Cross-layer Design for TCP Splitting Connections with Network Coding in DVB-RCS Networks

Kyu-Hwan Lee and Jae-Hyun Kim
Department of Electrical and Computer Engineering
Ajou University
Suwon, Korea
e-mail: {lovejiyoon7 and jkim}@ajou.ac.kr

***Abstract*—In this paper, we propose a cross-layer design for transmission control protocol (TCP) splitting connections with network coding in digital video broadcasting-return channel via satellite (DVB-RCS) networks. In particular, we propose not only a cross-layer architecture for interaction between TCP and the resource allocation (RA) scheme in the link layer but also a tuning algorithm for the TCP contention window (CWND) by using information on the RA in the link layer and the redundancy rate for network-coded packets. The simulation results show that TCP CWND can be adjusted by RA information in the proposed cross-layer design. Furthermore, through the transmission of network-coded packets and the proposed CWND tuning algorithm, TCP throughput is enhanced in lossy environment due to user mobility.**

Keywords*—Satellite communications, Cross-layer design, Performance enhancing proxy, TCP, resource allocation, Network Coding.

I. INTRODUCTION

Thanks to its large coverage areas without geographical limits, geosynchronous earth orbit (GEO) satellite communication is useful for scenarios such as rural environments, airplain/ship communications that do not have available terrestrial infrastructure [1]. However, transmission control protocol (TCP) has performance problems in satellite networks because TCP was designed for wired networks. In satellite communications, long propagation delay and packet loss in the wireless link can cause the significant degradation of the TCP performance [2]. Therefore, there are many researches on a performance enhancing proxy (PEP) to enhance the TCP performance in the satellite communication [2], [3]. The PEP is the network agent that improves the network performance between end-to-end nodes. Generally, the PEP can be configured by TCP split connections. TCP split connections use the customized protocol over satellite link to optimize TCP of satellite communication. Therefore, TCP splitting connections can overcome the TCP performance degradation in satellite communications. However, if the satellite resource for a satellite terminal (ST) is inappropriately allocated in the link layer, the customized protocol in splitting connections cannot be properly operated [4].

To enhance the interaction among protocols in different layers, many studies on the cross-layer design in satellite networks have been conducted [5]–[8]. In [5], the scheduler design based on a cross-layer design between the physical and the network layer was proposed. In [6], by exchanging information between TCP and link layers, congestion avoidance scheme was proposed to prevent queue overflow without the long delay. Authors of [7], [8] proposed the tuning scheme for the TCP congestion window (CWND) using the queue size in lower layers. However, to the best of our knowledge, a cross-layer design for TCP that directly uses information on the satellite resource allocation (RA) in the link layer has not been explored before. It is needed to tune the TCP CWND more accurately.

Although the power control and adaptive coding and modulation (ACM) are applied in the satellite communication, mobile STs experiences packet loss because of temporary link blockage caused by shadowing. TCP with network coding (TCP/NC) can be a solution to compensate for packet loss [9]. TCP/NC can mask losses by TCP using random linear network coding (RLNC), as well as alleviate the problem of packet loss in TCP because it uses network-coded redundancy (NC-R) packets. Therefore, in this paper, we propose a cross-layer design for TCP splitting connections with network coding in digital video broadcasting-return channel via satellite (DVB-RCS) networks. The main contributions of our paper are as follows.

1) A cross layer architecture for interaction between TCP and the RA scheme.
2) A tuning algorithm for the TCP CWND by using information on the RA in the link layer and the redundancy rate for NC-R packets.

The remainder of this paper is organized as follows: Section II describes related works. Section III presents the details of the proposed protocol. Section IV describes an evaluation of the proposed protocol. Finally, the conclusion will be followed.

II. RELATED WORKS

A. DVB-RCS system

DVB-RCS is a specification for an interactive satellite communication system [10]. In particular, it introduce a return channel via satellite. RCS networks is composed of a network control center (NCC), gateway, feeder, and STs. STs share time-frequency resources in the return link through a demand assignment multiple access (DAMA) scheme. When STs request the resources from NCC, the NCC assigns the resources and notifies a terminal burst time plan (TBTP) in the forward link to STs. DVB-RCS standard allows a fixed or a dynamic time slot allocations as follows [10], [11].

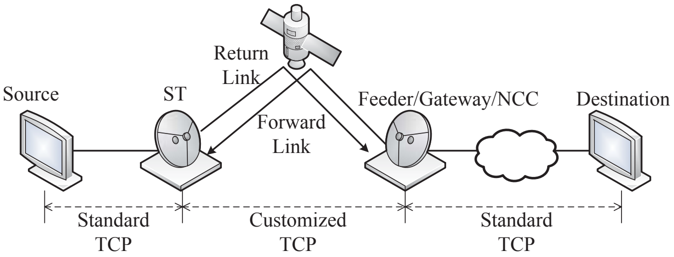

Fig. 1. Reference network model of the proposed protocol.

1) Continuous rate assignment (CRA) is a fixed and static allocation of resources agreed between the ST and the NCC in the initial set-up phase.
2) Rate-based dynamic capacity (RBDC) allocates capacity dynamically requested on the basis of rate measurements performed by the ST. Each request is absolute and overrides all previous requests from the same ST.
3) Volume-based dynamic capacity (VBDC) allocates capacity dynamically requested on the basis of data volume measurements performed by the ST. These requests are cumulative, indicating a total number of traffic slots that are needed to transmit all data currently present in the MAC queue.

B. *Reliable transmission with NC*

By the transmission of NC-R packets, the reliability of the packet transmission can be enhanced [9]. h NC-R packets are generated from k native packets by RLNC. Therefore, although some native packets are lost, all native packets can be recovered by NC-R packets if the number of received packets including native and NC-R packets is more than k [12]. For example, when $k = 3, h = 1$ and one of native packets is loss, the receiver can decode all the packets from 2 native and a NC-R packet.

III. PROPOSED PROTOCOL

The reference network model is shown in Fig. 1. It is composed of a source node, a destination node, ST, and the feeder. The feeder has the function of the gateway and the NCC in the reference network model. The source and destination nodes are connected to the ST and the feeder via the wired link, respectively. The ST is connected to the feeder via the satellite link. They also has the PEP. In the reference network model, the TCP splitting connection is applied. In particular, the customized TCP is used in the satellite link. In the link layer, STs uses the dynamic time slot allocation of RBDC. For mobile users, the proposed protocol uses the transmission of NC-R packets. However, for the fairness of RA among STs, the ST does not request the additional resource for the transmission of NC-R packets.

A. *Cross-layer Architecture*

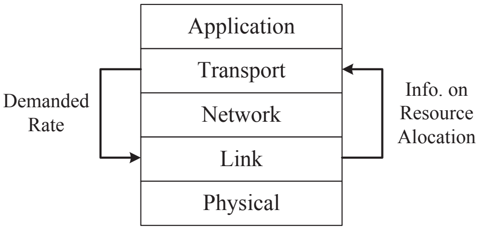

Fig. 2. Cross-layer architecture in proposed protocol.

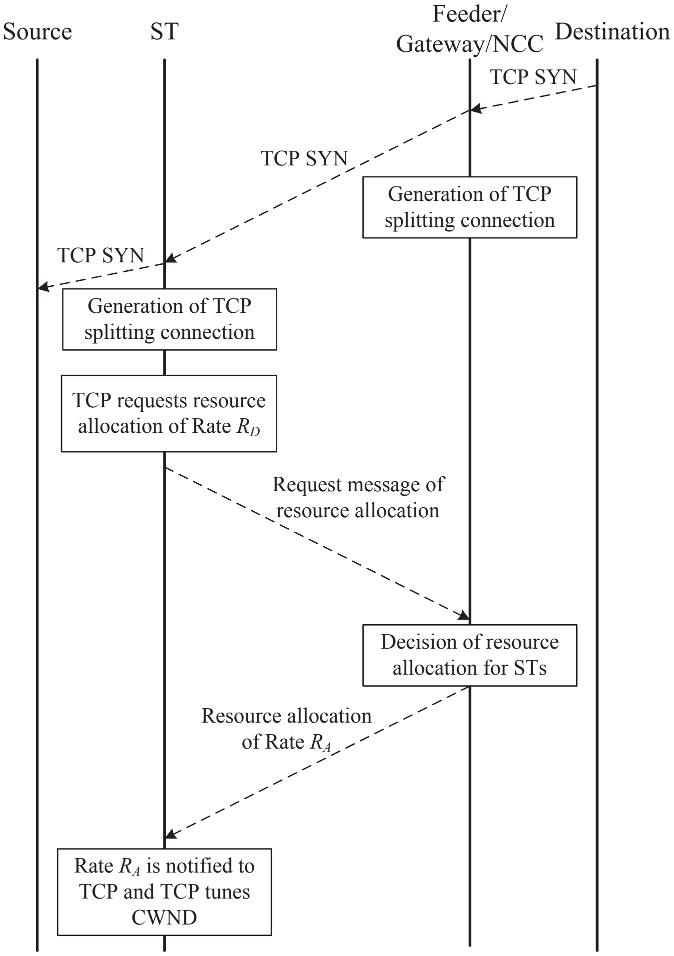

Fig. 3. Procedure of cross-layering information exchange.

The cross-layer architecture is shown in Fig. 2. In our cross-layer architecture, TCP provides information on its demanded rate, R_D to the DAMA agent in the link layer and gets information on the assigned rate, R_A from it. R_D is calculated as

$$R_\mathrm{D} = \frac{W_{\max,0}}{RTT_0}, \tag{1}$$

where $W_{\max,0}$ and RTT_0 are the default value of the maximum CWND and the round trip time (RTT) of the reference connection to which we aim to achieve our performance, respectively [13]. R_A is decided by the DAMA controller based on the channel state, the number of STs, etc [11]. Fig. 3 shows the procedure of the cross-layering information exchange. In TCP initiation procedure, the feeder intercepts the TCP SYN message using the PEP and it generates TCP splitting connections. The ST also intercepts the TCP SYN message and it generates TCP splitting. In the customized

TABLE I. SIMULATION PARAMETERS.

Parameter	Value
Header size (TCP/IP)	40 bytes
Header size(Link layer)	10 bytes
Packet size(TCP)	1024 bytes
RTT (Satellite link)	500 ms
RTT (Wired link)	10 ms
RTT_0	100 ms
Superframe size (Link layer)	500 ms
α	5%
β	10%

TCP of the ST, it requests RA of R_{D} to the DAMA agent. Upon receiving the request of RA from TCP, the DAMA agent sends the request message of RA including R_{D} and protocol overheads to the DAMA controller of the NCC. The DAMA controller then decides the resource allocation of R_{A} and its information is reported through TBTP in the forward link. Upon receiving TBTP, the DAMA agent of the ST reports R_{A} to the TCP and TCP tunes the CWND based on RA information.

B. TCP CWND considering RA and NC

In the proposed protocol, we consider the TCP CWND tuning based on RA information and the redundancy rate for NC-R packets. Therefore, the CWND, W_{P} is calculated as

$$W_{\mathrm{P}} = \frac{RTT \times R_{\mathrm{A}}}{(1+\alpha+\beta)\,L_{\mathrm{S}}}, \tag{2}$$

where RTT is the current RTT in the satellite network; L_{S} is the size of a TCP segment; α and β are the ratios of the overhead and the redundancy, respectively. α and β are

$$\alpha = \frac{L_{\mathrm{O}}}{L_{\mathrm{S}}}, \tag{3}$$

$$\beta = \frac{h}{k}, \tag{4}$$

where L_{O} is the size of the overhead including headers of the TCP/IP, and the link.

In the proposed protocol, the available resource to transmit TCP packets is reduced by the transmission of NC-R packets. However, TCP throughput can be enhanced in lossy environment due to user mobility because the packet loss is alleviated by the transmission of NC-R packets.

IV. PERFORMANCE EVALUATION

In the performance evaluation, we evaluated the proposed protocol in DVB-RCS networks in terms of the CWND, packet loss rate, and TCP throughput. We implemented an event-driven simulator in MATLAB. In the simulation, we consider parameters as shown in Table I [14]–[16].

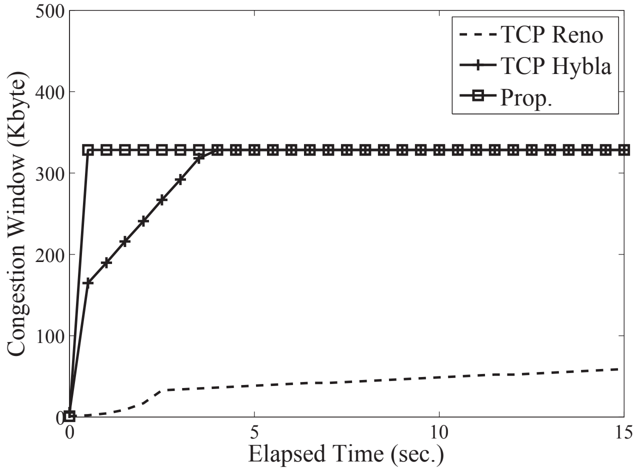

Fig. 4. CWND in DVB-RCS networks.

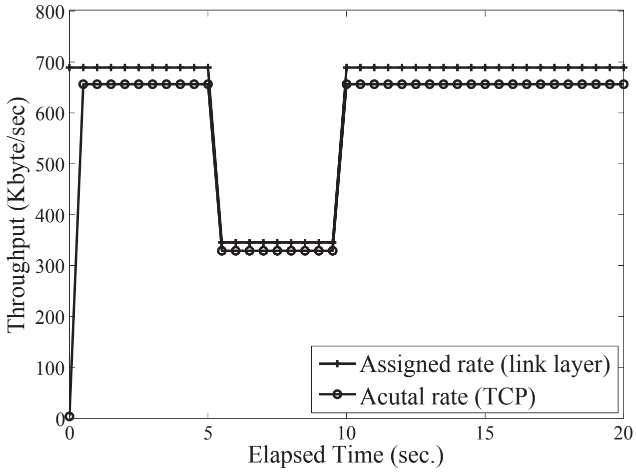

Fig. 5. TCP throughput in DVB-RCS networks.

In Fig. 4, we compare the TCP CWND of the proposed protocol with that of TCP Reno and TCP Hybla according to the elapsed simulation time [13], [14]. It is shown that TCP Reno and Hybla have slow convergence to the available CWND due to probing phases such as slow start and congestion avoidance. In particular, this probing phases in satellite networks can have negative influence on the performance of the short-lived TCP session. However, the available CWND can be used without probing phases in the proposed protocol because the proposed protocol use RA information. Actually, some initial delay occurs in the proposed protocol because the PEP needs for buffering TCP segments received from the source node via wired link. However, it is insignificant because RTT in wired link is very short as compared with RTT in satellite link. Fig. 5 shows R_{A} and TCP throughput in the proposed protocol. In this simulation, we assume that R_{A} is reduced from five to ten seconds in the elapsed simulation time due to rain attenuation or the increased number of users. It is shown that available resources is fully explored in TCP although it is slightly less than R_{A} due to overheads of protocol headers.

For the environment with mobile users, we evaluate the proposed protocol in terms of the packet loss rate and TCP throghput. In these simulation, we assume that the transmission of NC-R packets is used and R_{A} is 136.5 Kbytes/sec. Fig. 6 shows the TCP packet loss rate with NC. It is shown that the

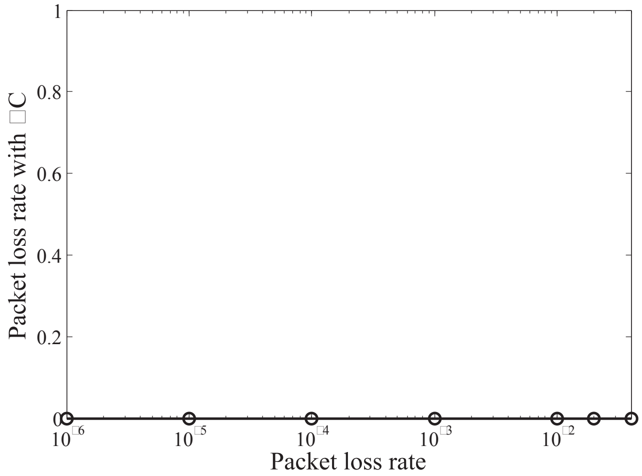

Fig. 6. Packet loss rate with NC in DVB-RCS networks.

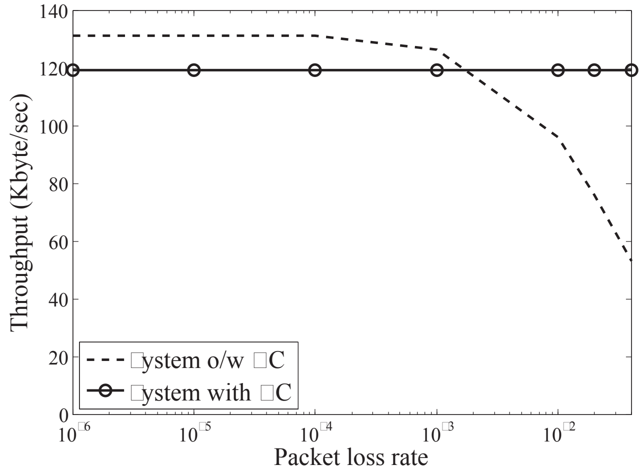

Fig. 7. TCP throughput with NC in DVB-RCS networks.

packet loss is recovered by the transmission of NC-R packets. Fig. 7 shows TCP throughput in the proposed protocol with and without NC. When the transmission of NC-R packets is used, the available resource in TCP of the proposed protocol is reduced. Therefore, the TCP throughput with NC is less than that without NC in the environment without packet loss. However, the proposed protocol with NC outperforms that without NC in terms of TCP throughput in the environment with packet loss. That is because there is no retransmission delay thanks to the transmission of NC-R packets.

V. CONCLUSIONS

In this paper, we proposed the cross-layer Design for TCP splitting connection with NC in DVB-RCS networks to tune the TCP CWND more accurately. To tune TCP CWND accurately, we used RA information from the link layer. In particular, we considered the transmission of NC-R packets to enhance TCP throughput in the environment with packet loss due to user mobility. Simulation results indicated that available resources is fully explored in TCP thanks to cross-layering between TCP and the link layer. Furthermore, the proposed protocol with NC outperformed that without NC in terms of TCP throughput in the environment with packet loss. Therefore, the proposed protocol can offer better TCP throughput in DVB-RCS networks and it can be applied to Internet via the satellite, airplain/ship communications, etc.

ACKNOWLEGEMENTS

This research was funded by the MSIP(Ministry of Science, ICT & Future Planning), Korea in the ICT R&D Program 2014 and National GNSS Research Center program of Defense Acquisition Program Administration and Agency for Defense Development.

REFERENCES

[1] M. P. Anastasopoulos, T. Taleb, P. G. Cottis, and M. S. Obaidat, "Feedback Suppression in Multicast Satellite Networks Using Game Theory," *IEEE Systems Journal*, vol. 6, no. 4, pp. 657–666, 2012.

[2] C. Caini, R. Firrincieli, and D. Lacamera, "PEPsal: A Performance Enhancing Proxy for TCP Satellite Connections," *IEEE Aerospace and Electronic Systems Magazine*, vol. 22, no. 8, pp. B–9–B–16, 2007.

[3] P. Davern, N. Nashid, C. J. Sreenan, and A. Zahran, "HTTPEP: a HTTP Performance Enhancing Proxy for Satellite Systems," *International Journal of Next Generation Computing (IJNGC)*, vol. 2, 2011.

[4] M. Luglio, C. Roseti, and F. Zampognaro, "Performance Evaluation of TCP-based Applications over DVB-RCS DAMA Schemes," *International Journal of Satellite Communications and Networking*, vol. 27, no. 3, pp. 163–191, 2009.

[5] E. Rendon-Morales, J. Mata-Diaz, J. Alins, J. L. Munoz, and O. Esparza, "Cross-layer Packet Scheduler for QoS Support over Digital Video Broadcasting-Second Generation Broadband Satellite Systems," *International Journal of Communication Systems*, pp. 1–20, 2012.

[6] F. Peng, L. Wu, and V. C. M. Leung, "Cross-layer Enhancement of TCP Split-connections over Satellites Links," *International Journal of Satellite Communications and Networking*, vol. 24, no. 5, pp. 405–418, 2006.

[7] M. Luglio, F. Zampognaro, T. Morell, and F. Vieira, "Joint DAMA-TCP Protocol Optimization Through Multiple Cross Layer Interactions in DVB RCS Scenario," in *Proc. IEEE IWSSC 2007*, Sep. 2007.

[8] "XPLIT: A Cross-layer Architecture for TCP Services over DVB-S2/ETSI QoS BSM," *Computer Networks*, vol. 56, no. 1, pp. 412–434, 2012.

[9] J. K. Sundararajan, D. Shah, M. Medard, S. Jakubczak, M. Mitzenmacher, and J. Barros, "Network Coding Meets TCP: Theory and Implementation," *Proceedings of the IEEE*, vol. PP, no. 99, pp. 1–23, 2011.

[10] "Digital Video Broadcasting (DVB);Second Generation DVB Interactive Satellite System (DVB-RCS2);Part 2: Lower Layers for Satellite standard," *ETSI EN 301 545-2*, pp. 1–195, 2012.

[11] D. K. Petraki, M. P. Anastasopoulos, and P. G. Cottis, "Dynamic resource allocation for DVB-RCS networks," *International Journal of Satellite Communications and Networking*, vol. 26, no. 3, pp. 189–210, 2008.

[12] M. Ghaderi, D. Towsley, and J. Kurose, "Reliability Gain of Network Coding in Lossy Wireless Networks," in *Proc. IEEE INFOCOM 2008*, Apr. 2008.

[13] C. Caini and R. Firrincieli, "TCP Hybla: a TCP enhancement for heterogeneous networks," *International Journal of Satellite Communications and Networking*, vol. 22, no. 5, pp. 547–566, 2004.

[14] M. Allman, V. Paxson, and W. Stevens, "TCP Congestion Control," RFC 2581, 1999.

[15] "Digital Video Broadcasting (DVB);Generic Stream Encapsulation (GSE) Protocol," *ETSI TS 102 606*, pp. 1–25, 2007.

[16] A. Munari, G. Acar, C. Kissling, M. Berioli, and H. P. Lexow, "Multiple access in DVB-RCS2 user uplinks," *International Journal of Satellite Communications and Networking*, pp. 1–18, 2013.