Improving SCION MP-QUIC with Bandwidth Reservations

Master's Thesis Project
ETH Zürich

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Project Duration: 6 months

Project Description

Multipath QUIC [1] has emerged as a promising transport protocol to improve throughput, resilience, and latency by concurrently leveraging multiple network paths. In today's Internet, however, end hosts are typically limited to one or two viable paths, which significantly constrains the (potential) benefits of this multipath transport. In contrast, the SCION architecture exposes a large set of path choices, enabling endpoints to fully exploit multipath communication. Beyond path diversity, SCION provides strong guarantees with respect to path control, isolation, and security.

We currently maintain a Rust multipath QUIC library using Cloudflare quiche [2] with support for SCION. While the library demonstrates the feasibility of combining multipath transport with path-aware networking, it is not yet production ready. In particular, it lacks (i) a concrete end-to-end use case, and (ii) integration with the current SCION-sdk Rust library [3], relying instead on an unmaintained implementation [4]. As a result, the library does not fully exploit SCION's unique capabilities or recent extensions, such as SNAP, which allows users outside of a native SCION network to benefit from SCION connectivity.

More importantly, while multipath QUIC can shift traffic across available paths, its ability to improve performance is limited when all paths experience congestion or when congestion is transient and path switching yields little benefit. In such scenarios, purely transport-layer adaptation may be insufficient. SCION's Hummingbird [5] hop-by-hop bandwidth reservation mechanism offers an alternative approach: rather than reacting only to congestion, the network can be explicitly requested to reserve and provide bandwidth guarantees.

However, several questions remain open:

- When should a transport protocol request bandwidth reservations?
- Can transport-layer congestion signals reliably predict the benefit of network-layer reservations? How can they be translated into reservation decisions?
- Can bandwidth reservations be integrated without excessive overhead or complexity?
- What is the latency of making a reservation-backed path available, and should reservations be applied end-to-end or incrementally expanded as needed?
- What concrete benefits do reservations provide compared to conventional multipath scheduling?
- How much can we abstract this from the user or application developer?

The primary objective of this project is to design, implement, and evaluate an adaptive bandwidth reservation mechanism for multipath QUIC over SCION. Concretely, the project aims to:

- Extend the existing multipath QUIC library with support for SCION's Hummingbird bandwidth reservation.
- Design algorithms that automatically trigger bandwidth reservations when congestion is detected and alternative paths do not provide sufficient performance gains.
- Develop a concrete use case and demo that clearly illustrates the advantages of adaptive bandwidth reservation.
- Evaluate the system in realistic scenarios and quantify its benefits and associated costs.

By tightly integrating multipath QUIC with SCION's bandwidth reservation capabilities, this work bridges the gap between transport-layer adaptability and network-layer guarantees. The results will provide practical insights into when and how explicit bandwidth guarantees should be used, and contribute toward a production-ready, performance-predictable QUIC transport over SCION.

Tasks

Below are the tasks that the student is required to accomplish in the scope of this project. Based on the findings that the student makes and the issues he encounters during his work on the project, the goals of the project can later be changed and the tasks can be revised.

- Review and update the existing multipath QUIC implementation to use the current SCION Rust libraries, including support for recent extensions such as SNAP.
- Design an interface between the QUIC transport layer and SCION's Hummingbird bandwidth reservation mechanism.
- Identify and define congestion signals at the QUIC layer that are suitable for triggering bandwidth reservation decisions.
- Design and implement algorithms for automatically requesting, extending, and releasing bandwidth reservations.
- Develop a concrete end-to-end use case showcasing adaptive bandwidth reservation in multipath QUIC over SCION.
- Analyze experimental results to quantify performance gains, overheads, trade-offs, and conditions under which reservations are beneficial.

Optional Tasks

- Investigate alternative reservation strategies, including end-to-end reservations and incremental (telescoping) reservation approaches.
- Implement fallback mechanisms for reservation failures, partial reservations, and reservation teardown.

Organization

The student will hold weekly meetings with the thesis advisor(s). During each weekly meeting, the student will be expected to briefly describe the work completed during the week. The student should promptly discuss any complications that arise (e.g. difficulty in understanding concepts or in creating tools) such that the advisor can assist the student in identifying alternative project directions. The advisor will assist the student toward completing any agreed upon milestones, as well as laying out the following week's goals.

Grading Scheme

Grade	**Description**
6.00	Design and implementation, as well as thesis are candidates for submission to an academic conference or workshop.
5.50	Thesis quality significantly exceeds expectations.
5.00	Thesis meets expectations.
4.50	Thesis partially meets expectations and has minor deficits.
4.00	Thesis meets minimum quality requirements; but has major deficits and is clearly below expectations

[1] https://multipath-quic.org/
[2] https://github.com/cloudflare/quiche
[3] http://github.com/anapaya/scion-sdk
[4] https://github.com/mystenlabs/scion-rs
[5] Hummingbird: Fast, Flexible, and Fair Inter-Domain Bandwidth Reservations. SIGCOMM '25. https://doi.org/10.1145/3718958.3750495