

CAIDA's IPv4 and IPv6 AS Core AS-level Internet Graph

http://www.caida.org/research/topology/as_core_network/

Archipelago January 2015

During a two-week period in January 2015, CAIDA researchers connected data using our distributed measurement infrastructure, Archipelago (Ark). For the IPv4 map, 118 Ark monitors in 42 countries on 6 continents probed paths toward 281 million /24 IPv4 networks. For the IPv6 map, the subset

of 47 IPv6-connected Ark monitors located in 25 countries on 6 continents concurrently probed paths toward 4.9 million IPv6 addresses. These measurements covered, correspondingly, 92.7% of the IPv4 routable prefixes and 89.3% of the globally routed IPv6 prefixes as seen in the Route Views Border Gateway Protocol (BGP) routing tables collected by Routeviews and RIPE NCC on January 1, 2015.

We aggregated the captured IP-level data to construct IPv4 and IPv6

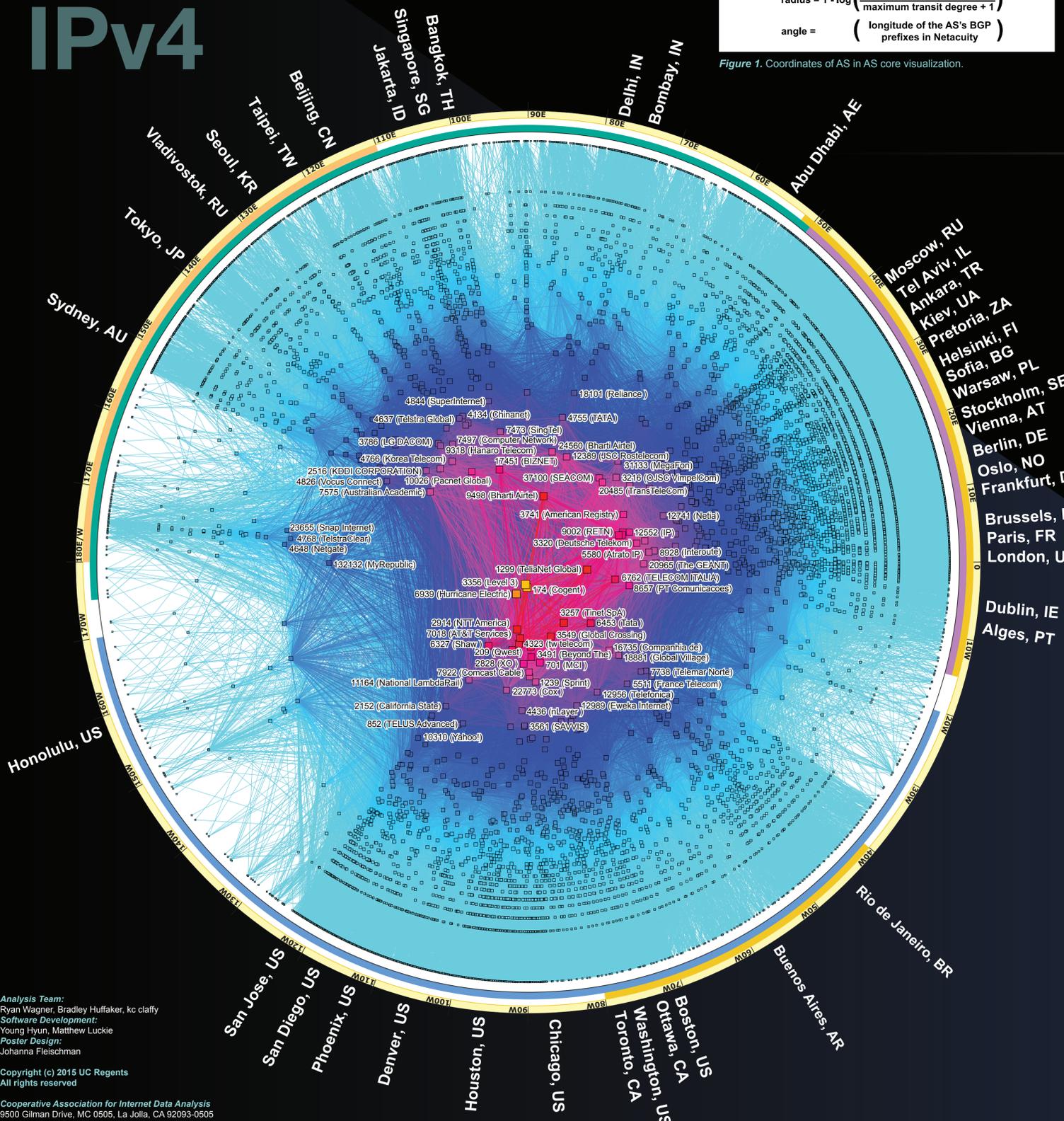
Internet connectivity graphs at the Autonomous System (AS) level. Each AS approximately corresponds to an Internet Service Provider (ISP). We map each observed IP address to the AS which announced it, i.e., to the origin (end-of-path) AS for the IP prefix representing the best match for this address in the BGP routing tables. The position of each AS node is plotted in polar coordinates (radius, angle) calculated as indicated in Figure 1.

$$\text{radius} = 1 - \log\left(\frac{\text{transit degree}(\text{AS}) + 1}{\text{maximum transit degree} + 1}\right)$$

$$\text{angle} = \left(\frac{\text{longitude of the AS's BGP prefixes in Netacuity}}{\text{maximum longitude}}\right)$$

Figure 1. Coordinates of AS in AS core visualization.

IPv4



Analysis Team:
Ryan Wagner, Bradley Huffaker, kc claffy
Software Development:
Young Hyun, Matthew Luckie
Poster Design:
Johanna Fleischman

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Cooperative Association for Internet Data Analysis
9500 Gilman Drive, MC 0505, La Jolla, CA 92093-0505
(858) 534-6000

Acknowledgments

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NIC Chile, NIC Mexico, NORDUnet, Nepal Research And Education Network, NetIX, Neterra Ltd, Northeastern University, Openmirrors asia - at Equinix SG1, Ottawa Internet Exchange, Public University of Navarra, QOcell, RIPE NCC, RNP, Rede ANSP / Projeto NARA, Registro.br, SURFnet, Simula Research Laboratory, Solido Networks ApS, Southern Methodist University, TKK, TWAREN, Technical University of Munich, Tinet, Torix, UCAD, US Army Research Lab, Univ. Twente, Universität Leipzig, Universitat Politècnica de Catalunya, University of Cambridge, University of Hawaii, University of Limerick, University of Melbourne, University of Napoli, University of Nevada at Reno, University of Oregon, University of Waikato, University of Washington, University of Zurich, VTR

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	Number of IP addresses	Number of IP links	Number of ASes	Number of AS links
IPv4	42,048,076 +12%	33,899,735 +9%	39,809 +7%	152,438 +17%
IPv6	71,391 +38%	186,567 +39%	5,326 +23%	21,820 +29%

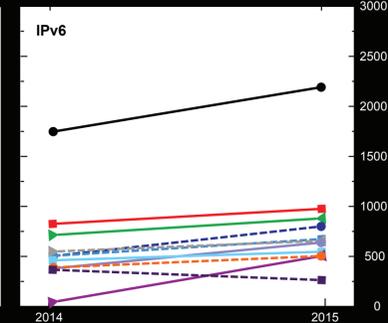
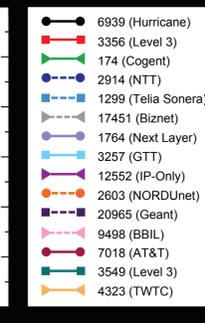
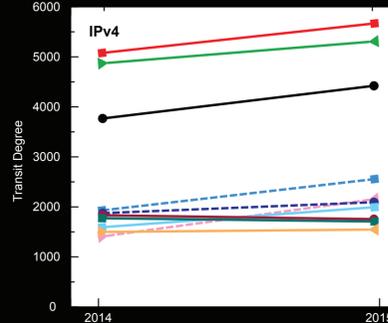
Analysis

As in previous years, the IPv6 graph exhibited faster relative growth than the IPv4 graph. From January 2014 to January 2015, the number of IPv6 ASes increased by 23% and the number of links connecting them increased by 29%. In the case of the IPv4 graph, the number of ASes increased by 7% and number of interconnection links increased by 17%. While relative growth was larger for IPv6, absolute growth was larger in IPv4: our IPv4 AS graph gained 2,623 ASes and 22,343 links since our 2014 graph, while our IPv6 AS graph gained 989 ASes and 4,964 links.

The three highest-degree (most-connected) IPv4 and IPv6 ASes in our measurements remained in the same position as in our 2014 data, but there were more changes in rank among lower-ranked IPv6 ASes than among similarly ranked IPv4 ASes. This difference in volatility is consistent with the younger and more dynamic growth pattern of IPv6.

Examining the dynamics of changes in node degrees (number of neighbors) provides additional insights into the internet's evolutionary trends. Candle plots in Figures 2 and 3 illustrate the distributions of relative AS degree changes that occurred between 2014 and 2015. Each bin in those plots either includes all ASes that had the same degree in 2014 data or spans several degree values to include at least 25 ASes. For each bin, the black line in the middle shows the median percentage of change, the vertical box is drawn between the 25th and 75th percentile values, and the vertical line ends at the 5th and 95th percentile values.

Figure 4 (Left and 5 (Right)). (IPv4/IPv6 Top Ranked ASes) Figures 4 and 5 show changes in connectivity for the 10 IPv4 and 11 IPv6 ASes that were ranked in the "Top 10" by transit degree in either 2014 or 2015. In the IPv4 graph, 8 ASes increased their degree while 2 decreased; the



median observed change was a 12% degree increase. The maximum degree growth of 55% was observed by Bharti Airtel (AS 9498). This large increase moved Bharti Airtel from 10th to 5th position in the ranking of ASes by transit degree. The only decrease in degree from 2014 to 2015 came from AS 7018 and AS 3549, both degrees dropped by 4% each, which had a marginal impact on the Top 10 rankings. In the IPv6 graph, 10 out of 11 ASes increased their degree, with a median increase of 26%.

AS 6939 Hurricane Electric remained the largest-degree IPv6 AS, increasing its degree from 1740 in 2014 to 2199 in 2015. The largest relative degree increase in the IPv6 graph came from AS 12552 IP-Only Networks, with an increase of 1281% from 37 to 511, making it the 9th highest ranked AS by degree in 2015. The AS that decreased most in degree in the IPv6 graph was AS 20965 Geant; its 45% drop from 368 to 202 removed it from Top 10.

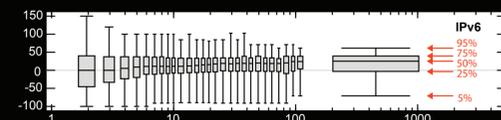
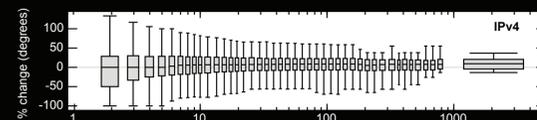
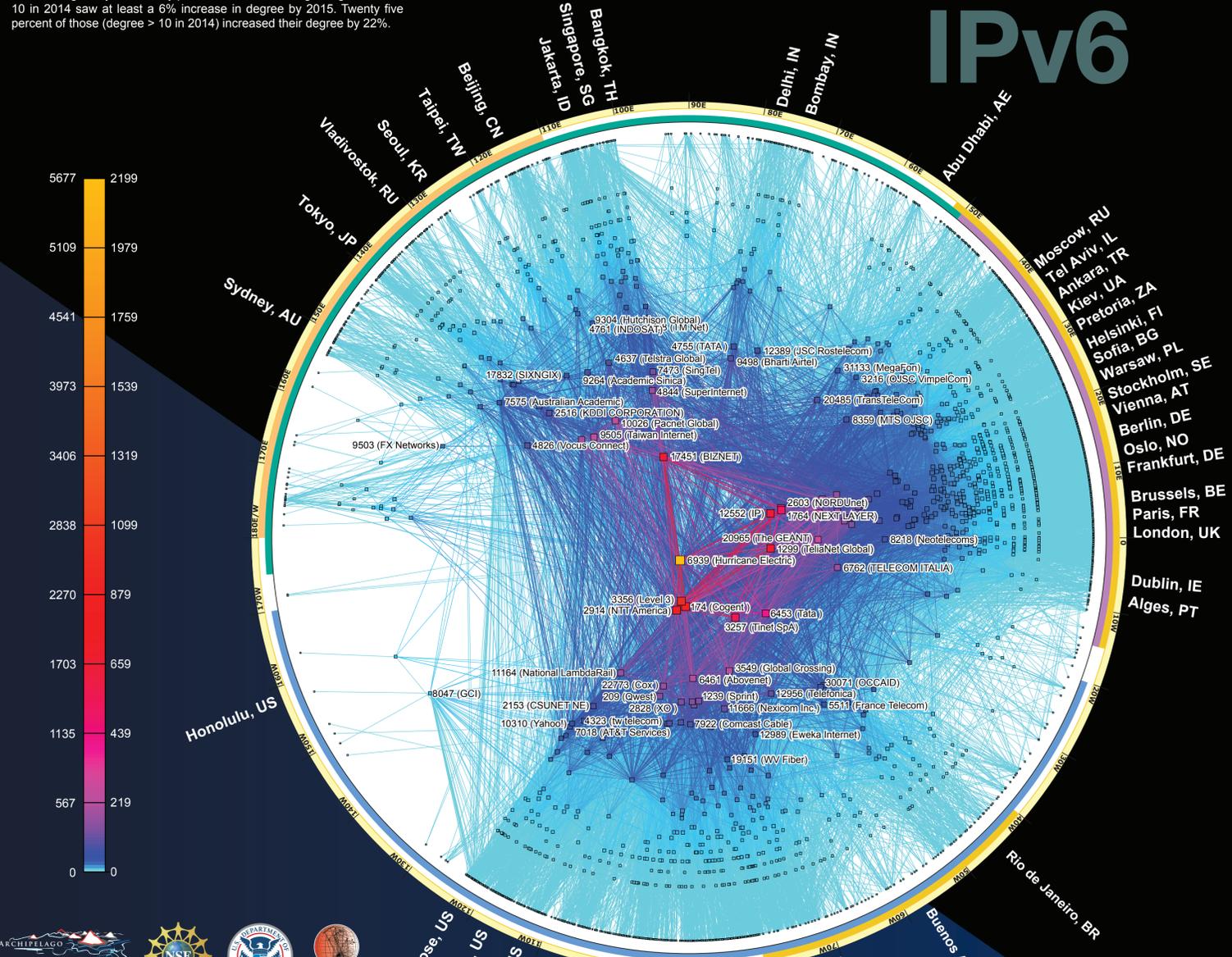


Figure 2 (Above). (Box-and-Whisker Plot IPv4) For ASes with degree less than 4 in 2014, the same number of ASes reduced and increased their AS degree by 2015. Fifty percent of ASes with degrees greater than 10 in 2014 saw at least a 6% increase in degree by 2015. Twenty five percent of those (degree > 10 in 2014) increased their degree by 22%.

Figure 3 (Left). (Box-and-Whisker Plot IPv6) For ASes with degree less than 3 in 2014, the same number of ASes reduced and increased their AS degree by 2015. The fraction of ASes that increased in size tended to increase as the degree increased. Only 50% of ASes with degrees less than 3 increased in size, while almost 75% of ASes with degrees larger than 100 did.

IPv6



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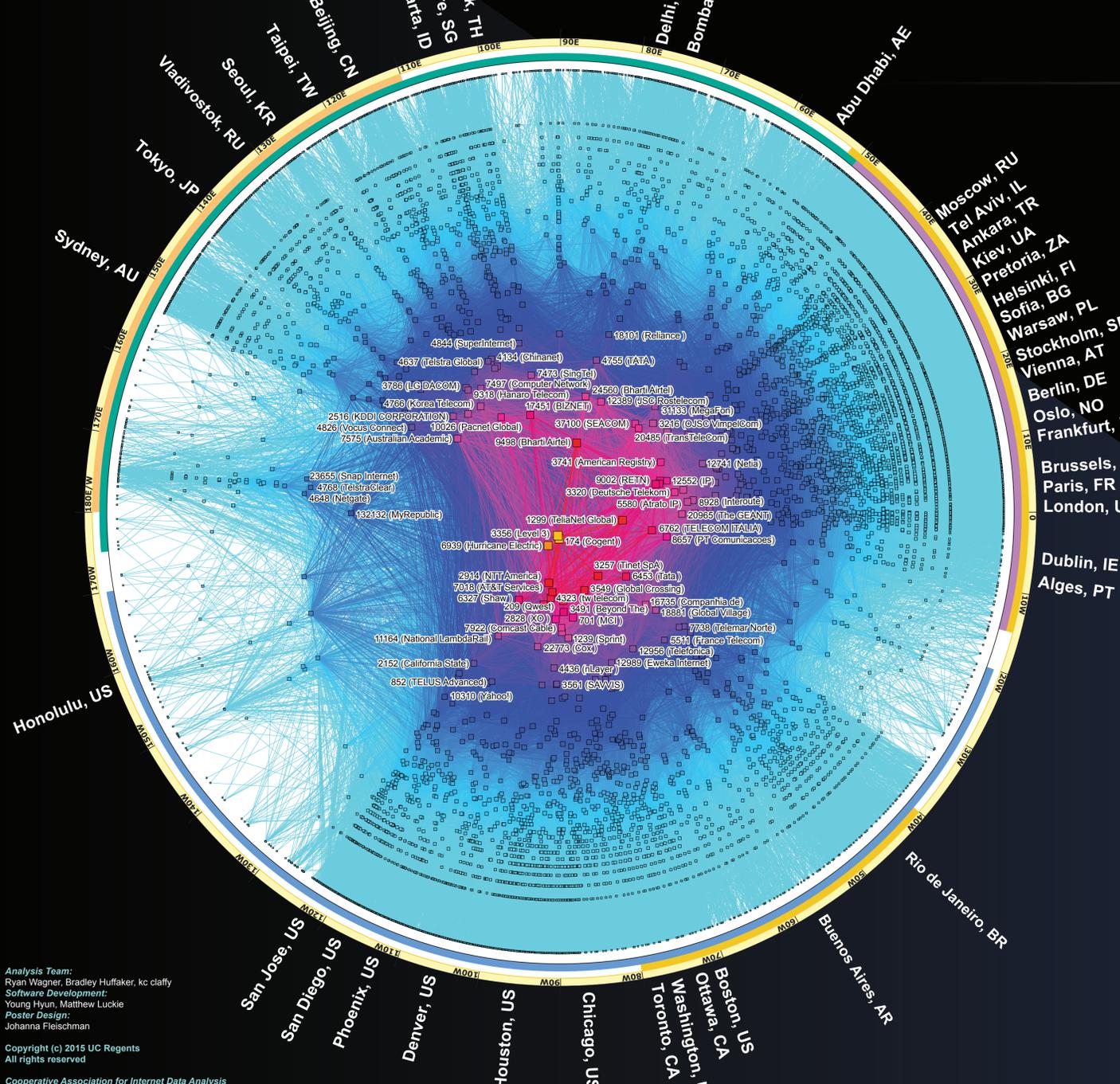
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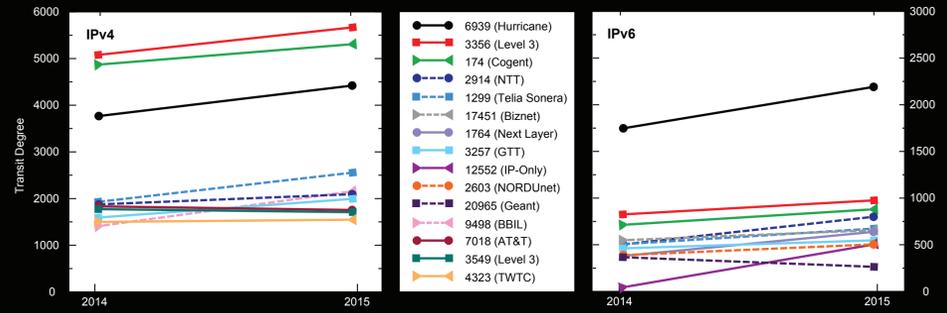
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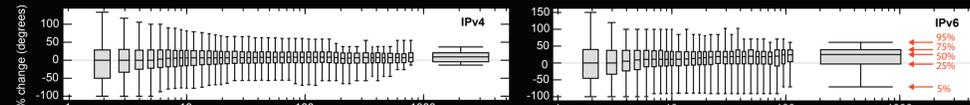
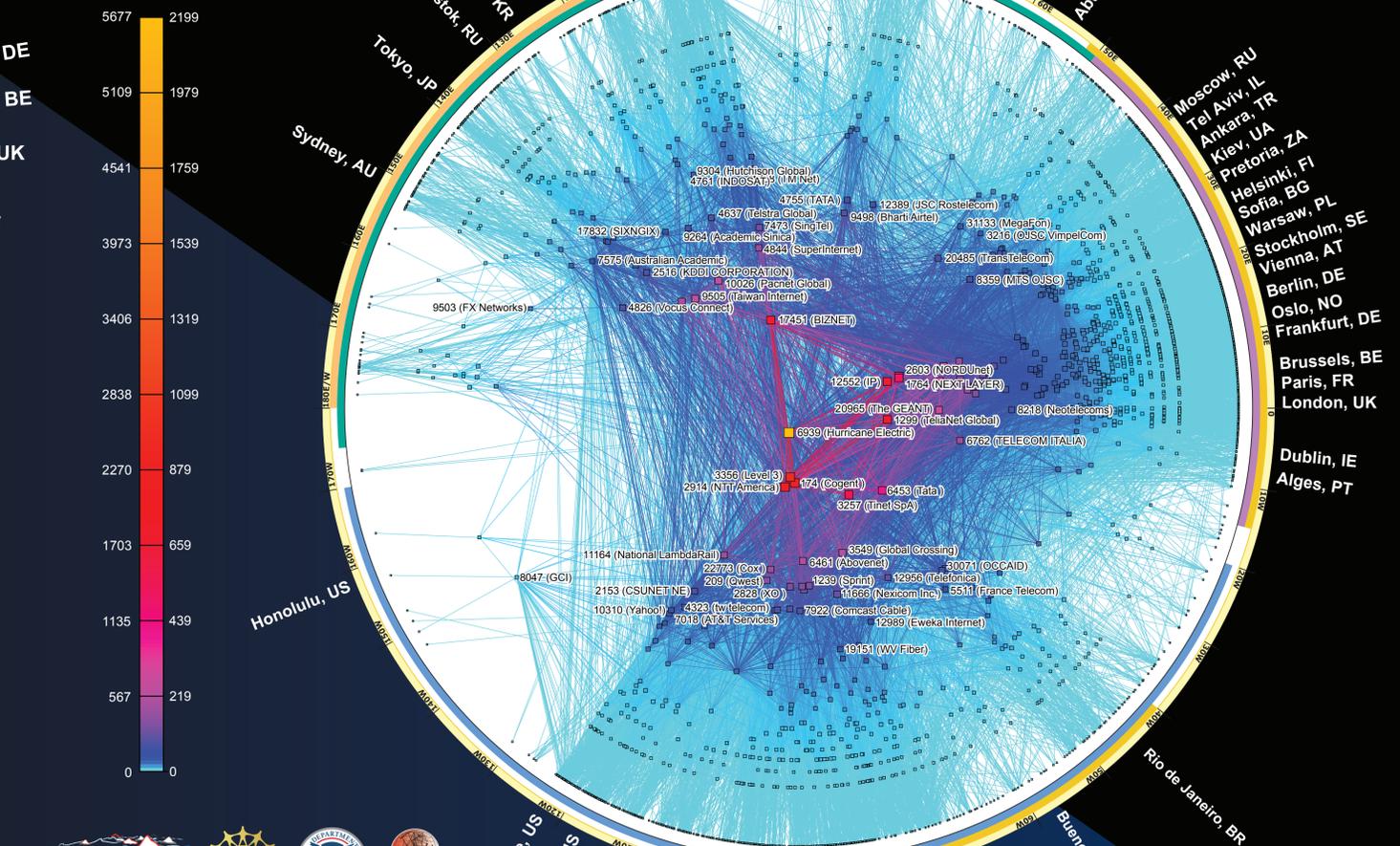


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