Measuring IPv6 Adoption in Africa

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Abstract. With the current IPv4 scarcity problem, deploying IPv6 is becoming increasingly important. This paper provides a first look at the state of IPv6 deployment in Africa. Using BGP routing data, we assess various aspects of IPv6 adoption. We find that, although most African countries suffer a deficit in IPv4 addresses, only 20% of African autonomous systems advertise IPv6 prefixes. IPv6 adoption is strong in Southern and Eastern Africa and weak elsewhere.

1 Introduction

In the past six years all Regional Internet Registries (RIRs), except AFRINIC, have allocated IPv4 blocks from their last /8 address block. Moreover, in 2015 ARIN completely exhausted its available IPv4 addresses. AFRINIC, however expects to run out of addresses in 2019. This places Africa in a good position to orderly manage the transition to IPv6. However, Africa faces two key challenges in the coming decades. First, the continent population is projected to grow exponentially [10]. Second, the Internet penetration rate is expected to grow by 25% in the coming three years. Addressing these challenges and pushing the Internet penetration even further requires a swift deployment of IPv6. Thus, AFRINIC has put considerable effort into educating Internet practitioners on the continent about IPv6. It has, in fact, organized over 200 training sessions in 45 countries. However, there is a lack of a comprehensive study that tracks the outcome of these efforts. In this paper, we take a small step in this direction. Using BGP routing data we track the number of African Autonomous Systems (ASes) that deploy IPv6, compare different economic regions, investigate the stability of IPv6 prefixes, and check whether African IPv4 prefixes are being transferred outside the continent.

We find that most African countries have far fewer IPv4 addresses than Internet users. However, IPv6 deployment in Africa remains at an abysmal 20%, a percentage that is lower than most of the other regions except for the Middle East. South and East African countries lead the adoption, while Northern and Western countries lag further behind. We also find that, currently, the routing stability of African IPv6 prefixes is comparable to the rest of the IPv6 Internet. African IPv4 prefixes seem to largely remain in Africa, indicating that the global exhaustion has a weak impact on Africa. Our findings point to avenues for improvements and underscore the need for a more comprehensive study of the African Internet in general and IPv6 in particular.

2 Related Work

Recently, there has been a growing interest in characterizing different aspects of Internet connectivity in Africa. Chetty *et al.* [2] studied the performance of mobile and fixed broadband connectivity in South Africa and underscored the importance of peering decisions. Gupta *et al.* [6] collected traceroutes between South Africa, Kenya, and Tunisia to investigate the interconnectivity between African Internet Service Providers (ISPs). The study underscored the poor connectivity between African ISPs and that most of them were more likely to be present at European IXPs than regional IXPs. This resulted in circuitous routing paths and consequently higher round trip delays. Zaki *et al.* measured webpage loading performance for users in Ghana and found that DNS resolution delay is the largest contributor. The measurement studies by Fanou *et al.* [4, 5] offered a wider view of the AS level topology interconnecting African ISPs, using data collected in 2014 from RIPE Atlas probes located in multiple African countries. The authors found differences in the transit and peering practices of ISPs across the African continent that depend on socio-economic factors. They also reported an extreme lack in Internet peering between African ISPs - most of the African ISPs peer with networks outside the continent, directly impacting the Internet quality-of-service and resilience. Our paper is the first to investigate the deployment of IPv6 in Africa.

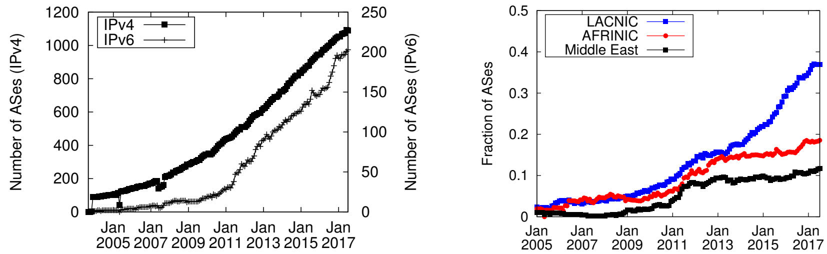
3 Datasets

In this section we briefly describe the datasets we employ in our study.
BGP data: University of Oregon's Routeviews [3] and RIPE NCC's Routing Information System [8] collect Internet routing data from a set of route collectors that establish BGP peering sessions with routers in different networks. We leverage information from these two data repositories to investigate the IPv6 deployment and stability of the routed prefixes within AFRINIC.
World Bank data: Through its open data initiative, World Bank publishes 237 datasets that cover topics from "Economy & Growth" to "Urban Development" [15]. In sections 4 and 6, we leverage World Bank data on the Internet penetration rate and population per country [15] to contextualize our results.

4 IPv4 vs IPv6 topologies

Figure 1(a) shows the number of African ASes originating IPv4 and IPv6 prefixes over time. The number of IPv6 ASes has started increasing rapidly since mid-2011. In general, the number of African ASes comprises a small fraction of the overall number of ASes in the Internet $\approx$ 1 in 50. Overall, 1089 and 203 ASes are advertising IPv4 and IPv6 prefixes, respectively. Figure 1(b) compares IPv6 deployment in Africa to Latin America and the Middle East[1]. Since 2014, IPv6 deployment in Latin America picked up and rapidly surpassed the other two regions. Note that LACNIC entered the post exhaustion phase in 2014. Further, IPv6 deployment in Africa is almost double that in the Middle East.

[1] Within the Middle East region we include countries listed in [12], but exclude Egypt as this country is registered within the AFRINIC region



(a) Number of IPv4 and IPv6 deploying ASes within AFRINIC.

(b) Fraction of dual stack ASes withtin AFRINIC, LACNIC and Middle East.

Fig. 1. Evolution of IPv4 and IPv6 topologies over time.

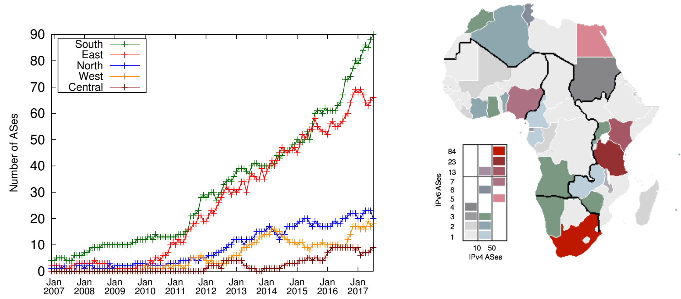
We further use the United Nations geoscheme [9] to divide Africa into sub-regions and compare IPv6 deployment across them. These sub-regions represent economical and cultural blocks. In the map in figure 2(a), we delimit with dark lines the five African sub-regions. In the same figure, we show the number of ASes deploying IPv6 in different sub-regions. Except for the central sub-region, the different sub-regions include comparable numbers of ASes that deploy IPv4.

Since 2011, most of the IPv6 deploying ASes appear to be registered in countries located in the *Southern* and *Eastern* sub-regions. These sub-regions account for more than 75% of the overall number of ASes in the AFRINIC IPv6 graph. Notably, North and West Africa lag behind despite their large populations. We further compare IPv6 adoption across countries as of July 2017. Figure 2(b) presents the number of ASes that deploy IPv4 and IPv6, respectively, per country. Overall, only 34 countries out of 54 deploy IPv6. We measure large discrepancies between countries. Most ASes in South Africa, Tanzania, and Kenya deploy IPv6. Egypt and Nigeria reflect an opposite trend. Both countries have a large number of ISPs and populations but IPv6 uptake is low. Interestingly, IPv6 adoption rate is higher for countries with small number of ASes (less than 10). These numbers again highlight the slow adoption in North and West Africa. To further understand the observed discrepancies, we use the Internet Penetration[2] per country collected from World bank [13]. We find that countries that deploy IPv6 have a higher Internet penetration rate. On average the Internet penetration rate is 27% and 11.6% for countries that deploy IPv6 and those that do not deploy it, respectively. Note that countries in the Northern sub-region have the highest Internet penetration rate, followed by the Southern and Eastern sub-regions. Hence, the lag of the Northern countries shows that IPv6 deployment is not mainly driven by Internet usage.

5 Stability of IPv6 prefixes

Another key aspect of IPv6 deployment is the stability of the routed prefixes compared to the IPv4 prefixes. To gain insight into the control plane stability of African IPv6 prefixes, we use BGP update dumps from the RIPE RIS RRC00 collector. We first identify 8 dual-stacked monitors that peer with RRC00 and provide a full routing table.

[2] The Internet Penetration within a country is given as percentage of the country's population.

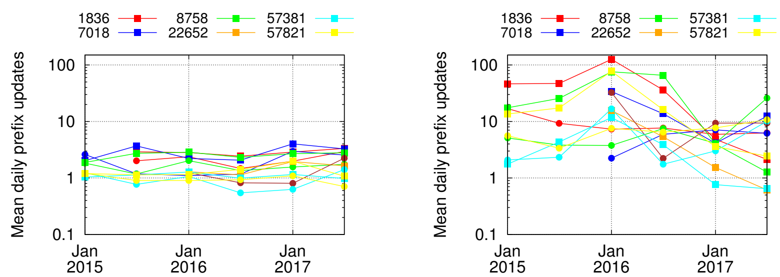


(a) Evolution of number of IPv6 deploying ASes per subregion within AFRINIC

(b) July 2017: IPv6 deploying ASes per country

Fig. 2. Number of IPv6 deploying ASes within the AFRINIC region.

Second, we count the number of updates per prefix sent by each of these monitors to the collector in six two-week periods in Jan'15, July'15, Jan'16, July'16, Jan'17, and July'17. Finally, we divide prefixes into African and non-African and compute the mean daily updates per active prefix for each period. The panels in figure 3 show the



(a) IPv4

(b) IPv6

Fig. 3. Mean daily updates per active prefix - African (squares), others (circles).

average daily prefix updates for African and non-African prefixes, for IPv4 and IPv6 respectively. African IPv4 prefixes exhibit a slightly higher average than non-African prefixes. Since the difference is very small, a plausible explanation could be differences in the length of convergence sequences, i.e., path exploration. Until July 2016, three monitors experienced a large mean daily updates for African IPv6 prefixes. This seem to normalize since January 2017, where African IPv6 prefixes start to exhibit daily means that are comparable to the rest of the Internet. Overall, IPv6 prefixes exhibit larger daily means compare to IPv4 prefixes. Our results, do not indicate that African IPv6 prefixes are particularly more unstable than the remainder of the IPv6 Internet.

6 Outlook and impact of IPv4 exhaustion

In this section, we assess the distribution of IPv4 addresses across Africa, which will be a key factor as AFRINIC enters the exhaustion phase. We also investigate the impact of mobility of African IPv4 prefixes. This is interesting since all other regions have entered the post exhaustion phase, which may encourage different actors to acquire prefixes that are allocated by AFRINIC.

6.1 Routed address space

African ASes contribute less than 4% and 11% to the global advertised IPv4 prefixes and IPv4 addresses, respectively. To understand whether IPv4 addresses are fairly distributed across Africa, we compute for each country the number of advertised IPv4 addresses over the number of Internet users. We obtain the latter value by using the World Bank's Internet penetration rate and the population of each country [13, 14]. Figure 4 shows the median, quartiles, maximum, and minimum value of this fraction per subregion and over time. Countries in the Southern sub-region have a larger fraction of IPs per user compare to other sub-regions. Almost all countries have fewer IPs than users, which indicates that ISPs in these countries are already resorting to IP-sharing schemes to serve their customers. Resorting to such solutions, however, may cause a number of issues for end-users (e.g., low performance of file transfer and video streaming sessions [1]). The projected rapid increase in the Internet penetration in African will likely exacerbate this sharing.

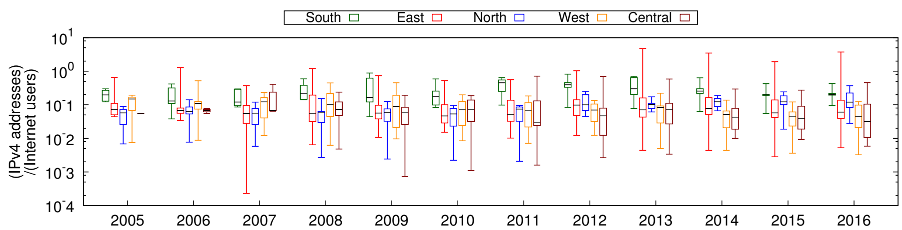


Fig. 4. Advertised IPv4 addresses/Internet users per region over time.

6.2 BGP movements

We employ the BGP-inferring methodology detailed in [7] to analyze IPv4 address space movements between AFRINIC and the other four RIRs (i.e., APNIC, ARIN, LACNIC, RIPE) that occur in the post exhaustion period. From 2011 to 2015, we identify 461 IP address space movements involving ASes registered in AFRINIC; 71% and 21% of these movements come from/to RIPE and ARIN, respectively. For the latter registry, most of the address blocks are exchanged between the US and different African countries. In the RIPE region, the top country in terms of IP movements is Great Britain, followed by Netherlands and Israel; 57.57% of the BGP movements in this region come from ASes registered in these three countries.

Reasons for the observed IP space movements include complex organizational changes or IP address space management. In June 2015, we infer 72 prefixes that move from AS33770 (Kenya Data Networks) to AS30844 (Liquid Telecommunications); the sender AS is registered in Kenya, while the receiver AS is registered in Great Britain. Investigating further these organizations we find that Kenya Data Networks was acquired by Liquid Telecommunications in 2013 [11]. Thus, the observed IP movements appear most likely due to organizational changes within Liquid Telecommunications. We find the same organization (i.e., Liquid Telecommunications) involved in another IP address space movement that occurred in July 2014; one /24 block moved from AS3300 (BT Global Services) to AS36937 (Neotel/Liquid Telecommunications South Africa).

The /24 block is registered in RIPE but has been collocated for BT via Neotel (organization acquired in 2017 by Liquid) in the AFRINIC region since May 2015. So far, our analysis does not point to an alarming rate of prefixes movements from Africa.

7 Discussion and conclusions

Using BGP routing data, this paper has taken a first look at IPv6 adoption in Africa. We find that only 20% of African ASes advertise IPv6 prefixes. Most of these ASes are in Southern and Eastern Africa. Surprisingly, countries with large populations in Northern and Western Africa lag behind. Further, there is no evidence that IPv6 adoption is picking up in Africa. We have not found any evidence that African IPv6 prefixes are particularly less stable. There is also no indication that ASes from other continents are attempting to acquire prefixes allocated by AFRINIC. Next, we plan to have a closer look at African routing stability, and IPv6 performance.

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