

CAIDA'S IPV4 AND IPV6 AS CORE: VISUALIZING IPV4 AND IPV6 INTERNET TOPOLOGY AT A MACROSCOPIC SCALE IN 2020

SINCE 2000, CAIDA HAS GENERATED AS CORE GRAPHS -- INTERNET TOPOLOGY MAPS ALSO REFERRED TO AS AS-LEVEL INTERNET GRAPHS -- IN ORDER TO VISUALIZE THE SHIFTING TOPOLOGY OF THE INTERNET OVER TIME, AS CAN BE SEEN IN THE HISTORICAL VIEW. FOR A DETAILED EXPLANATION OF THE METHODOLOGY USED IN GENERATING THE AS CORE VISUALIZATIONS, SEE THE MAIN IPV4 & IPV6 AS CORE PAGE.

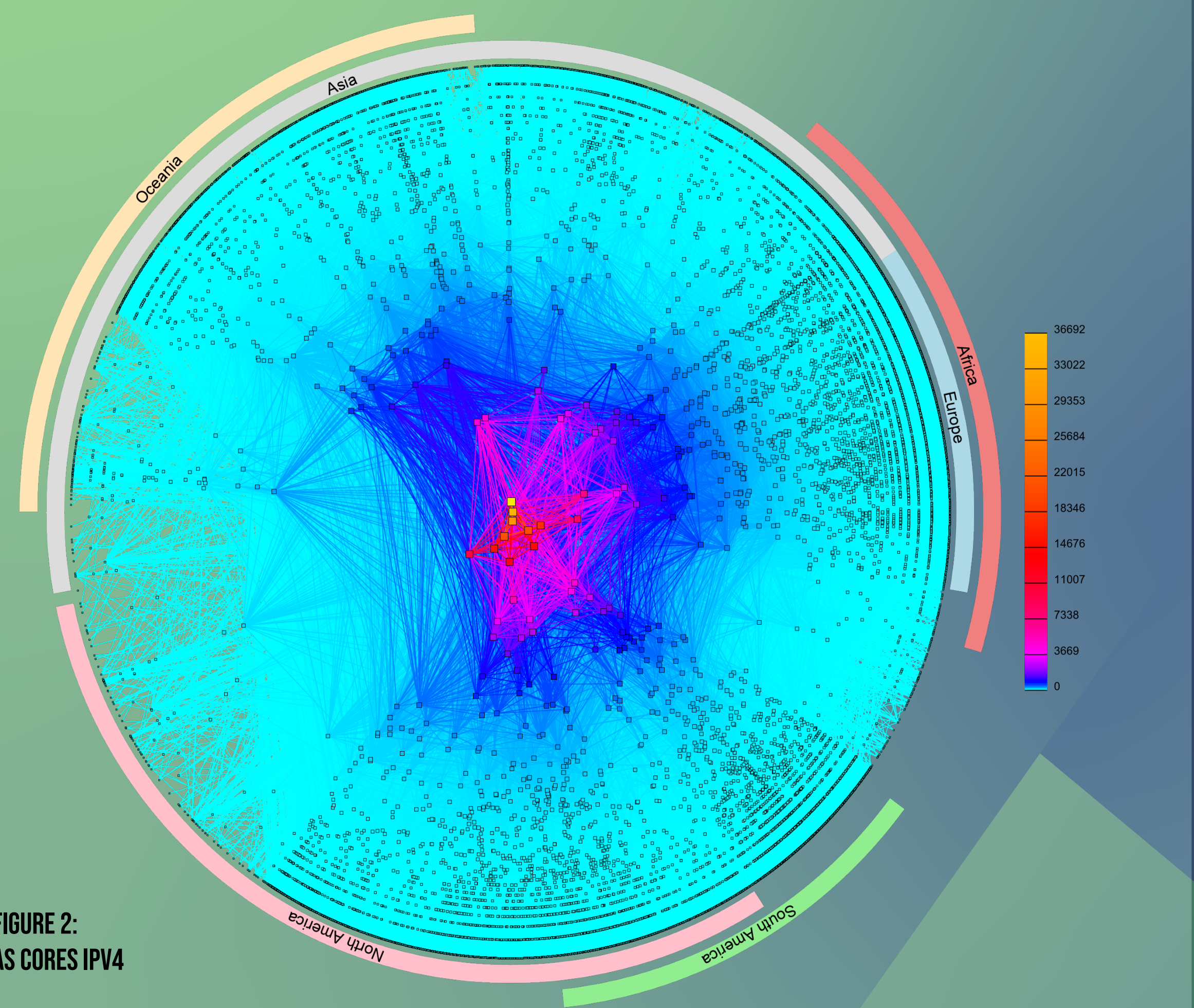
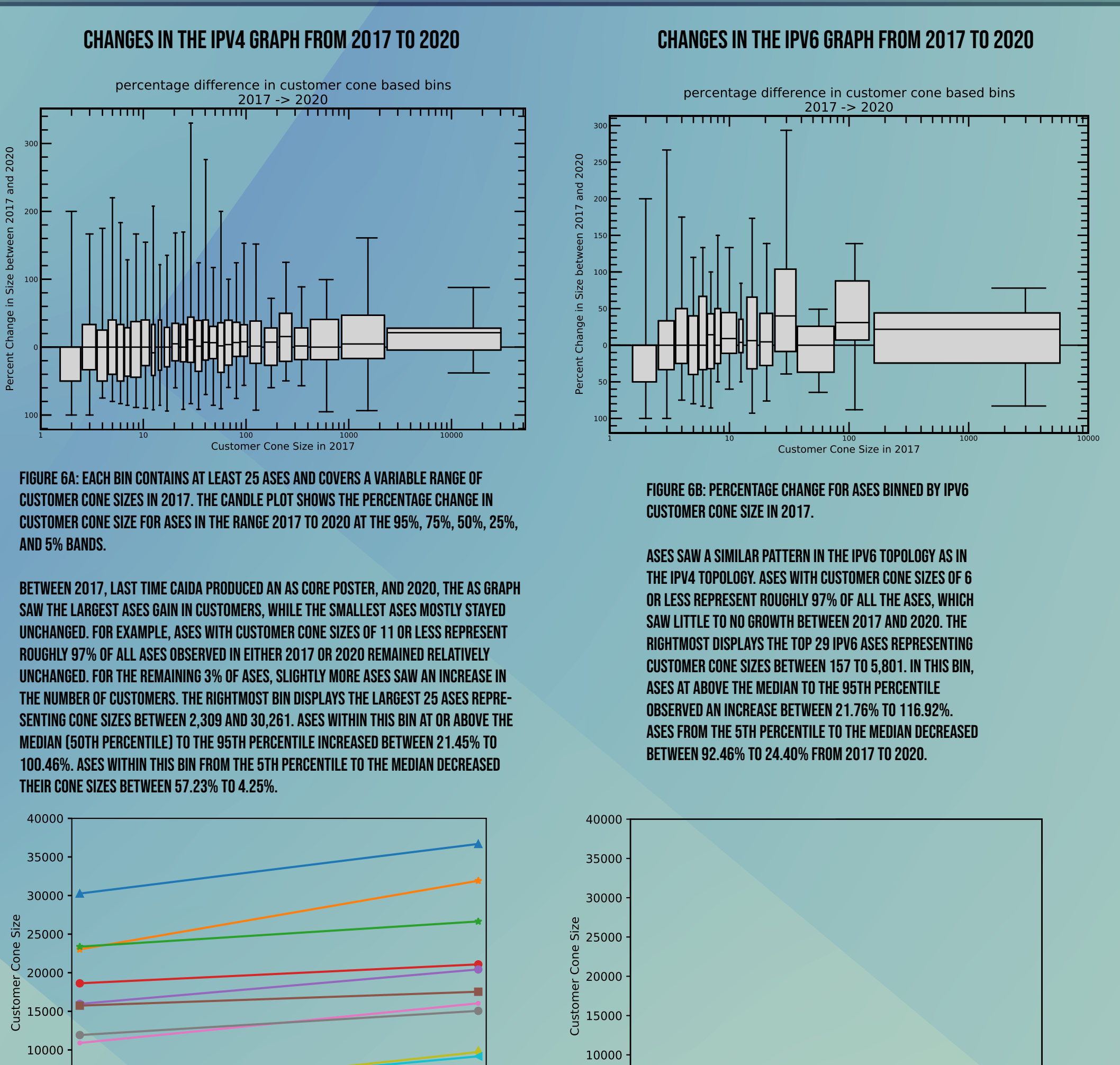


FIGURE 2: AS CORES IPV4



CHANGES IN THE IPV4 GRAPH FROM 2017 TO 2020

CHANGES IN THE IPV6 GRAPH FROM 2017 TO 2020

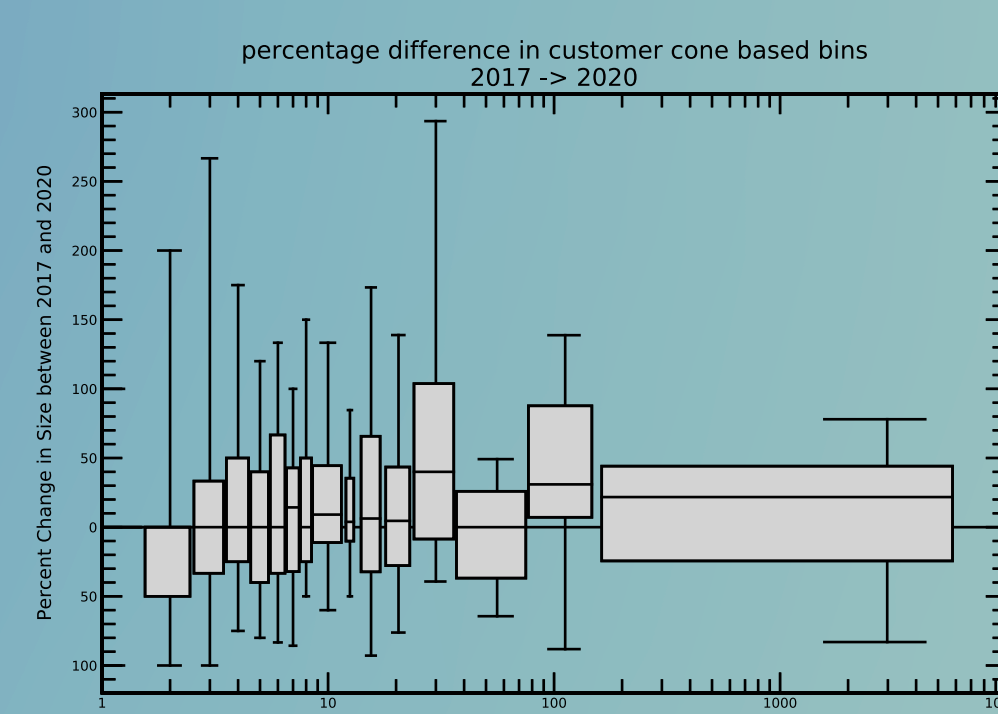
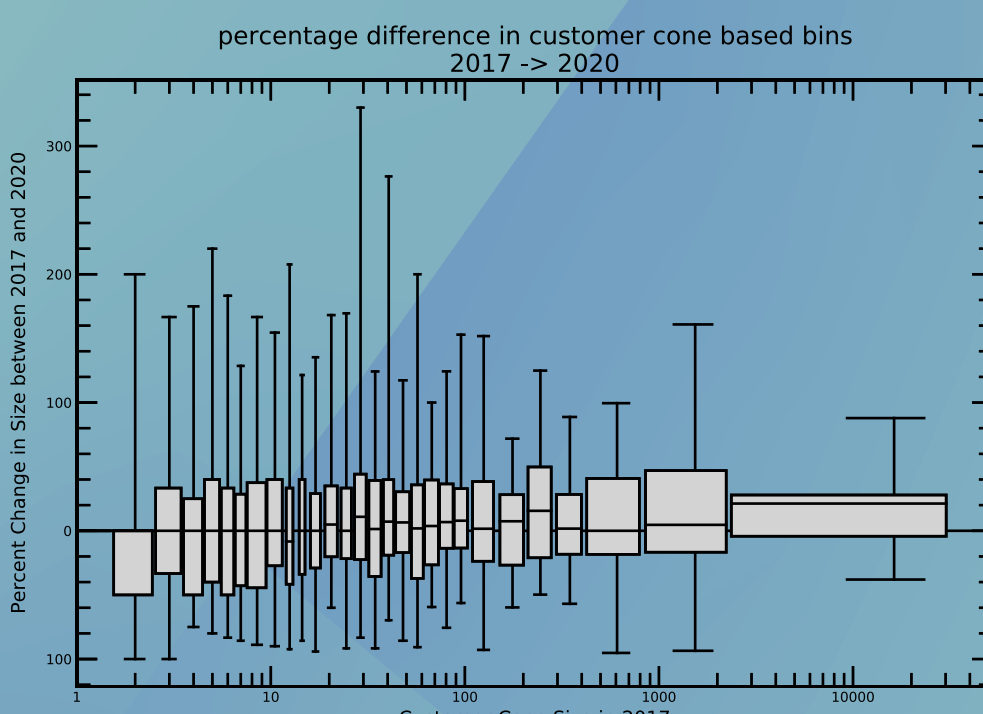


FIGURE 6A: EACH BIN CONTAINS AT LEAST 25 ASes AND COVERS A VARIABLE RANGE OF CUSTOMER CONE SIZES IN 2017. THE CANDLE PLOT SHOWS THE PERCENTAGE CHANGE IN CUSTOMER CONE SIZE FOR ASes IN THE RANGE 2017 TO 2020 AT THE 95%, 75%, 50%, 25%, AND 5% BANDS.

FIGURE 6B: PERCENTAGE CHANGE FOR ASes BINNED BY IPV6 CUSTOMER CONE SIZE IN 2017.

BETWEEN 2017, LAST TIME CAIDA PRODUCED AN AS CORE POSTER, AND 2020, THE AS GRAPH SAW THE LARGEST ASes GAIN IN CUSTOMERS, WHILE THE SMALLEST ASes MOSTLY STAYED UNCHANGED. FOR EXAMPLE, ASes WITH CUSTOMER CONE SIZES OF 11 OR LESS REPRESENT ROUGHLY 97% OF ALL ASes OBSERVED IN EITHER 2017 OR 2020 REMAINED RELATIVELY UNCHANGED. FOR THE REMAINING 3% OF ASes, SLIGHTLY MORE ASes SAW AN INCREASE IN THE NUMBER OF CUSTOMERS. THE RIGHTMOST BIN DISPLAYS THE LARGEST 25 ASes REPRESENTING CONE SIZES BETWEEN 2,309 AND 30,261. ASes WITHIN THIS BIN AT OR ABOVE THE MEDIAN (50TH PERCENTILE) TO THE 95TH PERCENTILE INCREASED BETWEEN 21.45% TO 100.46%. ASes WITHIN THIS BIN FROM THE 5TH PERCENTILE TO THE MEDIAN DECREASED THEIR CONE SIZES BETWEEN 57.23% TO 4.25%.

ASes SAW A SIMILAR PATTERN IN THE IPV6 TOPOLOGY AS IN THE IPV4 TOPOLOGY. ASes WITH CUSTOMER CONE SIZES OF 6 OR LESS REPRESENT ROUGHLY 97% OF ALL THE ASes, WHICH SAW LITTLE TO NO GROWTH BETWEEN 2017 AND 2020. THE RIGHTMOST DISPLAYS THE TOP 29 IPV6 ASes REPRESENTING CUSTOMER CONE SIZES BETWEEN 157 TO 5,801. IN THIS BIN, ASes AT ABOVE THE MEDIAN TO THE 95TH PERCENTILE OBSERVED AN INCREASE BETWEEN 21.76% TO 116.92%. ASes FROM THE 5TH PERCENTILE TO THE MEDIAN DECREASED BETWEEN 92.46% TO 24.40% FROM 2017 TO 2020.

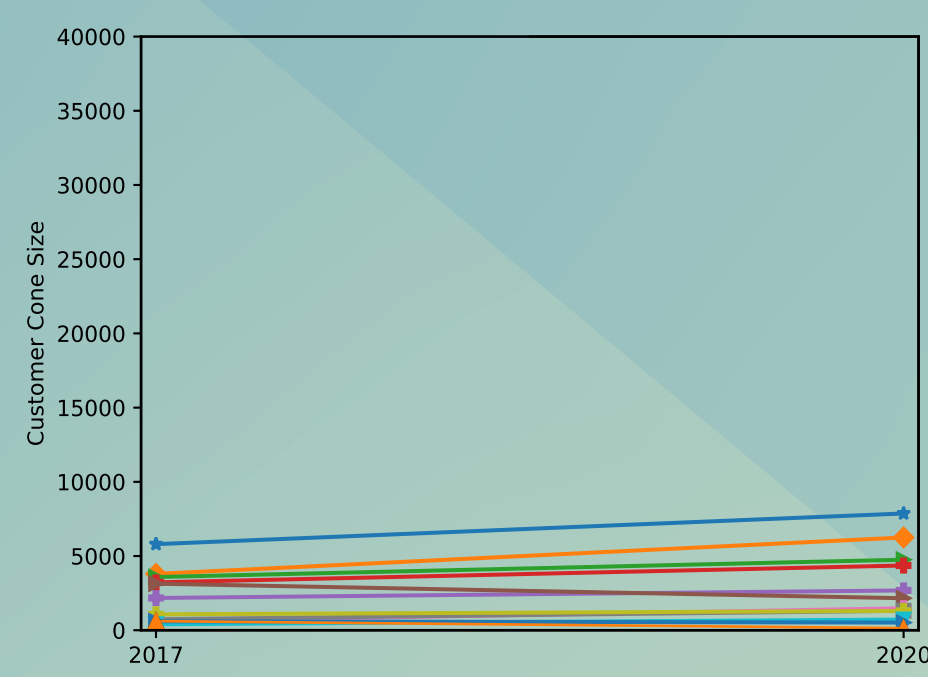
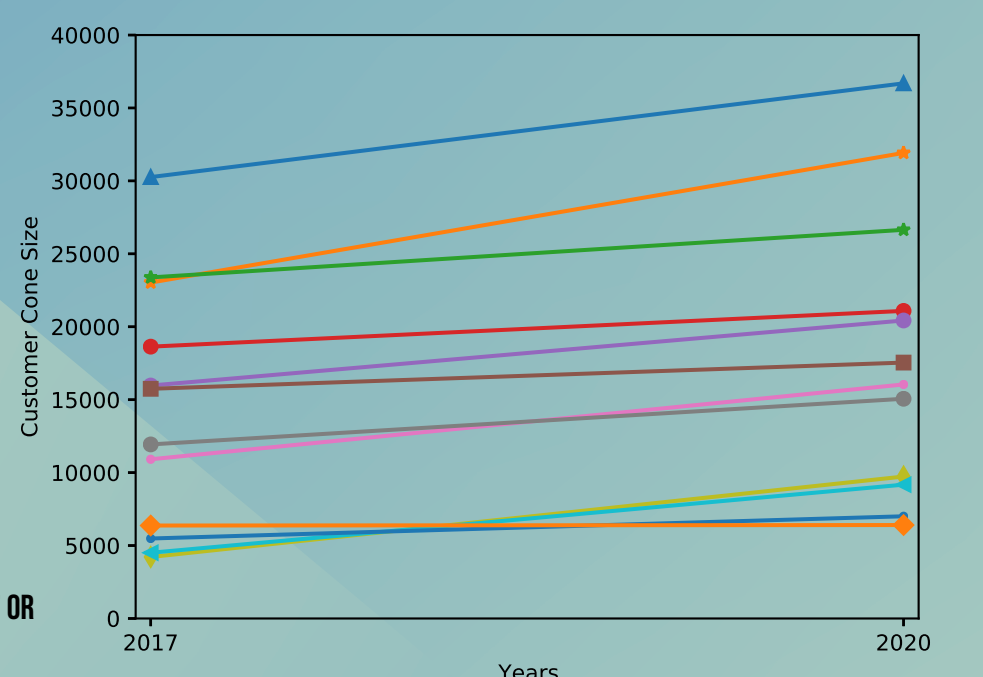


FIGURE 7A: TOP 10 ASes BY IPV4 CUSTOMER CONE SIZE IN 2017 OR 2020.

FIGURE 7B: TOP 10 ASes BY IPV6 CUSTOMER CONE SIZE IN 2017 OR 2020.

FIGURE 7A SHOWS THE CHANGE IN SIZE OF THE TOP 10 ASes WITH THE LARGEST IPV4 CUSTOMER CONES IN EITHER 2017 OR 2020. ALL OF THESE ASes INCREASED THEIR CUSTOMER CONE SIZE BETWEEN 2017 AND 2020. THE MEAN OF OBSERVED CHANGE WAS A 38.53% INCREASE, WITH A MEDIAN INCREASE OF 27.08%. THE LARGEST GROWTH WAS OBSERVED FOR BEYOND THE NETWORK AMERICA, INC. (3491) WITH A 130.87% INCREASE TO THEIR CUSTOMER CONE SIZE. LEVEL 3 COMMUNICATION REMAINED THE LARGEST ASes WITH A CONE SIZE OF 36,688 ASes IN 2020.

FIGURE 7B SHOWS THE CHANGE IN CUSTOMER CONE SIZE OF THE TOP 10 ASes IN 2017 OR 2020. OF THE 12 ASes SHOWN, NINE INCREASED IN SIZE, THE OTHER THREE DECREASED. IN TOTAL, THE MEAN CHANGE IN CONE SIZES OF ALL 12 ASes IS AN INCREASE OF 32.87%, AND A MEDIAN GROWTH OF 33.92%. THE NINE ASes WHO INCREASED OBSERVED A MEAN GROWTH OF 57.44%, AND A MEDIAN GROWTH OF 35.63%. THE LARGEST GROWTH WAS OBSERVED FROM ZAYO BANDWIDTH (6461), WHICH INCREASE BY 148.91%. OF THE THREE ASes WHO OBSERVED DECREASES TO THEIR CONE SIZES, THEIR MEAN DECREASE WAS 40.86% AND A MEDIAN DECREASE OF 31.28%. THE LARGEST IPV6 CUSTOMER CONE AS OF JANUARY 2020 WAS FROM HURRICANE ELECTRIC, INC (6939), WITH A CONE SIZE OF 7,868 ASes.

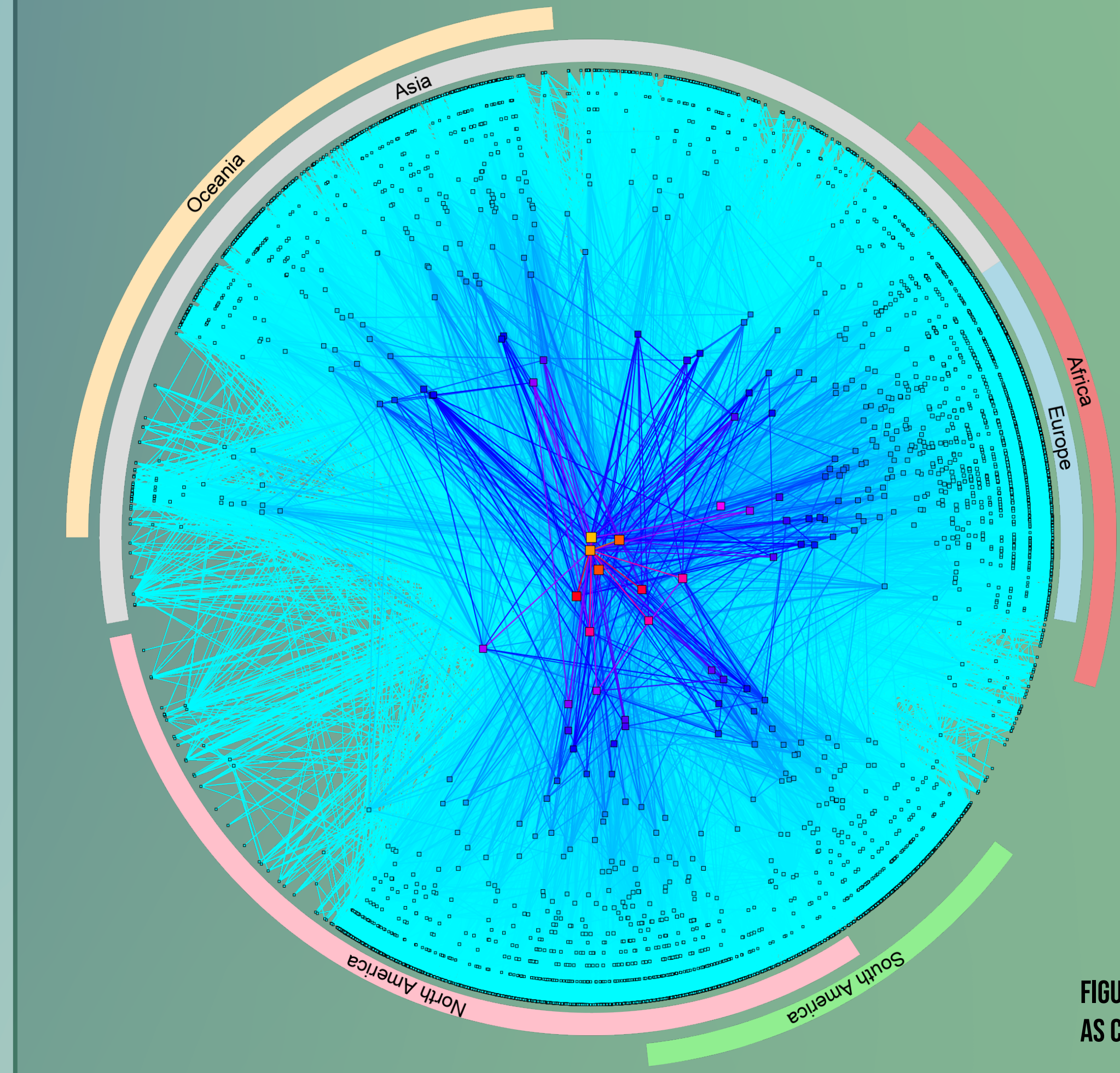
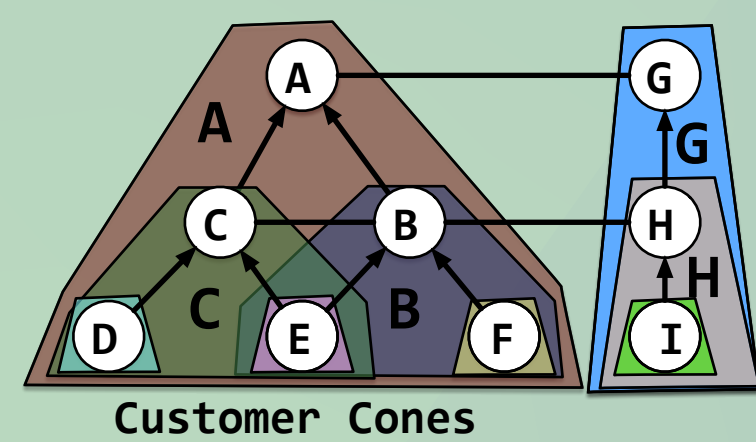


FIGURE 3: AS CORES IPV6

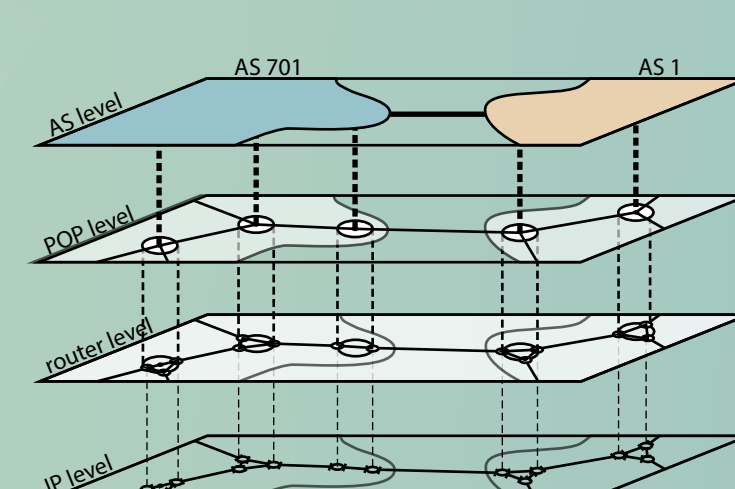
CUSTOMER CONE

AN AS'S CUSTOMER CONE IS THE SET OF ASes THAT WE INFER BASED ON BGP DATA DIRECTLY OR INDIRECTLY PAY THE AS TO CONNECT TO THE INTERNET, PLUS THE AS ITSELF. ON THE LEFT, A HAS THE LARGEST CONE WITH 6 ASes; H HAS TWO. IN BGP TERMS, AN AS'S CUSTOMER CONE CONTAINS THE SET OF ASes WE OBSERVE THE AS ANNOUNCE TO ITS PEERS OR PROVIDERS. THIS DEFINITION IS MORE CONSTRAINED THAN, BUT SIMILAR TO, THE SET OF ASes REACHABLE THROUGH ITS CUSTOMERS.

AS	Size
A	6
B	3
D	1



INTERNET LAYERS



THE INTERNET'S NETWORK TOPOLOGY IS OFTEN DIVIDED INTO FOUR LAYERS: AS, POP, ROUTER, AND IP. AN IP ADDRESS IS AN ATTACHMENT POINT (INTERFACE) OF A DEVICE ON THE INTERNET. THE ROUTER LAYER REFERS TO THE SET OF ROUTERS THAT TRANSFER AND ROUTE TRAFFIC -- A ROUTER MAY HAVE ANY IP ADDRESS INTERFACES ON IT. TO SUPPORT GEOGRAPHICALLY-AWARE TOPOLOGY ANALYSIS, WE AGGREGATE ROUTERS INTO POINTS OF PRESENCE (POPS), E.G., INTERNET EXCHANGE POINTS (IXPS). TO SUPPORT INTERDOMAIN (BETWEEN NETWORKS) TOPOLOGY ANALYSIS, WE AGGREGATE ROUTERS BY COMMON OWNERSHIP INTO AUTONOMOUS SYSTEMS (ASes).

DATA SOURCE

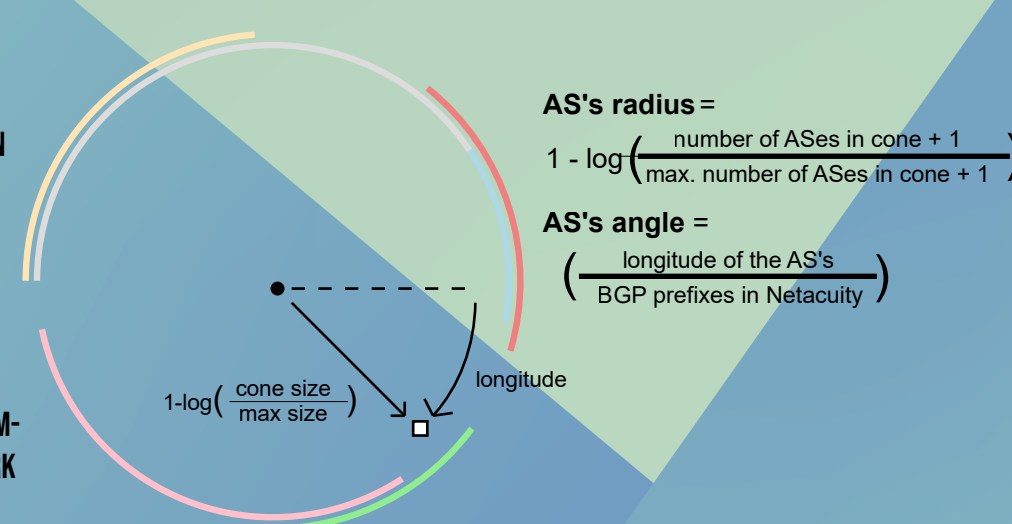
CAIDA'S AS CORE VISUALIZATION REPRESENTS A MACROSCOPIC SNAPSHOT OF ACTIVE (TRACEROUTE) AND PASSIVE (BGP) TOPOLOGY SAMPLES CAPTURED OVER THE FIRST FEW DAYS OF JANUARY 2020. EACH DOT REPRESENTS AN AUTONOMOUS SYSTEM (AS) WHICH APPROXIMATELY CORRESPONDS TO AN INTERNET SERVICE PROVIDER (ISP). THE GEOGRAPHIC LOCATION OF THE INDIVIDUAL AS IS INFERRED FROM THE WEIGHTED CENTROID OF ITS ADDRESS SPACE ACCORDING TO NETACILITY, A COMMERCIAL GEOLOCATION SERVICE. THE SIZE OF EACH AS IS EQUAL TO THE LOGARITHM OF ITS CUSTOMER CONE, THE NUMBER OF INFERRED DIRECT AND INDIRECT CUSTOMERS.

FOR THE IPV4 VISUALIZATION WE USED CAIDA'S JAN 2020 IPV4 INTERNET TOPOLOGY DATA KIT (ITDK) AND AS RELATIONSHIP DATA. WE OBTAINED THE RAW IPV4 TOPOLOGY DATA FOR THE ITDK BY PERFORMING TRACEROUTES TO RANDOMLY-CHOSEN DESTINATIONS IN EACH ROUTED BGP PREFIX USING 159 ARK MONITORS LOCATED IN 50 COUNTRIES.

THE AS RELATIONSHIP DATASET USED FULL RIBs COLLECTED BY 35 BGP COLLECTORS (17 FROM ROUTEVIEWS AND 18 FROM RIPE RIS) ACROSS THE FIRST FIVE DAYS OF JAN 2020. THE RESULTING AS TOPOLOGY CONTAINED 55,237 ASes, AND 162,709 AS LINKS FOUND IN UNION TO BOTH THE JANUARY 2020 ITDK AND AS RELATIONSHIP DATASETS.

FOR IPV6, WE USED JANUARY 2020 DATA FROM CAIDA'S AND IPV6 AS RELATIONSHIP, SINCE THE ITDK DID NOT INCLUDE IPV6 DATA. WE OBTAINED THE IPV6 TOPOLOGY DATA BY USING LONGEST MATCHING PREFIX TO MAP THE IPV6 ADDRESSES TO ASes. THE AS RELATIONSHIP DATASET USED THE SAME SET OF FULL RIBs FROM 35 BGP COLLECTORS ACROSS THE FIRST FIVE DAYS OF JANUARY 2020. THE RESULTING AS TOPOLOGY CONTAINED 12,246 ASes, AND 54,351 AS LINKS.

WE MAP THESE AS LEVEL GRAPHS INTO TWO, IPV4 AND IPV6, AS CORE GRAPHS. THE POSITION OF EACH AS NODE IS PLOTTED IN POLAR COORDINATES (RADIUS, ANGLE) CALCULATED AS INDICATED ABOVE.



CONCLUSION

THIS AS CORE VISUALIZATION ADDRESSES ONE OF CAIDA'S TOPOLOGY MAPPING PROJECT GOALS, WHICH IS TO DEVELOP TECHNIQUES TO ILLUSTRATE STRUCTURAL RELATIONSHIPS AND DEPICT THE EVOLUTION OF CRITICAL COMPONENTS OF THE INTERNET INFRASTRUCTURE. THE IPV4 DATA SHOWS THE RELATIVE GROWTH OF THIS INTERNET TOPOLOGY FROM 2017 TO 2020. THE NET CHANGE IN THE NUMBER OF IPV4 ASes BETWEEN 2017 AND 2020 WAS 13,680 (+32.91%), AND A 37,618 (+30.07%) INCREASE OF AS LINKS. THIS ALSO INCLUDES AN INCREASE OF 13,622,753 (+38.80%) UNIQUE IP ADDRESSES OBSERVED.

THE IPV6 DATA SHOWS THE RELATIVE GROWTH OF THIS INTERNET TOPOLOGY FROM 2017 TO 2020. THE NET CHANGE IN THE NUMBER OF IPV6 ASes WAS 1,691 (+16.02%), A 13,264 (+32.28%) INCREASE IN AS LINKS, AND A NET INCREASE OF 361,733,728 (+62.51%) IPS FROM 2017 TO 2020.

IPV4 YEAR	ASes	AS LINK	IPS	BGP MONITORS	ARK MONITORS
2020	55,237	162,709	48,729,584	34	158
2017	41,557	125,091	35,106,831	25	121

IPV6 YEAR	ASes	AS LINK	IPS	BGP MONITORS
2020	12,246	54,351	940,388,247	35
2017	10,555	41,087	578,654,519	26

FOR MORE INFORMATION ABOUT THE TOPOLOGY MAPPING PROJECT, SEE: [HTTPS://WWW.CAIDA.ORG/PROJECTS/MACROSOPIC/](https://www.caida.org/projects/macrosopic/)

FOR DETAILS ON OUR AS CUSTOMER CONE RANKING METHODOLOGY BASED ON INFERRING AS RELATIONSHIPS FROM BGP DATA, SEE CAIDA'S INTRODUCTION TO RELATIONSHIP-BASED AS RANKING AT: [HTTPS://WWW.CAIDA.ORG/DATA/AS-RELATIONSHIPS/](https://www.caida.org/data/as-relationships/)

ANALYSIS TEAM: DONALD WOLFSON, BRADLEY HUFFAKER, KC CLAFFY

SOFTWARE DEVELOPMENT: YOUNG HYUN, MATTHEW LUCKIE, ALEX MARDER, BRADLEY HUFFAKER, AMOGH DHAMHERE

POSTER DESIGN: MELISSA HERNANDEZ

COPYRIGHT (C) 2020 UC REGENTS ALL RIGHTS RESERVED.

CENTER FOR APPLIED INTERNET DATA ANALYSIS 9500 GILMAN DR. MAIL STOP 0505 LA JOLLA, CA 92093-0505 (858) 534-5000

ACKNOWLEDGEMENTS THIS WORK IS SUPPORTED BY THE USA NATIONAL SCIENCE FOUNDATION (NSF) UNDER GRANTS CNS-1513283 AND CNS-141477, AND BY THE DEPARTMENT OF HOMELAND SECURITY (DHS) SCIENCE AND TECHNOLOGY DIRECTORATE, CYBER SECURITY DIVISION (DHS S&T/CSD) N66001-12-D-0130 AND HHS233201600010C. THE WORK REPRESENTS THE POSITION OF THE AUTHORS AND NOT NECESSARILY THAT OF THE NSF, DHS, OR DRDC.

ARK HOSTS:

11 VERSATEL DEUTSCHLAND GMBH, AARNET, ARIN OPERATIONS, ATT SERVICES, INC., ADVANCED SCIENCE AND TECHNOLOGY INSTITUTE, AFRICAN NETWORK INFORMATION CENTER - (AFRINIC LTD.), AKAMAI TECHNOLOGIES, INC., AMAZON.COM, INC., AMSTERDAM INTERNET EXCHANGE B.V., AMT SERVICES SRL, ANGOLA CABLES, ARKANSAS RESEARCH AND EDUCATION OPTICAL NETWORK, ASIA PACIFIC ADVANCED NETWORK - JAPAN, BDCOM ONLINE LIMITED, BENIN TELECOMS INFRASTRUCTURES SA, BH TELECOM D.D. SARAJEVO, BME, BEANFIELD TECHNOLOGIES INC., BELL CANADA, BOUYGUES TELECOM SA, BRITISH TELECOMUNICATIONS PLC, CSC - TIETEEN TIETOTEKNIKAN KESKUS OY, CZ.NIC, Z.S.P.O., CABLENET COMMUNICATION SYSTEMS LTD, CALIFORNIA STATE UNIVERSITY, OFFICE OF THE CHANCELLOR, CALLPLUS SERVICES LIMITED, CANARIE INC, CENTURYLINK COMMUNICATIONS, LLC, CHARTER COMMUNICATIONS, CHARTER COMMUNICATIONS INC, CHINA TELECOM, COLORADO STATE UNIVERSITY, COM HEM AB, COMCAST CABLE COMMUNICATIONS, LLC, CONNECTICUT EDUCATION NETWORK, CONSORCI DE SERVEIS UNIVERSITARIS DE CATALUNYA, CONSORTIUM GARR, COX COMMUNICATIONS INC., DEPAUL UNIVERSITY, DOD NETWORK INFORMATION CENTER, EBOX, EKO-KONNECT RESEARCH AND EDUCATION INITIATIVE, ENTIDAD PUBLICA EMPRESARIAL RED.ES, FREETEL, S.R.O., FUNKFEUER - VEREIN ZUR FOERDERUNG FREIER NETZE (ZVR: 814804682), GENERAL COMMUNICATION, INC., GTT COMMUNICATIONS INC., GHANA INTERNET EXCHANGE ASSOCIATION, GOOGLE FIBER INC., HEANET, IP-MAX SA, ISPA SA, IUCC - ISRAEL INTERUNIVERSITY COMPUTATION CENTER, INFORMATION TECHNOLOGY SERVICES, IN17 (SWITZERLAND) LTD., INTERNET INITIATIVE JAPAN INC., INTERNET SYSTEMS CONSORTIUM, INC., INTERNETZ, JAGUAR NETWORK SAS, JISC SERVICES LIMITED, KISTI, KT RWANDA NETWORK LTD, KANSAS RESEARCH AND EDUCATION NETWORK, KANTONSSCHULE ZUG, KWAME NKURUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, LIBERTY GLOBAL B.V., LOUISIANA BOARD OF REGENTS/LOUISIANA OPTICAL NETWORK INITIATIVE (LONI), M1 LIMITED, MCI COMMUNICATIONS SERVICES, INC. D/B/A VERIZON BUSINESS, MCMC, MAURITIUS INTERNET EXCHANGE POINT, MERIT NETWORK INC., MEXICO INTERNET EXCHANGE, MIDCONTINENT COMMUNICATIONS, NANO, NORÐNET, NORTHLAND CABLE TELEVISION INC., NTS WORKSPACE AG, NATIONAL APPLIED RESEARCH LABORATORIES, NEPAL RE NETWORK, NETIX COMMUNICATIONS LTD., NETERRA LTD., NETWORK PLATFORMS (PTY) LTD, NEVADA SYSTEM OF HIGHER EDUCATION, ONATEL (OFFICE NATIONAL DES TELECOMMUNICATIONS, PTT), OVH SAS, OKLAHOMA NETWORK FOR EDUCATION ENRICHMENT AND, ON-RAMP INDIANA, INC., ORANGE BURKINA FASO, ORANGE S.A., PCW IMS LIMITED, PRIVATE JOINT STOCK COMPANY DATAGROUP, PARTNER COMMUNICATIONS LTD., PERSPECTIVA LTD., QCELL LIMITED, QUEEN MARY AND WESTFIELD COLLEGE, UNIVERSITY OF LONDON, RCH, RCS RDS SA, RANISOKUNA-OG HASKOLANET ISLANDS HF, REMATER, RESEAUX IP EUROPEENS NETWORK COORDINATION CENTRE (RIPE NCC), RWANDA INTERNET EXCHANGE POINT (RINEX) C/O RICTA, SBCOM LIMITED, SFR SA, SIDN LABS, SURFNET BV, SWITCH, SAN DIEGO SUPERCOMPUTER CENTER, SAN JUAN CABLE, LLC, SERBIAN OPEN EXCHANGE DOD, SHAHJUR ALAM, SINGTEL OPTUS PTY LTD, SPARK NEW ZEALAND TRADING LIMITED, SUDANESE RESEARCH AND EDUCATION NETWORK, TDC A/S, TELUS COMMUNICATIONS INC., TISPA - TANZANIA INTERNET SERVICE PROVIDERS ASSOCIATION, TALKTALK COMMUNICATIONS LIMITED, TECHNISCHE UNIVERSITAET MUEENCHEN, TEKSAVVY SOLUTIONS, INC., TELECOM MALAGASY, TELENOR NORGE AS, TELIA FINLAND OY, THE GEORGE WASHINGTON UNIVERSITY, THE UNIVERSITY OF WAIKATO, TORONTO INTERNET EXCHANGE COMMUNITY, TRUSTPOWER LTD, UNINETT AS, UNIVERSITAET STUTTGART, UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH, UNIVERSITY OF HAWAII, UNIVERSITY OF ILLINOIS AT CHICAGO, UNIVERSITY OF MARYLAND, UNIVERSITY OF OREGON, UNIVERSITY OF SOUTHERN CALIFORNIA, UNIVERSITY OF WISCONSIN MADISON, UNIVERSITY OF THE VIRGIN ISLANDS, VODAFONE ESPANA S.A.U., VEREIN ZUR FOERDERUNG EINES DEUTSCHEN FORSCHUNGNETZES E.V., VERMONT-IT LIMITED LIABILITY COMPANY, VODAFONE GMBH, VODAFONE KABEL DEUTSCHLAND GMBH, VODAFONE LIBERTEL B.V., VODAFONE PORTUGAL - COMUNICACOES PESSOAS S.A., WIDE PROJECT, WALY WOLNY, WICKED BANDWIDTH, INC, WIDEBAND NETWORKS PTY LTD, ZAMBIA RESEARCH AND EDUCATION NETWORK (ZAMREN).