Evaluating \textit{BDP\_FRAME} extension for QUIC

Nicolas Kuhn  
CNES  

Francklin Simo  
VIVERIS TECHNOLOGIES

David Pradas  
VIVERIS TECHNOLOGIES  

Emile Stephan  
ORANGE LABS

Abstract—The first version of QUIC has recently been standardized by the IETF. The framework of QUIC enables the proposition, negotiation and exploitation of extensions to adapt some of its mechanisms. As one example, the DATAGRAM extension enables the unreliable transmission of data.

The \textit{BDP\_FRAME} extension is a method that can improve traffic delivery by allowing a QUIC connection to remember the knowledge of path characteristics and exploit them when resuming a session.

This technical report presents the rationale behind fast convergence in SATCOM systems and evaluates the \textit{BDP\_FRAME} extension in emulated and live environments.

Index Terms—VPN, SATCOM, PEP, TCP

I. INTRODUCTION

The protocols deployed in the extremities can hardly be relevant for each of the links available on the Internet, due to their diversity ranging from “very high speed low latency” from data centers to “high throughput high latency” from satellite systems.

Systems exploiting satellites in geostationary orbit see their throughput increased to provide offers comparable to those of terrestrial systems. This increase in throughput, combined with the intrinsic latency of these systems, impacts congestion controls such as TCP. In order to make full use of the available capacity, these systems split the TCP connections into sub-segments to use suitable congestion control on the satellite segment [1].

These solutions can be applied at different levels of the protocol stack and are generally at the level of the transport layer in SATellite COMmunication (SATCOM), and in particular by adapting the Transmission Control Protocol (TCP). With a TCP PEP, the packet losses are distributed over three sub-segments and the control of congestion can be adapted on the satellite link. This can result in a reduction by half the loading time of a web page.

The end-to-end deployment of QUIC challenges these adaptations. Indeed, with QUIC (RFC8999 [2], RFC9000 [3] and RFC9001 [4]), the functionalities previously distributed between Hypertext Transfer Protocol (HTTP)1/1.1/2, Transport Layer Security (TLS) and TCP are shared between HTTP3, QUIC and UDP. As the UDP protocol is not in connected mode, it is not possible to cut out end-to-end communication as with TCP. In addition, QUIC was measured as taking a not insignificant part of the volume transmitted in a broadband access, in particular because of the actors implementing it, which are Google or Facebook. It is therefore necessary to understand the performance of the QUIC protocol in a deployment context that has not been, a priori, considered in its design.

The authors of [5] identify that the main challenges ahead of QUIC in SATCOM systems are: (1) tolerance to packet loss, (2) adapted buffer sizes at the end points, (3) adequate congestion control and (4) quickly exploiting the available capacity. As the server does not have a priori knowledge of the characteristics of the underlying system, the convergence of congestion control can introduce a significant delay before the flow of the communication is operated. An extension do QUIC currently under discussion at the IETF [6] is to record the RTT and congestion window parameters during a first connection and send them to the client in a \textit{BDP\_FRAME}. When the client wishes to reconnect to the server, the client returns this \textit{BDP\_FRAME} and the parameters of the previous connection can be used.

This technical report presents the rationale behind fast convergence in SATCOM systems and evaluates the 0rtt-bdp extension in emulated and live environments.
II. Configurations

This section presents the different configurations that are considered in this technical report.

The generic SATCOM system for a broadband access is shown in Figure 1. When QUIC is exploited at the end points, the TCP-PEP component disappears as shown in Figure 2.

![Fig. 1. End-to-end SATCOM broadband access - with TCP-PEP](image1)

![Fig. 2. End-to-end SATCOM broadband access - with QUIC](image2)

The configuration of the considered QUIC implementations are shown in Figure 3, the configuration of the end points TCP in Figure 4, and the configuration of the PEP in Figure 5. The PEP exploits PEPSal.

![Fig. 3. QUIC implementations and configurations](image3)

Unless specify otherwise, the bottleneck bandwidth on the forward link of the SATCOM system is set to 50 Mbps and the return link to 10 Mbps.

![Fig. 4. TCP end points configurations](image4)

![Fig. 5. PEP configurations](image5)
III. RATIONALE BEHIND CONGESTION CONTROL CONVERGENCE

This section provides some emulation results to illustrate the rationale behind better congestion control convergence and the relation between achieved throughput and transmitted file size.

The tests presented in this section exploits a two peers network. More details on the set up and the exploited platform can be found in GITHUB.

QUIC implementation in picoquic using BBR congestion control is exploited to transfer 500 KB, 1 MB, 10 MB and 100 MB files over RTT $\in [100 \text{ ms}; 500 \text{ ms}]$ and bottlenecks of 1 Mbps (forward) / 100 kbps (return), 10 Mbps (forward) / 2 Mbps (return), 50 Mbps (forward) / 25 Mbps (return) and 200 Mbps (forward) / 100 Mbps (return). Figures 6, 7, 8 and 9 represent the used bandwidth for various forward link bottleneck rate as a function of the RTT. The used bandwidth is computed as the ratio between the experienced goodput (ratio between the file size and the time it required to download) and the bottleneck data rate.

- when the data rate is high (e.g. 250 Mbps), even a 100 MB transfer does not utilize the available capacity;
- increasing the file size increases the link utilization.

Moreover, the results presented in this section show that there are many cases where the available capacity is not exploited. This is the case for large RTT but also the case for small RTT. The convergence of the congestion control has an impact on the transfer time and in general, the simple estimation of the transfer time using the file size and the data rate is wrong. Indeed, this estimation considers instant convergence of the congestion control.

The main conclusions are the following:
- with a 10 MB file and a data rate of 1 Mbps, the bottleneck is used for all RTT;
- for shorter files (e.g. 1 MB), increasing the RTT severely impacts link utilization;

1https://github.com/NicoKos/openbach-example-simple
IV. PERFORMANCE IMPROVEMENTS OF BDP_FRAME

A. BDP_FRAME extension in a nutshell

[6] presents three methods to exploit the transport parameters of a previous session when resuming a session: (1) local storage, where the server stores the parameters without negotiations with the client, (2) NEW_TOKEN, where a token that the client cannot read is exploited and (3) BDP_FRAME extension, where a token that the client can read is exploited. The core idea of the BDP_FRAME extension is illustrated in Figure 10 and resides in the following:

- during a previous session, the RTT, the congestion window and the IP of the peers are registered by the server and stored in a BDP_FRAME;
- during this same previous session or at the end of it, the BDP_FRAME is sent to the client;
- when resuming a session to the same server, the client sends the BDP_FRAME to the server;
- the server can exploit the parameters contained in the BDP_FRAME to adapt the congestion control parameters.

More details on the BDP_FRAME and the “0RTTBDP” activity in QUIC can be found in [6]. The local storage option, where the server stores the parameters when resuming a session is implemented in picoquic, along with a safety check that the parameters have not changed since the previous session. The BDP_FRAME option is also available in picoquic.

B. Emulated performance of BDP_FRAME

Figure 11 presents the received data rate as a function of time for QUIC, QUIC with 0RTT, QUIC with the BDP_FRAME extension, TCP with a PEP and TCP without a PEP. This illustrates that the 0RTT enables a faster connection establishment than QUIC without 0RTT but also illustrates how the BDP_FRAME further helps in quickly exploiting the available capacity.

Figure 12 shows the transfer time of 500 KB with three different implementations of QUIC with and without 0RTT, with TCP and with TCP-PEP.

A good news for SATCOM systems is that the three QUIC implementations provide results close to those of TCP. There are even cases (quicly without 0RTT or quicly with 0RTT or ngtcp2) where QUIC performs as good as TCP-PEP configuration.

The download time is reduced by 13% with the usage of the 0RTT with ngtcp2 and the reduction is negligible with quicly. Despite the important RTT of SATCOM systems, using the 0RTT does not seem to contribute much to the reduction of the transfer time of short files.

With picoquic implementation of QUIC, the exploitation of the 0RTT reduces the transfer time by 14% and by 58% with the BDP_FRAME extension.
V. 0RTTBDP and Variable Network Conditions

Section IV measured that the BDP_FRAME extension can result in very important reduction of file transfer time. However, the approach may be considered as aggressive and it is necessary to assess its performance in presence of competitive flows.

A. Performance of BDP_FRAME in congested environments

The scenario that is considered in this section is the following. At \( t = 0 \) seconds, a first QUIC connection transmits 100 MB between two peers (purple curve). Then, at \( t = 60 \) seconds, the QUIC connection resumes the connection (blue curve). However, in the meantime, at \( t = 45 \) seconds, a TCP flow has grabbed the available capacity (green curve). This scenario measures the received bit rate as a function of time in Figure 13 (without 0RTT), Figure 14 (with 0RTT) and Figure 15 (with BDP_FRAME). As a reminder, the 0RTT variant also exploits the characteristics of the previous session and both 0RTT and BDP_FRAME variants introduce safety checks as those proposed in [6].

Contrary to what could have been expected, because the exploitation of previous session parameters comes with safety nets, the resumed session is less aggressive than a standard slow-start approach.

B. Performance of BDP_FRAME in real life

To further assess the performance of the BDP_FRAME and its deployability, we have tested it using a real satellite broadband access. The exploited architecture is shown in Figure 16.

The picoquic server is hosted in private owned servers on the Internet. We exploited the KaSat satellite and upload 500 KB or 1 MB files, 50 times each, and use different picoquic clients.

The results of the experiments are shown in Table I. Using the 0RTT as opposed to the 1RTT can result in up to 33% reduction in transfer time for 500 KB. With the exploitation of the BDP_FRAME, the transfer time is reduced by up to 67%.

| File size (MB) | Without 0RTT | With 0RTT | With BDP_FRAME |
|---------------|--------------|-----------|----------------|
| Min DT (s)    | 3.12         | 3.87      | 2.43           |
| Average DT (s)| 11.34        | 17.15     | 7.59           |
| Max DT (s)    | 47.82        | 61.43     | 33.69          |

TABLE I
Real Satellite Access: Download Time (DT) of 500 KB and 1 MB
VI. Conclusion

This technical report illustrates the need for considering congestion control convergence when determining the transfer time of short objects. Just dividing the file size by the bottleneck data rate may provide wrong assumptions on the actual transfer time.

To improve the convergence of the congestion control in SATCOM environments, this technical report measures the performance of the $BDP_{FRAME}$ extension for QUIC that exploits the previously measured path characteristics when resuming a session. With picoquic implementation of QUIC, the exploitation of the 0RTT reduces the transfer time by 14\% and by 58\% with the $BDP_{FRAME}$ extension.

The approach may be considered as aggressive and it is necessary to assess its performance in presence of competitive flows. The evaluations illustrate that exploiting the previous parameters with a safety check can be less aggressive than a standard slow-start mechanism.

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