Robust Header Compression Over Long Delay Links

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Abstract—The enormous growth in the use of the IP-based multimedia and other applications has increased the need to use the available communication technologies including satellite and radio links efficiently. These wireless links generally induce high bit error rates and long delays. Moreover, the deployment of IP protocols over these links leads to significant header overhead. IP tunneling mechanisms, widely used in the network security, IPv4-to-IPv6 transition, and mobile networks also have long delay characteristics. This paper studies the behavior of one of the most commonly used Robust Header Compression (ROHC) mechanism over such long delay links and tunnels. We show the impact of long delay, high bit error rate, and packet reordering on ROHC performance. Some of the experiments have been conducted over L2TP tunnel between France and Korea. The results show that ROHC compression can be used over long delay links to reduce header overheads with certain limitations. The results presented in this paper will provide the basis for further designing header compression schemes specifically suited for links and tunnels with long delays.

I. INTRODUCTION

In recent years, there has been an enormous growth in the use of the IP-based multimedia and other applications. This has increased the need to use the available communication technologies including satellite and radio links efficiently.

However, these links have high bit errors and long round trip times. The one-way propagation delays are of the order of 300 ms for geostationary satellites (GEO). It may increase by more than one second due to intersatellite links, on board processing, and other network factors [1]. IP tunneling mechanisms which are widely used in the network security, IPv4-to-IPv6 transition, and mobile networks also have long delay characteristics since packets travel over the Internet. It has been reported that the long propagation delay is one of the main causes of adverse effects on the performance of network protocols such as TCP [2]. Moreover, the deployment of IP protocols in networks where link delay is high often leads to high header overhead. Header compression could be applied on such links to reduce the header overhead.

In this paper, we focus on the impact of long delay on header compression mechanisms. There has been some work done to study the behavior of TCP/IP’s VJHC [3] header compression scheme over high bit-error-rate (BER) and long delay links [4]. One of the most commonly used Robust Header Compression (ROHC) [5] has been previously studied in [6], [7]. However, there are no studies on examining the impact of delay and reordering on ROHC mechanism.

This paper examines the behavior of ROHC header compression over links with long delays especially satellite links and tunnels where delay can be as high as 300 ms. The results show that ROHC compression scheme can be used over long delay links to reduce the IP/UDP/RTP header overheads with certain limitations. The results presented in this paper will provide the basis for further designing header compression schemes specifically suited for links and tunnels where delays are high and packets can be reordered.

The paper is organized as follows. Following the introduction, section II provides an overview of ROHC and problems occur when ROHC is used over links with long delays. Section III lists some long delay links where ROHC compression could be applied. Section IV describes the experiment platforms. Section V presents the experiment results and analysis. Section VI concludes our discussion with future work.

II. ROBUST HEADER COMPRESSION

Many header compression schemes have been proposed for the Internet protocols in the past 15 years. ROHC [5] is the Robust Header Compression protocol which was developed and standardized by the IETF in 2001. ROHC supports compression of IP headers including IPv4 [8] and IPv6 [9], UDP [10], RTP [11], and TCP [12]. It intends to compress IP and following headers depending on the ROHC profile used when packets travel over a link (level 2). The link could be a PPP [13] connection over a serial link or L2TP [14] session. It could also be a SNDCP (Subnetwork Dependent Convergence Protocol) [15] connection in UMTS [16]. Some ROHC profiles such as IP-only, IP/UDP, IP/UDP/RTP have been defined and some new profiles such as IP/TCP [17] are still under definition. ROHC is known to be able to reduce the header size and performs well over wireless links where the packet loss rate is high. The IP/UDP/RTP profile of ROHC compresses the overhead of 40 bytes for IPv4 or 60 bytes for IPv6 into 2-3 bytes.

A. ROHC Framework

ROHC mechanism works by removing the redundant header fields and the redundant information in the packet flow. This subsection gives a basic overview of the ROHC mechanism.
Each ROHC entity consists of a compressor and decompressor. The compressor and decompressor maintain a context for each flow to store the information about the header fields. The ROHC compressor has three compression levels: Initialization and Refresh (IR), First Order (FO), and Second Order (SO). In the IR compression level there is no context for compression available. Thus the compressor sends a ROHC packet containing all the static and dynamic header fields information to establish the context. In the FO compression level it sends the change pattern of dynamic fields. In the last compression level SO, it sends encoded values of the RTP Sequence Number (SN) and Timestamp (TS) forming the minimal size packets. In case of some updates or errors in a stream, the compressor goes back to the lower compression levels. It returns to the SO level, which is the highest compression level after retransmitting the updated information and establishing again the change pattern at the decompressor. The decompressor decompresses the headers based on the header fields’ information of the context. In order to ensure correct decompression the context should be synchronized all the time.

The ROHC decompressor has three states, the first is No Context (NC) state in which there is no context synchronization. The second is Static Context (SC) state which is reached after the dynamic information in the context is lost. The third decompression state is Full Context (FC) state, which is reached when the decompressor has all the information about header fields and the entire context has been established. The decompressor usually works in the SC state and if it detects context damage, it moves to the initial states. The decompressor uses a “k out of n” failure rule by looking at the last n packets and if CRC failures have occurred for at least k packets, then it assumes context damage and transits to an initial state. The K1, N1 values are used to assume dynamic context damage and K2, N2 values are used to assume static context damage.

ROHC has 3 modes of operations: Unidirectional (U) mode, bi-directional Optimistic (O) mode, and bi-directional Reliable (R) mode. U mode is used for unidirectional links where feedback is not possible. The O mode and R mode are used for bi-directional links where feedback is possible. The O mode sends only negative feedbacks, optionally it can also send positive feedbacks. The R mode uses both negative and positive feedbacks. The decompressor manages the operation mode in which the system will work through the use of mode transitions that allow it to change from one mode to another, based on the link characteristics and the performance requirements.

We use our ROHC implementation in order to test the behavior of ROHC compression over long delay links. In the ROHC implementation, first the physical layer is established and then negotiation takes place to establish the ROHC negotiation channel parameters that in turn define the channel. After negotiation, the context space is allocated corresponding to different CIDs (Context Identifier), which differentiate each channel and all contexts. The contexts are initialized to the values specified in the ROHC standard [5].

The ROHC compressor can operate in any of the three modes, but it always starts in U mode and the ROHC decompressor always starts in the NC state.

### B. Compression Parameters and Encoding Method

The compression parameters of ROHC determine the efficiency and robustness of ROHC. The values of these parameters are not defined in the ROHC standard and are not negotiated initially, but are stated as implementation dependent. The compression parameters are following: \( L, IR \_\text{TIMEOUT}, FO \_\text{TIMEOUT}, \text{Sliding Window Width (SWW)}, K \) and \( N \). In U mode and O mode the ROHC compressor uses a confidence variable \( (L) \) in order to ensure the correct transmission of header information. This means sending the same header format packet of each compression level, at least \( L \) times for the first levels before transitting to SO compression level. If even a single packet reaches the decompressor the information gets communicated. In U mode, the compressor uses 2 timers, \( IR \_\text{TIMEOUT} \) and \( FO \_\text{TIMEOUT} \). The timer \( IR \_\text{TIMEOUT} \) is used to return to the IR compression level and to resend the static information periodically as there is no feedback from the decompressor to the compressor. If the compressor is in SO compression level, it uses \( FO \_\text{TIMEOUT} \) to go back to the FO compression level.

The ROHC standard recommends Window based Least Significant Bits (W-LSB) encoding method to compress the header fields like the RTP SN and TS whose values are usually subject to small changes. W-LSB encoding uses a Sliding Window of Width equal to SWW. With W-LSB, the compressor sends only the least significant bits and the decompressor uses these bits to construct the original value of the encoding fields. The number of bits required to send the changes depends on the SWW of the Sliding Window, which is maintained by the compressor. All the SN values, that the compressor believes have not reached the decompressor, are to be used and are kept in the Sliding Window. Thus the larger the SWW, the larger the number of bits required to be sent in the header format packets because only one value in the window should have those LSB SN bits for the correct decompression.

The ROHC scheme is being widely accepted by 3GPP [18] and 3GPP2 [19]. It is also being used by satellite modem manufacturers to attain better performance over satellite links.
ROHC is designed to work well over links such as cellular and satellite links. ROHC standard is not recommended for tunneling due to reordering of packets in tunneling. Nevertheless it is possible to use ROHC in tunneling resulting in more efficient tunneling mechanisms due to the reduced overhead. However, there may be problems regarding achieved throughput. The characteristics of the satellite links such as long delays and high error rate may also affect the performance of ROHC compression over long delay satellite links.

III. LONG DELAY LINKS

There are different types of delays in the IP network. The delay for an IP packet over a link consists of queueing delay, processing delay, propagation delay, and transmission delay. Propagation delay is negligible for most cases, excluding satellites. The propagation delay is considered as the link delay. The queueing delay depends on the factors such as buffer capacity, average queue length, and the queuing discipline.

In general, we consider that delay in the IP network mainly consists of buffering and link delay. Value of delay varies in different IP networks.

We consider 3 networks with high delays as following:

1) UMTS Network: In the UMTS network, buffering delay can be high. It may vary from 500 ms to 1 second in the RLC layer [20]. In the UMTS network, ROHC is used in the PDCP [21] layer which is above the RLC [22] layer.

2) Satellite Links/Network: The satellite links have high bit error rates and long round trip times. On satellite links, delay can be as high as 300 ms. The use of header compression in satellite networks helps in providing better quality of service and increased link efficiency by minimizing the effect of above factors.

3) Tunneling: In IP tunneling, the value of delay for an IP packet can be high depending on the network. In addition to the delay, IP tunneling can lead to reordering of packets. Though ROHC standard is not recommended for tunneling, we nevertheless look at the performance of ROHC to gain insight into what could be the problems in case of reordering of packets.

IV. EXPERIMENT PLATFORM

In this section, we describe the experiment platform and the tests conducted on the platform. The analysis of the results is done in section V. Figure 1 and 2 show the experiment platform 1 and platform 2 respectively. We conducted experiments on two different platforms. In the first part, we conducted experiments on the laboratory platform locally as shown in Figure 1. We used netem tool [23] to simulate the high delay and high error characteristics of a long delay link. The hardware topology of the test platform 1 consists of 3 machines: ROHC Compressor, ROHC Decompressor, and Netem. Netem is used to introduce high delay, BER (Bit Error Rate), and jitter on the (PPPlink) link between the ROHC C/D endpoints.

The experiments are conducted with the link delay of minimum value of 0 ms to maximum value of 2 seconds. It should be noted that the value of RTT (Round Trip Time) corresponding to a satellite link is of the order of 300 ms with one-way link delay in satellite networks of the order of 150 ms. The channel BERs considered are $10^{-5}$, $10^{-4}$, $5 \times 10^{-4}$, and $10^{-3}$. We also tested the performance of ROHC when there is reordering of packets in the network.

In the second step, we conducted experiments in the real network between France and Korea. The platform is shown in Figure 2. We set up a L2TP [14] tunnel (IP/UDP/L2TP/PPP tunnel) between the L2TP client in France and the L2TP server in Korea. ROHC C/D is installed on both the L2TP server/client. Video client streams the video stream (IP/UDP/RTP flow) from Video Streaming Server over the real L2TP tunnel. The video flow IP/UDP/RTP is being compressed by the ROHC compressor at the sender side and is being decompressed by the ROHC decompressor at the receiver side. We investigated the behavior of ROHC over L2TP tunnel between the two countries. This is important because L2TP and PPP links are, themselves, interesting in order to access the Internet (IPv6-IPv4 transition) using cellular [24] access or to join the private network of a service operator through any infrastructure.

V. EXPERIMENT RESULTS AND DISCUSSION

We use our ROHC implementation to study the performance of ROHC compression over long delay links. Our implementation stores the following ROHC parameters for each endpoint of the link: number of packets sent and received, size of each
packet sent, header size, compressed header length (CHL), compressed header packet type, number of packets discarded due to ROHC (ROHC loss), and the number of packets discarded after ROHC (Application loss). In this paper, ROHC loss is referred to as the number of packets discarded due to ROHC failure. Application loss is referred to as the number of packets discarded after ROHC i.e., erroneous data and has nothing to do with ROHC. We use IP/UDP/RTP video stream that send packets in which the SN (Sequence Number) and TS (Time Stamp) fields of the RTP header change with regular patterns. It should be noted that UDP checksum is enabled in our RTP application, adding 2 extra bytes to the ROHC compressed header. In the following subsections we analyze the behavior of ROHC header compression for different values of delays, BERs, and packet reordering in the network. We consider the optimal values of ROHC parameters in our tests. The values, based on [7], are: \(^1\) L = 5, K = 15, N = 17, IR_TIMEOUT = 300 packets, and FO_TIMEOUT = 90 packets.

A. Delay or Link Delay

In this subsection, we discuss the impact of delay on ROHC header compression in U, O, and R modes of operation. We examine ROHC compression efficiency and robustness with the increase in delay. Figure 3 and 4 show the impact of delay on ACL (Average Compressed Header Length) [6] and robustness in U, O, and R mode of ROHC. In U and O mode, ACL is almost constant and does not vary with delay. However, in R mode, ACL increases with increase in the value of delay. Thus, ROHC compression efficiency decreases with increase in delay. We also observed that value of delay affects the mode transition process of ROHC. When delay is 500 ms and above, mode transition fails in O and R mode. The reason that the compression efficiency suffers in R mode is that in U and O mode, SWW (that determines robustness as well as compression efficiency [5]) is fixed whereas in R mode SWW is a variable as given in [5]. The value of SWW = 15 is the best suited for U, O, and R modes when ROHC is used over wireless links [7]. We found that in R mode, compression efficiency of ROHC suffers when delay is high. ROHC does not work efficiently in the R mode when delay is high. When the delay is high, mode transition fails. This happens because mode transition depends on the reception of R-0 and R-1 ROHC packets as given in [5]. If SWW is large, the ROHC compressor needs more bits to represent LSB bits and packets like R-0 and R-1 cannot be sent. Moreover, a larger SWW needs more storage space and more computing efforts. Though, a larger SWW helps in improving the robustness because even when there are consecutive lost packets equal to SWW-1, compression still works well.

We consider SWW = 500 in order to make mode transition successful for higher value of delays in O and R mode. Although increasing the value of SWW decreases the compression efficiency. The results show that ROHC compression is the most efficient in O mode and worst in R mode when the delay is high.

Figure 4 shows percentage ROHC loss for different values of delay and BER in the three operation modes of ROHC. The results show that ROHC loss is different in each operation mode for different values of BER. In U mode, ROHC loss is highest for BER = 10^{-3} which is a high value of error. However, delay does not have any influence on U mode. In U mode, ROHC loss remains almost constant with increase in delay. In U mode, the error remains constant with the value of delay. This happens because the decompression in U mode will have to wait until a timeout occurs, and whether it detects context damage early or late it makes no difference.

In O and R mode, delay has an impact on ROHC compression. In O and R mode, ROHC loss increases with the value of delay. In R mode, the loss is lowest because in R mode the compressor adapts the value of SWW [5], extensively uses negative as well as positive feedbacks and, moreover, always uses a 7 or 8 bit CRC in packets that update the context. Hence, context damage is less likely in R mode. Moreover, in R mode the compressor uses some packets, which do not have any CRC bits, and they do not update the context, this also decreases the number of packets dropped and reduces the overall error as compared to U and O modes.

B. Packet Reordering

In the IP network, the phenomenon of packet reordering is common. Packet reordering leads to loss of packet sequence

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\(^1\) Though the study [7] considered only low delays, we found these values optimal for our long delay configuration.

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Fig. 4. ROHC performance for delay with different values of BER.
resulting in packet loss, and this affects the performance of the IP network. The out-of-order arrival of packets can cause apparent loss of data in real-time flows, such as VoIP and video.

In this paper, we look at how packet reordering affects ROHC behavior. We introduce packet reordering on the link for different values of BER. Netem introduces reordering in the following way: it takes as input the value of reordering jitter and then it introduces a random jitter (+ or -), with the maximum value equal to the input, in the packets that pass through Netem. Figure 5 shows percentage ROHC loss in the presence of packet reordering for different values of BER in U, O, and R mode of ROHC compression. The results show that ROHC performance is best in R mode even when there is high packet reordering. This is because R mode is reliable, uses adaptive value of SWW and the feedback mechanism is very strong in this mode. We can also see that as soon as reordering jitter increases to a high value of 5 ms or above, the impact of BER is almost constant as the error is itself high. In the presence of packet reordering, ROHC performance is worst in U mode. In U mode, percentage of ROHC loss is as high as 60-65% even for small reordering jitter of 5 ms. Packet reordering affects the U mode most, as there is no feedback mechanism in U mode.

C. ROHC over L2TP Tunnel

In the second part of our experiments, we tested ROHC compression in the real network over L2TP tunnel between France and Korea. Figure 2 illustrates the platform used in the experiment. ROHC performance was examined for different values of L in U and O mode. Also, we tested ROHC compression for different values of IR and FO timeouts in U mode.

We observed that ROHC header compression works fine in the real network over the tunnel between the two countries. We observed the traffic in the real network at different time periods and found that value of delay varies between 320 to 350 ms. There was no significant loss in the network and packet reordering was zero. Figure 6 shows average compressed header length (ACL) with the increase in the value of L in U and R mode of operation. The results show that, given insignificant packet loss, the ROHC compression efficiency decreases with the increase in the value of L. The optimal value of L is between 3 and 5. Figure 7 shows that the optimal value of IR_TIMEOUT is between 200 and 400.

Figure 8 shows percentage ROHC loss for different values of IR_TIMEOUT in U mode. Figure 9 shows percentage ROHC loss for different values of L in U and O mode.

VI. CONCLUSION

In this paper we examined the performance of ROHC header compression over long delay and high error rate links in U, O, and R mode of operation. We found that ROHC works fine over long delay and high error links with certain limitations. Compression efficiency of ROHC suffers when delay is high. The results show that ROHC compression is the most efficient in O mode when the delay is high. Delay does not affect
compression efficiency (i.e., it remains at a constant value) in U and O mode and does not affect ROHC loss in the U mode. Though ROHC loss is higher in U mode compared to O and R mode. A dynamic adaptation of the “context update” frequency depending on the error rate could help to reduce ROHC loss in U mode. We found that ROHC does not compress efficiently in R mode when delay is high. Nonetheless, the robustness shown in R mode during high delays and packet reordering outweighs that factor and the R mode proves to be highly robust in comparison to U and O modes.

It was also observed that value of delay affects the mode transition process of ROHC in O and R mode. When delay is 500 ms and above, mode transition fails in the bi-directional mode. We consider a larger value of SWW in order to make mode transition successful for higher value of delays in O and R mode. Although increasing the value of SWW decreases the compression efficiency. In spite of using a higher value of SWW, mode transition fails when delay is above 800 ms. This happens because mode transition in ROHC is dependent on certain type of ROHC packets. We suggested that mode transition in ROHC should not depend on certain type of ROHC packets i.e., R-0 and R-1 packets, but it should work independent of any type of packets.

The results presented in this paper could provide useful insight to the further designing header compression schemes, specifically suited for high delay links and tunnels. Our future work focuses on designing an improved header compression scheme suitable for IP tunnels with long delays and packet reordering characteristics on the basis of results presented in the paper.

REFERENCES