A Primer in Registration Data Access Protocol (RDAP) Performance

ICANN Office of the Chief Technology Officer

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This revision contains updates to reflect changes in the landscape of Registration Data Access Protocol (RDAP) deployment as of January 2022. The new measurements include the RDAP service deployed by the Latin America and Caribbean Network Information Centre and more than 90 new RDAP services deployed by ICANN-accredited registrars and top-level domain (TLD) registries in 2021. Previous measurement results for 2020 can be found in OCTO-024v1. ICANN appreciates the suggestions made by the community on OCTO-024v1.

This document supports ICANN's strategic goal to improve the shared responsibility for upholding the security and stability of the Domain Name System (DNS) by strengthening DNS coordination in partnership with relevant stakeholders. It is part of ICANN's strategic objective to strengthen the security of the DNS and the DNS root server system.

Executive Summary

The Domain Name System is essential to the overall functioning of the Internet. With millions of new domain names registered every year, it is important to have a mechanism that enables timely access to accurate details describing who has registered each domain. WHOIS has been the main communication protocol to query registration data for more than 35 years; however, it presents several limitations such as the lack of standardized query and response formats and the inability to authenticate users.

To overcome these limitations, in 2015, the Internet Engineering Task Force proposed a new protocol for standardizing registration data access while supporting Internationalized Domain Names and registration data, client authorization, and other features. Known as the Registration Data Access Protocol (RDAP), this new protocol enables access to registration data for current domain names, Internet Protocol addresses, and autonomous system numbers. This study investigates the performance of the RDAP services that have been deployed, as it is an ICANN requirement that generic top-level domain (gTLD) registries and ICANN-accredited registrars must implement an RDAP service by the end of August 2019.

As part of this study, from 10 December 2021 to 10 January 2022, over 7 million RDAP domain queries were executed from 10 different vantage points against RDAP services operated by four of the five regional Internet registries (RIRs), all gTLD registries, the ccTLD registries that have deployed RDAP, and all ICANN-accredited registrars. The measurements show that the average query response time was around 1 second; however, there are significant differences in response times depending on the RDAP operator. It was observed that, on average, the RIRs provided the fastest RDAP service, followed by gTLD registries, the ccTLDs, and the ICANN-accredited registrars. These results are in line with a previous measurement study conducted in 2020.

After performing exploratory statistical analysis of the RDAP query response time, several factors that impacted the response time were identified:

- **Query origin:** The source location of the query had a significant impact on the query response time. Queries originating from Europe and North America received, on average, faster responses than those from Asia or Africa.
- **Source IP address type:** Queries executed over IPv6 had, on average, shorter response times than those executed over IPv4.
- **Secure channel:** As RDAP leverages a secure communication protocol that provides encryption, it introduces additional overheads compared with WHOIS. It was observed that the time required to create a secure channel with the RDAP server accounted, on average, for 40 percent of the total response time.

Despite RDAP responses varying from a few hundred to hundreds of thousands of bytes, RDAP response size did not have a statistically significant impact on the response time.

1 Introduction

Internet identifiers — namely Internet Protocol (IP) addresses and domain names — are essential for the functioning of nearly all Internet protocols, e.g., routing protocols such as the Border Gateway Protocol or application layer protocols such as the Hypertext Transfer Protocol (HTTP). These identifiers are managed by a group of interdependent organizations that assign and allocate identifiers from the five Regional Internet Registries (RIRs), which manage Internet number identifiers for the thousands of domain name registries and registrars. The registries and registrars, in turn, manage the registration of Internet domain names.

To be able to identify who is responsible for a given identifier at any point in time, in the early 1980s, the WHOIS protocol was specified to provide access to registration information. Even though the original design of WHOIS presented several limitations, such as the lack of a standardized response format and an inability to authenticate users, it became the main mechanism for external parties to obtain registration data about Internet identifiers. This registration information is useful not only for network administrators to fix system problems, but also to combat threats such as spam or fraud. Thus, timely and accurate registration data is important and provides useful information for mitigating potential threats.

In 2015, the Internet Engineering Task Force proposed a new protocol to standardize registration data access while supporting Internationalized Domain Names (IDNs) and client authorization. It was envisioned that it would replace the WHOIS protocol. Known as the Registration Data Access Protocol (RDAP), this new protocol enables access to registration data for current domain names, Internet Protocol (IP) addresses, and autonomous system numbers (ASNs). By the end of August 2019, generic top-level domain (gTLD) registries and ICANN-accredited registrars were required by ICANN to implement RDAP.

Previous research by Interisle and by Viagenie examined whether RDAP service operators comply with ICANN's policies and deployment issues. The authors of this report are unaware of any prior study that examined how much time it takes to get a registration record via RDAP.

This study aims to assess the performance of RDAP services that have been deployed in response to the ICANN requirement that gTLD registries and registrars must implement an RDAP service by 26 August 2019. The study focuses on three different types of operators involved in the deployment of RDAP services: top-level domain (TLD) registries, ICANN-accredited domain name registrars, and the RIRs for comparison purposes only.

RDAP performance is measured in terms of response time and validity of the responses for the RDAP services provided by each of the operators. Response time is a critical metric as it determines the amount of time that any client must wait to obtain the response. The response time of RDAP is expected to be longer than the WHOIS protocol due primarily to the overhead introduced by a Transport Layer Security (TLS) handshake. The study uses remote active measurements to estimate the response time for accessing registration data of currently deployed RDAP services and identifies potential bottlenecks.

The rest of this report is structured as follows. Section 2 presents the methodology to measure the efficiency of RDAP. Section 3 describes the current deployment status of RDAP for each provider. Section 4 defines the metric used to measure the efficiency of each RDAP service. Section 5 presents the aggregated results, followed by Sections 6, 7, and 8, which present the results for RIRs, TLD registries, and ICANN-accredited registrars, respectively. Section 9 compares WHOIS and RDAP response times. Section 10 states the limitations of this study, and Section 11 gives conclusions from the study.

2 Methodology

A measurement infrastructure was deployed to estimate different metrics related to the performance of RDAP services. All measurements were conducted remotely by an RDAP client simply executing test RDAP queries against the RDAP servers. Because the probes were external to the RDAP server, metrics related to the internal usage of resources such as CPU or memory usage were not quantified. The method is quite simple and consists of two steps: (1) creating a random sample of queries and (2) executing the queries while recording the response and response time.

2.1 Creating a Sample of Queries

To test the response time of each RDAP service, it is necessary to create a sample list of queries. Some RDAP services allow queries for different types of resources: mainly IP addresses, ASNs, or domains. This study focused on domain queries as this is the object type that is common to all RDAP services, including those provided by RIRs, registries, and registrars. Moreover, RDAP queries querying for IP addresses and ASNs were also executed against RIRs' RDAP services. To capture potential differences among the responses of the same RDAP service, 100 different queries were created for each service. This threshold was chosen heuristically to make the measurement process viable in the client machines with limited resources.

Three different processes are followed to create RDAP queries depending on the type of RDAP operator: RIRs, TLD registries, and ICANN-accredited registrars.

2.1.1 RDAP Queries for TLD Registries

To create this sample list of domains, the following steps were followed:

1. Obtained a list of TLDs for which the Internet Assigned Numbers Authority (IANA) has an RDAP base URL listed in the bootstrap service.
2. For each TLD:
    a. If the zone file was available, e.g., via the Centralized Zone Data System, the authors obtained a random set of 100 domains. If the zones did not contain 100 domains, then the authors oversampled the domains.
    b. If the zone file was not available, the authors obtained a random set of 100 unique domains by extracting second-level domains from the results of a web search (e.g., Google query: " * site: 'TLD' "). If the results of the search did not contain 100 different domains, then additional domains were retrieved for TRANCO's list and oversampled without replacement until reaching 100 domains.
3. Created domain queries by appending the sample set of domains to each RDAP URL as stated in RFC 7482.

2.1.2 RDAP Queries for RIRs

Three different types of queries were created for RIRs, namely domain queries, IPv4 address queries, and autonomous system queries.

To create domain queries, the following steps were taken:

1. Obtained the list of regional RIR RDAP servers from IANA's bootstrap list.
2. For each RIR RDAP server, a set of 100 domains was created using the in-addr.arpa public zone files, as the RIR RDAP servers only provide registration data for the in-addr.arpa domains that are delegated.
3. Created domain queries by appending the sample set of domains to each RDAP URL from step 1 following RFC 7482.

To create queries for ASNs, the following steps were taken:

1. Obtained the assigned ASN for each RIR from IANA's ASN list.
2. For each RIR RDAP server, a set of 100 ASNs were selected from the list.
3. Created ASN queries by appending the sample set of ASNs to each RDAP URL from step 1, following RFC 7482.

Similarly, to create queries for IPv4 addresses, the following steps were taken:

1. Obtained the assignment of IPv4 prefixes for each RIR from IANA's IPv4 Address Space Registry.
2. For each RIR RDAP server, a set of 100 IPv4 addresses were selected within the set of allocated IPv4 prefixes.
3. Created IPv4 queries by appending the sample set of IPv4 addresses to each RDAP URL from step 1, following RFC 7482.

2.1.3 RDAP Queries for ICANN-accredited Registrars

To create queries for ICANN-accredited registrars, the following steps were followed:

1. Obtained the list of base URLs for the RDAP servers operated by registrars from IANA's bootstrap list.
2. For each domain in the .com zone file, obtained the corresponding registrar via the WHOIS protocol.
3. Obtained a sample of 100 domains for each registrar that had an RDAP server mapped in step 1 by using the registrar information of step 2.
    a. If there were not 100 .com domains, then the authors oversampled the domains.
    b. If there were no .com domains for a particular registrar, then the authors used the Spamhaus pDNS API to retrieve domains for that registrar by appending its name to the URL https://api.spamhaus.net/dbl/v1.2/registrar/.
4. Created domain queries by appending the sample set of domains to each RDAP URL from step 1, following RFC 7482.

2.2 Running the Queries

To measure the response time of the different RDAP services, 10 different virtual machines (VMs) acted as vantage points to conduct the measurements. Each virtual machine was located in a different autonomous system spread across six different continents to account for potential measurement biases due to routing. Figure 2.1 shows the location of these VMs. Table 2.1 specifies the network prefixes of these VMs along with the city and country where they were located.

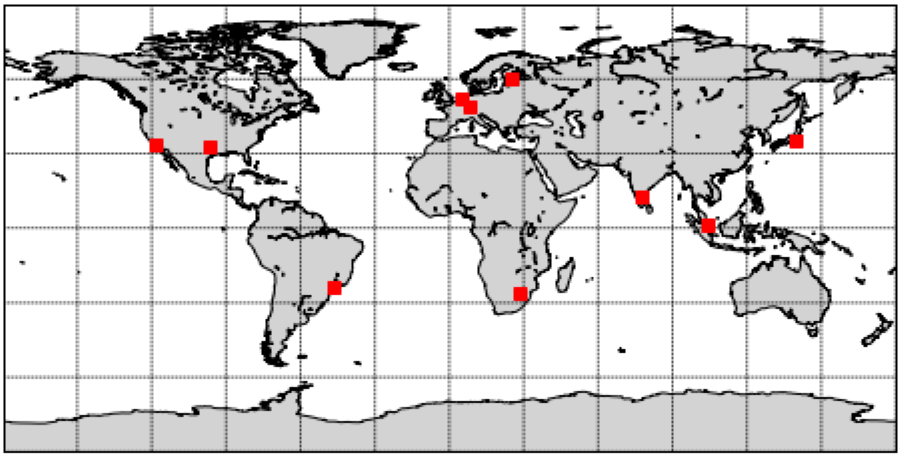

Figure 2.1. Location of the measurement VMs (red dots)

Prefix	ISO 3166 Country Alpha-2 Code	City or State
104.156.236.0/23	US	Texas
145.220.0.0/16	NL	Utrecht
208.77.188.0/22	US	California
35.247.192.0/18	BR	São Paulo
172.104.160.0/19	SG	Singapore
13.244.0.0/15	ZA	Cape Town
218.227.0.0/16	JP	Tokyo
51.210.0.0/16	FR	Paris
135.181.0.0/16	FI	Helsinki
206.189.128.0/20	IN	Bengaluru

Table 2.1. Prefix and location of the VMs

The queries ran periodically, e.g., every 10 minutes, and were executed at the same time from the different vantage points. However, each RDAP service was only queried once every 10 minutes by each vantage point. This is necessary to distinguish the RDAP services that share the same infrastructure. The RDAP services were grouped based on the IP address and the origin ASN of their domains.

Next, the RDAP queries were executed as follows:

1. Every 10 minutes, one random query for each of the RDAP services was selected.
2. The queries were executed and the response times were recorded.

The measurements were aimed at quantifying a response time. The response time is one of the most important metrics to track the performance of a REST API, because it captures the quality of service as experienced by the users. For the purposes of this study, response time is defined as the time elapsed from when an RDAP query is executed to when the response is received minus the time taken to resolve the domain name.

3 RDAP Services

During this investigation, the RDAP services provided by RIRs, TLD registries, and ICANN-accredited registrars were examined. The first but essential step before measuring the performance of these services is to identify where they are running. IANA provides the lists of the base URLs of these services as part of the RDAP bootstrap service.

In registries that operate multiple TLDs, some TLDs share the same RDAP URL. Thus, the number of URLs below does not equal the total number of TLDs in the DNS.

3.1 RIRs' RDAP Services

The base URLs of the RIRs' services are maintained by IANA and are published here. Each individual URL corresponds to one of five RIRs.

3.2 TLD Registries' RDAP Services

A total of 774 RDAP base URLs are specified by IANA in the TLD bootstrap service as of December 2021. However, these RDAP base URLs are not unique; thus, it is reasonable to assume that the same server provides the RDAP service for multiple TLDs. RDAP URLs whose domain names resolve to IP addresses belonging to the same ASN are grouped together. This is to avoid them from being queried more than once from the same vantage point during a measuring period. In total, 41 different ASNs were identified; 28 of these services provide registration data for more than one TLD.

3.3 ICANN-Accredited Registrars' RDAP Services

A similar process was followed to obtain a list of base URLs for the RDAP services provided by ICANN-accredited registrars. A total of 375 unique RDAP base URLs for registrars were specified by IANA's bootstrap list as of December 2020. Nevertheless, not all these URLs were run by independent service providers. Hence, the RDAP services are aggregated by ASN as in the case of gTLDs. In total, 182 different ASNs were identified.

4 The Performance Metric

The response time metric is defined based on the timing information provided by the curl tool: the time from the start of the request until the last byte is received minus the time to resolve the RDAP service domain name.

This time is computed by adding up the following times:

- **Connect time:** the time it took from the start of the connection until the connection to the remote host (or proxy) was established.
- **Appconnect time:** the time it took from the point at which a connection was established to when a TLS handshake with the remote host was completed.
- **Pretransfer time:** the time it took from the completion of a TLS handshake to the start of a registration data transfer.
- **Redirect time:** the time it took for all redirection steps to occur until the start of the final transfer.
- **Start-transfer time:** the time it took to complete the pretransfer to the point at which the first byte is received.
- **Transfer time:** the time it took from when the first byte is received until the last byte is received.

Note that some services redirect the queries to other URLs. In this case, the response time metric will also account for these redirections by calculating the total time from query to response, including any redirection.

5 Aggregated Results

After measuring the RDAP response time over four weeks from 10 December 2021 to 10 January 2022, a total of 4,102,096 valid measurements were collected. Around 1.13 percent of the measurements were discarded due to errors in the response.

5.1 Response Time

It was observed that, on average, RIRs provided the fastest RDAP service, followed by TLD registries and ICANN-accredited registrars. Of all queries, 95 percent were answered in less than 4 seconds. Table 5.1 shows the presence of outliers in the measurements. In the case of the RDAP response times provided by registrars, the standard deviation was 120 percent higher than the mean value. Looking at the maximum values, it is also worth noting that some queries took more than 10 minutes to get a response. These were extreme outliers as shown by the 99th percentile.

Response Time (sec.)

	Mean	Std. Dev.	Min.	50%	95%	99%	Max.
RIR	0.57	2.05	0.00	0.31	1.60	2.72	132.49
TLD	0.77	3.58	0.03	0.66	1.59	2.54	587.59
Registrar	1.11	2.44	0.01	0.74	3.17	6.66	806.00

Table 5.1. Summary of RDAP response times by operator type

Compared with the previous measurement carried out in 2020 (see OCTO-024v1), the average time of the RDAP services decreased in 2021. The same pattern seen in 2020 was also present in 2021: RIRs offered the fastest RDAP service, followed by TLD registries and ICANN-accredited registrars (see Table 9.1). It is worth noting, however, that the maximum response time increased.

This can also be observed in the cumulative distribution function shown in Figure 5.1. Here, the outliers in the case of the TLD registries and registrars are evidenced by the long tail of the distributions. For example, the average response time of registrars was more than 8 seconds.

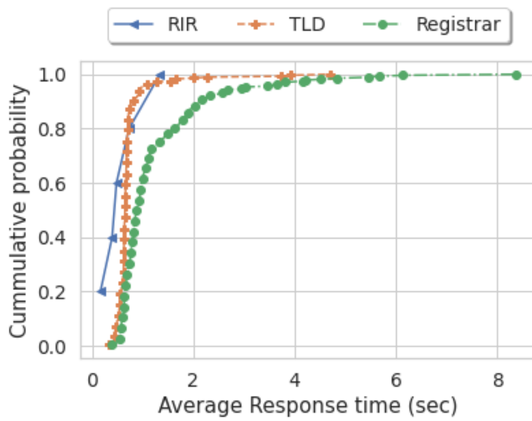

Figure 5.1. Cumulative distribution function of the average response time per RDAP operator

5.2 Breakdown of HTTPS Transaction Timings

All the queries in this study were performed using the Hypertext Transfer Protocol Secure (HTTPS); thus, the total response time was also affected by the TLS handshake. To understand the extent to which the HTTPS affects RDAP performance, the total response time is broken down into the five metrics explained in Section 4.

Table 5.2 shows the mean value of the different timings. Between 180 and 310 milliseconds were spent on average per RDAP query on the TLS handshake, and between 226 and 651 milliseconds were spent on transferring the response data.

Time (sec.)

	Connect Time	Appconnect Time	Pretransfer Time	Start-Transfer Time	Transfer Time	Redirect Time
RIR	0.11	0.18	0.00	0.22	0.06	0.05
TLD	0.14	0.30	0.00	0.27	0.05	0.02
Registrar	0.16	0.31	0.00	0.65	0.01	0.01

Table 5.2. Breakdown of the different average HTTP transaction times

As can be seen in Figure 5.2, on average, the TLS handshake took between 20 and 40 percent of the total response time. Most of the time (around 60 percent) was spent in starting the connection. Transferring the RDAP responses only accounted for less than 40 percent of the total response times, on average. However, these proportions differed between RDAP operators. For instance, queries against RIRs' RDAP services spent more time transferring the response than connecting to the server, which was partly due to the considerably large size of the RDAP responses provided by some RIRs.

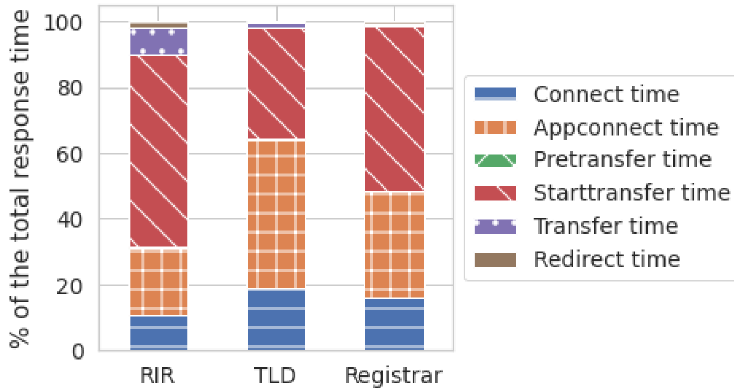

Figure 5.2. Breakdown of RDAP response times

5.3 Response Time by Vantage Point

The response time per query was also measured for each of the 10 vantage points deployed in locations across the globe. Significant differences were observed depending on the location from which the queries were run. Table 5.3 shows the main descriptive statistics for the response time by vantage point location. The response time measurements were significantly higher from the vantage points located in India, Japan, Singapore, South Africa, and Brazil.

Response Time (sec.)

Location	Mean	Std. Dev.	Min	50%	95%	99%	Max.
BR	1.26	2.51	0.01	0.92	2.72	6.63	288.47
FI	0.86	3.12	0.03	0.48	2.40	6.46	485.35
FR	0.81	2.63	0.02	0.41	2.36	6.60	450.95
IN	1.24	3.39	0.03	0.91	2.88	6.09	534.33
JP	1.25	1.96	0.05	1.07	2.62	5.88	239.68
NL	0.83	2.42	0.00	0.44	2.40	6.50	357.47
ZA	1.26	2.31	0.01	0.93	2.80	7.05	322.18
SG	1.19	3.25	0.02	0.85	2.75	6.22	549.93
US1	0.94	2.03	0.02	0.64	2.18	5.90	806.00
US2	0.88	2.80	0.02	0.56	2.28	6.06	550.40

Table 5.3. Response time by the location of the vantage point

The response time measurements suffered from a significant presence of outliers. This is represented by a high standard deviation and maximum values that in some cases were 20 times larger than the 99th percentile.

Figure 5.3 shows the box plots of response time distribution for each vantage point depending on the city where it is located. In that figure, outliers were removed, and the triangles show the average response time. Again, the vantage points in South Africa registered not only the highest average latency, but also the largest latency variance.

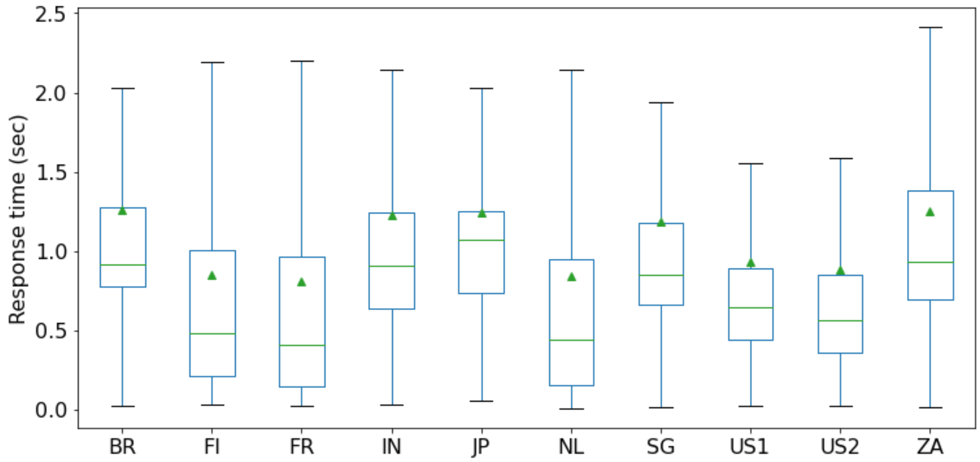

Figure 5.3. Response time by vantage point location

5.4 RDAP Response Size

Next, the response size in bytes for each RDAP query was calculated. The average response size of all the performed queries was around 5.2 kilobytes, with a standard deviation of 3.1 kilobytes. This evinces a great diversity of response sizes across the different RDAP services that were queried. Table 5.4 breaks down the response size statistics for RIRs, TLD registries, and ICANN-accredited registrars. As can be seen, registrars' RDAP services provided the shortest responses on average. Note that the extremely large response size was due to a repeated field in the RDAP response vCard.

Response Size (bytes)

	Mean	Std. Dev.	Min.	50%	95%	Max.
RIR	8,852	6,344	1,124	8,575	21,450	26,919
TLD	7,706	2,992	829	8,814	11,894	13,678
Registrar	4,406	2,541	285	4,067	9,524	14,385

Table 5.4. Summary of RDAP response sizes

Finally, a potential relationship between the response time and size was investigated. Figure 5.4 plots these variables against each one of the performed queries. A Pearson product-moment correlation coefficient was computed to assess the relationship between the response size and response time. No strong correlation was found (Pearson r≈0, p-value≈0).

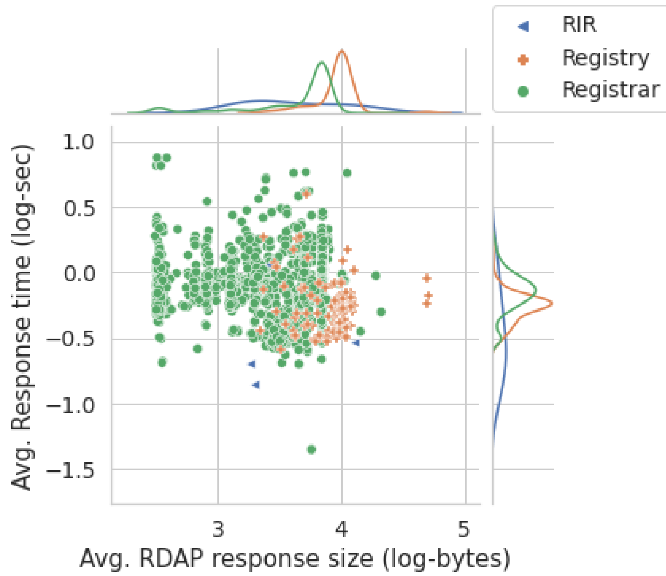

Figure 5.4. Response times versus RDAP response sizes per operator type

5.5 Response Time Versus the Source IP Address Type

A subset of the vantage points allowed the performance of RDAP queries using IPv6 addresses. From these, the same queries were performed using both IPv4 and IPv6 addresses. As can be seen in Figure 5.5, the average response time for queries over IPv4 was 1.06 seconds, while the same queries executed over IPv6 were responded to slightly faster, with an average response time of 0.87 seconds. Moreover, IPv4 queries suffered from more variance (with a standard deviation of 2.60 seconds) than IPv6 queries (with a standard deviation of 1.74 seconds). In this figure, outliers were removed.

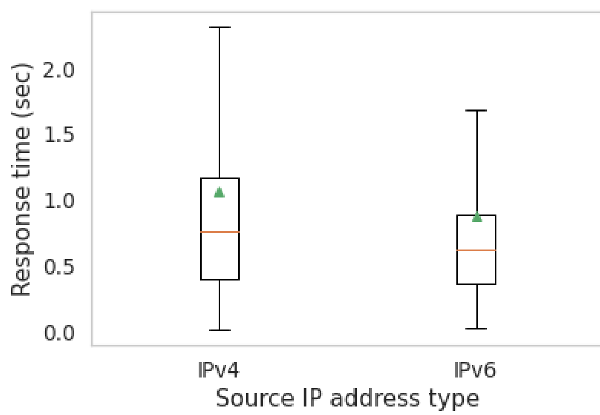

Figure 5.5. Response times by IP source address type

5.6 Response Time Versus the TLS Version

RDAP services use the TLS protocol to secure the communication between the client and the server. There are four main versions of this protocol, namely TLS1.0, TLS1.1, TLS1.2, and TLS1.3; though the first two have been deprecated by most browsers (along with the older secure sockets layer (SSL)). The TLS version is critical to the functioning of the RDAP service not only from a security perspective but also for performance. TLS1.3 improves both the latency and security level of the web service and thus is recommended.

For all the RDAP services, the supported TLS versions were measured. Figure 5.6 shows the percentage of RDAP services according to the TLS versions that are supported. The majority of RDAP services supported TLS1.2 and around 15 percent supported TLS1.3. It is also worth noting that a significant portion of the RDAP services supported SSL/TLS1.0/TLS1.1, which could lead to downgrade attacks. In particular, three RDAP services only supported TLS1.0 and SSL. Most of the RDAP services allowing deprecated TLS and SSL were operated by a registrar, and only one registry (operating four TLDs) allowed for the use of SSL. Note that only the last three columns show no support for deprecated versions.

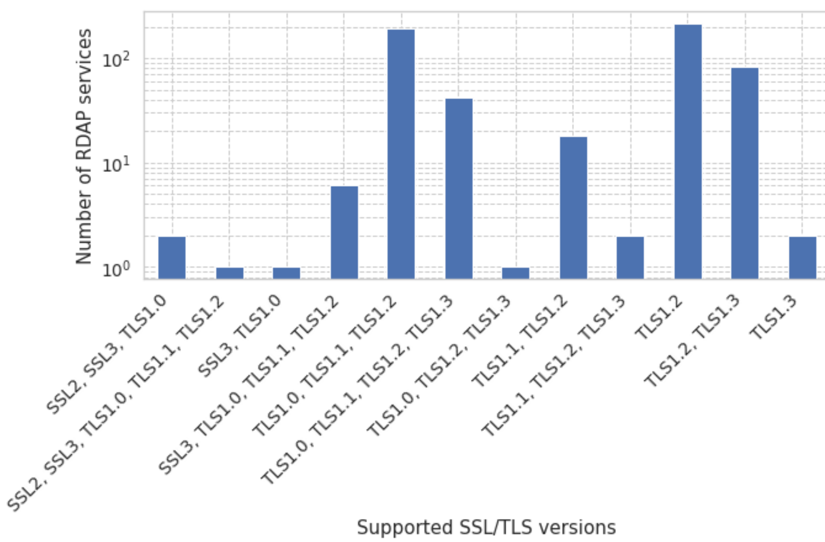

Figure 5.6. The number of RDAP services by the SSL/TLS versions used

Besides the nine RDAP services supporting deprecated TLS versions, most of the RDAP services did not comply with industry best security practices. For instance, public key infrastructure certificates had longer lifetimes and smaller Diffie-Hellman key sizes than recommended and supported weak ciphers. In fact, when benchmarked against Mozilla's "intermediate" SSL configuration (see https://ssl-config.mozilla.org/ for more details), only 1 percent of the RDAP services was compliant.

Finally, the response time of each RDAP query was compared depending on what TLS version was used. As expected, TLS1.3 provided the lowest latency and hence the fastest RDAP response. No significant differences were observed in the response time of those queries executed over TLS1.0 or TLS1.2.

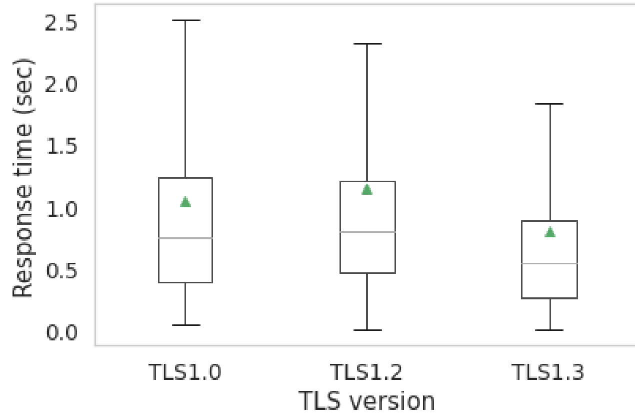

Figure 5.7. RDAP response time by TLS version

6 RIRs' RDAP Response Time

Table 6.1 shows the main descriptive statistics of the response time for the RIRs' RDAP service. The Latin America and Caribbean Network Information Centre's (LACNIC) RDAP service had the slowest response time on average, and the Asia Pacific Network Information Centre's (APNIC's) RDAP service is the fastest. It is also worth noting that there were some outliers in the measurements. For instance, some queries took more than 5 minutes to return the corresponding RDAP response. Again, these were extreme outliers, as 99 percent of all queries finished in less than 4 seconds.

	Response Time (sec.)						
RIR	**Mean**	**Std. Dev.**	**Min.**	**50%**	**95%**	**99%**	**Max.**
AFRINIC	0.74	3.39	0.03	0.59	1.46	1.75	132.49
APNIC	0.18	0.67	0.02	0.14	0.35	0.78	49.31
ARIN	0.47	0.63	0.03	0.26	1.46	2.75	24.03
LACNIC	1.34	0.66	0.04	1.20	2.54	2.89	203.00
RIPE NCC	0.39	0.39	0.00	0.28	1.05	1.73	40.10

Table 6.1. RDAP response times by RIR

Figure 6.1 shows the box plot (with outliers removed) for these same measurements to better illustrate the differences in the response time distribution among the RIRs. The RDAP service provided by LACNIC had the largest response time variance. APNIC research shows the smallest variance, which can probably be attributed to its RDAP infrastructure being deployed in the cloud.

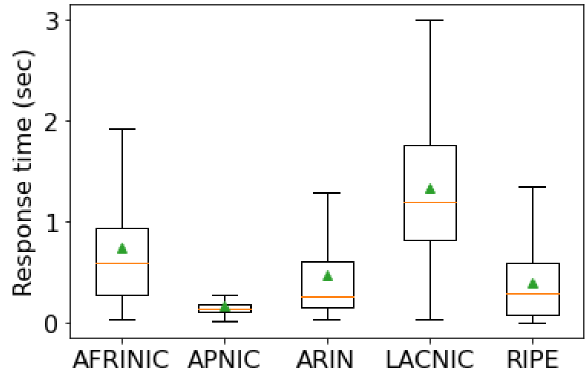

Figure 6.1. Box plots of response times by RIR

6.1 Response Time Versus Location

The response time per query was also measured for each of the 10 vantage points. Table 6.2 shows the summary statistics of these. Significant differences can be seen when comparing the response time for the different vantage points. For instance, the response time of the queries from the vantage points located in Japan and India were on average two times slower than the ones from France.

	Response Time (sec.)						
Location	**Mean**	**Std Dev.**	**Min.**	**50%**	**95%**	**99%**	**Max.**
BR	0.69	5.59	0.04	0.36	1.39	1.77	132.49
FI	0.43	0.71	0.03	0.22	1.52	2.19	49.31
FR	0.38	0.42	0.02	0.20	1.36	2.09	2.99
IN	0.76	0.62	0.06	0.57	2.11	2.78	7.20
JP	0.85	1.71	0.10	0.68	2.34	2.73	76.65
NL	0.67	0.75	0.00	0.41	2.60	2.86	16.15
ZA	0.55	0.58	0.03	0.29	1.81	2.49	2.99
SG	0.51	0.67	0.02	0.36	1.12	2.08	24.03
US1	0.65	0.67	0.05	0.56	1.53	2.33	28.03
US2	0.33	0.41	0.03	0.15	1.12	1.85	6.28

Table 6.2. RIRs' RDAP response times by the location of the vantage point

Figure 6.2 shows the box plots for the response time of each RIR depending on the regions (AF = Africa; AP = Asia, Australia, Pacific; EUR = Europe; LAC = Latin America and Caribbean; NA = North America). Just by comparing the size of the different boxes, a clear pattern can be observed independently of the RDAP operator: Queries executed from the same region as the RDAP operator were responded to faster on average than queries executed from a different region.

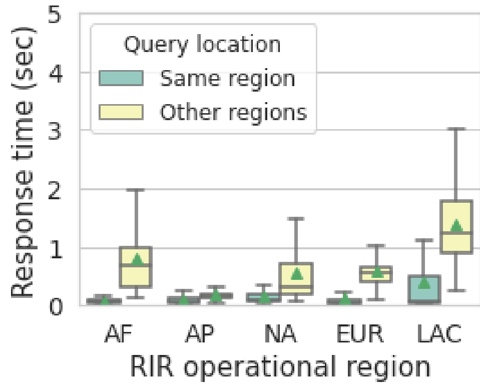

Figure 6.2. Response time distribution by the location of the query source and the operational region of the RDAP service operator

6.2 Response Time Versus the Source IP Address Type

A subset of the vantage points was allowed to perform RDAP queries using IPv6 source addresses. From these, the same IP queries were performed using IPv4 and IPv6 source addresses. As can be seen in Figure 6.3, no significant differences were found between the queries that used IPv4 and IPv6. The average response time for both was around 0.6 seconds. However, IPv4 queries suffered from more variance (with a standard deviation of 2.50 seconds) than IPv6 queries (standard deviation of 0.64 seconds).

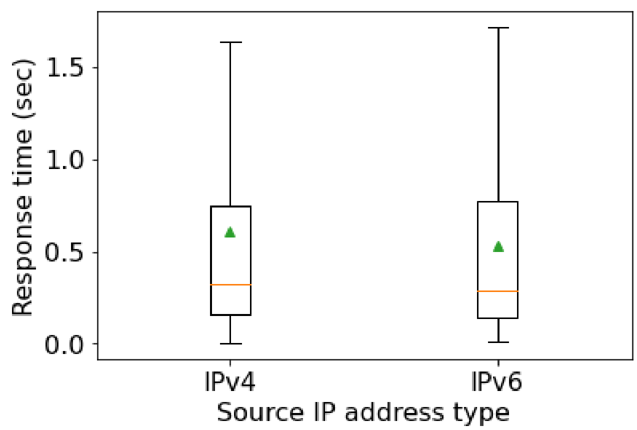

Figure 6.3. Response time by IP source address type

6.3 Response Time Versus the Response Size

Finally, the impact of the RDAP response size on the response time was investigated. While the format of the RDAP response is standardized, the amount of information varies per RIR. Figure 6.4 shows the response size distribution per RIR. As expected, there were differences in terms of response size. The American Registry for Internet Numbers' (ARIN's) RDAP responses were

8.85 kilobytes on average, while those of the Réseaux IP Européens Network Coordination Centre (RIPE NCC) and APNIC were less than 3 kilobytes on average.

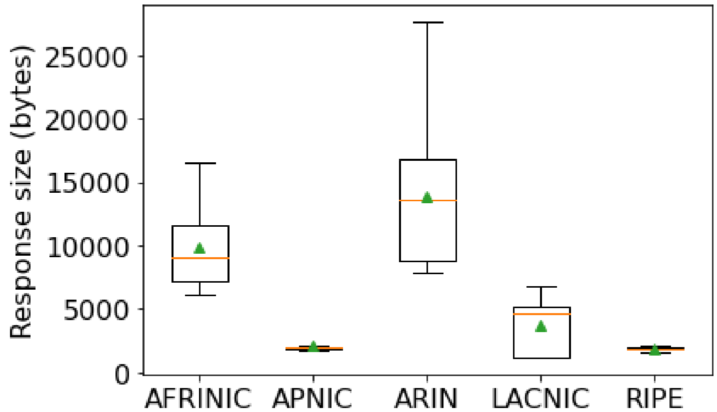

Figure 6.4. RDAP response sizes by RIR

While the responses from ARIN's RDAP service were larger on average, the average response time was still faster than the African Network Information Centre's (AFRINIC's) RDAP service. Figure 6.5. shows the response time versus the response size for all the RDAP queries executed against the RIRs' RDAP services. The Pearson product-moment correlation coefficient was computed to assess the relationship between the response size and response time. A weak positive correlation was found (Pearson r≈0.27, p-value≈0), which indicates that some larger responses took longer to be received.

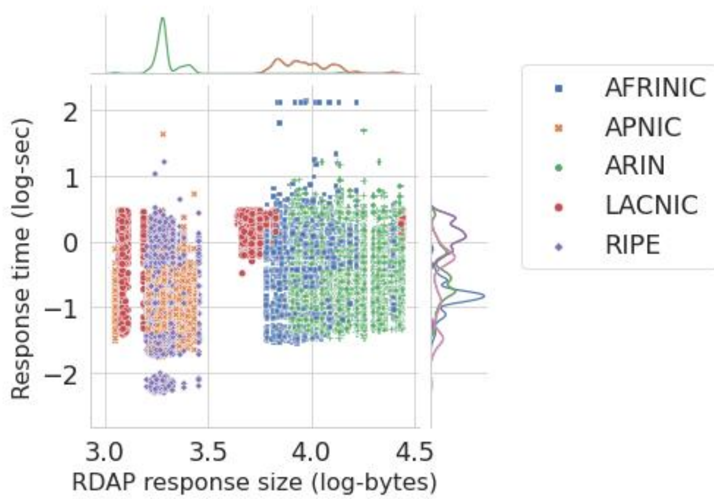

Figure 6.5. RDAP response size versus response time

6.4 Response Time Versus the Queried Object

RDAP allows for querying not only domain names but also other objects. To quantify whether the response time depends on the type of object that is queried, three different types of objects were used to retrieve registration information: IP addresses, autonomous system numbers, and domain names.

Figure 6.6 plots the distribution of the response time for these three different types. No significant differences were observed, with the average response time staying below 1 second independently of the type of object that was queried. However, RDAP queries for information regarding IP addresses suffered from outliers more frequently, which led to a slight increase in the median response time.

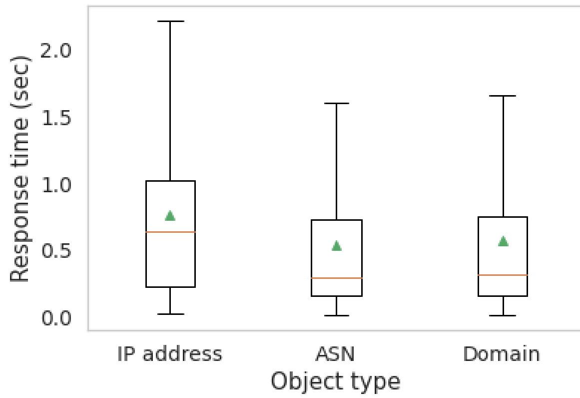

Figure 6.6. Response time by the type of queried object

7 TLD Registries' RDAP Response Time

Next, the response time for the RDAP services provided by various categorizations of TLD operators was analyzed. It is worth noting some relevant differences between the different servers. In particular, the response time was higher for RDAP servers providing ccTLD registration data than servers providing gTLD registration data. TLD registries were classified according to the type of TLD as stated in IANA's root zone database. As can be seen from Table 7.1, the average response time for ccTLDs was almost 0.95 seconds, while for gTLDs the average response time was 0.70 seconds.

Response Time (sec.)

Type	Mean	Std. Dev.	Min.	50%	95%	99%	Max.
ccTLD	0.95	3.67	0.05	0.78	1.98	2.59	357.47
gTLD	0.70	3.12	0.03	0.64	1.42	2.20	550.40

Table 7.1. RDAP response time by TLD type

From the box plots in Figure 7.1, it is clear that RDAP servers handling ccTLD registration data were generally slightly slower than those servers providing gTLD data. (Outliers have been removed from the box plots.)

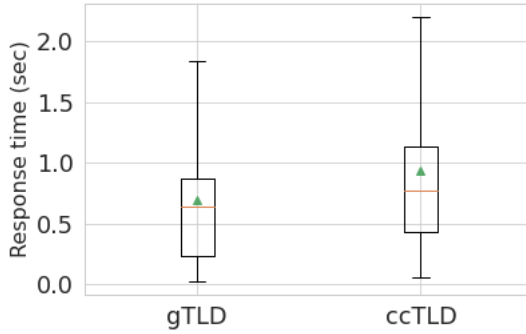

Figure 7.1. Response time distribution for RDAP servers by TLD type

7.1 Response Time Versus the Vantage Point

The analysis of the influence of vantage point on the response time for the TLDs' RDAP services showed similar patterns as the RIRs' RDAP services. The queries that ran from the vantage points in Brazil, South Africa, and India experienced the slowest RDAP response times (see Table 7.2).

Response Time (sec.)

location	Mean	Std. Dev.	Min.	50%	95%	99%	Max.
BR	1.02	2.01	0.03	0.91	1.85	2.64	288.47
FI	0.63	4.68	0.05	0.24	1.47	2.05	470.94
FR	0.49	2.60	0.03	0.18	1.27	1.98	288.90
IN	1.02	5.25	0.19	0.72	1.91	2.98	534.33
JP	1.07	1.67	0.05	1.07	1.52	2.52	239.68
NL	0.47	2.20	0.03	0.18	1.26	2.18	357.47
ZA	0.98	2.28	0.22	0.78	1.66	2.46	314.05
SG	1.02	5.16	0.07	0.81	1.79	2.81	549.93
US1	0.77	4.55	0.04	0.65	1.49	2.03	587.59
US2	0.71	4.41	0.05	0.56	1.44	1.97	550.40

Table 7.2. TLDs' RDAP response time depending on the location of the vantage point

7.2 Response Time Versus the Source IP Address Type

As mentioned before, a subset of the vantage points allowed us to perform RDAP queries using IPv6 source addresses. From these, the same queries were performed using IPv4 and IPv6 source addresses. As can be seen in Figure 7.3, no significant differences were found between the queries that used IPv4 compared with IPv6. Nevertheless, the response time for IPv4 queries was slower on average than queries effectuated over IPv6. Again, IPv4 queries suffered from more variance in the response time (with a standard deviation of 2.40 seconds) than IPv6 queries (with a standard deviation of 1.58 seconds).

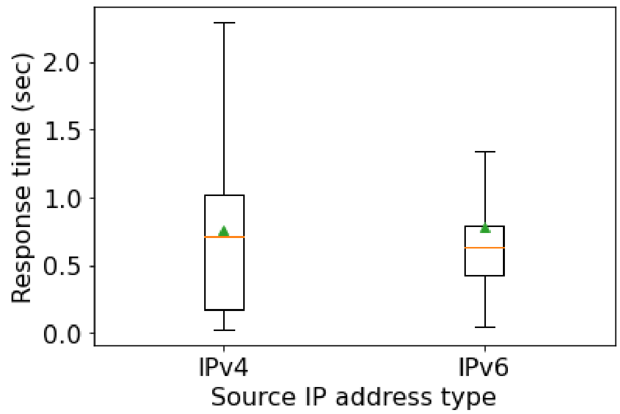

Figure 7.3. Response time by IP source address type

7.3 Response Time Versus the Response Size

Figure 7.4 shows that, in terms of response size, gTLDs' RDAP responses were slightly larger in terms of content size (~3.89 kilobytes) than those provided by ccTLDs' RDAP services (~3.63 kilobytes). Again, there was a huge variance among the different gTLDs.

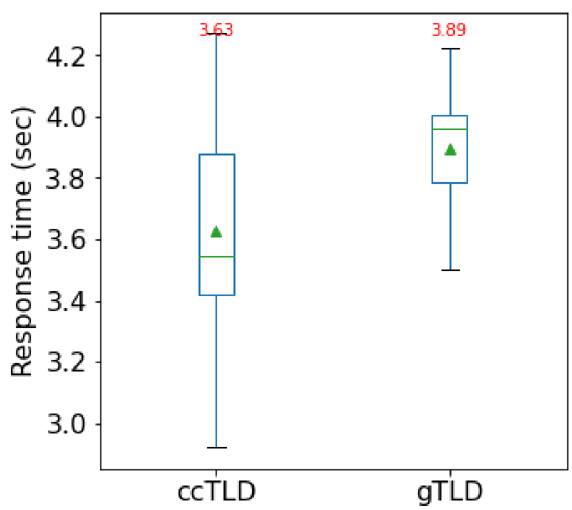

Figure 7.4. RDAP response sizes by TLD type

To further investigate why some ccTLDs have higher latency than the gTLDs, the response size in bytes for an RDAP query was computed. Figure 7.5 shows these metrics against each other for each TLD type. The Pearson correlation coefficient (Pearson r=0.01, p-value=0.0) shows that there is no evidence that these delays in the RDAP responses are due to higher response sizes.

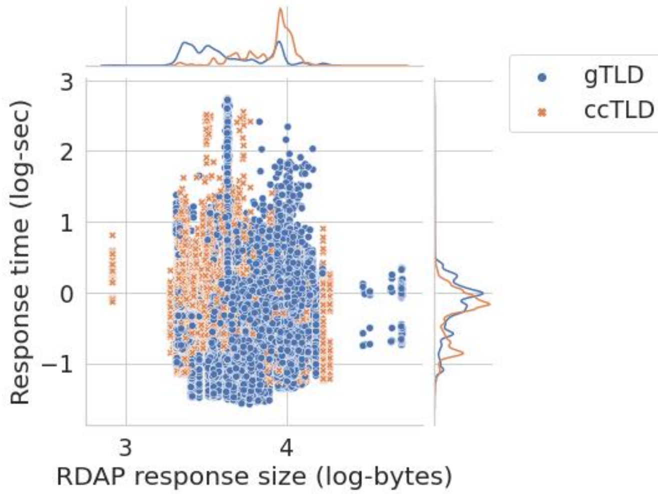

Figure 7.5. RDAP response size versus the response time

8 ICANN-Accredited Registrars' RDAP Response Time

While more than 2,400 ICANN-accredited registrars provide RDAP services, only a total of 2,066 were probed. As described in the methodology section, these were registrars whose RDAP Base URL was present in IANA's bootstrap service and for which sample domains could be extracted from the .com zone file or from Spamhaus' passive DNS tool. Thus, registrars that had no domain in the .com zone file as of December 2021 were not included in the measurement.

The response times for the different registrars that belong to a particular family are grouped. A "registrar family" is a group of registrars that are under a common ownership or have a parent or subsidiary relationship. Table 8.1 shows the statistics of the RDAP response time for the different registrar types. Registrars with family groups exhibit larger variance, while the median response times are very similar.

Response Time (sec.)

Registrar Type	Mean	Std. Dev.	Min.	50%	95%	99%	Max.
Family	1.16	3.39	0.02	0.78	2.76	7.52	806.00
Individual	1.09	2.34	0.01	0.74	3.31	6.66	768.72

Table 8.1. RDAP response time based on whether a registrar belongs to a family of registrars

To further visualize the differences in response times among registrars' RDAP services, the top 50 registrars with the slowest response times were selected. Figure 8.1 shows the distribution of the response times for these registrars (with outliers removed). As can be seen, the variance differs significantly among the different services.

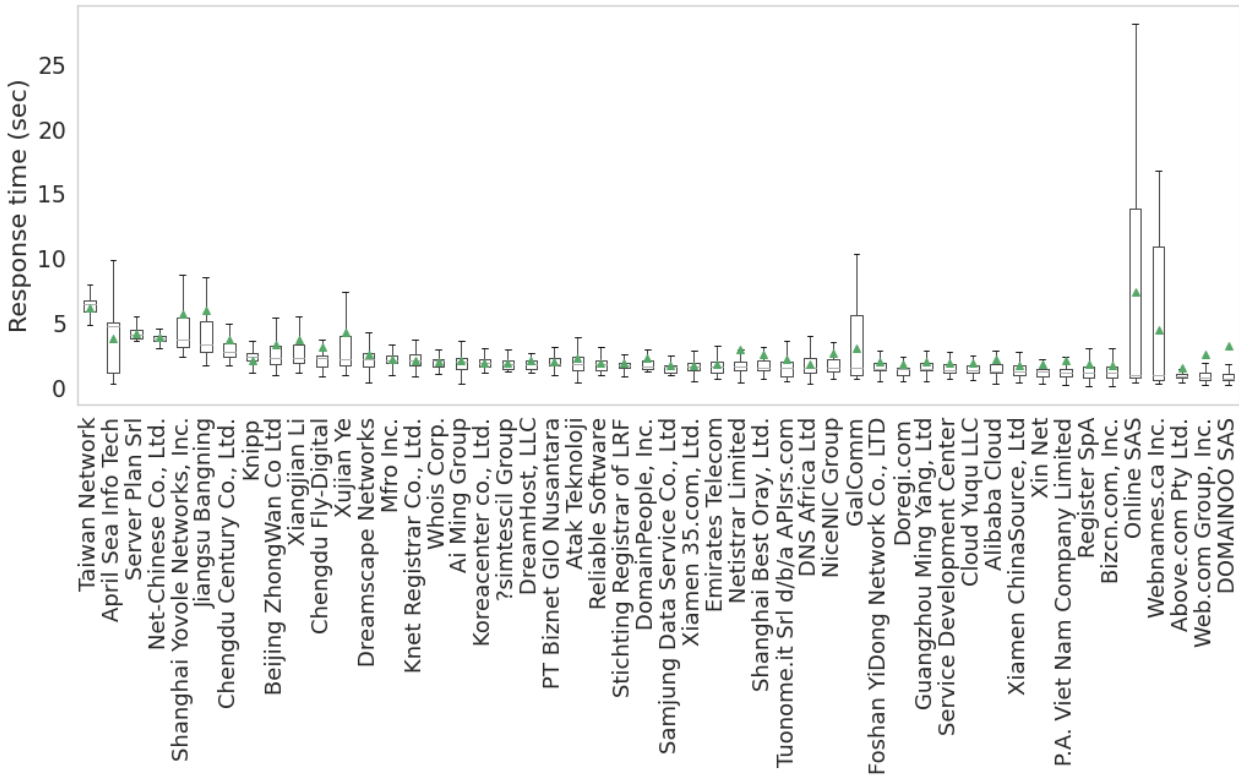

Figure 8.1. Query response time distribution for the top 50 slowest registrar RDAP services

8.1 Response Time Versus the Vantage Point

As in the previous cases, a vantage point from which the RDAP queries were executed affected a response time. Table 8.2 shows the summary statistics of the responses time per vantage point.

	Response Time (sec.)						
Location	**Mean**	**Std. Dev.**	**Min.**	**50%**	**95%**	**99%**	**Max.**
BR	1.37	2.28	0.01	0.98	3.38	6.73	246.15
FI	0.96	2.56	0.04	0.54	2.69	6.70	485.35
FR	0.93	2.73	0.02	0.46	3.11	6.68	450.95
IN	1.34	2.66	0.03	0.97	3.67	6.33	374.05
JP	1.35	2.06	0.05	1.07	3.38	6.62	98.77
NL	0.96	2.54	0.02	0.48	3.04	6.67	269.43
SA	1.39	2.39	0.01	0.99	3.42	7.13	322.18
SG	1.28	2.35	0.02	0.92	3.33	7.11	363.42
US1	1.00	4.00	0.02	0.64	2.66	5.95	806.00
US2	0.97	2.15	0.02	0.58	2.88	6.12	241.30

Table 8.2. Registrars' RDAP response times depending on the location of the vantage point

8.2 Response Time Versus the Source IP Address Type

As can be seen in Figure 8.3, no significant differences were found between the queries that used IPv4 source addresses and those that used IPv6 source addresses. Nevertheless, the response time for IPv4 queries was 10 milliseconds slower on average than queries executed over IPv6. Again, IPv4 queries suffer from more variance in the response time (with a standard deviation of 2.89 seconds) than IPv6 queries (with a standard deviation of 1.80 seconds).

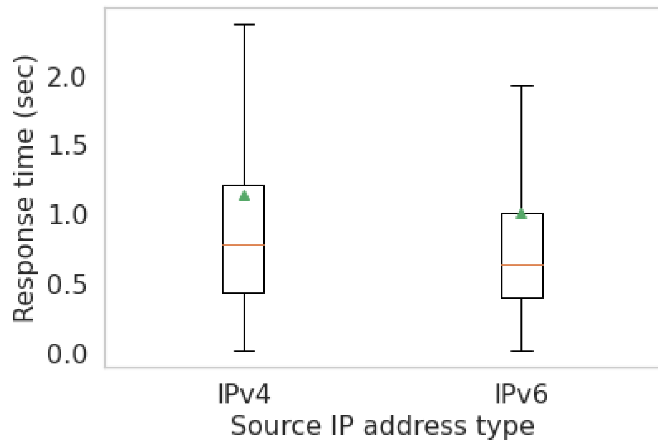

Figure 8.3. Response times by IP source address type

8.3 Response Time Versus the Response Size

In terms of response size, the average RDAP response size of the queried registrars was around 4.5 kilobytes. Again, there was a significant variance in response sizes among the different registrars (with a standard deviation of 2.3 kilobytes). The fact that some registrars belong to a family did not make any difference in terms of the response size.

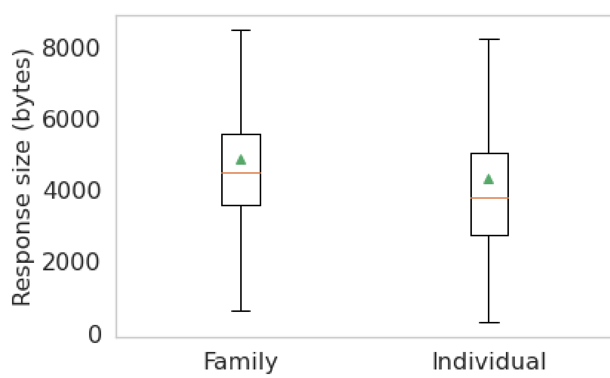

Figure 8.4. Response sizes of registrar family and individual registrars

Finally, the relationship between response size and response time was investigated. Figure 8.5 shows these metrics against each other for each query and against a registrar's RDAP service. The Pearson correlation coefficient (Pearson r=0.015, p-value=0.0) shows that there is no relationship between response time and response size.

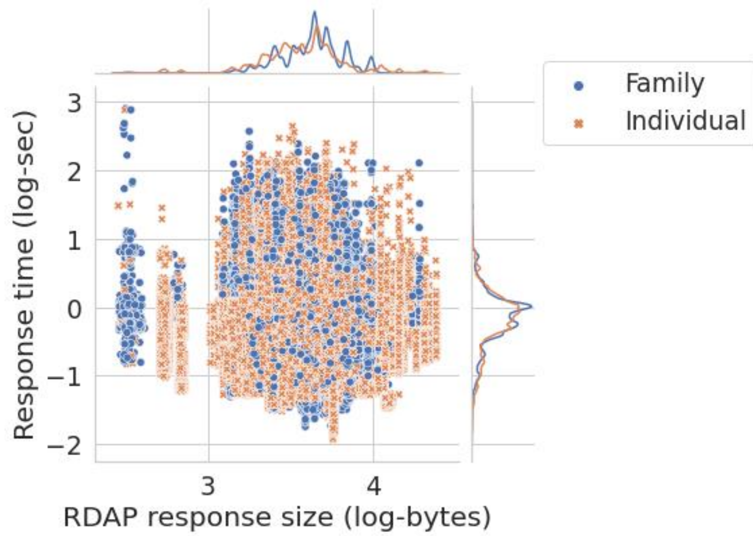

Figure 8.5. RDAP response size versus the response time

9 WHOIS Versus RDAP Response Time

For the RDAP services described in Section 2, WHOIS queries were executed over port 43 using the same 10 vantage points in parallel to the RDAP queries. The response time of these queries is shown in Table 9.1.

	Response Time (sec.)					
	Mean	**Std. Dev.**	**50%**	**95%**	**99%**	**Max.**
RDAP	1.31	2.76	0.90	2.56	6.26	640.16
WHOIS	1.17	5.53	0.29	2.01	39.01	879.94

Table 9.1. Response times of RDAP versus WHOIS queries

Table 9.1 shows the main statistics of the response time for both WHOIS and RDAP queries. There were two main takeaways: (1) WHOIS and RDAP response times were not significantly different on average (mean) while they are different in their median values; (2) WHOIS response times had larger variance with more outliers than RDAP queries which explains the difference in median response times. Figure 9.1 shows the distribution of the response times for all the queries performed with RDAP and for the same type of query performed via WHOIS. As can be seen, 50 percent of the WHOIS queries were answered within the first 300 milliseconds, while only 15 percent of the total number of RDAP queries were responded to within the same time frame.

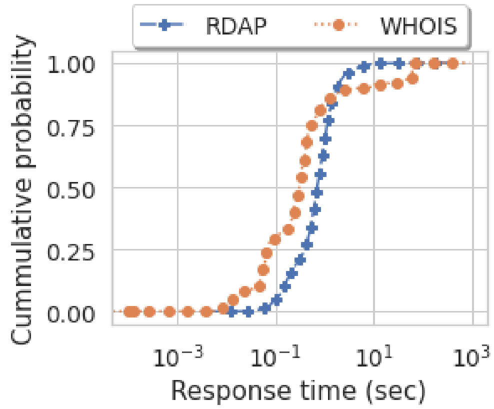

Figure 9.1. Response time for WHOIS versus RDAP queries

10 Limitations

- As with any active measurement study, this investigation suffers from the potential biases that a limited set of vantage points might create. While 10 different vantage points distributed across multiple autonomous systems were used, it is unknown whether queries run from different autonomous systems could experience different response times.
- The study was purposefully designed to not stress the RDAP services. With a rate of one RDAP query every 5 minutes, the measurement should not have saturated any of the RDAP services. It remains unknown how the services would respond under heavier query loads. It is also possible that some services were under heavy use by other parties at the time our queries were made.
- For a minority of RDAP services, it was not possible to find a sample set of domains.
- Not all the vantage points allowed running queries over IPv6. The variance in response time might be impacted by the number of queries over IPv6.
- The validity of the RDAP responses was only assessed against the first level of conformance ("rdapConformance": ["rdap_level_0"]) and the presence of no errors.

11 Conclusions

The current deployment of RDAP services is diverse and, while 95 percent of all performed domain queries were answered under 4 seconds, some queries can take up to several minutes to be answered. Registrars' RDAP services are currently the slowest on average, while RIRs' RDAP services are the fastest.

Several factors influenced the response time. The source location of the query had a significant impact on the response time. Queries originating from Europe and North America received faster responses than those from Asia or Africa. Queries executed over IPv6 had lower response times than those over IPv4. The response size did not seem to have a significant impact on the response time. RDAP queries leveraging TLS1.3 had the lowest latency and hence the quickest RDAP response. There were no notable differences in response times between queries conducted over TLS1.0 and TLS1.2.

When comparing RDAP to WHOIS, the measurements showed that the median RDAP response time is three times longer with RDAP than with WHOIS. This can be partly attributed to the use of HTTPS, because on average 40 percent of the RDAP response time is spent on establishing a secure connection.