QUICker connection establishment with out-of-band validation tokens

Erik Sy*, Christian Burkert*, Tobias Mueller*, Hannes Federrath*, Mathias Fischer*
*University of Hamburg, Germany
Email: {sy, burkert, mueller, federrath, mfischer}@informatik.uni-hamburg.de

Abstract—QUIC is a secure transport protocol and aims to improve the performance of HTTPS traffic. It is a design goal of QUIC to reduce the delay overhead of its connection establishment. However, an initial handshake enforcing strict validation of the client’s source address still requires two round-trips. QUIC provides address validation tokens which allow saving a round-trip during the address validation upon repeat connections. In this work, we extend the existing address validation mechanism by out-of-band validation tokens. The proposed tokens allow sharing address validation between the QUIC server and trusted entities issuing these tokens. This practice allows saving a round-trip time for the address validation also during initial connection establishments. Furthermore, we introduce distribution mechanisms for these tokens using DNS resolvers and QUIC connections to other hostnames. We evaluate our proposal based on the duration of QUIC’s connection establishment and find that it can save up to 50% of the delay overhead of an initial handshake. Moreover, we analyze the benefit of out-of-band validation tokens for popular websites. For this analysis, we assume a usual transatlantic connection with a round-trip time of 90 ms. We find that 100% of the connections required to retrieve the websites can save a round-trip time during their initial handshakes by deploying our proposal. Furthermore, our results indicate that 363.6 ms in total can be saved of all connections that are required to retrieve an average website. Overall, we report huge performance improvements for QUIC’s connection establishment without compromising the user’s privacy or communication security.

I. INTRODUCTION

This paper investigates the design of the currently standardized QUIC protocol [8]. This secure transport protocol is designated to replace TLS over TCP within the upcoming HTTP/3 version [3]. As the world wide web is closely tied to the Hypertext Transfer Protocol (HTTP) and the standardization work on QUIC receives widespread support, we expect the QUIC protocol to be widely deployed on the Internet within the next years.

The majority of web traffic is short-lived connections for which the connection establishment presents a significant delay overhead [9]. QUIC aims to reduce this delay overhead as it presents a performance limitation. For example, QUIC provides the feature of zero round-trip time handshakes that enables the client to directly send encrypted requests without waiting for the server’s first handshake messages. However, the feature is only available for repeat connections between the same client-server pair. So far, QUIC’s initial handshake still causes two round-trips if a strict validation of the client’s claimed source address is assumed. One round-trip accounts for the cryptographic connection establishment and the other for a challenge-response mechanism known as stateless retry, which validates the source address claimed by the client to prevent IP spoofing attacks.

To improve the performance of QUIC’s initial handshake, we propose in this work a mechanism to conduct the address validation upon the first connection establishment without causing an additional round-trip. To illustrate the basic idea, we assume a website (google.com) that trusts a DNS resolver (Google DNS) to issue address validation tokens. Thus, if a client resolves google.com at Google DNS, it retrieves also a valid token for its source address. Subsequently, the client includes this out-of-band validation token in its connection request sent to google.com. Later, the web server validates that the presented token matches the claimed source address of the client. If so, the address validation is completed and in total, a round-trip time has been saved during this process.

To put this into perspective, a typical round-trip time is below 45 ms in North America and below 90 ms for transatlantic connections [18]. Nonetheless, there exist regions in the world suffering from high network latencies, often exceeding 300 ms [5]. Thus, a saved round-trip time has a significant impact on the performance of the connection establishment.

In summary, this paper makes the following contributions:

• We propose out-of-band validation tokens that enable a shared address validation between a QUIC server and trusted entities issuing such tokens.
• We introduce mechanisms to distribute out-of-band validation tokens via DNS resolvers and other QUIC connections.
• We demonstrate the performance improvements gained by out-of-band validation tokens. Our results indicate that our proposal saves up to 50% of the delay overhead of initial QUIC connection establishments. Furthermore, the distribution of out-of-band tokens via DNS resolvers allows saving a round-trip time on up to 100% of the connections required to load an average website.

The remainder of this paper is structured as follows: Section II briefly introduces QUIC’s stateless retry and describes the performance problems of QUIC’s connection establishment that we aim to solve. Section III summarizes the proposed out-of-band validation token. Evaluation results and a discussion of our proposal are presented in Section IV. Related work is reviewed in Section V. Section VI concludes the paper.
II. PROBLEM STATEMENT

In this section, we review the stateless retry mechanism as known from IETF QUIC [8]. Subsequently, we introduce the performance problem of QUIC’s source address validation that we aim to solve. Then, we describe briefly the threat model at hand.

A. Stateless retry

QUIC servers can optionally include a challenge-response mechanism in the handshake to validate the client’s source address before proceeding with the cryptographic connection establishment. In the following, we first describe the protocol flow of this mechanism, which is known within the QUIC terminology as a stateless retry. Subsequently, we present details on the generation of address validation tokens.

a) Protocol flow: Figure 1 provides an overview of a stateless retry during a client’s connection attempt. It is shown, that the client starts the connection attempt by sending its ClientHello message. In case of a stateless retry, the server responds with a retry packet that contains an address validation token. Upon receiving the server’s response, the client must repeat the received token when resending its ClientHello message. This mechanism allows the server to validate the client’s source address because the client proofs that it can receive packets at the claimed IP address. However, this mechanism increases the delay of the connection establishment by a round-trip time. Note, that a server can abort the connection establishment if, during a stateless retry, a received token does not validate the claimed IP address.

b) Token generation: The draft of the QUIC protocol does not suggest a specific mechanism to implement the generation of tokens because the server creating this token is also consuming it. As requirements, these tokens should be difficult to guess and the server should construct them using probabilistic encryption. Probabilistic encryption ensures that the client does not receive the same token multiple times because this would facilitate correlating connections established using these tokens to the same user [15]. Thus, the construction of these tokens might use the Advanced Encryption Standard (AES) with a secret key length of 128 bits (16-byte) deploying an authenticated encryption mode such as Offset Codebook (OCB) or Galois/Counter Mode (GCM). The plaintext may consist just of the client’s IP address and a cryptographic nonce is used as the initialization vector (IV).

As clients have no possession of the secret key, these tokens present an opaque data block for them. Furthermore, it is not feasible for clients to generate valid tokens for arbitrary source addresses.

This mechanism of source address validation is called stateless because the server is not required to keep state about issued tokens but only needs to know the algorithm for the token creation and the secret key to validate a presented token. By sharing this secret key among a group of servers, a validation of token can be performed by a member of this group that did not issue the token itself. For example, a stateless retry can request the client to conduct the handshake with another server instance for the purpose of load-balancing. In this case, the other server needs the used secret key to validate that the presented token matches the claimed source address.

c) Address validation for future connections: To allow a strict address validation without causing a retry and an additional round-trip, the QUIC server can issue tokens via the new_token frame over an already established connection. The client caches this token for use in future connections. If the client wishes to establish a fresh connection to the same server, it includes the cached token within its initial packet. Upon receiving the client’s initial packet, the server validates that the presented token matches the claimed source address. If this is the case, the server accepts the claimed source address as validated and proceeds with the cryptographic connection establishment. In total, this practice saves a round-trip time compared to the source address validation using a stateless retry.

B. Performance limitations of QUIC’s address validation

A stateless retry increases the delay overhead of the connection establishment by a round-trip time and therefore presents a performance penalty. Validation tokens for future connections mitigate this problem for revisits to the same hostname. However, these tokens are not available for the first connection establishment to a specific hostname. Furthermore, a presented validation token for future connections can be invalid if it expired or the client’s source address (as seen by the server) changed in the meantime. Upon receiving such an invalid token, the server responds with a stateless retry if the address validation is required before proceeding with the cryptographic connection establishment. Thus, there exist several situations in which a stateless retry is likely to occur during the establishment of a connection leading each time to a performance penalty of a round-trip time.

Note, that on average the retrieval of a website requires about 20 connections to different hostnames [16]. This indicates, that web browsing causes a large number of short-lived connections for which the connection establishment can present a significant overhead. Furthermore, websites require on average four sequential connection establishment for their
retrieval because downloaded resources often trigger new connections to different hostnames [16]. Thus, improving the establishment of each connection by a round-trip time reduces the loading time of a website significantly, as the last sequentially established connection benefits often multiple times from these savings.

C. Threat model

This section defines our threat model to clarify the security considerations of the presented problem.

We assume that the generated validation tokens are cryptographically secure. As a result, it is not feasible for the considered adversary to generate a valid token for an arbitrary source address. However, the attacker can spoof the source IP address of its outgoing packets.

The considered security threat affects the objective of availability. Hereby, the adversary can attempt to directly exhaust the resources of a QUIC server by requesting connections from several spoofed source addresses. This eventually leads to a denial-of-service attack if the server spends too many resources on the connection requests from clients claiming unvalidated source addresses.

Furthermore, the adversary can also spoof the source address of a victim’s endpoint. If so, the QUIC server will send its response to the victim’s source address, which is known as a reflection attack. In this scenario, the adversary aims to saturate the bandwidth available to the victim’s endpoint. Note, that the server response can be larger than the adversary’s initial packets. Therefore, this approach may amplify the data volume of the attack on the victim’s availability compared to a direct attack by the adversary on the victim’s endpoint.

III. OUT-OF-BAND VALIDATION TOKEN

This section introduces the out-of-band validation token for the QUIC protocol. Subsequently, distribution mechanisms for such out-of-band tokens are proposed using DNS resolvers and QUIC connections to other hostnames.

A. Token design

Address validation tokens present a defense mechanism against source address spoofing by malicious clients. For this purpose, the QUIC server compares the claimed client address with the previously observed source address encoded in the presented token. So far, only QUIC servers themselves can issue address validation tokens for their connections. Out-of-band validation tokens extend this mechanism by allowing external entities to issue these tokens.

The generation of these tokens follows a similar approach as described in Section II-A. Thus, the QUIC server is required to share instructions and a secret key with the corresponding external entity, that allow the generation of valid out-of-band tokens for the client’s source address. Upon receiving an out-of-band token, the client imports it in its cache, marks it as received by an external entity, and associates the QUIC server’s hostname to it. To establish a fresh connection to the respective hostname, the client includes a cached token in the send initial packet. If the client’s cache contains several tokens, the client must prefer the usage of validation tokens received by the QUIC server itself over cached out-of-band tokens.

The server may share different secret keys with different external entities. This approach allows a selected invalidation of tokens that have been issued using a specific secret key. Thus, the QUIC server can revoke the secret key provided to an external entity if, e.g., a large number of unrequited connection request is observed that use tokens issued by the same key. If a setup with dedicated secret keys per external entity is deployed, it is recommended to attach an identifier to the token, that indicates which key was used to generate the specific token.

Note, that according to the draft of IETF QUIC [8] the server treats an invalid token as if the client did not present a token. Thus, the number of required round-trips during the connection establishment is identical if the client presents an invalid out-of-band token or the client’s connection request does not contain a token at all.

B. Token distribution mechanisms

To substantiate the real-world benefit of out-of-band tokens, we present in this section two distribution mechanisms for such tokens. First, we introduce the distribution via the Domain Name System (DNS). Then, we describe a distribution mechanism using QUIC connections to other hostnames for this purpose.

a) Distribution via DNS resolver: To save a round-trip time via the proposed out-of-band tokens, the client needs to receive the token before sending the connection request to the corresponding QUIC server. Furthermore, clients usually do a domain name query to look up the source address before they send their connection request. Thus, DNS seems to be a suitable place to distribute out-of-band tokens as the connection request often directly follows the corresponding DNS lookup. Figure 2 provides a schematic of this proposed distribution mechanism. This proposal is not limited to a specific DNS standard and can be applied at least to the traditional DNS [10] and newer versions deploying transport encryption such as DNS over Transport Layer Security (DOT) [7] and DNS
over HTTPS (DOH) [6]. In general, the DNS protocol needs to be extended by a new record type which we define as QUICTOKEN.

If the client wishes to establish a fresh QUIC connection to a domain name for which it has not a cached token for future connections available, it queries the domain name (including the QUICTOKEN record type) as shown in Figure 2. The DNS resolver proceeds with the default resolution of the source address associated with the domain name. Additionally, if the DNS resolver supports the record type QUICTOKEN and is capable to generate valid out-of-band tokens for this queried domain name, it can include such a token in the response sent to the client.

Note, that to construct valid out-of-band tokens, the resolver needs to be trusted by the server hosting the specific domain name. Thus, the respective server operator shared in advance the instructions and the secret keys required to generate valid tokens for this domain.

Upon receiving the source address and the token, the client can construct its QUIC connection request and attach the obtained out-of-band token to it before sending it to the received source address. Subsequently, the server validates the presented token and proceeds with its usual connection establishment.

To sustain the instruction that client should not reuse tokens across different connections, it is required that the record type QUICTOKEN must not be cached by any other than the client. This rule avoids that DNS caches store the token and distribute it upon future request.

A limitation of this distribution mechanism arises if the DNS resolver is located within the same private network as the client. In this case, the client’s source address as seen by the DNS resolver might mismatch the publicly visible source address as seen by the QUIC server. Thus, the address validation is likely to fail because the source address encrypted in the token does not match the claimed source address as observed by the QUIC server. We think that only a very limited number of clients is affected by this issue, which can be solved by for example moving the DNS resolver to a public IP address.

Another limitation presents the computational overhead introduced to the DNS resolver with the task of constructing out-of-band validation tokens. Large connection-oriented DNS can have about 24K active connections and serve up to 230k queries per second [19]. Thus, it seems beneficial to use a hardware-accelerated cipher suites such as AES within the token generation which can construct the required number of tokens per second on commodity hardware [12].

b) Distribution via other QUIC connections: This distribution mechanism assumes that the client establishes first a QUIC connection to hostname A before it sends a connection request to hostname B. Furthermore, we assume that hostname B allows hostname A to issue valid out-of-band tokens for its service and therefore shares instructions and its secret key required to construct these tokens for arbitrary source addresses. We propose a new EXTERNAL_TOKEN frame for the QUIC protocol, which allows QUIC server to provide clients with out-of-band tokens for arbitrary hostnames. However, tokens for future connections to the same hostname A must use the existing NEW_TOKEN frame. Note, that tokens for future connections are regarded as trustworthy as they are issued by the same server which is also consuming them. However, out-of-band tokens are not treated as trustworthy because the client does not validate that the entity issuing these tokens is authorized to do so. Compared to the NEW_TOKEN frame of the QUIC protocol, tokens received via the EXTERNAL_TOKEN frame are only used to establish a fresh connection if the client would otherwise send the connection request without an attached address validation token.

Figure 3 provides a schematic of this distribution mechanism. It is shown, that the client has an established QUIC connection to hostname A. Hostname A reasons based upon its provided response, that the client is likely to establish a connection to hostname B. To speed up this connection establishment between the client and hostname B, hostname A decides to provide an out-of-band token for the client’s source address valid for hostname B.

Upon receiving this EXTERNAL_TOKEN frame from hostname A, the client validates that it posses no token for future connections for hostname B. If so, the client establishes a fresh connection to hostnames B by attaching the received out-of-band token to its connection request. Otherwise, the client will prefer to include its cached token for future connections (received in a previous connection to the hostname B) in the connection request to hostname B. Upon receiving the client’s connection request, hostname B validates the included address validation token and proceeds with the usual connection establishment.

It seems reasonable to expect that a QUIC server will only issue out-of-band tokens for other hostnames for which it is likely that the client will soon connect to them. To avoid that the client uses out-of-band tokens issued by a hostname A for which it is unlikely to establish a connection to the consuming hostname B within a short period, these tokens should have an expiration mechanism. It seems like five minutes.
are a reasonable expiration time for tokens received via the EXTERNAL_TOKEN frame.

IV. EVALUATION AND DISCUSSION

To substantiate the feasibility of our proposal, we evaluate and discuss in the following aspects of its performance, security, privacy, and scalability.

A. Performance

In this section, we present a performance evaluation for out-of-band tokens. First, we describe our results with respect to the establishment of a single QUIC connection. Subsequently, we evaluate the performance impact of our proposal on an average website visit.

a) Benefits for single connections: Using an out-of-band token to validate the client’s source address saves a round-trip compared to using a stateless retry. Figure 4 shows QUIC’s initial handshake where the client presents an out-of-band token within the initial packets sent to the server. In case of a valid token, the server directly proceeds with the cryptographic handshake by sending its ServerHello message. The cryptographic handshake follows the TLS 1.3 protocol. Thus, the server uses transport encryption to transmit its Encrypted Extensions (EE), Certificate (CERT), Certificate Verify (CV) and Handshake Finished (FIN) messages. In total, it requires only one single round-trip from the ClientHello until the client transmits its own FIN message and is ready to send encrypted application data. As the QUIC protocol is still work in progress, there exist only experimental implementations of its design. Thus, we will use a simulation to approximate the performance benefit of our proposal on the delay overhead of the connection establishment. For this simulation, we approximate the delay overhead for the initial connection establishment as shown in Equations 1 and 2. Here, \( t_{\text{Default}} \) and \( t_{\text{Proposal}} \) indicate the delay overhead for the current status quo and our proposal, respectively. Furthermore, RTT denotes the round-trip time between both peers and \( t_{\text{proc}} \) marks the total time required by the peers to process the connection establishment.

\[
\begin{align*}
    t_{\text{Default}}(\text{RTT}) &= t_{\text{proc}} + 2 \times \text{RTT} \quad (1) \\
    t_{\text{Proposal}}(\text{RTT}) &= t_{\text{proc}} + \text{RTT} \quad (2)
\end{align*}
\]

Within our simulation, we assume that the processing of the connection setup \( t_{\text{proc}} \) takes \( 40 \text{ ms} \) independently of the round-trip time. We chose \( 40 \text{ ms} \) because this approximates the time by the TLS 1.3 over TCP protocol stack for a similar task [16].

The results are shown in Figure 5. We find, that the green, dashed line indicating our proposal provides significantly better results than QUIC’s status quo marked by a red, dotted plot. The performance improvement achieved by our proposal depends on the RTT. Assuming a transatlantic connections with around-trip time of \( 90 \text{ ms} \) [13], we find that a connection establishment using or proposal requires on 60% of the default delay overhead. Furthermore, we compute that our proposal reduces the investigated delay overhead by 50% when RTT converges to infinity.

b) Gains for web browsing: As the QUIC protocol will be a building block of the upcoming HTTP/3 network protocol, it seems interesting to evaluate the performance impact of our proposal on the retrieval of popular websites. A recent study reported [16], that the retrieval of popular websites requires on average 20.24 encrypted connections to different hostnames. For this evaluation, we assume that all of these hostnames support the QUIC protocol and that they all enable the client’s DNS resolver to issue out-of-band tokens. Thus, we find that we can save a round-trip time during each connection establishment if the corresponding web server enforces a strict source address validation before proceeding with the cryptographic handshake.

Furthermore, it is found by [16], that the retrieval of an average website requires up to 4.04 sequentially established connections. This finding can be attributed to the fact, that
a retrieved web resource often triggers the establishment of additional connections to retrieve further resources. Thus, saving a round-trip time via the proposed out-of-band tokens allows in total to save on average 4.04 round-trips until all required connections are established. Assuming a round-trip time of 90 ms, as it is typical for transatlantic connections [18], we find that 363.6 ms can be saved until the last connection required to retrieve an average website is established.

B. Security

In this section, we review possible security concerns with respect to out-of-band validation tokens. First, we address the impact of our proposal on the mitigation of Denial-of-Service attacks. Then, we look at risks arising from using address validation tokens from possibly unauthorized origins.

a) Denial-of-Service attacks: By sharing the instructions and the secret keys to generate address validation tokens with other entities, the risk that this confidential information gets compromised increases. In case of a compromise, an adversary can issue tokens for arbitrary source addresses. Thus, the adversary can send connection requests with a spoofed source address to the QUIC server, that contain a valid token for the claimed address. As a result, the server experiences a large number of unrequited connections that consume its available resources up to a Denial-of-Service. To mitigate such an event, the server should monitor the number of unrequited connections associated with trusted secret keys. If this number exceeds a threshold value, it seems reasonable to revoke that specific secret key. After such a revocation all tokens issued by using this key are treated as invalid, which prevents against Denial-of-Service attacks associated with that key. However, the revocation of a secret key might also cause a stateless retry for legitimate connection requests and thus causes a performance degradation for these connection attempts. To address this security versus performance tradeoff, it seems reasonable to provide different secret keys to different entities. Thus, a revoked key affects only validation tokens expected to be issued by a specific entity. In total, a key revocation provides an effective mechanism to protect against the considered Denial-of-Service attacks (see Section II-C).

b) Unauthorized origins: Within our proposal, the client does not validate whether an external entity is authorized by the affected QUIC server to issue out-of-band tokens. Thus, it is necessary to review the case in which an unauthorized external entity issues invalid out-of-band tokens. The draft of IETF QUIC [8] instructs that servers treat invalid tokens (for future connections) as if the client did not present a token at all. Therefore, the client experiences no drawbacks by presenting an invalid out-of-band validation token and in total, the client does achieve the same performance as including no token in the connection request. However, if the client has a valid token for future connection and an invalid out-of-band token from an unauthorized origin in its cache, then only a connection request including the token for future connections can save a round-trip during the address validation. Concluding, tokens for future connections are more trustworthy, as they have been retrieved within an authenticated connection to the QUIC server, which is also consuming them. For this reason, the usage of tokens for future connections should be preferred over out-of-band validation tokens because the client does not validate that a trust-relation exists between the entity issuing the out-of-band tokens and the QUIC server consuming them. However, out-of-band tokens are advantageous compared to using no token at all, as they can reduce the delay overhead of the connection establishment by up to a round-trip time but always achieve at least the performance of a handshake without a token.

C. Privacy

QUIC’s address validation tokens can be used to link the connection in which the token was issued to the future connection where the same token is presented by the client [15]. The proposed out-of-band token allows the same correlation across both connections in which the corresponding token is exchanged. However, in the case of out-of-band tokens, the entity issuing the token might differ from the one to whom it is presented to during the connection request. Thus, the privacy aspects of the proposed token are different from the known address validation token for future connections as it enables the linking of user activities across different entities. To evaluate the privacy impact of our proposal, we first investigate the distribution of tokens via DNS resolvers. Subsequently, we review the issuing of out-of-band tokens via QUIC connections to other hostnames.

a) Distribution via DNS resolvers: First of all, we find that the described correlations of a client’s connections are only feasible if the involved entities collaborate with each other. We note, that a collaboration between a DNS resolver and a QUIC server does provide significant opportunities to identify the same client across these services, e.g., the close temporal proximity between DNS lookups and subsequent connection requests to QUIC servers. We conclude, that a collaboration between both services can already reduce the client’s anonymity set based on the time of the corresponding requests. Moreover, the client’s source address will usually be the same when communicating with the DNS resolver and the QUIC server, which further facilitates the linking of the user’s activities. Furthermore, the DNS resolver can respond with a unique server source address upon the client’s DNS query, which is especially feasible for IPv6 addresses. Subsequently, both services can use this address to link the user across their services. Possibly, further opportunities to link users arise from the usage of DNS record types other than address records (A or AAAA) such as entries for Encrypted Server Name Indication (ESNI) for TLS 1.3 [17]. In total, it seems not feasible to prevent user tracking between DNS provider and QUIC server operators if these entities collaborate with each other.

b) Distribution via other QUIC connections: Similar to the DNS-based scenario, different operators of QUIC server can share their clients’ source addresses and the time of the requests to match user profiles across services. However, web applications are usually capable to trigger a request to another
URL using a HTTP redirect or hyperlink. This allows the collaborating entities to encode a client identifier within the used URL. Thus, if the client follows the received HTTP redirect or hyperlink, both collaborating entities can share the respective client’s profile based on this unique client identifier. Concluding, it does not seem to be feasible to prevent user tracking across collaborating QUIC servers in a real-world context.

To mitigate the privacy impact of our proposal, we recommend expiring out-of-band tokens within short periods. As proposed in [13], ten minutes seem to be a reasonable limit for comparable mechanisms that enable user tracking.

D. Scalability

The proposed distribution mechanisms require the establishment of trust-relations between different hostnames or even services. Large corporations such as Google or Cloudflare that cover several thousands of websites and provide their own popular DNS resolvers can easily deploy our proposal for their own services. Furthermore, it seems feasible that large Internet corporations establish the required trust between each other based on personal contacts to allow issuing out-of-band tokens across their services. As a result, this practice would only benefit the client’s connection establishment with these few online services, while most online services do not significantly benefit from the performance improvements achieved via out-of-band tokens.

To make this proposal available to every web service, it requires an automated approach to establish the required trust-relations and subsequently share, update and possibly revoke the secret keys required for issuing out-of-band tokens. Possibly, it requires a trusted entity similar to the CA/Browser Forum which can provide a whitelist of trustworthy DNS resolvers. This whitelist can be used by QUIC servers to share their secret keys required for issuing out-band-tokens with these DNS resolvers.

With respect to out-of-band tokens issued by other QUIC servers, a deviation of the ACME protocol [1] seems plausible to automate the process of establishing trust and conducting the required key management. Here, the QUIC server first validates the legitimate interest of another QUIC server to issue out-of-band tokens. Legitimate interest can be argued if the server, which intends to issue out-of-band tokens serves hyperlinks or HTTP redirects to the corresponding server, that consumes the out-band validation tokens. If the interest is valid, both servers will subsequently exchange the required key material to issue such tokens.

To the best of our knowledge, there do not exist any protocols suitable for these tasks. Thus, we hope that this brief discussion of the scalability problem at hand fosters further research and development on the design of such protocols, that makes out-of-band validation tokens available to every web service.

V. RELATED WORK

Performance improvements of the QUIC protocol with respect to the performance penalty caused by a stateless retry are actively discussed within the Internet Engineering Task Force (IETF) QUIC working group. These discussions focus so far on extending the number of entities that are allowed to issue address validation tokens for other hostnames either based on existing TLS trust-relations [13] or based on the source address from which a respective hostname is served [11]. Both prior contributions have limited applicability to avoid stateless retries.

[13] does not mitigate a stateless retry during the first connection to a member of a group of hostnames that have an exiting trust-relation with each other. Furthermore, these groups are usually rather small [16], thus only about 60% of connections established during the first visit of an average website can benefit from this approach. However, validation tokens obtained from a member of such a group can be considered as trustworthy because these members share secret cryptographic state with each other such as a private key of a X.509 certificate.

[11] proposes to bind validation tokens to the address of the server, similar to the approach of the TCP Fast Open protocol [4]. This approach is limited as it does not mitigate a stateless retry upon the first visit to a specific source address and performance gains can only be realized on repeat connections to a hostname served from the same source address. Furthermore, the feature of connection reuse in HTTP/2 [2] allows using an established connection to a server at a specific source address to request resources for another virtual host on the same server. This feature of HTTP reduces the chance that a client requests another connection to the same server at the same source address. Thus, it remains so far unclear to which extend this proposal improves the status quo.

This work extends the applicability of the discussed related work because clients can use out-of-band tokens upon the first connection request to any QUIC server, assuming that their DNS resolver is capable to provide a corresponding token. Thus, this proposal outperforms the related work by saving up to 100% of the stateless retries usually required if a strict source address validation is enforced. To the best of our knowledge, this work is the first to propose the distribution of address validation tokens via DNS.

VI. CONCLUSIONS

This paper proposes out-of-band validation tokens for a shared address validation between a QUIC server and trusted entities issuing these tokens. Our evaluation indicates, that the proposed tokens enable significant performance gains for clients and servers without affecting the user’s privacy and communication security.

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