Dissecting the African Internet: An Intra-Continental Study

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Abstract—Africa has the lowest rate of Internet penetration in the world. This is set to change with Africa predicted to be a major driving force in expanding global uptake. Despite this, recent studies have observed generally poor Internet performance on the continent. This paper presents a large-scale measurement study of the African Internet. It focusses on mapping the performance and topological characteristics of intra-Africa connectivity. Our analysis discovers a series of “communities”, in which countries have built up low delay interconnectivity, dispelling the myth that intra-delays in Africa are universally poor. Unfortunately, this does not extend to the remainder of the continent, which typically suffers from excessively high inter-country delays, often exceeding 300ms. To explain this, we explore the intra-continental topology to discover a number of shortcomings, most notably an excessive reliance on international transit providers rather than local peering.

I. INTRODUCTION

Africa currently has the lowest rate of Internet penetration in the world [1], with many unable to afford access [26]. This is set to change with Africa predicted to be a major driving force in expanding global uptake. Despite this, recent studies have observed generally poor performance on the continent, e.g., slow download speeds [12]. Although the exact causality is yet to be seen, there are a number of general trends that can be highlighted, including the use of high-delay access technologies and suboptimal country-level topologies [11]. We argue that understanding and quantifying these issues is critical for not only their short-term amelioration, but also for informing future design and deployment strategies, e.g., for CDNs in the region. Importantly, the underdeveloped (but rapidly expanding) nature of Africa’s Internet ecosystem means that this must be done now.

Although there have been a number of seminal studies that have explored global Internet performance and topology [5], [10], [28], the diversity of networking infrastructure across Africa makes them largely inapplicable. Of particular interest is the means by which the 54 countries of Africa are interconnected; only by improving this can a local Africa-wide Internet ecosystem flourish. For example, the deployment of much-needed African datacentres depends on underlying connectivity to make them available to the wider region [17]. Thus, in this paper we ask a simple question: What is the inter-country performance in Africa, and how is it impacted by topology and interconnection strategies? Our long term goal is to exploit this newfound understanding for informing future protocol and application developments in the region.

Answering the above question, however, requires vantage points across Africa — a challenge which has prevented many studies from focussing on Africa. Hence, we exploit a new platform, Speedchecker (a commercial measurement service), which has around 850 probes in Africa. This allows us to cover 322 networks and 52 countries (§III). Our measurements reveal a highly uneven performance distribution, with some countries exhibiting European-like delays (e.g., South Africa → Botswana takes 25ms), whilst others suffer from delays exceeding 300ms (going up to 900ms). For context, typical latency in North America is <45ms and <30ms for Europe [2]. This leads us to explore patterns and cluster countries into groups of high connectivity (§IV). This reveals distinct geographical patterns, as well as a number of unusual corner cases, where more distant countries actually have lower delay than nearer countries (§V). We find that some countries and regions have built up relatively low delay infrastructure, although many others have not. To explore this, we inspect the continent’s topology to identify key issues in the region (§VI). We find that the use of intercontinental transit (rather than local interdomain peering) plays a key role in inflating delays. This sees Africa→Africa packets leaving the continent via international transit, simply to re-enter again in a circuitous manner. This dramatically increases network operator costs, due to the high prices charged for international transit [8]. It also makes certain common infrastructure deployment practices unworkable, e.g., it makes little sense to deploy content servers at regional exchange points if networks do not peer there [12]. Whereas we quantify the performance impact these decisions have, we also observe cases in which using European or American upstream providers actually results in better performance than using African upstream networks. Such observations best highlight the immediate challenges in the region, and help explain the difficulty in accessing and deploying services on a continent-wide basis (as exemplified by several studies [19], [23]). Our findings offer targeted insight into how these problems can be addressed (§VII).

II. RELATED WORK

Recent studies have begun to recognise the traffic engineering problems in Africa’s Internet topology [7], [11], [14], [15]. Primarily, these studies have highlighted Inter-
net performance issues that are attributed to a lack of peering amongst Africa’s ISPs. Due to this, models that aim to predict global latencies have consistently modelled Africa as the slowest in the world [16], [18]. Studies have also looked at inefficient DNS configurations, a lack of local content caching servers, as well as a lack of cross-border cable systems [12], [17], [30].

Gilmore et al. [14] performed a logical mapping of Africa’s Internet topology, highlighting the router level and Autonomous System (AS) level paths followed by intra-Africa traffic. Their analysis was based on traceroute data obtained from measurements conducted from a single vantage point in South Africa towards all AFRINIC allocated IP addresses. The key limitation of this work was that it only contained one-way paths from South Africa.

Gupta et al. [15] increased the number of vantage points, although they still exclusively launched probes from South Africa. Similarly, Chavula et al. [7] used 5 nodes from the CAIDA Archipelago platform to conduct logical topology mapping for Africa’s national research and education networks. They found that over 75% of Africa’s inter-university traffic followed intercontinental routes. Although more extensive than [14], these restricted studies are still small-scale and provide insights into a small number of countries and networks. To the best of our knowledge, the first study to take a more wide-area perspective was by Fanou et al. [11]. This work launched traceroute measurements from 90 ASes. Their results too showed a lack of direct interconnection amongst African ISPs.

Our research differs from these past works in three key ways. First, our focus is not on enumerating traceroute paths leaving the continent. Instead, we strive to characterise the performance of the inter-country interactions. Our rationale is that the future success of local services depends on high performance underlying connectivity within the whole region (not leaving the region). We therefore provide insight into the readiness of countries to host and provide services to neighbouring countries across Africa. Second, we do not simply observe network performance — we explore the causality behind high delays, and the implications of the topology configurations observed. Further, unlike prior studies, we utilise this data to identify the key clusters of connectivity in the region. Third, our study achieves the above goals on a scale not seen before, covering 52 countries and 319 networks across Africa. To the best of our knowledge, this paper constitutes the widest and deepest analysis of the African Internet available.

III. DATA COLLECTION

Collecting data samples that represent regional connectivity is not trivial, as it requires many vantage points (located in a diverse set of networks). We therefore begin by describing our collection of path data across Africa.

A. Measurement platform

Due to the deficit of research infrastructure in Africa, there are only two feasible platforms for launching our measurements: (i) RIPE Atlas,¹ which is known for providing a worldwide network of physical probes to their members; and (ii) Speedchecker,² a platform consisting of software agents installed on desktop clients. The Speedchecker platform offers Internet performance monitoring through ICMP ping, DNS and traceroute. Both platforms have probes deployed in Africa. At the moment of writing, RIPE Atlas had 229 active probes in Africa, covering 36 African countries, whilst the Speedchecker platform has nearly 850 installations covering 52 countries. Unfortunately, RIPE Atlas also has a strong bias towards university networks, as well as around half of all probes hosted in South Africa. In contrast, Speedchecker covers 91% of African countries and is not biased towards university networks. Hence, for this study, we select Speedchecker.

Note that using other global measurement platforms and datasets (e.g., CAIDA’s Ark) would be unsuitable as they have few vantage points in Africa and therefore can only trace paths routes into Africa — not within the continent.

B. Data collection

We have used Speedchecker to collect two core datasets based on latency and topology measurements. Latency data was collected by launching pings from all Africa-based Speedchecker probes to randomly selected Speedtest servers located in African countries. There are 213 Speedtest servers in Africa, covering 42 countries (from 54). Note that this leaves countries where we have sources (Speedchecker clients) but not destinations (Speedtest servers). In these cases, we cannot compute the intra-country delays, and therefore exclude them from later analysis. Full details of Speedtest and its locations can be found online.³ The measurements were launched four times a day, at 00:00, 06:00, 12:00, and 18:00 probe time.⁴ In each case, we randomly selected up to 20 probes from all countries in that time zone. These probes were then instructed to launch 10 consecutive pings (one second apart) to their randomly chosen Speedtest server. Following this, the Speedchecker API returns the minimum ping delay observed, giving us the “best” observed performance at that time period.

By repeating this each day for 3 months, we garnered comprehensive delay measurements across the continent, consisting of 42.2k ping samples. To quantify the coverage, Figure 1 presents the percentage of networks that the Speedchecker probes covered across each country (we take the overall count from the AFRINIC allocation files). In total, our data covers 319 networks across 52 African

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¹http://www.atlas.ripe.net/
²http://www.speedchecker.xyz/
³http://www.speedtest.net/
⁴Note that the times were based on the local time zone
countries. As shown in Figure 1 (top CDF), 50% of the countries had at least 20% of their networks probed.

To complement the raw delay measurements, we also launched a parallel traceroute campaign using the same setup. At 00:00, 06:00, 12:00, and 18:00 local time, we launched traceroutes from up to 20 random probes in that timezone, targeting random Speedtest servers across Africa. This campaign covered 49 countries, and consisted of 31.5k traceroute measurements from 207 distinct networks. For each router hop within the traceroute data, we attached the Autonomous System (AS) using the RIPE Routing Information Service.\(^5\) We also attach the location of each hop using MaxMind GeoLite2-City. We restrict ourselves to country-level analysis, as this has been found to have high accuracy [27].

IV. Clustering Communities of Connectivity

One of our goals is to detect the strengths and weaknesses of the connectivity in the African Internet. As a precursor to this, we analyse the relationships between countries by clustering them based on their latencies.

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\(^5\)http://ris.ripe.net/

A. Clustering methodology

We convert the latency measurements into a graph structure \((G)\) that represents connectivity between countries. Each node in the graph is a country, whilst a link represents a set of latency measurements between two countries. The links are weighted by the median latency observed.

Once the weighted undirected graph \(G\) is computed, we cluster countries based on their latency-defined distance using the Louvain algorithm [3]. The Louvain community detection algorithm is based on the modularity function, which performs clustering based on the measure of partition between communities found in a network. Let \(G = (V,E)\) be the graph of vertices \(V\) representing countries and \(E\), a set of undirected edges representing latencies. Suppose \(u,v \in V\), \(e(u,v) \in E\) has a weight \(w(u,v)\), which is the median latencies from \(u \rightarrow v\) and \(v \rightarrow u\). The community detection algorithm partitions the graph into communities, \(C\), as expressed by Equations (1) and (2). This is very similar to the problem identified by Newman et al. in [22].

\[
\forall c_i \in C \cap c_j = \emptyset, \forall c_i, c_j \in C
\]

(1)

(2)

The quality of the partitioning is measured using modularity \(Q\) [21], where \(-1 < Q < 1\). We define modularity as the difference between the number of intra-cluster communities and the expected number of edges. Executing the algorithm outputs the set of strongly connected communities. It is expressed as follows:

\[
Q = \sum_{c \in C} \left[ \frac{\sum_{i \in c} w_{i,j}^2}{2m} - \frac{(\sum_{i \in c} m_{i,j}^2)}{4m^2} \right]
\]

(3)

where \(\sum_{i \in c} w_{i,j}\) is the sum of all weights (latencies) of the all internal edges of a community \(c\) and \(\sum_{j \in c} m_{i,j}\) is the sum of weights (latencies) from edges incident to any vertex in community \(c\), \(m = \sum_{e(u,v) \in E} w_{u,v}\) is used to normalise the modularity and is obtained by adding the latencies across the entire graph. Once we know how to calculate modularity, we run the Louvain algorithm [24] to greedily maximise the modularity gain when moving a vertex \(u\) to community \(c\).

B. Clustering results

The algorithm returns countries grouped into four different clusters, which correspond to the regions of Northern, Southern, Eastern, and Western Africa. Figure 2 presents a map of the clusters. Unsurprisingly, the clusters follow clear geographical properties. However, there are a number of unusual trends: most noticeably, Guinea, Liberia and Benin on the West coast, with neighbouring countries from a different cluster. Similarly, Madagascar,
Seychelles and the islands of the Indian Ocean, are clustered alongside countries in the North. Somalia, on the East coast, is clustered with countries on the West coast. This suggests that geography is not the sole factor in defining delay. We explore this in §V and §VI.

The clustering algorithm also returned two special cases: Angola and Ethiopia, which were placed in separate clusters on their own. To understand this, we take a closer look at their latency profiles. Figure 3 depicts the distribution of RTTs between these countries and all other countries in the four clusters. We show Libya as an example of a country that shows typical trends. It can be seen that Libya exhibits very different delays across the different clusters. It has low delay to countries in the Northern cluster, but high delay to all others. In contrast, Angola and Ethiopia have roughly equivalent performance to countries within all clusters. For example, the median delay from Angola to all clusters is consistently above 200 ms. This explains why the algorithm could not allocate them to any clusters.

To allocate them to an appropriate cluster, we manually inspect the data. The median delay from Angola ↔ Western cluster is 273 ms, which is 1.33x the median intra-cluster delay. The other options considered resulted in 8x, 2.7x, and 6.8x to the Eastern, Northern, and Southern clusters. Hence, we allocate Angola to the Western cluster. We computed the same ratios for Ethiopia, which were placed in separate clusters on their own. To understand this, we take a closer look at their latency profiles. Figure 3 depicts the distribution of RTTs between these countries and all other countries in the four clusters. We show Libya as an example of a country that shows typical trends. It can be seen that Libya exhibits very different delays across the different clusters. It has low delay to countries in the Northern cluster, but high delay to all others. In contrast, Angola and Ethiopia have roughly equivalent performance to countries within all clusters. For example, the median delay from Angola to all clusters is consistently above 200 ms. This explains why the algorithm could not allocate them to any clusters.

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V. Quantifying Delay in Africa

Before exploring the topology of Africa, we quantify the performance attained between its countries. Performance could be captured by many metrics, however, we exclusively focus on round trip times (RTT) as a proxy for connectivity quality. Note that it is widely reported that delay is now the most prominent bottleneck of protocol and application performance [4], [9].

A. Exploring inter-country delays

Figure 5 presents a heatmap of the inter-country median delays observed (where the country originating the measurement is displayed vertically on the left and the target country is displayed horizontally on top). As expected, the lowest delays can mostly be observed within intra-country delays. There are also a number of inter-country delays that exhibit similarly low delay characteristics. These are primarily countries with close geographical proximity. For example, the delay between Tunisia and Algeria is just 48ms. This can be compared against the intra-country delays within these countries, which are 25ms and 44ms respectively. Examples of non-neighbouring countries with delays below 90ms include Kenya and Zimbabwe at 85ms, and Mauritius and Tanzania at 80ms.

To generalise this, Figure 4 presents a CDF of the inter and intra country delays. For context, we include the same data from the Latin America and the Caribbean (LAC) region using the same Speedchecker methodology (taken from [13]). Across the entire Africa dataset, intra-country latencies average at 78ms. This is significantly higher than that seen in more developed regions; the average monthly latency in North America is <45ms and <30ms for Europe [2]. Our results are, however, close to the 76ms measured in the LAC region [13] (which is in a similar process of Internet development). However, the story is significantly different when comparing inter-country delays, also shown in Figure 4. Africa has a mean of 280ms, whilst the LAC region has only 154ms; a factor of 1.8x. 9% of inter-country delays exceed 400ms, and 2% exceed 500ms (shown in red). Again, this can be compared against the measurements performed in the LAC region, where less than 1% of country pairs have a latency greater than 500ms. In fact, these African delays are so poor that they go well beyond the sensitivity analysis ranges used by past studies that inspect the impact of network delay on things like web page load times [29] and video streaming performance [20]. For example, ranges of only 0–100ms were tested in [20]. In other words, past application performance studies would need to be entirely repeated with vastly higher delay parameters to understand their behaviour in Africa.
of inter-cluster delays, the Southern and Eastern clusters have the lowest delay between them (median of 92ms). For allocating development funding, this offers an effective measure for general quality of regional connectivity.

There is, however, a key limitation in the above analysis. Small countries in close proximity will naturally have lower propagation delays (assuming direct links). Thus, in some cases, low RTT may simply be a property of geography. To address this, we next normalise the delays based on the geodesic path between the source and destination; this captures the delay stretch. We compute the stretch, for each ping sample, \( p \), as:

\[
\text{stretch}^p = \frac{d}{(\text{RTT}^p)} \sqrt{\frac{c}{0.66}}
\]  

(4)

where \( d \) is distance to the destination and \( c \) is the speed of light. We reduce \( c \) by a factor of 2/3 to approximate propagation time through optical fibre [25]. \( \text{RTT}^p \) is taken as the minimal RTT (in seconds) measured from a given ping sample, \( p \). The stretch therefore the ratio between the optimal observed RTT and the theoretical minimum RTT.

Figure 6b shows a heatmap containing the stretch value between each cluster. High values indicate strong connectivity; for example, a value of 20 indicates that the speed of the packet is 20% of the maximum theoretical speed. By comparing figures 6a and 6b we immediately identify differences. In figure 6b, some inter-cluster delays are actually lower than intra-cluster delays when measured using this normalised metric. In other words, some low observed RTTs are a property of geography — the clusters are still highly suboptimal. A good example is the Southern ↔ Eastern cluster, which has a high median delay of 92ms, yet performs far better when normalised by distance. Whereas Southern ↔ Southern only attains 7% of the optimal speed (46ms), Southern ↔ Eastern gains 16%. That said, there are some results that are consistent between the two heatmaps, namely the poor performance of the Western cluster. To explore why this might be, we initially checked Somalia, as it is actually geographically located on the Eastern coast (cf. Figure 2). However, curiously, Somalia actually has the fastest intra-cluster ping measurements in the Western cluster; located.
at around 20% of 0.66c. The ping speeds in the remaining countries, instead, attained around just 5% of 0.66c. The next section explores the reason for these unusual findings.

VI. DISSECTING PATHS ACROSS AFRICA

The previous section has highlighted the high network delays suffered when traversing countries in Africa. Next we inspect the reasons behind this using the topology maps obtained via our traceroute campaign.

A. Exploring topological traits

To begin, Figure 8 presents the distribution of hop counts across all traceroutes within the same clusters (i.e., where the Speedchecker client and Speedtest server are in the same cluster). It can be seen that the traceroutes originating from the Eastern cluster have marginally fewer hops than the others (median 5 router hops). Curiously, however, the Western cluster (which is the worst performing) also has fewer AS (median 3) and router-level (median 6) hops than the Northern and Southern clusters. This suggests that the higher delays are not simply driven by hop counts. Thus, Figure 9 presents a geographical map showing the upstream providers serving all networks sampled in each country. This offers immediate insight into the reasons behind the high delays previous seen. We find that a significant number of networks rely on upstream providers outside of the continent (e.g., via remote peering [6]). Considering all traceroutes, we find that 37.8% go through upstream providers outside of Africa. The remainder inside Africa are heavily biased towards a few prominent countries, namely South Africa and Mauritius via the West Indian Ocean Cable Company (WIOCC). 6.6% and 4.5% of traces upstream through them, respectively. Hence, although the hop counts do not differ significantly, the locations of the networks do. Figure 10 presents the most popular countries for hosting upstream networks. It can be seen that South Africa offers the most upstream provision, followed by the UK and US. Interestingly, the use of the these upstreams differs substantially based on cluster, with regional hubs emerging, e.g., Uganda for the Eastern cluster and South Africa for the Southern cluster.

Next, we inspect the specific upstream networks involved in these AS hops. Table I presents a list of the top upstream providers ranked by the number of edge networks connected to them by their first AS hop. The Top 10, alone, provide services to nearly half of all sampled networks. Rather than observing local tier-2 operators, the list is dominated by international tier-1 operators. Anecdotally, many African network operators prefer to use such services due to their perceived reliability and international reputation (despite the performance conse-

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6We define upstream as the first AS hop after the origin AS hosting the Speedchecker client.
TABLE I: Top 10 networks providing direct upstream access to African networks (first AS hop considered). Percentage is based on the fraction of traceroutes the ASN appears as a direct upstream.

<table>
<thead>
<tr>
<th>Rank</th>
<th>ASN</th>
<th>Network info.</th>
<th>Perc.</th>
<th>Centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>174</td>
<td>Cogent Communications</td>
<td>10.3%</td>
<td>0.195</td>
</tr>
<tr>
<td>2</td>
<td>3356</td>
<td>Level 3 Communications</td>
<td>7.4%</td>
<td>0.087</td>
</tr>
<tr>
<td>3</td>
<td>37100</td>
<td>SEACOM</td>
<td>7.1%</td>
<td>0.065</td>
</tr>
<tr>
<td>4</td>
<td>6762</td>
<td>Sparkle (TIM Group)</td>
<td>6.6%</td>
<td>0.071</td>
</tr>
<tr>
<td>5</td>
<td>30844</td>
<td>Liquid Telecom</td>
<td>5.9%</td>
<td>0.137</td>
</tr>
<tr>
<td>6</td>
<td>5511</td>
<td>France Telecom (Orange)</td>
<td>3.9%</td>
<td>0.044</td>
</tr>
<tr>
<td>7</td>
<td>57023</td>
<td>Oranlink</td>
<td>2.3%</td>
<td>0.003</td>
</tr>
<tr>
<td>8</td>
<td>6453</td>
<td>TATA COMMS. - US</td>
<td>2.2%</td>
<td>0.013</td>
</tr>
<tr>
<td>9</td>
<td>16637</td>
<td>MTN</td>
<td>2.1%</td>
<td>0.029</td>
</tr>
<tr>
<td>10</td>
<td>5713</td>
<td>Telkom SA Ltd</td>
<td>2.0%</td>
<td>0.019</td>
</tr>
</tbody>
</table>

The above has shown that many countries rely on international and intercontinental upstream providers. An obvious follow-up is what proportion of paths from each country follow these intercontinental routes. To answer this, we inspect the hops taken through each AS on a per-sample basis. Figure 11 shows the percentage of traceroute hops that traverse each region. For each traceroute we elaborated the sequence of distinct ASes that the traceroute went through. Each stage in the figure indicates the AS path traversed so far. The first column corresponds with 0 hop count (origin), the second one with the first hop count, etc. The first observation is that a large fraction of traceroutes have their first hop in an overseas regions (50%), in particular through Europe. Our data shows that Europe acts as a major Internet provider to networks across Africa (35%), and to the Northern cluster in particular (transiting ≈40% of the cluster’s traceroutes). Considering the geographic distance, it is surprising that 12% of African connections are routed through N. America. Arabia and Asia only account for 3% of outgoing paths. This also disproves the theory that only Northern African countries rely on Europe and Arabia.

Figure 11 further shows that intercontinental hops are not limited to the immediate (first hop) upstream provider. We find that even edge ASes that utilise African upstream providers see their traffic leaving the continent (potentially without their prior knowledge). This is because their upstream providers, in turn, utilise international transit rather than local peering. In total, 28% of interdomain packet handling we observe has at least one AS hop in another continent, and 14% are routed via overseas parties for as many as 4 interdomain hops before returning to African operators. A particular case of this phenomena is the traffic exchange between N. America and Europe: 3.5% of the traceroute paths are routed between these two locations, even though all source and destination locations are within Africa. Naturally, this becomes a challenging problem to address as it is outside of the control of African edge networks, which largely depend on the routing decisions made by their upstream operator.

B. What are the performance implications?

The above shows that a large number of operators choose to utilise upstream providers outside of their own country (or even continent). To explore the implications of this, Figure 13 presents the minimum delay from African ASes to their upstream providers, i.e., the minimum RTT to the first hop outside the edge AS. We use the minimum to capture the best possible scenario.

It can be seen that networks using upstream providers within their own cluster gain the best first-hop performance (median 40ms). Curiously, the Western cluster is amongst the best performing when using this metric. Note, however, that the use of a local upstream provider does not guarantee high end-to-end performance. For example, in the Western cluster, 3.15% of traceroutes exiting the cluster are still intercontinental despite the use of a local first-hop upstream.

As a consequence of this, it can also be seen that regions that utilise intercontinental upstream providers gain far lower performance. For instance, Southern networks that use Southern upstream providers witness a minimum of 47ms delay; this can be compared against 227ms when using N. American providers. Strange though, intercontinental delays are lower than some inter-cluster delays. Southern networks that use upstream providers in the Northern cluster see a minimum delay of 299ms. In fact, on average, clusters are marginally closer to overseas
upstreams than to upstreams in other African clusters (180 vs. 195 ms). That said, intra-cluster upstream consistently outperform both of these scenarios.

We can also investigate the overall impact these decisions have across our entire set of latency measurements. We split all ping samples into (i) networks that use an upstream provider within the same cluster; (ii) networks that use an African upstream in another cluster; (iii) networks that use an overseas provider for over 50% of traceroutes observed. Figure 12 presents CDFs of RTTs seen within each group. It can be seen that, indeed, the best performing networks are those that upstream through a transit network within their own cluster (203 ms median). In line with earlier discussions, the delta between networks using international providers and those based in other African clusters is limited (268 vs. 243 ms median).

To take an initial step towards evaluating the potential performance enhancements of networks using local interconnection, we briefly experiment with alternative upstream configurations. Specifically, for intra-cluster latencies, we replace the overseas upstream hops from all paths by the median intra-cluster hop. Implementing such a policy would result in significant performance enhancements, with an 81% improvement for networks in the Eastern cluster (21 ms to 4 ms), as well as 45% (60 ms to 33 ms) and 72% (47 ms to 13 ms) for the Northern and Southern clusters respectively. This therefore reveals the significant enhancements caused by removing foreign transit networks.

C. Revisiting Angola and Ethiopia

We have already highlighted the problems with allocating Angola and Ethiopia to clusters (§IV). This motivates us to explore the topological reasons that caused the result. Note these were allocated to the Western cluster which consistently has performed the worst. To explain these results, we start by inspecting the upstream provision. Angola and Ethiopia have very different upstream selections: Ethiopia upstreams entirely through overseas providers, whilst Angola does it for 34% of the paths observed. In the case of Ethiopia, paths go through Europe (70%) and North America (30%). Considering the latency penalty of long haul links (Ethiopia \(\rightarrow\) Europe at 354 ms, and Ethiopia \(\rightarrow\) North America at 144 ms), the high RTT values are primarily driven by these circuitous routes. In contrast, Angola uses African upstream providers in 66% of traceroute samples. This makes it a more interesting case as, theoretically, it should therefore avoid connectivity through long haul links. However, when including the second AS hop, we find that an additional 16% of traceroute samples go through the Southern cluster and are subsequently routed through Europe, adding to a total of 50% overseas paths (routed either direct or indirectly). In other words, despite networks in Angola not directly using international transit, their upstream providers do so. When combined, this distorts delays from both Ethiopia and Angola and pushes them away from the centre on any of the existing clusters, explaining the observations made in §IV.

These patterns also explain the poor performance exhibited by the Western cluster in general. For example, whereas the median intra-cluster delay of the Southern cluster is 46 ms, it is 215 for the Western. When looking into the topology of the Western cluster, we further noticed that just 38% of hops occur between ASes within the cluster. Those intra-cluster hops benefit from shorter distances and have a median delay of 24 ms. The rest of hops are mostly Western \(\rightarrow\) Europe hops (9.4%) which account for an added 132 ms (each way), and Europe \(\leftrightarrow\) Europe (21%), with marginal penalties. Thus, whereas other regions have built up strong intra-cluster connectivity, the Western region still lacks this.

VII. Conclusions and Future Work

This paper has evaluated inter-country latencies across Africa. We have quantified latencies across 91% of African countries, and by inspecting traceroutes have identified a number of failings in the regional topology that require urgent attention. To the best of our knowledge, this is the largest scale study of its kind in Africa (§III).

There are several key conclusions to draw. We have found that many intra-country delays in Africa have reached relatively developed levels (§V-A). We observed a set of intra-country samples below 40 ms (e.g., Benin, Egypt, South Africa), and below 30 ms (Ivory Coast, Réunion, Mauritius). Furthermore, we identify a series of
country clusters, which have also built up strong interconnectivity. Universally characterising the African Internet as poor is therefore misplaced. However, by corollary, this means that inter-cluster delays are significantly worse (§IV). Our clustering has shown that performance varies heavily based on region: Whereas some clusters have relatively low levels of delay (e.g., the median intra-cluster delay in the South is just 46ms), other areas have consistently high delay (§V-B). For example, the Western cluster suffers from intra-cluster delays that are similar to its inter-cluster delays. Our analysis confirmed that this is largely driven by the use of transit providers, who route traffic through Europe and N. America (§VI). Curiously, this was not necessarily the immediate upstream provider chosen by the edge network but, instead, intermediate operators who transit out of the continent after 2 or 3 AS hops. This makes it difficult for edge networks to unilaterally address the problem. Our work therefore offers an effective means for automatically extracting regions and networks that critically require more local peering and interconnection. Only by addressing these issues will it become possible for high performance service hosting and interaction across the entire African continent.

There are many remaining topics to explore, such as the relationship between physical infrastructure and delay. For those countries with a direct physical connection, it would be expected that RTT would be lower. In order to find a relationship between infrastructure and RTT, there is need for further analysis of the submarine or terrestrial cables. It is also worth noting that inter-country delays are only one part of the problem, and it is necessary to investigate delays between countries and popular web/content infrastructure. Further, we believe that linking the findings to regional strategies (e.g., deployment of IXPs) would reveal a more complex evolving picture. Finally, we wish to revisit a number of other studies (e.g., web performance evaluations) to understand how they perform with more realistic African-level delays.

References