On The Diversity of Interdomain Routing in Africa

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Motivation

- Some knowledge of physical infrastructure
- Lack of knowledge of Local ISPs peering or transits habits
  1. Gilmore *et al.* mapped router-level and AS level graph of intra African traffic
     - More than one week snapshot taken from ZA[1]
     - Map looking like a tree with ZA at its root
     - Focus on visualisation
  2. Gupta *et al.* studied the ISPs interconnectivity in Africa
     - 66.8% of paths from their vantage points in Kenya, Tunisia, and ZA towards GGC hosted in Africa leave the continent
     - Focus on CDNs
- We investigate access to access networks connectivity

[1] 2-letter Country Code of **South Africa**

Motivation

- Perceived QoS is poor
  - High Latency & Low bandwidth

E.g.: Traceroute between adjacent ISPs in Niger

```
 1     3 ms    35 ms     1 ms  192.168.1.1
 2    73 ms    41 ms     8 ms  41.138.60.254
 3   505 ms    49 ms     8 ms  41.138.54.21
 4   583 ms   123 ms    19 ms  41.138.54.1
 5   667 ms   207 ms   164 ms  if-12-1-1.core4.LDN-London.as6453.net [80.231.76.29]
 6   431 ms   485 ms   653 ms  if-8-1509.tcore1.L78-London.as6453.net [80.231.76.50]
 7   661 ms   623 ms   658 ms  if-3-6.tcore1.PYE-Paris.as6453.net [80.231.130.86]
 8   169 ms   141 ms   305 ms  if-9-3.har1.PV0-Paris.as6453.net [195.219.224.73]
 9   428 ms   346 ms   133 ms  tengige0-0-0-3.pastr1.Paris.opentransit.net [193.251.250.5]
10   838 ms   129 ms   919 ms  gigabitethernet8-0-0.pascr4.Paris.opentransit.net [193.251.243.121]
11   920 ms   277 ms   887 ms  optbenin-6.GW.opentransit.net [193.251.254.186]
12   849 ms   357 ms   750 ms  172.16.14.1
13   700 ms   341 ms   416 ms  dns1.orange-niger.ne [41.203.159.2]
```

Traceroute performed on July 17, 2013 from an end-user of SONITEL towards the DNS of ORANGE-NIGER

- Transit costs are high
  - About US $600 millions per year spent in transit fees for intra-African traffic (AU, 2008)

Initiatives to localize transit

- Our objectives
    - Map the current African Internet topology
    - Observe its evolution as more local interconnections are established thanks to AU & ISOC's initiatives[2] promoting IXPs


AXIS Workshop in Mauritania


AXIS Workshop in Benin


AU launching Namibia IX


AXIS Workshop in Liberia


AXIS Workshop in Burkina Faso

[2] http://pages.au.int/axis

Contributions

- Identify ISPs playing major role in transit in Africa
- Analyze the impact of the characteristics of the observed interdomain paths on the end-to-end delay
- Compare v4 to v6 routing infrastructure
- Discover new peering links and IXPs

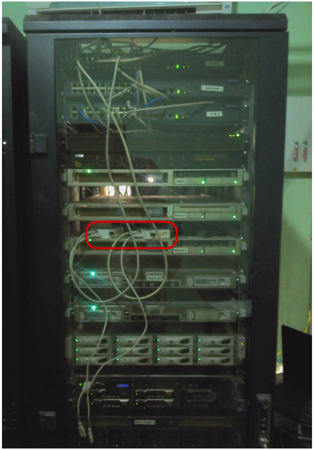
Methodology

1. Deploy vantage points on the continent
   - RIPE Atlas probes
   - Goal: build a measurement network
   - Challenges
     - Find a relevant number of hosting locations in Africa
     - Find cheap and robust devices (power outages and surges)
     - Fulfill legitimate security and privacy conditions of ISPs
2. 3 measurements campaigns over 6 months
3. Data processing
   - From traceroutes to AS sequences
     - IP to AS mapping with raw data sanity check
     - Identify major actors of African Interdomain transit
   - From traceroutes to country paths
     - IP to Country lookup with 6 DBs & Validation
     - Identify intercontinental paths serving continental connectivity

Data Collection: Our Deployment

21 probes deployed in 15 ASes hosted in 11 African countries (ISPs, IXPs, and Universities)

Countries hosting our probes in Africa



Deployment in University of Abomey Calavi (UAC), Benin

3 Measurement Campaigns

- 1st campaign: 675k v4 paris-traceroutes
  - All v4 probes
  - Entire continent
  - November 30, 2013 - April 06, 2014
- 2nd campaign: 408k v4 and 21k v6 paris-traceroutes
  - All the v4 and v6 probes
  - Southern Africa
  - June 01 - August 01, 2014
- 3rd campaign: 3k v4 paris-traceroutes
  - v4 probes
  - Gambia (GM)
  - August 6 - 16, 2014

Data Collection: 214 probes & 90 ASes involved

Country	ASes	Used	% ASes	% IPs
Angola	36907, **17400**	2	6.1%	4.8%
Benin∗	37090, 28683, 37292	15	37.5%	73.2%
Burkina Faso∗	25543, 8513, 37073	4	28.6%	64.9%
Botswana	*14988*, **37678**	3	11.1%	81.7%
Ivory Coast∗	36974, 29571	3	16.7%	68.8%
Cameroon	16637, 15964	2	7.7%	32.9%
Ethiopia	24757	2	50%	33.3%
Gabon	16058	1	11.1%	81.2%
Ghana∗	30988, 29614, 37140	2	6%	19.5%
Gambia	37309, 37524, 327719, 37323, 25250	5	71.4%	80.8%
Kenya	12556, 37061, 15399	4	3.9%	5.5%
Lesotho	**37057**	1	10%	68.5%
Morrocco∗	30983, 6713	2	25%	61.6%
Madagascar	37054, 37608	3	25%	48.8%
Mauritania∗	8657	1	33.3%	24.6%
Mauritius	37006, 37100, 23889, 30844, 327681, 3215	10	12.5%	80.5%
Mozambique	30619, 42235, **31960**, 6939∗	4	37.5%	8.9%
Namibia	36996, **33763**	4	13.3%	31.1%
Nigeria∗	30988, 30984	3	1.5%	0.9%
Niger∗	37205, 37385	4	28.6%	33.3%
Rwanda	37228, 37006	2	12.5%	66.5%
Seychelles	36867, *36958*, 36902, **37343**	20	50%	34.7%
Sudan	37197	1	14.3%	4.1%
Senegal∗	8346, 37196	4	66.7%	76.8%
Swaziland	**19711**		16.7%	68.6%
Togo∗	30982	1	50%	41.4%
Tunisia	2609	2	10%	27%
Tanzania	37045, 36909, *37084*, **37182**, **33765**	4	10.4%	24.1%
Uganda	37063	2	2.9%	12.3%
South-Africa	32653, *10474*, **36877**, 37542, *2018*, **37172**, 37251, **37358**, 5713, **12258**, **6968**, 33762, 37497, *37520*, *3741*, 29975, 16637, 22355, **11845**, **37618**, 37403, 36937, 37457, *6083*, 37253 , *37105*, 18931∗	100	7.8%	40.2%
Zambia	*37043*, **37154**, **30844**	2	18.8%	5.9%
Zimbabwe	**30844**	1	6.2%	3.2%

Step 1: IP to AS Mapping with TC & ASes classification

- Mapping process

Example

$$P_{trace}(ip_s, ip_d) = ip_s, ip_2, ip_3, ip_4, ip_5, ip_6, ip_7, ip_8, ip_9, ip_d$$

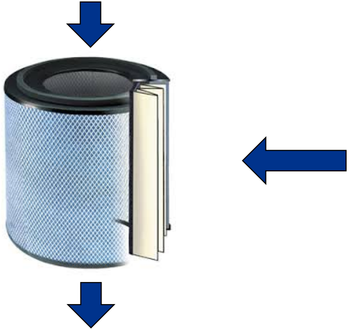
$$Mapping_{ip\rightarrow AS}(P_{trace}(ip_s, ip_d)) = \underbrace{ip_s, ip_2}_{AS_s}, \underbrace{ip_3, ip_4, ip_5, ip_6}_{AS_1}, \underbrace{ip_7, ip_8}_{AS_2}, \underbrace{ip_9, ip_d}_{AS_d}$$

$$P_{trace}(ip_s, ip_d) \xrightarrow{Mapping_{ip\rightarrow AS}} Path(AS_s, AS_d) = (AS_s, AS_1, AS_2, AS_d)$$

- 164 ASes in our dataset characterized given their geographical scope on the Internet: *WAf*, *EAf*, *SAf*, *RAf*, *Int*

Step 1: Raw Data Sanity Check

Collected Raw Data



1,862 v4 AS pairs & 116 v6 ones

Paths processing

1. Store paths whose AS source and destination match those of the probes
2. Try and complete remaining paths ends based on learned adjacencies
3. Convert AS path into AS sequence

Step 2: IP to Country lookup with 6 DBs & Validation

- **Goal:** locate 8,328 v4 & 465 v6 IPs found in traceroutes
- 6 inconsistent DBs: OpenIPMap (*OIM*), Reverse DNS (*RDNS*), Maxmind GeoIP DB (*MM*), Team Cymru DB (*TC*), AFRINIC (*AF*), Whois DB (*Whois*)
- Cross-correlation: identical CC for 65.2% v4 and 62.8% v6 IPs

	IPv4 entries		IPv6 entries			IPv4 entries		IPv6 entries	
DB	**Cover.**	**Trust**	**Cover.**	**Trust**	**DB**	**Cover.**	**Trust**	**Cover.**	**Trust**
OIM	26%	93.8%	30.1%	92.8%	*TC*	86.7%	71%	99.1%	79.4%
RDNS	56.7%	88.8%	46.7%	78.5%	*AF*	36.2%	93%	56.7%	83.7%
MM	83.9%	74%	99.1%	71.4%	*Whois*	85.6%	68%	43.2%	67.7%

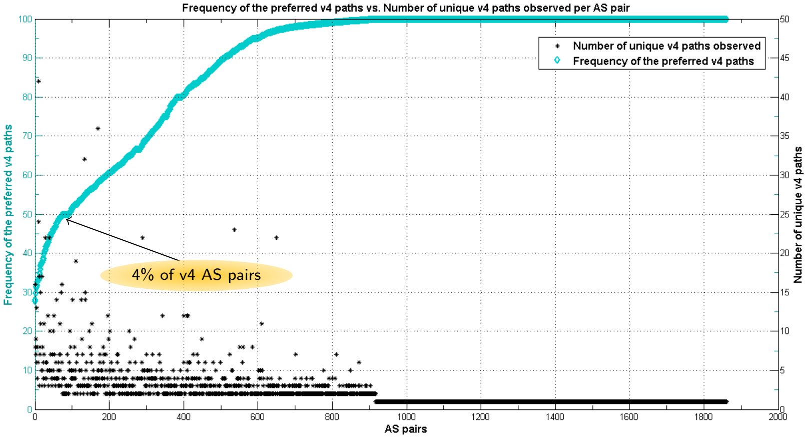
- 28.9% of v4 and 35.9% of v6 IPs geolocated by a delay-based tie-breaking approach
- 94.1% of v4 and 98.1% of v6 IPs associated with a location
- Country path (set of countries traversed by each IP path) inference

Result accuracy

- Caveats & Limitations
  - Not all probes deployed at the beginning of the 1st campaign
  - 7.2% of ASes allocated by AFRINIC involved
  - IP ranges allocated per country partially covered
  - Either an *unknown* or *unresolved* AS in 40.6% (35.9%) of the unique v4 (resp. v6) paths
- Our dataset vs. RouteViews + RIPE RIS + PCH (2013-2014)
  - Our dataset contains end-to-end african paths
  - 733 v4 (resp. 35 v6) AS adjacencies are not visible in public datasets among 960 v4 (resp. 63 v6) ones

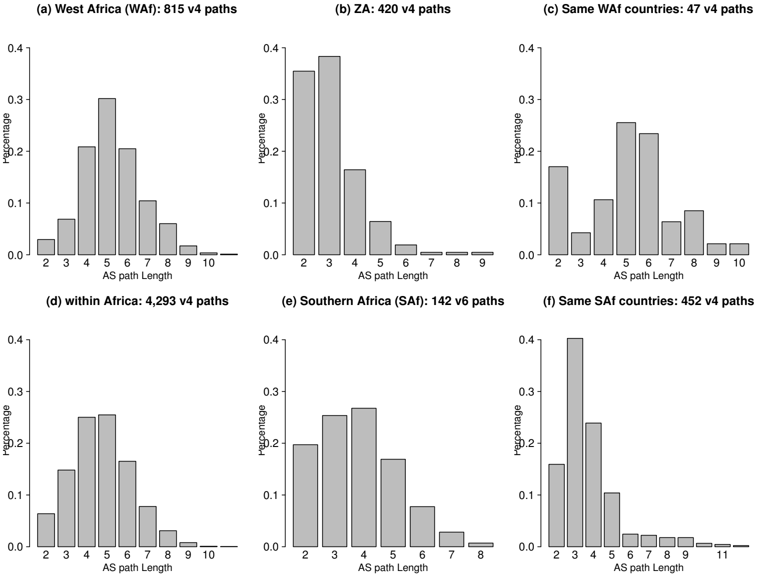
Paths dynamics: Preferred path per v4 AS pair

We identify, per AS pair, the most frequently used unique path during the campaign (its preferred path).



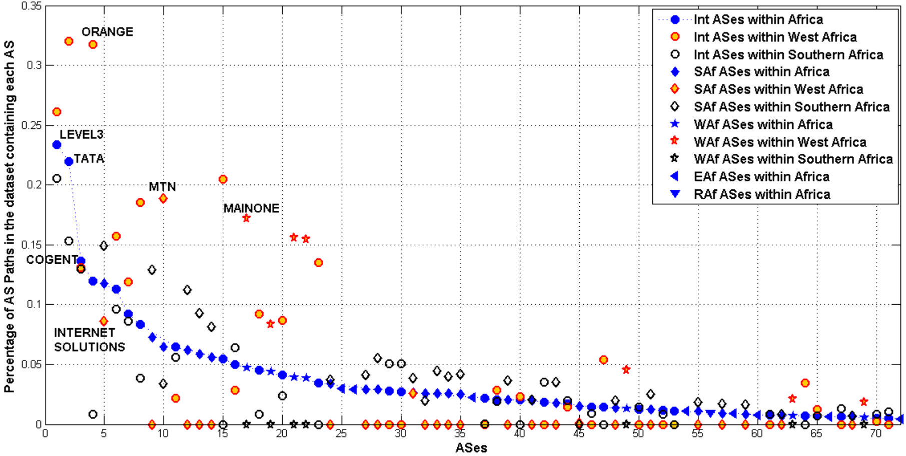
Frequency of the preferred v4 paths vs. Number of unique paths observed per AS pair

AS path length distribution



Path length distributions for all paths and for some African regions

AS-Centrality: How is the market shared among ISPs?

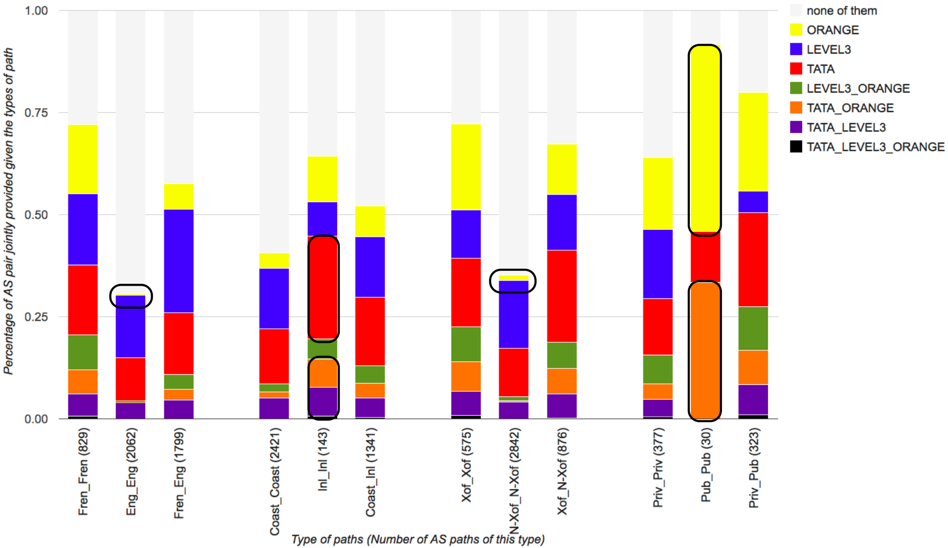


ASes are sorted according to their AS-Centrality within the African interdomain topology (blue curve)

AS-Centrality: Summary

1. Entire continent
   - 4 top ASes from US and FR
   - LEVEL3 (US) with 23.4% of the AS paths, TATA (US) with 22%, COGENT (US) with 13.6% & ORANGE (FR) with 12%
2. In West Africa
   - The market share of ORANGE drastically increases
   - TATA and ORANGE dominate with respectively 32% and 31.7% while LEVEL3 serves 20% of the AS paths
   - MTN (ZA) found on 18.9% of the paths
   - Most central **local** AS: MAINONE (NG) with 17.2%
3. In Southern Africa
   - No ISP found to completely dominate the region
   - Local ASes diversify their transit offerings and resort a lot on peering

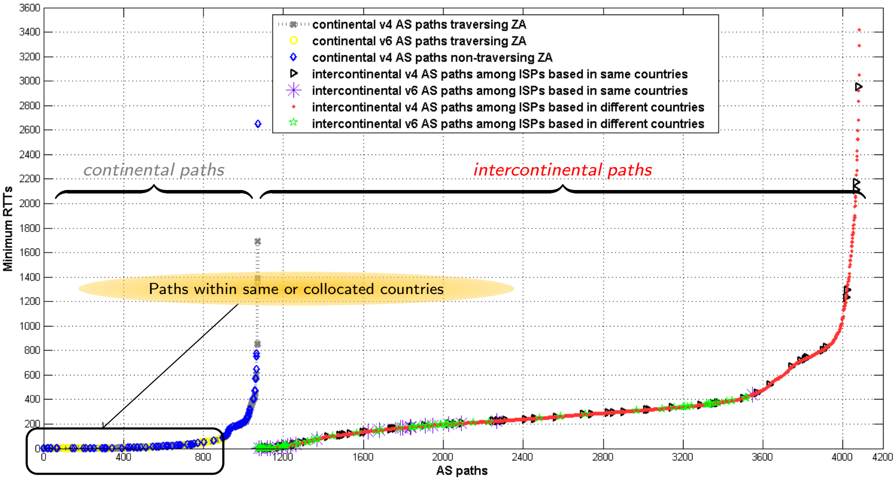
Technico-economic Insights on Routing Trends



Joint AS-centrality of LEVEL3, TATA, and ORANGE depending on the type of path

Distribution of Minimum RTT on the AS Paths

Minimum RTTs from November 30, 2013 to August 01, 2014



Minimum RTT distribution per AS path

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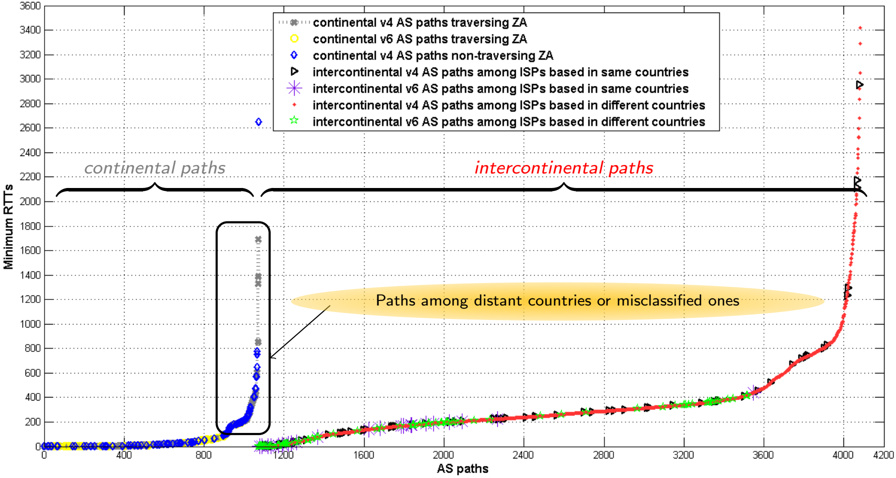

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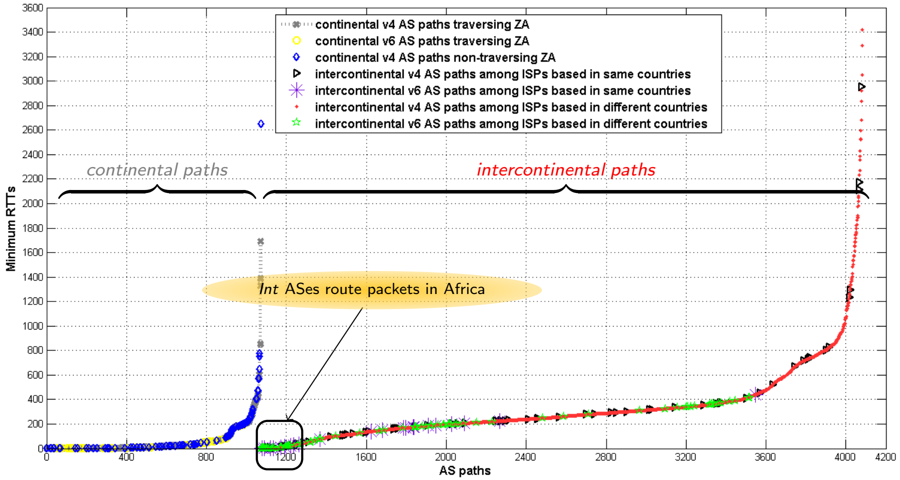

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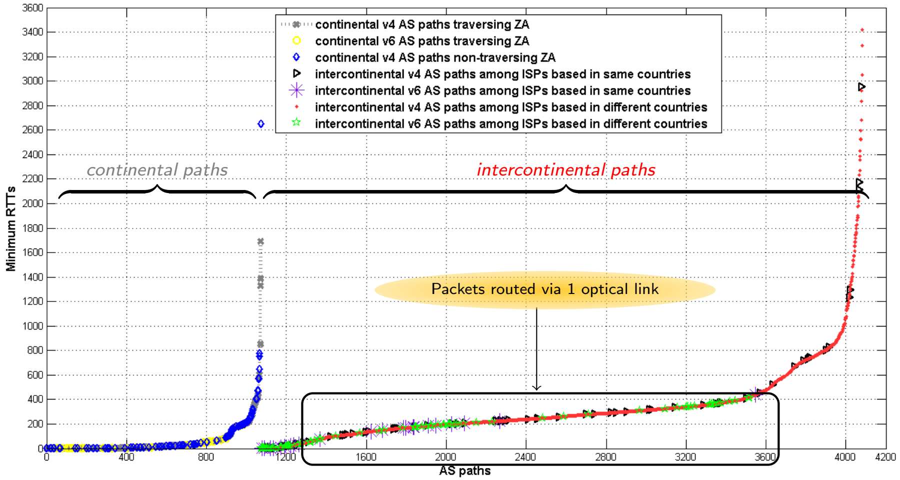

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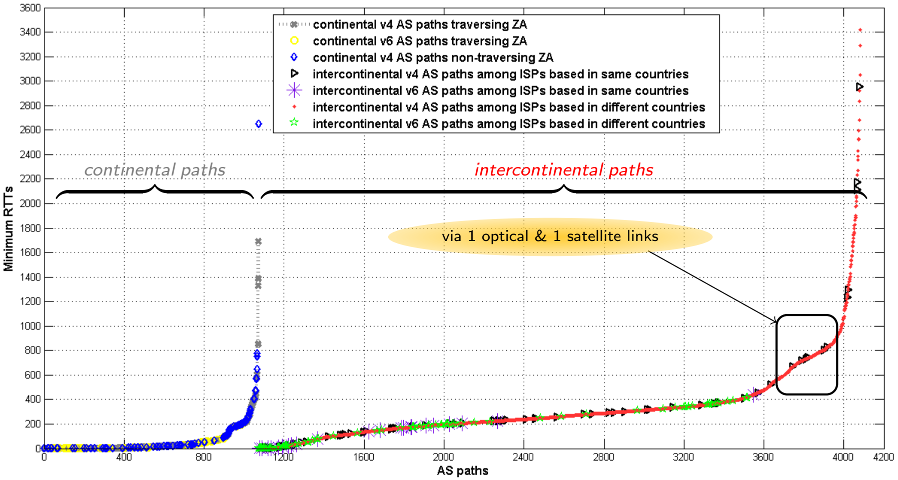

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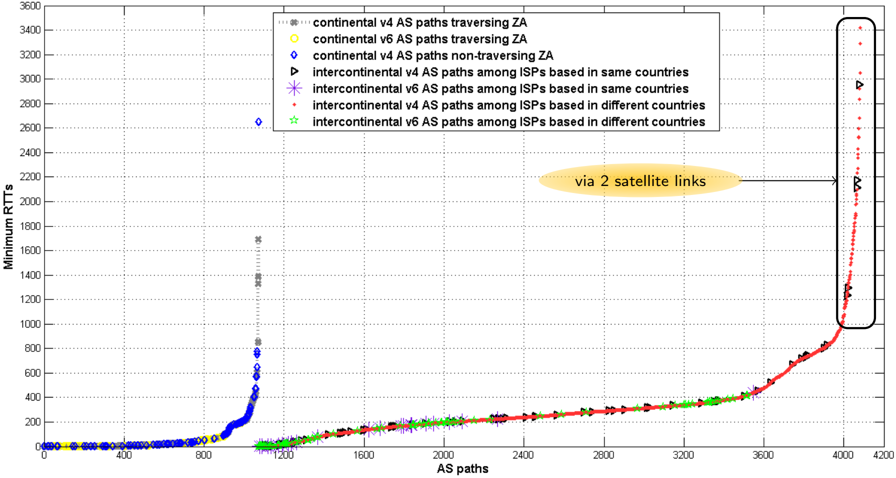
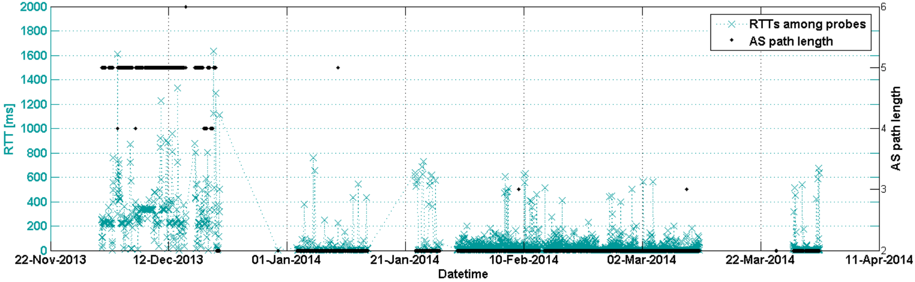


Minimum RTT distribution per AS path

IXPs found in our traces

- IXP Prefixes & peers collected from PCH, PeeringDB & CAIDA datasets
- Frequently used IXPs traversed by 58.6% of the paths going through ZA
  - **JINX**, ZA
  - **CINX**, ZA
  - **DINX**, ZA
  - **NAPAfrica**, ZA
- Recently established IXPs
  - **Seychelles-IX**, SC: CWS, Intelvision, Telecom Seychelles, and Kokonet Ltd
  - **SIXP**, GM: QCell, NetPage, and GAMTEL
  - **Benin-IX**, BJ: Benin Telecom, Isocel, Omnium des Telecoms et de l'Internet (OTI SA)

Emergence of new IXPs: case of Benin-IX, BJ



RTTs from BENIN TELECOM to ISOCEL TELECOM during Benin-IX[3] (BJ) establishment

- IX-Members hosting our probes: AS28683 (Benin-Telecom), AS37090 (Isocel Telecom), AS37292 (OTI SA)
- Delay drops from 314ms on average before December 20th, 2013 to 42ms on average after January 2nd, 2014

[3] http://www.benin-ix.org.bj

Conclusion

1. The African interdomain topology is quite stable over time
2. Africa is large
3. Observing it from a couple of location is not enough
4. ZA not affected by the lack of interconnection among ISPs
    - ZA is adopted as a hub for West-East communications
    - IXPs in ZA appears on 58% paths traversing ZA
5. Transit habits vary throughout the continent
6. Frequent usage of IXPs such as JINX, DINX, CINX, NAPAfrica, etc
7. Emergence of recently established IXPs, first benefits of initiatives promoting peering

Acknowledgements

- Whoever hosts a RIPE Atlas probe within their network
- RIPE Atlas Ambassadors
- Collaborating Institutions
  - **AFRINIC**
  - **ISOC**

Paper published at PAM (Passive and Active Measurement Conference) 2015 and available at http://wan.poly.edu/pam2015/papers/67.pdf

Technical report available at https://fourier.networks.imdea.org/external/techrep_amc/

E-mail: roderick.fanou@imdea.org

Thank You !

Questions ?

References

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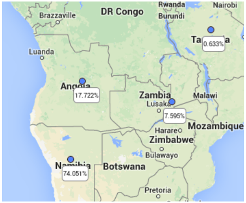
BACKUP

ASes classification

We characterize the 164 ASes of our dataset given their geographical scope on the Internet.

Geoloc. of AS37385, a *WAf* AS

Geoloc. of AS12556, a *EAf* AS



Geoloc. of AS33763, a *SAf* AS

Geoloc. of AS37529, a *RAf* AS

Geoloc. of AS3491, a *Int* AS

Source: `https://stat.ripe.net`

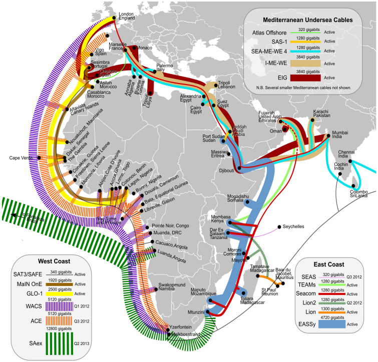
Previous work on Internet topology discovery

Extensive research: router and AS level

1. CAIDA launched Archipelago
   - 94 monitored probes,
   - only 5 deployed in Africa
2. PingER Project quantifies the digital divide
   - 46 African countries involved
   - only BF and ZA host a monitoring site
3. Augustin *et al.* mapped the IXP substrate
   - 223 of the 278 IXPs with known prefixes located in the world.
   - Unsuccessful attempts to infer many of the IXPs in Africa, as the continent only hosted 4 Looking Glasses.

Motivation

- No knowledge of African ISP peering or transit habits
  - A few previous studies for some specific countries
- Some knowledge of physical infrastructure
  - Satellite links, submarine cables



African Undersea Cables

Motivation

- No knowledge of African ISP peerings or transits habits
- Some knowledge of physical infrastructure
  - Fragmented terrestrial optical infrastructures

Terrestrial deployment of the optical fiber

Ongoing work

1. Measure the connectivity between African ISPs and the rest of the world
2. Establish a cost model for IP transit in Africa to
   - explain economically the lack of peering on the continent
   - and exhibit ground truth data and incentives for peering
3. Analyze traffic flows exchanged by ISPs