ABSTRACT
In this paper, we study the potentials of passive measurements to gain advanced knowledge about QUIC deployments. By analyzing one month backscatter traffic of the /9 CAIDA network telescope, we are able to make the following observations. First, we can identify different off-net deployments of hypergiants, using packet features such as QUIC source connection IDs (SCID), packet coalescence, and packet lengths. Second, Facebook and Google configure significantly different retransmission timeouts and maximum number of retransmissions. Third, SCIDs allow further insights into load balancer deployments such as number of servers per load balancer. We bolster our results by active measurements.

1 INTRODUCTION
Revealing the setups of large service providers, i.e., hypergiants, is a long-standing research challenge [3, 13, 20]. Gaining insight into deployed infrastructure and specific protocol configurations may help guide the development of protocols and assess their reliability. Since this knowledge raises economic and security concerns it is often not publicly documented.

The QUIC protocol [17] has been designed to improve Web performance [7, 27, 33] and to reveal minimal meta-information [31]. It is still emerging but successfully adopted by hypergiants [21, 26, 34]. Prior research that studied the deployment of QUIC used active measurements or passively captured flow data—a measurement method that is not always appreciated by operators [14] and data that is hard to get.

In this paper, we focus on passively collected data that results from malicious traffic, to gain a better understanding of QUIC deployments at hypergiants. Overall, we are able to identify QUIC configurations for Cloudflare, Google, and Facebook, and gain new insights into the load balancer infrastructure of Facebook, summarized in Table 1. In detail, we contribute the following:

1. We discuss the potential and need of information encoding in QUIC Connection IDs in large load balancer deployment scenarios. (§ 2)

2. We introduce a measurement method to learn about QUIC deployments, including local system stack configurations and infrastructure setups, based on passive measurements. (§ 3).

3. We present how encoded information in Connection IDs can be used to fingerprint hypergiants. To this end, we make benign use of QUIC attack traffic. (§ 4)

4. We quantify the number of layer 7 load balancers of a single hypergiant, a previously hidden property. (§ 4)

5. We validate our results with controlled scanning campaigns and infer QUIC-aware load balancing. (§ 4)

Our measurement method is non-intrusive, easy to deploy, and will allow for observations in the future because it relies on Internet background radiation (IBR) caused by unsolicited malicious QUIC traffic. We argue that QUIC IBR will persist, similar to TCP IBR, which has been observable for more than 25 years [15].

2 PROBLEM STATEMENT, RELATED WORK
In this section, we provide basic background about QUIC and discuss implications of common hypergiant deployments for QUIC.

2.1 QUIC Overview
Connection setup. A common QUIC 1-RTT handshake is depicted in Figure 1. All QUIC sessions start with an Initial sent by a
A record: request

Handshake: DCID=C1, SCID=S2

L4LB

L7LB

VIP X

Init./Handshake: DCID=C1, SCID=S2

Init. DCID=S1, SCID=C1

Figure 1: Connection establishment using QUIC. Client connection ID (C1) is consistently used during the connection establishment but the initial server ID (S1) can be replaced by the server with another ID (S2).

A server replies with an Initial and a Handshake packet, either combined in a single (packet coalescence) or two separate UDP datagrams, which need to be confirmed by the client using an Initial ACK and an additional Handshake. The server will resend Initial and Handshake packets when the retransmission timeout (RTO) expires due to missing acknowledgements and the maximum number of retransmissions has not been reached.

QUIC tries to hide metadata but Initial and Handshake messages carry data about the QUIC network stack deployed. An Initial packet includes the QUIC version a client offers and a server agrees on. Connection IDs carry data about the QUIC network stack deployed. A server replies with an Initial ACK and a Handshake.

Connection IDs. During a handshake, servers and clients agree on connection identifiers (CID). CIDs ensure that changes in addressing or ports do not cause connection tear downs, e.g., during client migration. QUIC differentiates between source and destination identifiers (SCID, DCID), seen from the sending endpoint.

Since the client cannot guess the server CID during the initial message, it uses a temporary value (S1 in Figure 1), which can be replaced by the server (ID S2). SCIDs and DCIDs are part of the unencrypted QUIC long header. This makes them available to on-path middle boxes such as load balancers and enables observing CIDs in passive measurements without knowing the originally selected TLS secrets. CIDs are chosen randomly but may also encode information similar to TCP SYN cookies. To ensure high entropy despite information encoding and to prevent collisions between multiple connections, CIDs range between 8 and 20 bytes.

2.2 QUIC in Hypergiant Deployment

Common load balancer deployments. To steer client requests to a point of presence (PoP) that is close to the client, based on the requested service (e.g., facebook.com, whatsapp.com), many hypergiant sites use the DNS (see Figure 2) or anycast [19, 28]. Related virtual IP addresses (VIP) often belong to a mid-size network (e.g., /24) that represents the frontend cluster. The network belongs either to the hypergiant AS (on-net deployment) or to a third party provider (off-net deployment) [13]. Similar to NATs and CGNATs [25], a VIP in a load balancer neither maps to a physical interface nor a single host, instead multiple server instances will respond to it. When a client initiates an application handshake with a VIP, the handshake message is forwarded to a layer 4 load balancer (L4LB) based on equal-cost multipath. This L4LB checks whether the destination IP address of the packet is configured as a VIP. On success, the L4LB applies consistent hashing of the 5-tuple (i.e., source and destination addresses and ports as well as transport protocol type) to tunnel the packet to a layer 7 load balancer (L7LB) via IP encapsulation. The L7LB completes the handshake with the client and serves the application layer request. The number of VIPs is a bad indicator for the size of off-net deployments [12], thus we focus on enumerating L7LBs behind VIPs.

QUIC-aware load balancing. QUIC challenges common load balancing deployments for two reasons. First, QUIC allows for client migration but many load balancers rely on the common 5-tuple. Any client that changes the source IP address while maintaining a connection state invalidates this 5-tuple, leading to a different mapping of client to L7LB. This is why QUIC-aware load balancers [9] have to forward traffic based on QUIC connection IDs.

Second, QUIC consumes and retires connection IDs (e.g., during client migration). Since new connection IDs are negotiated in encrypted packets, they must be generated at the L7LB, the service endpoint. The transition from an old to a new connection ID is hidden even from a QUIC-aware L4LB. This obfuscation prevents a L4LB from relaying packets consistently.

To tackle this limitation, L7LBs have two options: Either they can share their active CIDs with the L4LBs. Such deployment would introduce synchronization overhead between load balancers. Or parts of the connection ID encode the L7LB. The encoded information reveals information about the server infrastructure but does not conflict with client privacy. In §3, we use this information, captured in passive measurements, to explore load balancer infrastructure.

Measurement opportunities with QUIC. Current measurement methods that identify load balancers or larger CDN infrastructure use traceroute-like tools (e.g., [3, 32]) or build on IP addresses made available via the DNS (e.g., [1, 8]). While active probing and DNS can quantify the number of VIPs they do not identify L7LBs because multiple L7LBs may share the same VIP of a single frontend cluster. Observing the number of L7LBs, however, might reveal (i) load balancer life cycles or update patterns, (ii) DDoS resiliency, and (iii) expected user volumes and therefore potential business decisions.

Prior work enumerates 5-tuple L7LBs by active probing of vulnerable QUIC implementations [30], showcased in a testbed. In this paper, we introduce a passive method, bolstered by active measurements, that discovers QUIC-aware L7LB by utilizing standardized QUIC protocol mechanics to understand implementations in the wild.
3 MEASUREMENT METHOD AND SETUP
We analyze QUIC Internet background radiation (IBR) to learn about QUIC deployments. We consider two perspectives, (i) the local QUIC stack in use and its configuration, and (ii) larger infrastructure deployments of distributed QUIC servers.

3.1 Method

Basic idea. To capture unsolicited incoming traffic we use a network telescope. Network telescopes typically cover between /8 and /24 IPv4 address space. They capture scans (i.e., in our case QUIC clients) as well as backscatter traffic (i.e., replies from servers to spoofed addresses of the telescope). Despite being a relatively young protocol, QUIC IBR is present [23].

We argue that the proposed approach is future-oriented since it makes use of two types of traffic (scans and backscatter) that will experience enhanced visibility with increasing QUIC deployment. In particular, backscatter traffic triggered by attackers will increase because spoofed traffic remains a largely unsolved challenge in IPv4 and IPv6 [5] and enables QUIC INITIAL floods [23].

On-net vs. off-net server deployments. We identify hypervariant on-net deployments by mapping source IP addresses of backscatter traffic to autonomous systems (ASes) in order to check whether these ASes belong to, e.g., Google. Assuming that the larger infrastructure deployment of a CDN is rather homogeneous across networks, we identify patterns of QUIC traffic features of on-net deployments and compare with traffic coming from non-hypervariant ASes—our assumption has been confirmed by hypervarians.

Identifying load balancers. L7 load balancers complete common HTTPS and more recently QUIC handshakes. We identify specific load balancer instances by using information encoded in the QUIC header, more specifically in the QUIC connection ID. Hyperviants such as Facebook structure this ID such that it includes a unique host ID, which represents the actual L7LB. We treat the connection ID structure of Facebook as ground truth because it is used in the Facebook QUIC implementation [16]. In the following, we present the first method and analysis that utilize this encoding.

3.2 Data Sources and Setup

Passive measurements. We utilize the UCSD Network Telescope [4], a /9 IPv4 darknet operated by CAIDA, to observe QUIC IBR. If not noted otherwise, we analyze packets captured from January 1-31, 2022. To compare with deployments right before publication of QUIC v1, we include QUIC IBR from April 1-30, 2021.

We mark all packets with source port UDP/443 as QUIC responses (i.e., backscatter) and all packets with destination port UDP/443 as QUIC requests (i.e., scans). We remove false positives based on the packet payload using Wireshark dissectors, as proposed in prior work [23], and exclude requests from academic and industrial scan projects [6]. We verified Wiresharks QUIC detection by manually checking QUIC connections to well-known QUIC servers. All packets were correctly identified and dissected by Wireshark.

In total, we find 87.4M QUIC IBR packets during our main measurement period. After classification and sanitization, we find 1.7M QUIC scan packets (8.1× compared to 2021) and 5.2M QUIC backscatter packets (4.4× compared to 2021). This means that sanitization removes 92% of packets, which mainly consist of research scans targeting the complete /9 telescope; those scans have little significance to our analysis, since research infrastructure is well-documented and does not have to be inferred.

Active measurements. We use two active measurements to verify our passively collected results and to trigger traffic where passive data is statistically sparse.

First, research scan data from Zirngibl et al. [34]. This measurement campaign combines weekly stateful and stateless scans of the complete IPv4 space to reveal QUIC server deployments, supported QUIC versions, and CDN off-net deployments. We utilize this data to identify off-net deployments and extract QUIC specific transport parameters [17] shared during the handshake. It is noteworthy that this data quantifies VIP addresses, not L7LB instances.

Second, we conduct active measurements to understand load balancer scenarios at content providers. Google, Facebook, and Cloudflare have publicly announced that they use consistent hashing at their load balancers [10, 11, 29] to direct related requests to the same endpoint. We connect multiple times to known QUIC servers (represented by a VIP, detected by our telescope or Zirngibl et al. [34]) of these content providers while varying the source port of our outgoing packets. When the connection establishment is successful, we log the server connection IDs (representing L7LBs) and map to previous QUIC connection attempts, details see Appendix D. We perform our scans shortly after our main measurement period from a single scanning probe within a university network. We carefully monitor our probe for any signs of blocklisting.

4 RESULTS
In our backscatter data, we observe traffic from 1655 Google, 246 Facebook, and 78 Cloudflare on-net server VIP addresses. These servers cover 8.3% (Facebook), 1.3% (Google), and 0.1% (Cloudflare) of all servers that successfully answer an HTTP3-header request, as detected by Zirngibl et al. [34]. Although we passively observe only a small share of VIPs, we later argue that this still enables representative measurements due to homogeneous server configurations, which hyperviants aim for to simplify maintenance.

4.1 QUIC Stack Configurations

QUIC versions. Just by observing background radiation it is clearly visible that client and server implementations rapidly adopt

| QUIC Version | Clients [%] | Servers [%] |
|--------------|-------------|-------------|
| QUICv1       | 0.1         | 77.7        |
| Facebook mvfst 2 | 17.5       | 21.2        |
| draft-29     | 30.2        | 0.5         |
| others       | 4.1         | 8.8         |

Table 2: QUIC versions used by clients and servers visible in telescope traffic in Apr. 2021 and Jan. 2022. We count QUIC sessions (i.e., same SCID, DCID, source and destination IP address) once, and stress larger increase. We find a rapid adoption of QUICv1 in 2022.
Figure 3: UDP packets observed since first reception of an SCID. Servers resend Initials/Handshakes if no client ACK is received within the retransmission timeout (RTO). The different timeout values can be used to derive hypergiant off-net servers.

Table 3: Passively captured types of packets with a QUIC long packet header. Only Google predominantly uses coalescing.

| QUIC packet type | Packets from source network [%] |
|------------------|---------------------------------|
| Initial          | Cloudflare Facebook Google Remaining |
| Handshake        | 56.029 47.695 23.239 46.960 |
| 0-RTT            | 40.682 52.305 23.742 43.767 |
| Retry            | 0.000 0.000 0.289 0.187   |

Coalesced packets

|          | Cloudflare Facebook Google Remaining |
|----------|-------------------------------------|
| Initial & Handshake | 3.289 0.000 52.730 9.082 |

the most recent QUIC version (see Table 2). In contrast to active scans [24, 26, 34], backscatter traffic reveals the version a client and server agreed upon, i.e., the version that is used and not only offered. When a client suggests unsupported versions, a server answers with a version negotiation message that includes all supported versions. We only observe such a message from one server.

We sanitize the client scan traffic by removing acknowledged scanning projects [6]. This leaves us with less popular, i.e., undocumented or unknown, and malicious scanners (e.g., bots), which are upgrading rapidly as well. Acknowledged scanners utilize well-documented scanning behaviour and infrastructure. They make use of non-existing QUIC version numbers [26] to trigger version negotiation behaviour, which enables (i) enumerating QUIC servers and (ii) listing all supported QUIC versions by the server. Overall, removing these scanners prevents bias in our QUIC version analysis.

Coalescing packets and packet lengths. QUIC allows the coalescence of multiple QUIC packets into one UDP datagram. Our backscatter shows that Google and Cloudflare use packet coalescence, while Facebook does not (see Table 3). Since the minimum QUIC packet size is 1200 bytes [17], coalescence indicates advanced QUIC implementations that improve efficiency by avoiding unnecessary padding.

We present distinct patterns for each hypergiant regarding the distribution of packet lengths because of coalesced packets and various padding behaviors in Appendix E.

Resending behavior. Figure 3 depicts the time gap between the first Initial and subsequent Initial and Handshake messages of the same connections, resent by QUIC servers replying to spoofed traffic. Peaks indicate common configurations of when and how often these messages were sent again. All deployments use exponential backoffs but exhibit different configurations that decide when to switch to such backoff. For Google and Facebook, the initial resend timeouts are 0.3s and 0.4s, respectively. Furthermore, the maximum number of resents differs (see Figure 4), showing that servers require different amounts of resources to keep connection states.

Overall, we detect shorter resend timeouts and fewer resents for Google and Cloudflare compared to Facebook. These results indicate that Google and Cloudflare react faster to packet loss and potentially expect shorter delays between clients and servers than Facebook. Google and Cloudflare also reserve less resources to repair faulty connections. This leads to less vulnerability to QUIC INITIAL flood attacks, which build states. Also, for future measurements, this means that Facebook servers will create more backscatter per connection, which has to be considered to prevent wrong conclusions.

4.2 What do we learn from SCIDs?

SCIDs can only leak data if hypergiants indeed use them to encode information. Such encodings distort the uniform distribution of specific values in the SCID. Figure 5 visualizes the frequencies of SCID nybble values at a given position (index), as monitored in the backscatter traffic. Frequencies that diverge from the expected value \( \frac{1}{32} = 0.063 \) (light-yellow and -green) show SCIDs encoding specific information. We observe that SCIDs received from Google are nearly randomly distributed. Facebook and Cloudflare (not shown) repeatedly use reoccurring values at specific positions within the SCID. This indicates that some hypergiants indeed encode information in SCIDs.

Cloudflare SCIDs. Cloudflare is using connection IDs with a length of 20 bytes and the first byte is always set to 0x01. Despite the
Table 4: SCID lengths visible in backscatter traffic from various ASes. Cloudflares 20 bytes SCID is a prominent feature.

| Origin AS | SCID length [Bytes] | Unique SCIDs [#] |
|-----------|---------------------|------------------|
| Cloudflare| 20                  | 170              |
| Facebook  | 8                   | 63615            |
| Google    | 8                   | 111825           |
| Remaining | 8 (4, 12, 14, 20)   | 29294 (162)      |

low number of SCIDs we receive from Cloudflare AS (see Table 4), we argue that these results are not biased. Our large-scale active measurement data set confirms their preference for this fixed first byte and, in a prior post [18], Cloudflare acknowledged the benefits of encoding information in QUIC IDs. It is unlikely that Cloudflare applies the IETF draft for Generating Routable QUIC Connection IDs [9], though, as the first byte would indicate a connection ID length of 1 or include random bits.

**Facebook SCIDs.** The Facebook QUIC implementation allows encoding details about hosts, workers, and processes within an SCID (details see Appendix B). Given higher densities for some values in the first three bytes we conclude that Facebook currently uses the host and worker IDs. Our data also reveals that Facebook uses SCID version 1, confirmed by active scans, leading to a max of 65,536 host IDs. Active probing of known on-net servers shows the use of 37,684 host IDs. Backscatter alone already revealed 7,122 host IDs (19%).

**Google SCIDs.** Google uses random SCIDs, clearly visible in the frequency pattern. When probing Google servers with randomly chosen DCIDs, we find that Google servers echo the first 8 bytes of the client chosen DCID in the SCID. This means that our backscatter exposes what clients send to Google, and clients should send random connection IDs (§ 2).

**Passively detecting off-net servers using SCIDs.** We now detect off-net servers based on QUIC protocol properties. We analyze all QUIC servers emitting backscatter that are deployed in non-hypergiant ASes. Our feature vectors consist of SCID structure, packet inter arrival times, etc. and combinations of them (for all features, see Appendix C). We use these feature vectors to identify off-net candidates and verify them by searching for names associated with the respective hypergiant. To this end, we actively (i) connect to candidates to inspect TLS certificates and (ii) check DNS PTR records.

First, we use the SCID information only. For Cloudflare, we find three candidates but none of them allow for QUIC connections for further verification. For Google, we are not able to detect any off-net candidates. For Facebook, we identify 308 candidates which reply to connection requests, i.e., allow for verification. We find that 303 servers indeed belong to Facebook (TPR 1.0, FPR 0.019).

Second, we improve the SCID-based detection. We find that Facebook off-net servers use low numbers for host IDs, confirmed by active probing of 45k Facebook off-net VIPs. Consequently, we use the first 9 bits of the host ID for detection. Using this new predictor, we detect 303 off-net deployments but reduce the false positive rate substantially (TPR 1.0, FPR 0.02), details see Appendix C.

Figure 5: Rel. frequency of values used in SCIDs from Google (random) and Facebook (structured). The non-uniform distribution indicates information encoding by Facebook.

4.3 Load Balancer Infrastructure

Using active scans towards hypergiant, we now gain a deeper understanding of their QUIC deployments and validate our passive measurements. By handcrafting QUIC handshakes based on the properties we observed passively, we now check (i) how many Facebook VIPs are required to observe all L7LBs and (ii) whether load balancers use the QUIC CID to relay packets.

A single VIP is enough to observe all L7LB hosts of a Facebook frontend cluster. To infer how much backscatter has to be received to enable significant analysis, we focus on Facebook since only Facebook confirms that they encode L7LB host IDs in their SCIDs. To this end, we scan all VIP addresses within Facebook AS 32934. For each VIP, we complete 20k handshakes while successively decreasing the client port. The number of unique host IDs converges quickly: On average, we detect 85% of all IDs after 1k handshakes per VIP. Our observation is limited to Facebook on-net deployments, since host IDs are unique per cluster. In contrast, we find host IDs being reused in off-net deployments.

We then identify clusters of VIPs that share at least one host ID by computing the Jaccard index on host IDs between VIPs. We find the minimum at 0.996, i.e., VIPs either share all host IDs or none. In total, we detect 112 clusters with 22 VIPs each, and three clusters with 21, 20 and 44 VIPs, respectively. We conclude that it is sufficient to probe or observe backscatter from one VIP to determine the number of all L7LBs of a specific cluster.

**Facebook on-net clusters are large in Asia.** We geolocate [22] on-net clusters to derive where Facebook deploys more or larger clusters. We find no correlation between the number of clusters per continent (≈30 clusters in Asia, Europe and North America) and the number of L7LBs per cluster (see Figure 6). The median number of L7LBs per cluster, however, is significantly higher in Asia (453 vs. 339.5 in EU and 292 in North America). We conjecture three reasons for this: (i) the number of available peering points is per se limited, (ii) political instabilities in specific regions and regulations limit additional data centers, and (iii) high population and hence user density per region. All three reasons may lead Facebook to not increase the number of PoPs but to provide more L7LB instances per PoP. Our results shed first light on these Asia-specific cluster characteristics.

**Inferring same server instances.** To validate whether different host IDs are assigned to individual L7LBs, we detect recurring
We measure the distribution of delays until a successful follow-up handshake. We utilize that packets that are matched to an existing connection instance track QUIC connection states per host and worker, and that different host IDs lead to individual L7LBs (i.e., no timeouts).

**CID-aware load balancers only at Google.** Using our method to infer server instances, we also infer load balancer types. We measure the distribution of delays until a successful follow-up handshake. We actively scan 9815 Google and 714 Facebook VIP addresses. Despite a different 5-tuple, the Google handshakes fail for about 240 seconds. This means that we reach the same server instance behind a load balancer, which is a strong indication of CID-aware load balancing. For Facebook, we can immediately complete follow-up handshakes, which indicates a common 5-tuple load balancing. We confirm this observation by inspecting the server-suggested CIDs, which encode a new host and worker ID. Overall, Google does not encode information in their CIDs but uses CID-aware load balancing. The results for Facebook reveal the opposite with information encoded in CIDs but no CID-aware load balancing. This is surprising because Facebook’s load balancer *katran* [11] has first code fragments for CID-aware routing already implemented.

**5 DISCUSSION, CONCLUSION, OUTLOOK**

In this paper, we showed how meta-information encoded in the QUIC header can be utilized to analyze deployment scenarios of hypergiants. Although QUIC was designed to hide meta-information, we find that efficient load-balancing or client migration requires additional information encoding. This information leaks details about the serving infrastructure, i.e., hypergiants, but not clients.

Our method successfully reveals deployed configurations of local QUIC stacks and larger distribution infrastructures—passive, in a non-intrusive way—but still face some open challenges.

**Can we expect more QUIC backscatter in the future?** By comparing results of active QUIC and TLS/TCP scans, we find that hypergiants still operate more TLS/TCP servers (Cloudflare 3×, Facebook 2×, and Google 10×) [34]. For these three HGs, the number of active QUIC servers increased by ≥10% in the first third of 2022. Furthermore, based on our telescope data, we find that the amount of backscatter traffic increased by 440% from 2021 to 2022. Both observations suggest more backscatter traffic in the future.

**Why do we need active measurements at all?** Even though we observe QUIC backscatter traffic with a relatively large network telescope, the amount of QUIC traffic is lower compared to other ecosystems because QUIC deployment is still emerging. This prevents us from deriving strong conclusions for some deployment cases now, but this might change in the future. Active measurements help us to verify our passive observations and to increase our sample set where data is not significant. Given that QUIC deployments (and backscatter) are increasing, we expect that even more parts of our analysis can soon be based on passive measurements alone.

**Will deployment of structured connection IDs increase?** Structured CIDs may serve as a fingerprint of specific hypergiants, but Google currently does not use them. We argue that their usage will increase over time since they simplify fine-grained provider controlled routing. Advanced QUIC features such as client migration even require additional data encoded in such IDs to enable efficient load balancing. For this purpose, the IETF designs routable CIDs [9], which might facilitate more deployment in the future.

**Is passive data biased?** Network telescopes capture scans and responses to spoofed traffic. This does not necessarily provide insights into Web clients but our proposed view complements active scans of QUIC servers in two directions. First, it exposes QUIC clients that are used for benign or malicious scans. Second, instead of measuring QUIC features current server deployments may provide, we measure what clients and servers agree on when they communicate. Given that spoofed traffic is primarily triggered by malicious activities (e.g., botnets), our data provides indirectly insights into software deployed in such environments.

Our telescope does not receive traffic from all PoPs and VIPs but we were able to show that a single VIP is enough to unveil a substantial part of L7LBs for a given PoP. Given that homogenous configurations across PoPs are common because they ease maintenance, we argue that not observing all PoPs is not a short-coming. We currently do not capture significant backscatter of other hypergiants such as Fastly. Based on our complementary active measurements and discussions with the operator community, we are confident, though, that the insights resulting from the captured traffic are valid. Understanding the reasons for not seeing backscatter from all QUIC-enabled hypergiants (e.g., less attacks or filtering) will be part of our future work.
Table 5: Facebook SCID structure includes clear text host IDs and reduces randomness to less than half of the SCID length.

| SCID Version | Version | Host ID | Worker ID | Process ID | Remaining random bits |
|--------------|---------|---------|-----------|------------|----------------------|
| 1            | 0-1     | 2-17    | 18-25     | 26         | 27-63                |
| 2            | 0-1     | 8-31    | 32-39     | 40         | 2-7,41-63            |

Table 6: Performance of classifying off-net Facebook servers based on backscatter traffic. IP addresses were assigned to content providers using subject alt names in certificates collected with QScanner.

| Classifier                          | TPR     | FPR     | TNR     | FNR     | Precision | Recall   |
|-------------------------------------|---------|---------|---------|---------|-----------|----------|
| Inter arrival time                  | 0.772277| 0.268191| 0.731809| 0.227723| 0.644628  | 0.772277 |
| SCID & Inter arrival time           | 0.772277| 0.045738| 0.954262| 0.005738| 0.914062  | 0.772277 |
| SCID & coalescence & Inter arrival time | 0.772277| 0.045738| 0.954262| 0.005738| 0.914062  | 0.772277 |
| QUIC packet length                  | 0.96700 | 0.328482| 0.671518| 0.000000| 0.656522  | 0.996700 |
| SCID & coalescence & QUIC packet length | 0.96700 | 0.145530| 0.854470| 0.000000| 0.811828  | 0.996700 |
| Coalescence                         | 1.00000 | 0.931393| 0.068607| 0.000000| 0.403462  | 1.00000 |
| SCID                                | 1.00000 | 0.193347| 0.806653| 0.000000| 0.765152  | 1.00000 |
| SCID & coalescence                  | 1.00000 | 0.178794| 0.821206| 0.000000| 0.778920  | 1.00000 |
| SCID off-net (low host ID)          | 1.00000 | 0.027027| 0.972973| 0.000000| 0.958861  | 1.00000 |

fbcdn.net, whatsapp.com. Table 6 presents true positive rate, false positive rate etc. of identifying Facebook off-net servers.

E DETAILS ON PACKET DISTRIBUTION

Figure 7 shows typical QUIC packet lengths and combinations (packet coalescence). Google and Facebook packet length features contribute the majority of the remaining traffic.

D METHOD TO DETECT LAYER 7 LOAD BALANCERS

To validate whether different host IDs are assigned to individual L7LBs, we conduct the following measurement: (i) We complete a QUIC connection handshake towards a VIP address. (ii) After a successful handshake, we keep the connection open but idle. (iii) Each second, we try to establish a follow-up QUIC connection towards the same VIP address, i.e., we send INITIALs with a different 5-tuple by changing the client port, and also change to a new client CID C2 but keep using the same server CID S1. (iv) Reaching the same server instance leads to a timeout of the follow-up handshake. A new server instance, however, will complete the handshake.

This method should not be used in the presence of IP anycast. In case of Facebook, our proposed method works, though, since Facebook utilizes a single /24 prefix per PoP, which means that we always reach the same PoP while scanning a specific destination VIP.

Our method differs from prior work [30] since it exploits well-defined behavior codified in the RFC. Furthermore, we are able to distinguish between 5-tuple load balancers and CID-aware load balancers.

Figure 7: Top-7 QUIC packet lengths observed by Content provider excluding GQUIC packets. A comma-separated value means the packets were found in one UDP packet. Traffic originating from the remaining ASes share observed packet sizes for Facebook and Google.