Path Selection for Multiple Paths In QUIC
draft-dawkins-quic-multipath-selection-01

Abstract

   In QUIC working group discussions about proposals to use multiple
   paths, an obvious question came up - given multiple paths, how does
   QUIC select paths to send packets over?

   The answer to that question may inform decisions in the QUIC working
   group about the scope of any multipath extensions considered for
   experimentation and adoption.

   This document is intended to summarize aspects of path selection from
   those contributions and conversations.

   It is recognized that path selection is not the only important open
   question about QUIC Multipath, but other open questions are out of
   scope for this document.

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[1](1). Introduction

   In QUIC working group [QUIC-charter] discussions about proposals to
   use multiple paths, an obvious question came up - given multiple
   paths, how does QUIC select paths to send packets over?

The answer to that question may inform decisions in the QUIC working group about the scope of any multipath extensions considered for experimentation and adoption.

This document is intended to summarize aspects of path selection from those contributions and conversations.

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1.1. Why We Should Look at Path Selection Strategies Now

One of the first questions that's come up in discussions about multiple paths for QUIC has been about path selection. As soon as an implementation has multiple paths available, it must decide how to use these paths. The [RFC9000] answer, relying on connection migration, is "if you have multiple paths available, you can validate more than one connection at a time, but you only send on one connection at a time, and you migrate to another connection when you decide sending on the current connection is no longer appropriate. How you decide to migrate to another connection is up to you".

That has been a fine answer for many of the implementers who have worked on the first version of QUIC, and have deployed it in their networks. For other implementers, targeting other use cases and other networking environments, it may not be sufficient.

To take only one example, one of several presentations at [QUIC-interim-20-10] described aspects of 3GPP Access Traffic Steering, Switch and Splitting support (ATSSS), which contained four "Steering Modes" as part of Rel-16 in 2019 [TS23501], each of which corresponding roughly to a path selection strategy described in Section 3 of this document. A study on "ATSSS Phase 2" [TR23700-93] included four more Steering Modes for Rel-17, expected to be finalized in mid-2021, and none of these eight (so far) Steering Modes are based on QUIC - they are based on Multipath TCP ([RFC8684] or simple IP packet forwarding. And if that were not enough, a proposal for a study on "ATSSS Phase 3" [S2-2104599] was provided to the SA2 145-e meeting in May 2021. Some of the ATSSS strategies rely in 5G network internals and don't translate to the broader Internet, but most do translate, and 3GPP participants certainly aren't the only people thinking about path selection strategies.

Since the various proposals presented at [QUIC-interim-20-10] were developed in isolation from each other, the path selection strategies that they reflect may be similar between proposals, but not quite the

same, and none of the proposals presented had more than two
strategies in common with any other proposal.

Given the number of path selection strategies being considered,
implemented, and even deployed in any number of venues, and the
potential for combinatorial explosion as described in Section 3.10,
it seems that identifying common aspects of path selection
strategies, sooner rather than later, is important.

1.2. Notes for Readers

This document is an informational Internet-Draft, not adopted by any
IETF working group, and does not carry any special status within the
IETF.

Please note well that this document reflects the author's current
understanding of past working group discussions and proposals.
Contributions that add or improve considerations are welcomed, as
described in Section 1.4.

1.3. Minimal Terminology

In this document, "QUIC multipath" is only used as shorthand for
"QUIC using multiple paths". It does not refer to a specific
proposal.

In this document, "path selection strategy" means the policy that a
QUIC sender uses to guide its choice between multiple interfaces of a
QUIC connection for "the next packet".

This document adopts three terms, stolen from [TS23501], that seemed
helpful in previous discussions about multipath in the QUIC working
group.

o Traffic Steering - selecting an initial path (in [RFC9000], this
   would be "validating a connection, and then using it". Although
   an [RFC9000] client can validate multiple connections, the client
   will only use one validated connection at a time.

o Traffic Switching - selecting a different validated path (in
   [RFC9000], this is something like "migrating to a new validated
   connection", although whether connection migration as defined in
   [RFC9000]) would be sufficient is discussed in Section 4).

o Traffic Splitting - using multiple validated paths simultaneously
   (this would almost certainly require an extension beyond
   connection migration as defined in [RFC9000]).

"Traffic Steering" does not require any extension to [RFC9000], and
is not discussed further in this document. The focus will be on
"Traffic Switching" and "Traffic Splitting".

1.4. Contribution and Discussion Venues for this draft.

(Note to RFC Editor - if this document ever reaches you, please
remove this section)

This document is under development in the Github repository at
https://github.com/SpencerDawkins/quic-multipath-selection.

Readers are invited to open issues and send pull requests with
contributed text for this document, but since the document is
intended to guide discussion for the QUIC working group, substantial
discussion of this document should take place on the QUIC working
group mailing list (quic@ietf.org). Mailing list subscription and
archive details are at https://www.ietf.org/mailman/listinfo/quic.

2. Background for this document

A number of individual draft proposals for "QUIC over multiple paths"
have been submitted to the IETF QUIC and INTAREA working groups,
dating back as far as 2017. The author thinks that the complete list
is as follows (and reminders for proposals he missed are welcomed):

o [I-D.an-multipath-quic]

o [I-D.an-multipath-quic-application-policy]

o [I-D.an-multipath-quic-traffic-distribution]

o [I-D.chan-quic-owl]

o [I-D.deconinck-quic-multipath]

o [I-D.deconinck-quic-multipath],

o [I-D.huitema-quic-mpath-req]

o [I-D.huitema-quic-mpath-option])

o [I-D.liu-multipath-quic]

o [I-D.piraux-intarea-quic-tunnel-session]

[I-D.bonaventure-iccrg-schedulers] has also been submitted to the
Internet Congestion Control Research Group [ICCRG-charter] in the

Internet Research Task Force. It contains specific proposals for
implementing some multipath schedulers, and includes some discussion
of path selection relevant to this document.

One point of confusion in QUIC working group discussions was that the
various proposals (also using Multipath TCP [RFC8684], so not all
proposals were QUIC-specific) discussed in working group meetings and
on the QUIC mailing list were from various proponents who weren't
solving the same problem. This meant that no two of the use cases
presented at the QUIC working group virtual interim on QUIC Multipath
[QUIC-interim-20-10] were relying on the same strategies.

It seemed useful to collect the path selection strategies described
in those proposals, to look for common elements, and to write them
down in one place, to allow more focused discussion.
[I-D.dawkins-quic-what-to-do-with-multipath] was intended to
summarize, at a high level, various proposals for the use of
multipath capabilities in QUIC, both inside the IETF and outside the
IETF, in order to identify elements that were common across
proposals. This draft tries to describe the impact of these various
strategies on potential QUIC Multipath extensions.

One element that is certainly worth considering is whether the path
selection strategies that have been proposed can be satisfied using a
small number of "building block" strategies.

3. Overview of Proposed Path Selection Strategies

The following strategies were discussed at [QUIC-interim-20-10], and
afterwards on the QUIC mailing list. These are summarized in this
section, are described in more detail in
[I-D.dawkins-quic-what-to-do-with-multipath], and are attributed to
various proposals in that document.

o Active-Standby - described in Section 3.1

o Latency Versus Bandwidth - described in Section 3.2

o Bandwidth Aggregation/Load Balancing - described in Section 3.3

o Minimum RTT Difference - described in Section 3.4

o Round-Trip-Time Thresholds - described in Section 3.5

o RTT Equivalence - described in Section 3.6

o Priority-based - described in Section 3.7

   o Redundant - described in Section 3.8

   o Control Plane Versus Data Plane - described in Section 3.9

   o Combinations of Strategies - described in Section 3.10

3.1. Active-Standby

   The traffic associated with a specific flow will be sent via a
   specific path (the 'active path') and switched to another path
   (called 'standby path') when the active access is unavailable.

3.2. Latency Versus Bandwidth

   Some traffic might be sent over a network path with lower latency and
   other traffic might be sent over a different network path with higher
   bandwidth.

3.3. Bandwidth Aggregation/Load Balancing

   Traffic is sent using all available paths simultaneously, so that all
   available bandwidth is utilized, likely based on something like
   weighted round-robin path selection. This strategy is often used for
   bulk transfers.

3.4. Minimum RTT Difference

   Traffic is sent over the path with the lowest smoothed RTT among all
   available paths, in order to minimize latency for latency-sensitive
   flows.

3.5. Round-Trip-Time Thresholds

   Traffic is sent over the first path with a smoothed RTT that meets a
   certain threshold.

3.6. RTT Equivalence

   When multiple paths each have sufficiently similar smoothed RTTs,
   traffic is sent over all of these paths. This is similar to
   "Bandwidth Aggregation/Load Balancing", with the additional
   qualification that not all available paths are used for this traffic.

3.7. Priority-based

   Priorities are assigned to each path (often by association with
   network interfaces). Traffic is sent on a highest-priority path

until it becomes congested, and then "overflows" onto a lower-
priority path.

3.8. Redundant

Traffic is replicated over two or more paths. This strategy could be
used continuously, but is more commonly used when measured network
conditions indicate that redundant sending may be necessary to
increase the likelihood that at least one copy of each packet will
arrive at the receiver.

3.9. Control Plane Versus Data Plane

An application might stream media over one or more available paths
(based on one of the other strategies named in this section), but
might send ACK traffic or retransmission over a path specifically
chosen for that purpose. This is more likely to be beneficial if the
path characteristics differ significantly between available paths -
for example, satellite uplink/downlink stations connected by both
higher-bandwidth Low Earth Orbit satellite paths and lower-bandwidth
cellular or landline paths.

3.10. Combinations of Strategies

In addition to the strategies described above, it is also possible to
combine these strategies. For example, a scheduler might use load-
balancing over three paths, but when one of the paths becomes
unavailable, the scheduler might switch to the two paths that are
still available, in a way similar to Active-Standby. This is very
much an example chosen at random - potentially, there are many
combinations that could be useful.

4. Implications for QUIC Multipath

This section summarizes potential implications for "Multipath QUIC"
of path selection strategies described in Section 3, dividing them
between "Traffic Switching" (Section 4.1) and "Traffic Splitting"
(Section 4.2).

4.1. Selecting a Single Path Among Multiple Validated Paths ("Traffic Switching")

If a sender using Active-Standby (described in Section 3.1) does not
perform frequent path switching, it can likely be supported using
connection migration as defined in [RFC9000] without change.

o The caveat here is that connection migration can include the also-
   implicit assumption that an endpoint can free up resources

associated with the previously-active path. If connection
migration happens often enough, the endpoint may spend
considerable time "thrashing" between allocating resources and
quickly freeing them. Of course, if a sender is frequently
selecting a new path for connection migration, this probably
degenerates into one of the other path selection strategies.

Some path selection strategies could be supported by a mechanism as
simple as the one proposed in [I-D.huitema-quic-mpath-option], which
replaces "the implicit signaling of path migration through data
transmission, by means of a new PATH_OPTION frame" (this isn't
intended to imply the proposal is simple, only the explicit
signaling), if the receiver uses this option to notify the sender of
the preferred path. For example, Minimum RTT Difference (described
in Section 3.4) and Round-Trip-Time Thresholds (described in
Section 3.5) likely fall into this category.

Some path selection strategies are exploiting a relatively long-lived
difference between paths - for example, Latency Versus Bandwidth
(described in Section 3.2), Priority-based (described in
Section 3.7), and Control Plane Versus Data Plane (described in
Section 3.9) may fall into this category. One might wonder why these
senders would need to use a single "multipath connection", rather
than multiple [RFC9000] connections, for these cases, but if there is
a reason to use a single multipath connection, a mechanism similar to
the one proposed in [I-D.huitema-quic-mpath-option] could also be
used in these cases.

4.2. Selecting Multiple Active Paths ("Traffic Splitting")

Some path selection strategies are treating more than one path as a
set of active paths, whether the sender is performing "Traffic
Splitting" (as defined in Section 1.3)), as is the case for Bandwidth
Aggregation/Load Balancing (described in Section 3.3) and RTT
Equivalence (described in Section 3.6), or simply transmitting the
same packet across multiple paths, as is the case for Redundant
(described in Section 3.8).

For these cases, a more complex mechanism is likely required.

4.3. Arbitrary Combinations

Because it is simple enough to imagine various combinations of
strategies (as described in Section 3.10), it seems important to
understand what basic building blocks are required in order to
support the strategies that seem common across a variety of use
cases, because interactions between strategies may have significant

   implications for QUIC Multipath that might not arise when considering
   strategies in isolation.

   This seems especially important because existing proposals for QUIC
   Multipath don't use the same vocabulary to describe path selection
   strategies, so implementations may not behave in the same way, even
   if they are each using a strategy that seems to be common.

5. Next Steps

   If this discussion is useful, it may also be useful to take the next
   step, and identify potential building blocks that can be used to
   construct the path selection strategies described in Section 4.1 and
   Section 4.2.

6. IANA Considerations

   This document does not make any request to IANA.

7. Security Considerations

   QUIC-specific security considerations are discussed in Section 21 of
   [RFC9000].

   Section 6 of [I-D.ietf-quic-datagram] discusses security
   considerations specific to the use of the Unreliable Datagram
   Extension to QUIC.

   Some "Multipath QUIC"-specific security considerations can be found
   in the corresponding section of [I-D.deconinck-quic-multipath].

   Having said that, it may be best to repeat the security
   considerations section from [I-D.huitema-quic-mpath-option]: "TBD.
   There are probably ways to abuse this.".

8. Acknowledgments

   Your name could appear here. Please comment and contribute, as per
   Section 1.4.

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