Network Coding Enhancing in a TCP Splitting Satellite Communication System

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Abstract

TCP faces challenges over satellite network due to the presence of long propagation delay and packet losses. The combination of satellite link characteristics causes reduced performance in TCP data transfers. To achieve reliable communication over satellite links, many solutions have been proposed to mitigate the problem. However, each of solutions cannot address all the issues reside on satellite links. In this paper, we propose to incorporate network coding on TCP splitting satellite segment. It introduces network coding that operates only on the satellite link between the gateway and the satellite terminal, with a minimum protocol stack change. In this scheme, it employs redundant packets to mask packet loss over a satellite links. The degree of redundancy is optimized based on the link error rate on the wireless channel. As simulation result shows the proposed scheme achieves high and stable throughput by tolerating the channel conditions on satellite link.

1. Introduction

TCP continues to be the primary transport protocol in satellite networking environment. However, it faces challenges due to long propagation delay and significant packet losses on the wireless satellite channel. A well-known solution to Internet communication paths that include satellite link is performance enhancing proxy (PEP) based TCP splitting [1]. It divides the end-to-end TCP connection by isolating the satellite link from the terrestrial network. On the satellite portion, advanced schemes are employed to combat wireless channel losses, usually some specialized TCP versions. However, due to erasure wireless channel between the gateway and satellite terminal, the end clients generate triple- duplicate acknowledgments (TDA) to respond for the lost packets. This severely affects the TCP performance as the link loss increases [2]. Therefore, TCP splitting is not enough to achieve desirable throughput in erasure satellite channel.

Network coding departs from the conventional data transmission mechanisms by allowing mixture of information at the source and introduces redundant information mechanism using a random linear network coding (RLNC) approach [3][4][5]. It makes a lossy channel as lossless channel to TCP using RLNC. In this paper, we propose to incorporate network coding into TCP-splitting satellite network, allowing its use with minimal changes to the protocol stack. These two solutions are not mutually exclusive; so it is likely that these solutions can be used together to improve transmission performance of TCP over erratic satellite links by masking the losses from TCP and to avoid under-utilized resources on prolonged periods of time.

2. System Model

The protocol stack considered in this work is shown in Fig. 1. The satellite segment is isolated from the terrestrial networks using TCP splitting. A TCP flow is generally terminated at the gateway to the satellite link, and a new TCP session is setup on the other side of the satellite link to complete the connection. The terrestrial segments have short RTT and error free, and can apply standard TCP versions and satellite segment is long RTT and error-prone. It allows also to employ advanced schemes on satellite segment to combat wireless channel losses. Then it introduces network coding layer (NEC) on the protocol stack that operates only on the satellite link, between the gateway and the satellite terminal which is independent of terrestrial connection.

3. Operation of the Proposed Scheme

The combination of the distributed PEP and network coding is designed to improve TCP performance over satellite Links.

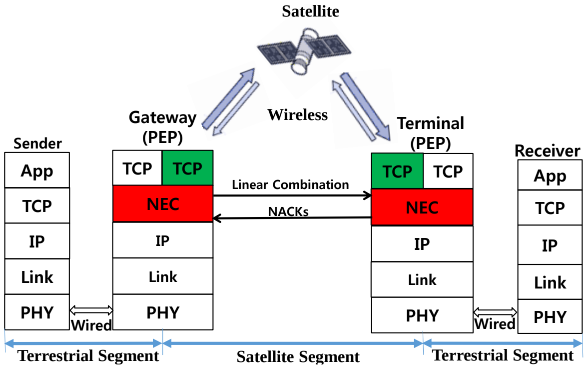

Fig. 1. Proposed protocol stack

TCP splitting solutions minimize the effect of RTT on the congestion control of the terrestrial networks as well as allows also to apply network coding on the satellite segment independent of the terrestrial networks. Fig. 2 shows the NEC operation between the gateway and satellite terminal. It reveals buffering, packet forwarding and negative acknowledgment (NACK) mechanism for retransmission block request and the RTT value of each block. The NEC at gateway starts encoding after receiving m native packets from the upper layer (TCP). Using random linear combination of the native packets, it creates the same batch of native coded packets with additional redundant packets referred to as blocks. The NEC linearly combines the packets by the following equation:

$$(Y_1,\dots,Y_n)=(X_1,\dots,X_m)\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \quad (1)$$

where $X_i(1\le i\le m)$ and $Y_j(1\le j\le n)$ are the original packet and the encoded packet respectively, and a_{ij} is the encoding coefficient from a finite field. Each group of m packets generates a block which is a set of n linear combinations (block, *B = 1, 2… m-1, m… n-1, n*) and assigned with identical id. In network coding, redundant linear combination(*r*) is an important parameter in the design of RLNC protocol(*r= n-m*). The redundancy degree must be carefully designed in order to cope up with link errors, it means that it needs to consider the link error to adaptively calculate the redundant packets. This parameter depends on the packet error rate, ρ . Then the number of redundant packets (overhead) is estimated by Equation (2):

$$r=m\frac{\rho}{1-\rho} \quad (2)$$

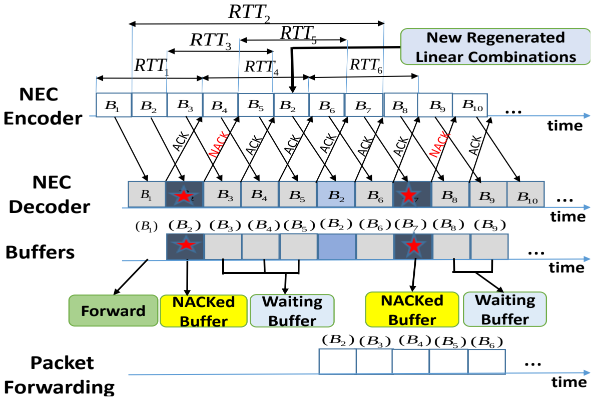

Fig. 2. Encoding, decoding and packet forwarding in NEC

where m is coding window size and ρ is packet error rate and is accurately approximated over adaptive wireless channel communication [6]. The generated block is forwarded to IP layer for transmission sequentially over the satellite channel. Once the NEC layer at satellite terminal receives m innovative coded packets of a block, a reversal process of packet encoding will be takes placed using Gaussian elimination techniques [7]. When the received block is successfully decoded, the NEC will deliver the upper layer and the terminal will forward the decoded packets to the client. Up on receiving data packets, the clients send an ACK to the gateway through the satellite terminal. Note that the NEC layer at the satellite terminal must also confirm to its NEC counterpart at the gateway in order to delete the m packets (correctly decoded packets at the receiver) from its buffer.

In case the received block is failed to decode (e.g block 2 shown on Fig. 2) due to bit inversion on the wireless link, it is stored on the NACK buffer of the NEC layer and at the same time it requests the gateway for retransmission of additional combinations by sending NACK command. Subsequent block(s) which are correctly received and decoded by the satellite terminal are buffered on a waiting storage of the NEC layer until the NACKed block (B2) is recovered. This is to address the order issue in TCP due to random packet loss. Once B2 is decoded correctly, it is forwarded together with the decoded data packets from waiting buffer to their respective client receiver(s). This keeps the order delivery of information to the application and masks the duplicate ACK generated by the end clients as well as avoids the wrong interpretation of packet losses on wireless satellite channel. The computational time as well as the NACKing mechanism for error correction causes to increase the RTT which affects the overall performance. But this RTT is only confined on the satellite segment and the satellite segment usually enhances some specialized TCP version that increases its congestion window independent of the propagation delay.

4. Simulation Result

To validate our idea, we use throughput as a performance metric relative to the packet error rate. We assume that large enough buffer size in both the gateway and satellite terminal of the NEC layer and constant propagation delay between them. The simulation parameters are given in table 1.

Table 1. Simulation setup parameters

Parameter	Value
RTT	500ms
Time out	1500ms
Packet size	1500byte
Maximum window size	64kb

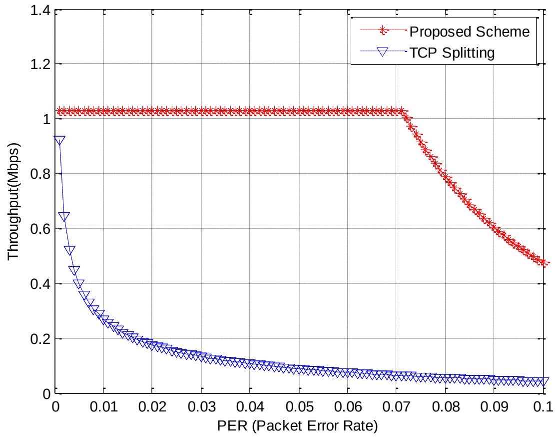

Fig. 3. Average throughput vs packet error rate

As the result shows in Fig. 3, connection splitting PEP solution (TCP splitting) severely degrades its throughput as the satellite channel becomes worse i.e. packet error rate increases. However, the proposed scheme maintains stable throughput in higher PER. It also enables to use the available resources in higher error rates by avoiding unnecessary reduction in transmission rate.

5. Conclusions and Future Works

The proposed scheme utilizes network coding to introduce information redundancy to cope with link error rate over isolated satellite networks using the TCP splitting. It uses also NACK mechanism for incorrectly received blocks in order to correct lost packets by hiding from TCP. Coding process is seen at the TCP sender as a slight average RTT increase of the satellite link, but this RTT only confined on the satellite segment using the TCP splitting. As shown in the simulation result, the proposed scheme improves the TCP performance over erratic satellite channel. In our future work, analytical modeling the proposed scheme by considering all the parameters that affect the performance of TCP in satellite communications.

Acknowledgment

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