Vantage Point Selection for IPv6 Measurements: Benefits and Limitations of RIPE Atlas Tags

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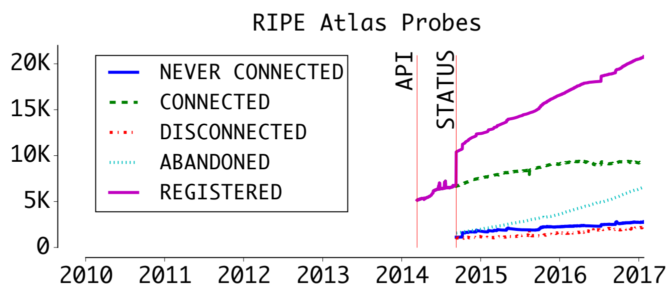
***Abstract*—RIPE Atlas consists of ~9.1K probes (as of Jan 2017) connected in core, access and home networks. RIPE Atlas has recently (Jul 2014) introduced a tagging mechanism for fine-grained vantage point selection of probes. These tags are subdivided into user and system tags. User tags are based on a manual process which is largely dependent on proactive participation of probe hosts. We show that only ~2.8% of probe hosts ever update their user tags which may lead to user tags that tend to become stale over time. System tags on the other hand being automatically assigned and frequently updated (every 4 hours) are stable and accurate. We show an application of system tags by performing a vantage point selection of dual-stacked probes. This exploration reveals that with ~2.3K (~26%) connected dual-stacked probes, RIPE Atlas provides the richest source of vantage points for IPv6 measurement studies. These dual-stacked probes span 88 countries and cover 822 ASNs. ~83% of these dual-stacked probes are connected within access networks with 782 probes deployed at homes with native IPv6 connectivity. These home dual-stacked probes are evenly split across DSL, cable and fibre deployments. We show that IPv6 latencies from these probes to RIPE Atlas anchors appear comparable to IPv4, although IPv4 performs marginally better. By applying a correlation against APNIC IPv6 user population estimate, we further reveal underrepresented countries (such as BE and JP) which would benefit from deployment of more probes for IPv6 measurement studies.**



NEVER CONNECTED	2795	13.44%
CONNECTED	9116	43.86%
DISCONNECTED	2265	10.90%
ABANDONED	6609	31.80%
REGISTERED	20785	100.0%

Fig. 1. *Evolution of RIPE Atlas probes by their connection status. The plot is generated using the probe archive API [1] which provides probe metadata since Mar 2014. The API was updated to also report the status information of each probe starting Sep 2014. ~9.1K probes are connected out of ~20.7K registered probes as of Jan 2017.*

I. Introduction

RIPE Atlas [2], [3] consists of ~9.1K (as of Jan 2017) hardware probes connected all around the globe as shown in Fig. 1. These probes perform active measurements (see Table I) to ascertain the network performance of the global Internet. A majority of these probes are running measurements either from the core or from within access networks. A discernible number of probes are also hosted by volunteers within their home network. RIPE Atlas provides public APIs [4], [1], [5] (starting Feb 2013) to programmatically provision measurements on these probes. However the probe selection (until recently) was limited to either geographic-based (using latitude and longitude) or network origin-based (using network prefixes) filters. In order to cope with this limitation, RIPE Atlas has introduced (starting July 2014) a tagging mechanism [6] that allows tags to be applied on individual probes. These tags are subdivided into system and user tags. The *system* tags are tags automatically applied by RIPE Atlas based on results collected from built-in (see Table I) measurements. In addition to system tags, hosts can also voluntarily tag their own probes using ***user*** tags. A capability to filter vantage point selection based on these tags was recently (starting Oct 2014) made available. The system tags being directly derived from measurements and being frequently updated (every 4 hours) are fairly stable and accurate. The accuracy of user tags on the other hand is largely dependent on the proactive participation of hosts to not only tag, but also update their tags as and when network environments around the probe change. This may therefore lead to stale user tags that do not reflect the current network situation of the probe. In this paper, we provide 4 main **contributions** –

– We show that system tags (see Section III) have improved the vantage point selection process by exhibiting

TABLE I
A LIST OF BUILT-IN MEASUREMENTS PERFORMED BY PROBES BY DEFAULT AS OF JAN 2017. (*) IN THE TARGET INDICATE MULTIPLE SERVERS WITHIN THE DOMAIN.

MEASUREMENT	TARGET
ping, ping6	first hop, second hop (derived from traceroute measurements), *.root-servers.net, *.atlas.ripe.net
traceroute, traceroute6	*.root-servers.net, *.atlas.ripe.net, topology4.dyndns.atlas.ripe.net, topology6.dyndns.atlas.ripe.net, labs.ripe.net
dns, dns6	*.root-servers.net: TCP (SOA), UDP (SOA, version.bind, hostname.bind, id.server, version.server)
sslcert, sslcert6	www.ripe.net, atlas.ripe.net
http, http6	www.ripe.net/favicon.ico, ip-echo.ripe.net

a case study on selecting ~2.3K (~26%) dual-stacked probes.

- Our region-based analysis (see Section IV) reveals that dual-stacked probes span 88 countries with ~91% of probes concentrated in the RIPE and ARIN region. A correlation against APNIC IPv6 user population estimate reveals underrepresented countries (such as BE and JP) which would benefit from deployment of more probes for IPv6 measurement studies.
- Our network-based analysis (see Section V) reveals that probes span 822 ASNs with ~83% of dual-stacked probes connected within access networks. We show that 782 dual-stacked probes are connected in home networks with an even split across DSL, cable and fibre deployments. IPv6 latencies from these probes to RIPE Atlas anchors appear comparable to IPv4, although IPv4 performs marginally better.
- Our exploration of user tags reveals that only ~2.8% of probes hosts ever update their user tags (see Section VI) which may lead to user tags that tend to become stale over time.

II. Background and Related Work

We provide a brief survey on performance measurement platforms that exist today. Archipelago (Ark) [7] is a platform developed by CAIDA that uses monitors in coordination to map the topology of the Internet. Ark started in 2007 and consists of ~170 hardware monitors as of Jan 2017. DIMES [8] (a software agent) and iPlane [9] (an overlay on top of existing infrastructures) are platforms that coexist with Ark and have a similar goal of mapping the topology of the Internet. SamKnows [3] on the other hand is a platform developed in close collaboration with ISPs and regulators with a goal to assess broadband performance of end-users. SamKnows started in 2008 and consists of ~70K hardware probes. BISmark [10] is an academic initiative by researchers at Georgia Tech. The goal is to build a platform which is similar to that of SamKnows. It started in 2010 and consists of ~420 hardware probes deployed around the globe. perfSONAR [3] is a collaborative initiative to build a performance monitoring framework that can identify and isolate problems in network paths that are used for scientific data exchange. perfSONAR is supported by ESnet, Internet2, GÉANT and RNP academic networks. Netradar [11] and Portolan [12] are emerging mobile measurement platforms. We further refer the reader to surveys [3], [13] that discuss these performance measurement platforms in greater detail.

RIPE Atlas with ~9.1K hardware probes (as of Jan 2017) is the largest open platform today. It plays a critical role in not only providing operational support to network operators but also facilitating measurement-based research. Few studies have used RIPE Atlas for measuring IPv6 networks. For instance, Emile Aben in [14] (2013) using a sample of ~1K RIPE Atlas probes show that ~10% of these probes have fragmentation problems in IPv6. Andra Lutu *et al.* [15] (2014) run `traceroute` from ~100 RIPE Atlas probes to measure reachability of IPv6 prefixes. They show that IPv6 limited visibility prefixes are generally reachable, however dark visibility prefixes are largely not. Jen Linkova in [16] use a sample of ~1K RIPE Atlas probes to show that packets with IPv6 extension headers are often dropped in the Internet. Rodérick Fanou *et al.* in [17] (2015) use RIPE Atlas probes to study the state of interdomain routing in Africa. They observed that IPv6 penetration is largely concentrated in South Africa with all measured continental IPv6 paths traversing ZA. We take this further and profile all dual-stacked RIPE Atlas probes. This helps us to not only identify the possible network−based and region−based bias that comes with using dual-stacked probes for IPv6 measurement studies but also identify underrepresented areas to help remove this bias.

III. System Tags

System tags are automated tags generated by the RIPE Atlas system. Fig. 2 shows the timeseries of top ten system tags sorted by the number of connected probes. These system tags highlight the state of DNS (such as `system-resolves-a-correctly` *et al.*) and the state of IP connectivity (such as `system-ipv6-works` *et al.*) of the vantage point and are based on insights derived from continuous built-in measurements (see Table I) performed by the probes. Fig. 3 shows the distribution of all system tags across connected probes as of Jan 2017. In order to provide increased protection against spoofing attacks, special-case tags are applied on probes (such as `system-resolver-mangles-case`) whose resolver implements case mangling of DNS requests [18]. Similarly, `system-dns-problem-suspected` is set when only IP-level connectivity (with no DNS activity) is observed while the tag `system-firewall-problem-suspected` is set

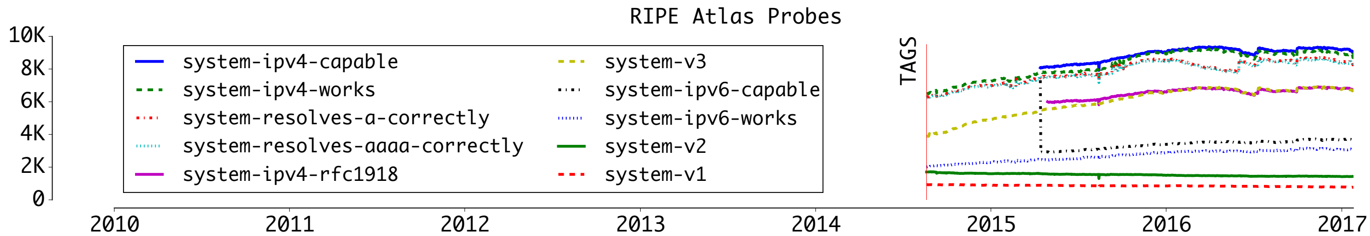


Fig. 2. *Time series of top 10 system tags sorted by the number of connected probes. Popular system tags help identify the probe hardware and highlight the state of DNS and IP connectivity of probes.*

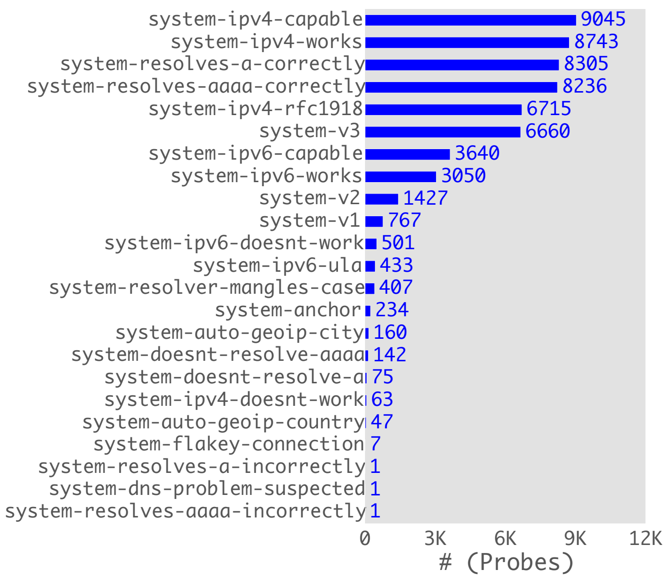


Fig. 3. *Distribution of connected probes based on system tags as of Jan 2017.*

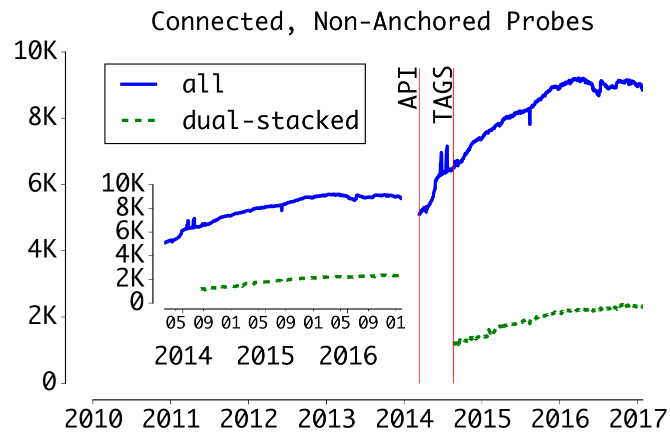


Fig. 4. *Evolution of connected dual-stacked probes. The plot is generated using the probe archive API [1] which provides probe metadata since March 2014. The API reports probe tags starting August 2014. Around 25.99% (2301 / 8855) of all connected non-anchored probes are dual-stacked as of Jan 2017.*

when only DNS activity is visible. Given RIPE Atlas consists of three versions (v1, v2, and v3) of hardware probes and anchors (which are dedicated servers that are used as sinks of measurement traffic to measure connectivity and reachability of a region), system tags (such as `system-v1` *et al.*) are also provided to allow hardware-based calibration of the probes. Using such a calibration, we were able to discover [19] (2015) that older versions of the probes experience load issues due to their hardware limitations. This observation has been further confirmed [20] (2015) to show that these delays are more pronounced in situations where older version of probes are loaded with concurrent measurements.

John P. Rula *et al.* in [21] (2015) recently performed a factor analysis of the stratified sampling process used in the SamKnows / FCC Broadband America study. They motivated towards an approach that takes network and region based diversity into account to maintain the integrity of the sampling process. In this pursuit, using tag assisted vantage point selection we explore the region– and network–based diversity of connected dual-stacked probes within the RIPE Atlas platform. Fig. 4 shows the evolution of dual-stacked probes using these system tags. We define *dual-stacked probes* as probes with the same ASN over IPv4 and IPv6. This condition allows us to filter out hosts that use a 6in4 (such as Hurricane Electric) tunnel [22] for IPv6 connectivity. This is useful to ensure only probes with native IPv4 and IPv6 connectivity are used for studies such as comparing IPv4 and IPv6 latencies to services over the Internet. We further only consider probes dual-stacked when they are tagged with `system-ipv4-works` and `system-ipv6-works` tags. The system evaluates each probe every 4 hours for all system tags by inspecting results obtained from built-in (see Table I) measurements. For instance, Stéphane Bortzmeyer in [23] (2013) has shown that using a sample of 1K RIPE Atlas probes, 10% of the probes believe to have IPv6 connectivity but fail when IPv6 measurements are provisioned on them. He went further in [24] (2014) to show that using a sample of 500 RIPE Atlas probes, only ~60% of the probes are behind resolvers that can resolve DNS names that are served by IPv6-only nameservers. These studies were one of the triggers that resulted in the introduction of `system-ipvX-works` tags. By using `*-works` instead of `*-capable`, such measurements tend to have more useful results. As such, the presence of these tags allow us to ensure selected dual-stacked probes are in fact able to reach out to services over both IPv4 and IPv6 on the Internet. As can be seen ~25.99% (2301 / 8855) of

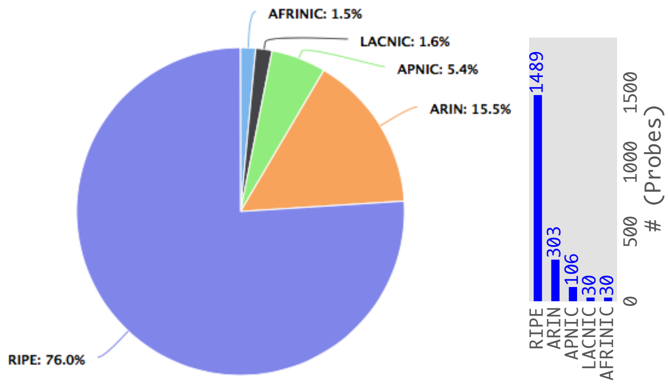


Fig. 5. *RIR-based distribution of dual-stacked probes. The plot is generated using the RIPE Atlas Probe API [4] and RIPE Data API [25]. ~91% of dual-stacked probes are connected within the RIPE and ARIN region.*

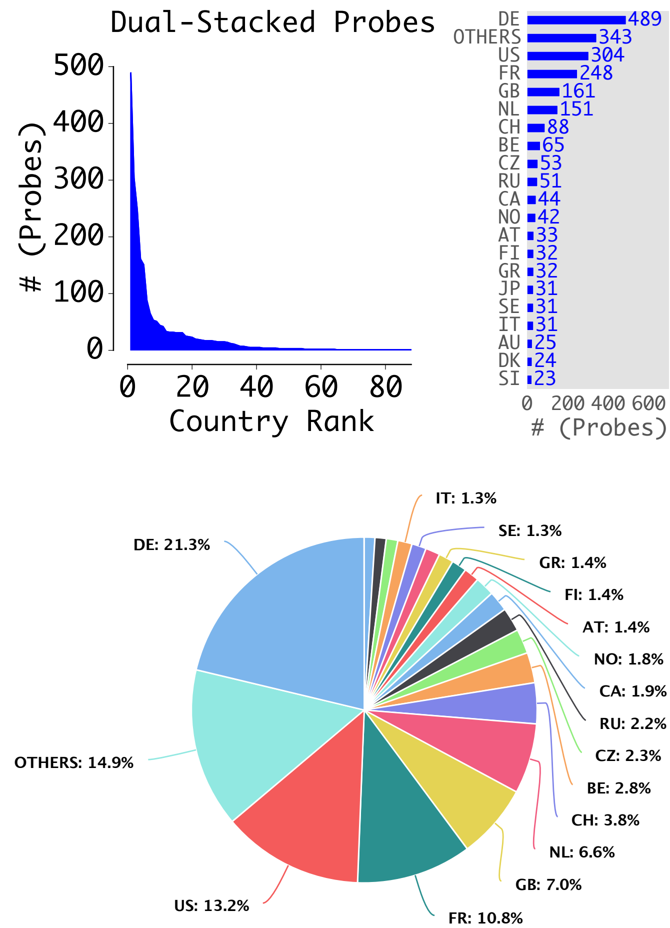


Fig. 6. *Country-based distribution of dual-stacked probes. The plot is generated using the RIPE Atlas Probe API [4]. The countries are ranked by the number of deployed probes. 88 countries are covered by dual-stacked probes. The entire list is made available at: http://goo.gl/UdEe1Q*

all connected and non-anchored probes are dual-stacked as of Jan 2017. To put numbers into perspective, this is more than the number of CAIDA Ark [7] dual-stacked probes (77 out of 170 as of Jan 2017) with native IPv6 connectivity. We use this definition of dual-stacked probes in the rest of the paper.

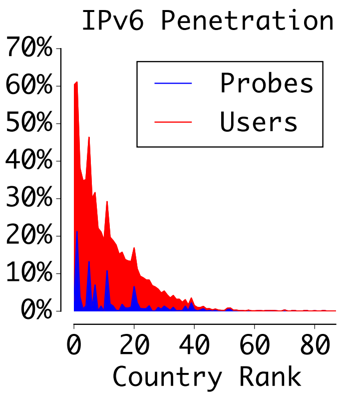
IV. IPv6 Probes by Region

In order to study IPv6 probes by region, we use the RIPE Data API [25] to map the IP endpoint used by each dual-stacked probe to the RIR that allocated the encompassing prefix of the IP endpoint resource. The registration information is derived from each RIR's WHOIS [26] service. Using this mapping we cluster the probes by RIR region. Fig. 5 shows this RIR-based distribution of dual-stacked probes. It can be seen that ~91% of the dual-stacked probes are connected within the RIPE and ARIN region. We further used the RIPE Atlas Probe API [4] to split the RIR region by country. This country information is provided by probe hosts during initial registration. The system also uses geolocation services in case the user does not provide this information. For instance, the `system-auto-geoip-country` and `system-auto-geoip-city` system tags are used specifically for this purpose. These system tags are overidden when a user manually geolocates the probe. Fig. 6 shows this country-based distribution of dual-stacked probes. As can be seen, a large number of dual-stacked probes are connected in Germany, US, France, Netherlands and UK. However, even though probes span 88 countries, some countries with a large IPv6 userbase serve only a small fraction of dual-stacked probes. For instance, we know that Belgium with ~48.5% penetration is currently leading IPv6 adoption rates (as of Jan 2017) according to Google IPv6 adoption statistics [27]. However, it does not even fall within the top 5 countries with the largest number of dual-stacked probes. As such, the probe deployment likely does not reflect the dual-stacked user population across the globe. Using the APNIC dataset [28], we performed a correlation (see Fig. 7) of percentage of dual-stacked probes against the percentage of IPv6 user population. An associated table shows the top 10 countries with a large IPv6 userbase that have a small fraction of dual-stacked probes. For instance, it can be seen that JP with ~19% IPv6 usage ratio and ~22M IPv6 users serve only ~1.4% (31/2301) dual-stacked probes. We hope this analysis will help improve the deployment of probes in such underrepresented countries with a large IPv6 userbase.

V. IPv6 Probes by Network

We further used the RIPE Atlas Probe API [4] to cluster the dual-stacked probes by their origin AS. Fig. 8 shows this AS-based distribution of dual-stacked probes. Using this information with the country-based distribution (see Fig. 6), it can be seen which service providers contribute to the large fraction of probes within the top countries. For instance, dual-stacked probes within Germany are largely represented by Deutsche Telekom and Kabel Deutschland. Similarly Comcast has high representation within US, Proxad within France and XS4ALL within Netherlands.

Selecting ISPs: Although Fig. 8 shows that top ASes hosting the highest number of probes are ISPs, it must also be noted that not all probes are deployed in service provider



	USERS	PROBES
BE	57.4%	2.8%
LU	34.2%	0.6%
GR	33.7%	1.4%
CH	34.3%	3.8%
PT	29.2%	0.7%
IN	22.0%	0.1%
US	33.2%	13.2%
EC	18.8%	0.1%
DE	39.9%	21.3%
JP	19.8%	1.4%

Fig. 7. *Correlation (left) of percentage of IPv6 users against dual-stacked RIPE Atlas probes by country. The countries are ranked by the percentage of IPv6 users as of Jan 2017. The estimation of number of IPv6 users is available from APNIC dataset [28]. A delta comparison (right) reveals the top 10 countries with a large IPv6 userbase that would benefit from more deployment of dual-stacked probes.*

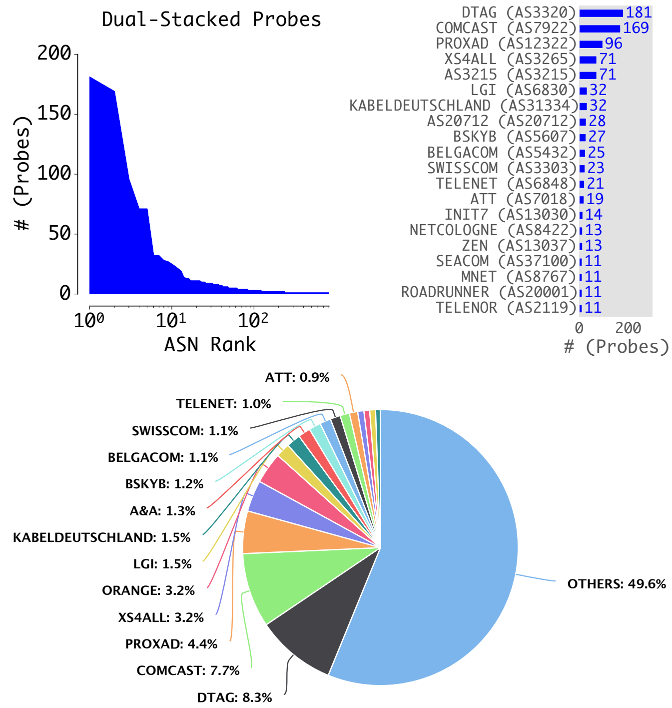
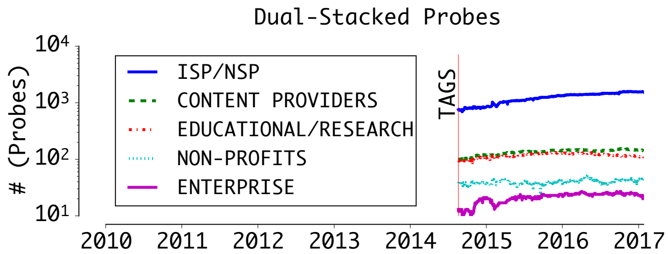


Fig. 8. *AS-based distribution of dual-stacked probes. The plot is generated using the RIPE Atlas Probe API [4]. The ASNs are ranked by the number of deployed probes. A large number (822) of ASNs are covered by dual-stacked probes. The entire list is made available at: http://goo.gl/bR5JEd.*

networks. From the perspective of vantage point selection, it is essential to be able to select probes deployed in a specific type of a network that spans multiple ASes and countries. We therefore, searched the literature for techniques that can classify ASes by network type. Xenofontas Dimitropoulos *et al.* in [29] (2006) apply machine learning techniques to classify ASes into six categories: a) large ISPs, b) small ISPs, c) customer networks, d) universities, e) IXPs, and f) NICs. They use data from CAIDA Ark [7], RouteViews, and Internet Routing Registry (IRR). This study however is dated. PeeringDB [30] which is a database holding peering information of participating networks serves as a living, viable alternative today. Aemen Lodhi *et al.* in [30] show that the information maintained within this database is reasonably representative of network operator peering and is also up-to-date. Therefore we used PeeringDB to map ASes hosting dual-stacked probes by their network type information. Not all ASes hosting dual-stacked probes could be mapped to a network type due to missing AS information encompassing ~19.3% (443 / 2301) dual-stacked probes (as of Jan 2017) in the PeeringDB database. Fig. 9 shows the evolution of dual-stacked probes by network type. It can be seen that ~83% (1540 out of 1858) of the dual-stacked probes are deployed in service provider networks. As a result, the RIPE Atlas platform is a potential platform for measuring native IPv6 performance delivered by service provider networks.

Selecting Residential Probes: Furthermore, not all dual-stacked probes that mapped to a service provider network are particularly deployed within a home network, but may also be hosted deep within access or backbone network of a service provider. In order to identify residential probes, we used the RIPE Atlas measurement creation API [5] to provision one-off `traceroute` measurements towards RIPE Atlas anchors. We created separate measurements for each ISP in order to cycle through all available target anchors. This allowed us to evenly distribute the measurement load inside the platform. Measurements were performed using the ICMP Paris probing method [31] implemented in the `evtraceroute` busybox applet within the platform. We define *residential probes* as probes that are directly wired to the home gateway. In order to achieve this, we searched for probes whose $hop1$ was in a private IPv4 address space [32], but $hop2$ was in a public IPv4 address space. This criteria eliminates the situation where the service provider uses a private address space within the access network unless a probe is situated at the edge of last-mile. This also ensures we do not incorrectly classify a probe connected to business lines (which likely crosses multiple hops of private addresses before reaching out through the main router) as a residential probe. It is possible that there may be home probes that are connected to multiple layers of NAT. It's also possible that some (although a smaller fraction) home probes may not be connected to any NAT. The heuristic will filter out these situations, however, note that this maybe an accepted tradeoff since it will more affect the coverage and less likely the accuracy of inferred residential probes. Fig. 10 shows the fraction (~60.5%) of residential dual-stacked (782) probes deployed in service provider networks.

Categorizing Residential Probes by Access Technology: We further classify residential dual-stacked probes into DSL, cable and fibre service providers. UPnP discovery messages can be used to reveal access technology used on the WAN interface of a home gateway. Lucas DiCioccio *et al.* [33] use `netalyzr` [34] to send Universal Plug and Play (UPnP) dis-



ISP/NSP	1540	83.0%
CONTENT PROVIDERS	139	7.5%
EDUCATION/RESEARCH	110	6.0%
NON-PROFITS	45	2.4%
ENTERPRISE	21	1.1%

Fig. 9. *Evolution of dual-stacked probes by network type as mapped by PeeringDB [30]. An associated table shows the number (and fraction) of dual-stacked probes within each network type as of Jan 2017. ~83% of dual-stacked probes are connected within service provider networks.*

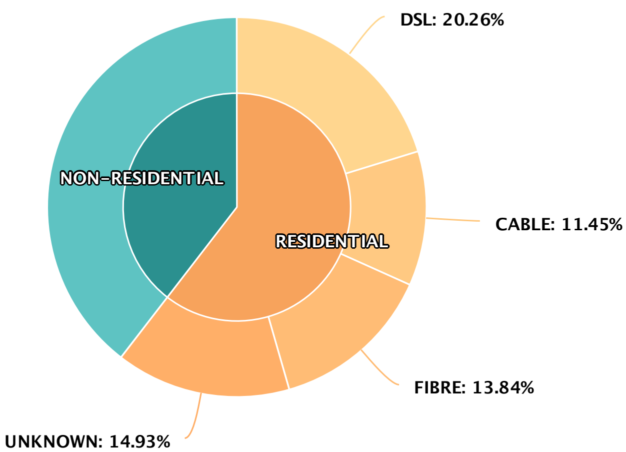


Fig. 10. *Distribution of dual-stacked probes deployed in service provider networks. ~60.5% (782) of probes are wired to a home gateway. Amongst residential probes, ~20.26% (262) are connected to DSL, ~11.45% (148) are connected to cable while ~13.84% (179) are connected to fibre networks.*

covery messages to home gateways. They show how responses from these queries can reveal access technology used on the WAN interface. The measurements were performed on 120K homes in 2012, but only 35% of the gateways were found UPnP enabled. 10% of the gateways were connected further to a modem device, while 3% of the homes had more than one UPnP gateway. Even more, UPnP responses are not always accurate. In any case, since RIPE Atlas probes currently do not support a measurement that can perform UPnP queries and since this technique has been proven to be unreliable [33], we instead rely on user tags (see Section VI) to categorize residential dual-stacked probes by the access technology used by the home gateway. Fig. 10 shows the split distribution of residential dual-stacked probes by access technology. It can be seen that this being an even split of dual-stacked probes across access technology can serve as a good sample for IPv6

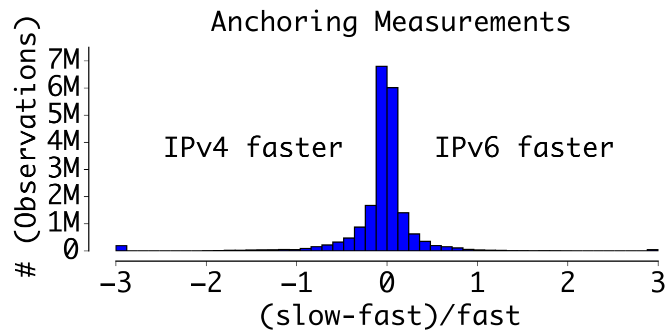


Fig. 11. *5^{th} percentile comparison of latencies over IPv4 and IPv6 from 2941 RIPE Atlas probes to 149 RIPE Atlas anchors using a month-long (Sep-Oct 2015) dataset consisting of 20M data points. The latencies appear comparable, although IPv4 tends to show marginally better performance. The raw dataset is available at: http://goo.gl/dOJL5Q*

measurement studies from home networks.

Example: Measuring IPv6 Performance: A practical application of using these dual-stacked probes is to determine performance of IPv6 relative to IPv4. We use these dual-stacked probes to measure IPv6 performance towards RIPE Atlas anchors. We used a month-long dataset of `ping` measurements provisioned towards 149 anchors. Fig. 11 shows the 5^{th} percentile latency comparison between IPv4 and IPv6. The 5^{th} percentile was used to illustrate the best case scenario. It can be seen that IPv4 and IPv6 latencies between RIPE Atlas probes and RIPE Atlas anchors are comparable, although relative performance in IPv4 still seems marginally better. It should be noted that this measurement carries the region–based (see Section IV) and network–based (see Section V) bias of deployed probes and may miss observations from some countries (see Fig. 7) with a large IPv6 userbase.

VI. User Tags

In addition to system tags, RIPE Atlas also allows probe hosts to tag their *own* probes with additional tags. Given the sample space of words that can be used for user tags is large, the visibility of user tags is set to private by default. This allows the system to not automatically offer the tag words to other users. The RIPE Atlas team periodically checks newly entered user tags and approves the ones that seem to be of general use. The approved user tags are then made available to other users. RIPE Atlas also periodically sanitizes the word space by merging similar tags. For instance, administrators can merge `v6-tunnel`, `ipv6-tunnel` and `tuneled-ipv6` into one user tag. This ultimately helps achieve sane vantage point selection for the large number of probes supported by the system. Fig. 12 shows the distribution of these user tags across connected probes. It is worth noting that a large number of probes did benefit in the beginning when some of these user tags (such as `nat`) were automatically applied to probes to initially seed the system. Fig. 13 shows the timeseries of top 10 user tags sorted by the number of connected probes. As can be seen popular user tags (`nat`, `no-nat`, `home`, `dsl`,

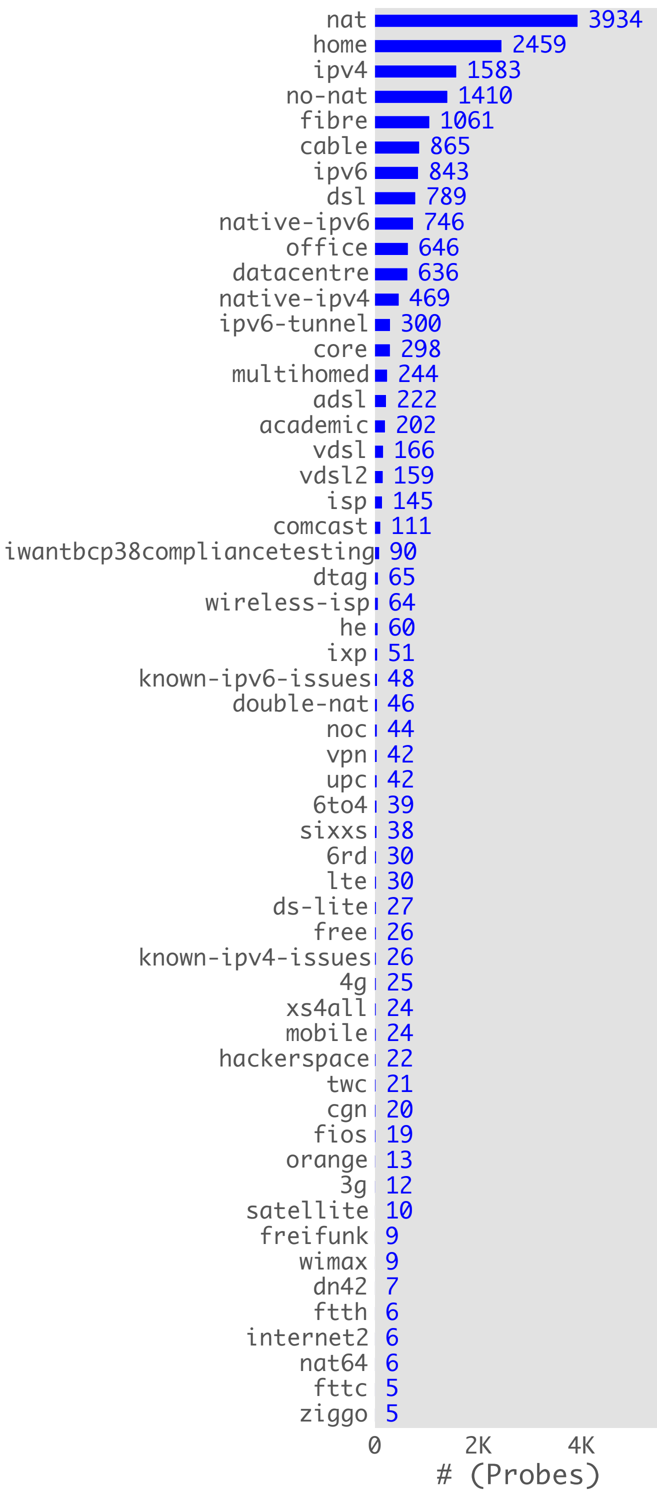


Fig. 12. *Distribution of connected probes based on tags manually assigned by probe hosts as of Jan 2017.*

cable, fibre) are centered around probes deployed in residential settings.

Although system tags being generated directly by the RIPE Atlas platform are stable, the accuracy of user tags is largely

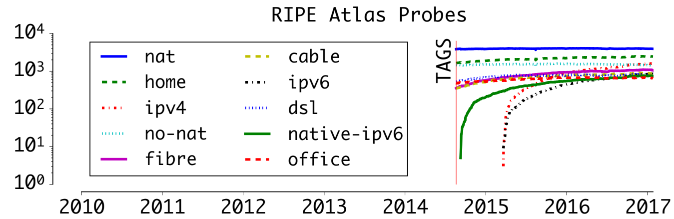


Fig. 13. *Time series of top 10 user tags sorted by the number of connected probes. Popular user tags are centered around home probes.*

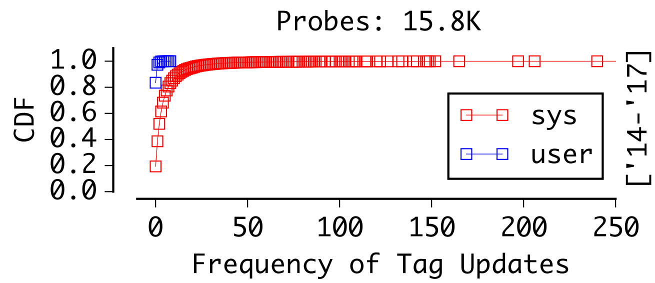


Fig. 14. *Frequency of tag changes over time. ~2.8% of probe hosts ever update their user tags. On the other hand more than half of the probes (~61.4%) received at least one update on system tags with ~13.1% of probes receiving atleast 10 updates. Whenever user tags are changed, more tags are added / deleted (upto 7 tags changed at once) when compared to system tags.*

dependent on the proactiveness of the host. Even though this is not expected to happen often, the host needs to update probe tags as and when network conditions change. For instance, in situations where a host forgets to change a tag due to change in either service subscription or even worse moving the probe to a new location, vantage point selection based barely on user tags would lead to entirely different measurement results. Fig. 14 compares the frequency of tag (user and system) changes over time. It can be seen that only ~2.8% of probes received any updates on their user tags. As such, we introduce the notion that user tags tend to become stale over time. In the future we plan to associate a tag creation timestamp to allow a predictive weighting of user tag accuracy. Furthermore, we plan to utilise built-in measurements to identify if a user-tag is plausible and contact volunteers in situations where there is suspicion on the accuracy of a user tag.

VII. Conclusion

We showed that probe hosts do not update their user tags frequently which may lead to user tags that tend to become stale over time. System tags on the other hand refresh every 4 hours and are therefore stable and accurate. We showed the utility of system tags by performing a region–based and network–based vantage point selection of dual-stacked probes. Although some regions and networks with a large number of probes can produce a sampling bias, the exploration revealed that RIPE Atlas provides the richest source of vantage points (~2.3K) for IPv6 measurement studies. This exploration also helped us identify underrepresented regions (such as BE and

JP) with a large IPv6 user base that can benefit from increased deployment of probes.

VIII. Acknowledgements

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