4. If the condition of resource shortage is solved, the cwnd value of the ST can be unlocked with the reception of standard ACKs that are not modified by the NCC/PEP.

In the presence of many STs contending for the use of the satellite bandwidth with DVB-RCS, the DAMA controller has to schedule their service taking into account a fair sharing of resources since STs may experience different channel conditions. The performance evaluation of the above technique is not the subject of this paper, focused on cross-layer signaling for our PEP proposal and the relationship with SI-SAP. The interested reader may refer to [15] where a similar scheme is presented and where it has been shown that for a 10 MB file transfer, the cross-layer approach with PEP-spoofer allows a transfer time reduction of 26% with respect to *Continuous Rate Assignment* (CRA) in the presence of a packet error rate of 2%. This performance enhancement is due to the combined effect of both the traffic prediction for the DAMA request and the PEP-spoofer to control the congestion in the satellite network.

Note that our PEP-spoofer at the NCC makes use of ACK at transport layer, similarly to the M-TCP approach [16], but there are some differences because in our scheme the ACK contains a cwnd* value for the return link flow, while in M-TCP the ACK contains a receiver window value used for the forward link flow. In our scenario, both approaches could be combined.

In this study, the use of modified ACKs is an example of in-band cross-layer signaling. While, the use of primitives on the control plane is an example of out-of-band signaling. Problematic seems the MAC $\rightarrow$ TCP relation at the NCC (upward signaling), since no conventional mechanism is available to convey information from layer 2 to layer 4 in the BSM model. Since layer-by-layer signaling is an inefficient approach for cross-layering (OSI classical method), cross-layer signaling for our PEP-spoofer could be supported by the *Cross-Layer Signaling Shortcuts* (CLASS) method [9] that is an improvement of the *Internet Control Message Protocol* (ICMP) [17] to punch holes in the protocol stack so that local out-of-band shortcuts are created for the exchange of signaling among non-adjacent layers. Practically, a lightweight ICMP version is used for internal cross-layer signaling, while ICMP is used for external cross-layer signaling. An ICMP message is always encapsulated into an IP packet.

4 Conclusions

Broadband communications based on GEO satellite represent an interesting option to connect to the Internet in many areas of the world. The problem is that TCP is penalized by huge propagation delays and packet losses. A way to accelerate TCP is to make use of PEPs in gateways. In this paper, we have studied a type of PEP that operates on the TCP traffic sent by STs through an NCC/gateway that acts as a PEP-spoofer on ACKs flowing in the opposite direction. Our main interest is on the adopted cross-layer signaling and related information exchange among layers. Our integrated PEP proposal is non-transparent and requires the application of new cross-layer signaling at the PEP/NCC/gateway. A further study (based on simulations) is needed to optimize the characteristics of the PEP proposal and the threshold values used to decide the situation of buffer congestion.

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