Internet Performance Measurements for Education and Research Network in Kenya

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Abstract. KENET operates the national research and education network (NREN) of Kenya and has deployed Internet Measurement tools that are used for network performance monitoring. This paper focuses on the deployment of perfSONAR and how it has been utilized for end-to-end network performance measurements by researchers in Kenya who need to collaborate with researchers in other parts of the world. perfSONAR is a widely-deployed test and measurement infrastructure that is used by science networks around the world to monitor and ensure network performance. The paper introduces some of the measurement metrics that can be queried from the openly accessible data archive provided by the infrastructure based on real measurements done from within the KENET network. End-to-end measurement metrics provided by the deployed infrastructure is important for researchers, policy makers and regulators especially in Africa where such measurement metrics are not openly available or collated.

Keywords: KENET · Internet measurement · perfSONAR · ESNET
TCP throughput measurement · One-way ping · Latency measurement

1 Introduction

The Kenya Education Network (KENET)[1] is the National Research and Education Network (NREN) of Kenya. It operates the national network that interconnects universities and research institutions. The national network is in turn connected to the global research networks through the regional research and education network (RREN) for East and Southern Africa, UbuntuNet[2]. UbuntuNet in turn is connected to GEANT[3] in Europe as well as the commodity Internet service providers. This research network allows Kenyan researchers to collaborate with other researchers in any of the global research networks such as CENIC[4] in California or TENET[5] in South Africa. To effectively support the researchers in Kenya, KENET has put in place internet performance measurement tools that are able to provide required visibility to the network operations center (NOC). These tools assist KENET engineers to quickly diagnose and

[1] Kenya Education Network, https://www.kenet.or.ke
[2] Ubuntunet Network, https://www.ubuntunet.net/network-topology
[3] GEANT, https://www.geant.org/
[4] CENIC, http://cenic.org/about/about-overview
[5] TENET, http://www.tenet.ac.za/

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isolate network performance problems before they impact the service level agreements of the member institutions.

Most data network performance measurements deployed in networks are geared towards passive collection of metrics. These metrics mainly provide an indication of the network connectivity utilization and performance, which are used to ensure the achievement of service level agreements (SLAs). Passive measurements such as Simple Network Management Protocol (SNMP) [1] and Netflow [2] measure real traffic and/or provide metrics related to the real traffic traversing the network. However, these tests do not inject substantial traffic into the measured network.

There are situations which require that the network under measurement be stressed to ascertain the capacity limitations or to find subtle signs of impending faults in the network. These measurements not only require injection of measurement traffic into the test network but also active measurement of the test packets to ascertain the performance of the network. Specifically, active measurements are employed when measurements traverse networks that are not controlled by the entity conducting the tests [11].

Research networks are designed to be able to effectively handle large data transfers between research centers and facilities, or to support real-time applications. Examples of research facilities that require large data transfers include grid computing facilities, high performance computing (HPC) centers and open access data repositories (OADRs). Real time applications include telemedicine application and high-definition video conferencing that support research collaboration. These applications are very sensitive to packet loss and jitter. Packet loss may result in loss of communication for a telemedicine procedure, or lead to ineffective access of the shared computing infrastructure due to inability to adequately scale the TCP window [3]. To effectively equip a network operations center (NOC) of a research network with the visibility to support real time applications, both active and passive measurements tools must be used.

Active measurements such as accurate TCP throughput tests are essential in determining situations when the network is congested or losing packets. TCP throughput measurements based on the IEFT RFC6349 [4] are affected by several factors like packet loss, cross-traffic, end-to-end delay, throttling, test device resource contention, and TCP buffers.

End-to-end delay and packet loss affect the TCP throughput measurements in diverse ways. Delay coupled with TCP receive window configuration of the test devices can limit the maximum throughput measurement even on a lossless path. It is therefore imperative that the end-to-end delay measurement be as accurate as possible to ensure integrity of the TCP throughput measurement result. Delay measurements on the other hand require accurate time measurement between the test devices thus a need to ensure synchronized time in the test devices.

Finally, packet loss can affect TCP throughput measurement by limiting the ability of the TCP window to scale to a level that allows for measuring the full capacity of the network under test. Additionally, TCP window scaling can be affected by the TCP implementation of the software being used; for instance, different operating systems have different implementations of TCP with recent releases of operating systems and kernels enabling TCP auto-tuning feature by default. Other improvements to the TCP stack implementations such as TCP New Reno [5], Binary Increase Congestion Control

(BIC) [6] and CUBIC [7] that exhibit better TCP congestion control in high bandwidth-high delay connections [9], also known as long-fat networks (LFNs).

One of the widely deployed toolkits that is designed to facilitate the measurement and collection of active performance metrics is perfSONAR. perfSONAR is an Internet measurement toolkit that is designed to provide end-to-end network measurement traversing multiple networks under the same or different management domains [8, 13]. The infrastructure is deployed in developed country NRENs and Science Networks because it not only helps to identify and isolate problems in real-time but also enhances the network operations and support functions of network providers.

This paper discusses KENET's deployment of the perfSONAR measurement nodes and how they have been used to support Kenyan researchers collaborating with other researchers in other countries with similar deployments. The paper highlights the perfSONAR internet measurement infrastructure setup at KENET, the applications that support the internet measurements and a few use cases. Finally, the paper summarizes the benefits of the measurement infrastructure and the need to deploy more perfSONAR internet measurement nodes in Kenya and Africa in general.

2 Internet Measurement Infrastructure at KENET Network

As the NREN of Kenya, KENET's first objective in the internet measurements sphere is to provide Internet users and regulators with tools of measuring the quality of broadband Internet. Secondly, KENET purposes to support internet engineering and policy research by graduate students and faculty. Finally, KENET aims to provide the global Internet community with tools that can be used to measure the quality of Internet in Kenya.

To achieve the mentioned objectives, KENET has put in place open source Internet measurements tools [10] such as Measurement Lab[6], RIPE Atlas Probes[7] and perfSONAR. Each tool provides a different functionality and in some cases, the tools complement each other. For the purposes of research data transfers and real-time connectivity, KENET extensively uses the perfSONAR toolkit. The toolkit is used to provide automated measurements that are scheduled and fully integrated with the out-of-band alerting system (e.g., using Mobile GSM network, SMS alerts are sent to NOC technical teams). This has greatly improved the response time of the KENET NOC in the event of a performance degradation on KENET's in country connectivity or international capacities.

In an effort geared towards ensuring the correct metrics are measured, KENET has put in place scheduled measurements of critical network performance metrics like network throughput, loss rates, delay and jitter. The results obtained from these measurements are stored in a searchable database to provide point-in-time analysis of performance events on the network. Performance metrics are collected using seven (7) dedicated distributed

[6] Measurementlab.net, https://www.measurementlab.net

[7] RIPE Atlas - RIPE Network Coordination Centre, https://atlas.ripe.net

measurement nodes placed strategically on the KENET network at the geographical Points of Presence (PoPs). Two (2) nodes are located at KENET data centers hosted in two (2) separate universities in Nairobi. The other nodes are located at KENET PoPs hosted by different universities in the Kenyan towns of Nakuru, Eldoret, Kisumu, Mombasa and Meru as shown in the KENET network coverage map in Fig. 1.

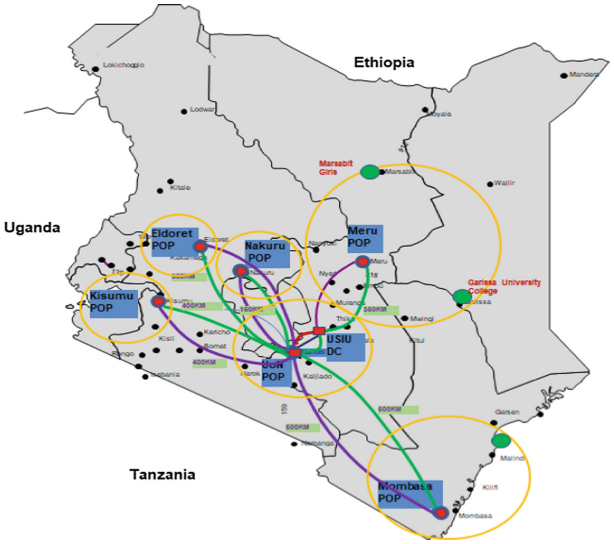


Fig. 1. KENET measurement node placement

The perfSONAR toolkit is designed to provide scheduled or on-demand measurement with the ability of incoming measurement control to reduce resource contention on the measurement host. In addition, the toolkit has the ability of measurement archiving that allows querying of the collected metrics on-demand based on the data access policies of the hosting institution(s). Some of the test measurements possible on the framework include both TCP and UDP throughput measurements; one-way delay measurements [12]; round trip time; and one-way packet loss among others.

For researchers, the toolkit provides archived open access data that can be queried and analyzed for policy and research purposes. With a large data set, queries done against archives in different countries can facilitate access to unique open internet measurement data.

3 KENET perfSONAR Implementation

KENET set up the perfSONAR measurement infrastructure in the year 2015 with support from International Networks group at Indiana University (IN@IU)[8] and the Network Startup Resource Center (NSRC)[9]. The infrastructure is composed of dedicated measurement equipment. The selection of the hardware and base system configuration was done to ensure that the measurement devices introduce no bottlenecks that would affect the metrics collected. In addition, the test devices are installed with an Operating System that has TCP auto-tuning enabled and a test scheduler to avoid concurrent tests being conducted.

On the base system, several software applications have been enabled on the nodes and other supporting applications within KENET. Each application contributes to the full functionality of the system by conducting scheduled or on-demand measurement. Whenever the metrics collected do not meet the minimum thresholds set, an alarm is raised. The tools enabled on the perfSONAR toolkit installed at the seven nodes are powstream[10], owampd[11], iperf[12], iperf3[13], bwctl[14], pScheduler[15] and ntp[16]. Other supporting software independent of the test nodes are esmond[17] for data archiving, MaDDash[18] dashboard application for data visualization, Nagios Core[19] and SMS Server Tools[20].

The visualizations are organized as a summary in a grid[21] and allows for interrogation of the data collected over time. This data can also be queried using the perfSONAR esmond[22] client application programming interface (API). Out of band SMS notification is integrated into the system using Nagios Core network monitoring that forwards the alerts to SMS Server Tools which uses GSM network for sending SMS notifications. Figure 2 shows the network monitoring for measurement notifications.

[8] International Networks at Indiana University, http://internationalnetworks.iu.edu/index.html

[9] Network Startup Resource Center, https://www.nsrc.org/

[10] powstream, http://software.internet2.edu/owamp/powstream.man.html

[11] owampd, http://software.internet2.edu/owamp/owampd.man.html

[12] iperf, https://sourceforge.net/projects/iperf2/

[13] iperf3, http://software.es.net/iperf/

[14] bwctl, https://software.internet2.edu/bwctl/

[15] pScheduler, https://fasterdata.es.net/performance-testing/network-troubleshooting-tools/pscheduler/

[16] ntp, http://doc.ntp.org/4.1.0/ntpd.htm

[17] esmond: ESnet Monitoring Daemon, http://software.es.net/esmond/

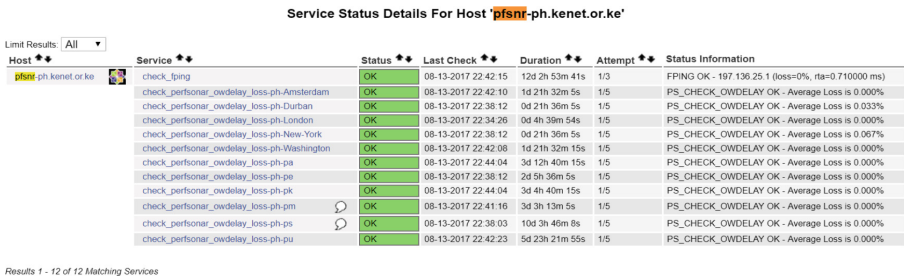
[18] MaDDash, http://software.es.net/maddash/

[19] Nagios Core, https://www.nagios.org/projects/nagios-core/

[20] SMS Server Tools. http://smstools3.kekekasvi.com/

[21] KENET MaDDash - Monitoring and Debugging Dashboard, http://maddash-uon.kenet.or.ke/maddash-webui/

[22] perfSONAR Client REST Interface, http://software.es.net/esmond/perfsonar_client_rest.html


Service Status Details For Host 'pfsnr-ph.kenet.or.ke'

Limit Results: All

Host	Service	Status	Last Check	Duration	Attempt	Status Information
pfsnr-ph.kenet.or.ke	check_fping	OK	08-13-2017 22:42:15	12d 2h 53m 41s	1/3	FPING OK - 197.136.25.1 (loss=0%, rta=0.710000 ms)
	check_perfsonar_owdelay_loss-ph-Amsterdam	OK	08-13-2017 22:42:10	1d 21h 32m 5s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%
	check_perfsonar_owdelay_loss-ph-Durban	OK	08-13-2017 22:38:12	0d 21h 36m 5s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.033%
	check_perfsonar_owdelay_loss-ph-London	OK	08-13-2017 22:34:26	0d 4h 39m 54s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%
	check_perfsonar_owdelay_loss-ph-New-York	OK	08-13-2017 22:38:12	0d 21h 36m 5s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.067%
	check_perfsonar_owdelay_loss-ph-Washington	OK	08-13-2017 22:42:08	1d 21h 32m 15s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%
	check_perfsonar_owdelay_loss-ph-pa	OK	08-13-2017 22:44:04	3d 12h 40m 15s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%
	check_perfsonar_owdelay_loss-ph-pe	OK	08-13-2017 22:38:12	2d 5h 36m 5s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%
	check_perfsonar_owdelay_loss-ph-pk	OK	08-13-2017 22:44:04	3d 4h 40m 15s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%
	check_perfsonar_owdelay_loss-ph-pm	OK	08-13-2017 22:41:16	3d 3h 13m 5s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%
	check_perfsonar_owdelay_loss-ph-ps	OK	08-13-2017 22:38:03	10d 3h 46m 8s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%
	check_perfsonar_owdelay_loss-ph-pu	OK	08-13-2017 22:42:23	5d 23h 21m 55s	1/5	PS_CHECK_OWDELAY OK - Average Loss is 0.000%

Results 1 - 12 of 12 Matching Services

Fig. 2. Integration of measurement alerts for SMS notification

4 Use Cases and Measurement Results

The perfSONAR measurement infrastructure is currently being used by different stakeholders to enhance their daily work and research. The following groups are some of the active users of the infrastructure or consumers of the data generated and archived using the perfSONAR infrastructure at KENET: NOC engineers, groups of researchers who need real-time applications or high data transfers, and global Internet measurements research community.

4.1 Supporting KENET NOC Engineers

The KENET NOC engineers are currently the most active users of the perfSONAR measurement infrastructure at KENET. KENET NOC benefits from the perfSONAR measurements by getting real-time notifications whenever the set performance measurement metrics are not meeting required thresholds. This is enhanced by integration of out-of-band SMS notifications system which has improved the resolution times for any performance degradation happening on the KENET backbone or transit networks. The second use of the measurement infrastructure at KENET is provision of network visibility. Automated visibility of the network is achieved through throughput, latency and packet loss measurements between KENET's main distribution points to the regional POPs. Table 1 shows the measurement results between two measurements nodes in Nairobi (at University of Nairobi and at United States International University) indicating packet loss and reduced network throughput because of dark fiber link degradation. Table 2 shows daily summaries of throughput measurement results between the measurement node at KENET's regional POP in Nakuru to Nairobi indicating degradation of third-party managed connection that lasted five days as highlighted in the table. In each case, the NOC engineers were alerted automatically and diagnosed the problem rapidly.

Network Performance Monitoring is the third use of the perfSONAR measurement infrastructure deployed at KENET. The measurement tools assist the KENET NOC to identify and resolve packet loss and throughput problems on the KENET backbone network arising from deteriorated fiber, loss of upstream connections or other factors

Table 1. Throughput & packet loss measurement trends indicating fiber deteroriation between UoN & USIU nodes

Source	Destination	Timestamp	Throughput	Loss (%)
pfsnr-ph.kenet.or.ke	pfsnr-pu.kenet.or.ke	01/08/2017 01:44	941.61	0.00%
pfsnr-ph.kenet.or.ke	pfsnr-pu.kenet.or.ke	01/08/2017 05:57	941.56	0.00%
pfsnr-ph.kenet.or.ke	pfsnr-pu.kenet.or.ke	01/08/2017 09:09	941.52	0.00%
pfsnr-ph.kenet.or.ke	pfsnr-pu.kenet.or.ke	01/08/2017 14:09	0.08	3.28%
pfsnr-ph.kenet.or.ke	pfsnr-pu.kenet.or.ke	01/08/2017 15:06	0.62	1.59%
pfsnr-ph.kenet.or.ke	pfsnr-pu.kenet.or.ke	01/08/2017 22:42	941.41	0.00%
pfsnr-ph.kenet.or.ke	pfsnr-pu.kenet.or.ke	02/08/2017 01:37	941.74	0.00%

Table 2. Throughput measurement trend indicating capacity constraint of managed service

Source	Destination	event_type timestamp	throughput
pfsnr-pa.kenet.or.ke	pfsnr-ph.kenet.or.ke	throughput 21/06/2017 00:00	921.78
pfsnr-pa.kenet.or.ke	pfsnr-ph.kenet.or.ke	throughput 22/06/2017 00:00	853.18
pfsnr-pa.kenet.or.ke	pfsnr-ph.kenet.or.ke	throughput 23/06/2017 00:00	394.36
pfsnr-pa.kenet.or.ke	pfsnr-ph.kenet.or.ke	throughput 24/06/2017 00:00	162.69
pfsnr-pa.kenet.or.ke	pfsnr-ph.kenet.or.ke	throughput 25/06/2017 00:00	87.15
pfsnr-pa.kenet.or.ke	pfsnr-ph.kenet.or.ke	throughput 26/06/2017 00:00	50.96
pfsnr-pa.kenet.or.ke	pfsnr-ph.kenet.or.ke	throughput 27/06/2017 00:00	550.99
pfsnr-pa.kenet.or.ke	pfsnr-ph.kenet.or.ke	throughput 28/06/2017 00:00	933.21

before they severely impact the network. Table 3 shows the scheduled end-to-end measurement results between perfSONAR probes in Nairobi, Kenya and those in Washington DC, USA. The results are used to monitor the quality of links between Kenya and the US that support collaborating researchers.

Table 3. Hourly summary measurement metrics (Nairobi, Kenya and Washington DC, USA)

Source	Destination	Timestamp	Delay(ms)	Packet loss (%)
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 09:00	121.25	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 10:00	121.52	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 11:00	121.65	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 12:00	121.68	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 13:00	121.66	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 14:00	121.45	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 15:00	120.38	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 16:00	120.60	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 17:00	120.38	0.00
pfsnr-ph.kenet.or.ke	wash-owamp.es.net	27/10/2017 18:00	120.39	0.00

Other notable use of the platform has been identification of un-optimized dynamic routing & route flaps due to OSPF redistribution which affect performance to selected users of the KENET network. KENET also regularly conducts on-demand performance

measurement of third-party procured managed capacity as part of the network connectivity commissioning tests. This platform has been very handy in providing the appropriate measurement tools with results that are a true depiction of the implemented service by the provider.

4.2 Real-Time Applications for Research Groups

Research collaboration is very active in Kenya, with Kenyan researchers actively collaborating with their peers in Africa and other parts of the world, particularly in North America. To effectively collaborate, the researchers are supported by real-time applications such as video and web conferencing where different research groups collaborate online and hold meetings without the need to physically travel for face-to-face meetings.

For example, the deployment of a perfSONAR node at the Academic Model Providing Access to Healthcare (AMPATH) has enabled better support of real-time applications for researchers in the field of medicine and public health at Moi Teaching & Referral Hospital in Eldoret, Kenya. The researchers collaborate with their peers in North American Universities led by Indiana University. The quality of the links can be monitored not only by KENET NOC but also by network engineers at AMPATH or Indiana University. For example, KENET could extract the metrics shown in Table 4 from the archived Open Internet measurements data.

Table 4. Sample measurement metrics from measurement node in Eldoret

Source	Destination	Timestamp	Throughput	Delay (ms)	Packet metrics		
					Retrans count	Loss (%)	Duplicates
pfsnr-pe.kenet.or.ke	pfsnr-ph.kenet.or.ke	27/10/2017 09:37	699.02	1.95	40	0.00	0.00
pfsnr-pe.kenet.or.ke	pfsnr-ph.kenet.or.ke	27/10/2017 10:24	672.75	1.65	51	0.00	0.00
pfsnr-pe.kenet.or.ke	pfsnr-ph.kenet.or.ke	27/10/2017 14:15	693.35	2.06	24	0.00	0.00
pfsnr-pe.kenet.or.ke	pfsnr-ph.kenet.or.ke	27/10/2017 21:47	705.39	2.40	23	0.00	0.00
pfsnr-pe.kenet.or.ke	pfsnr-ph.kenet.or.ke	27/10/2017 23:44	680.16	2.21	27	0.00	0.00
pfsnr-pe.kenet.or.ke	pfsnr-ph.kenet.or.ke	28/10/2017 04:56	706.77	1.86	20	0.00	0.00
pfsnr-pe.kenet.or.ke	pfsnr-ph.kenet.or.ke	28/10/2017 07:10	658.32	1.91	55	0.00	0.00

4.3 Global Internet Measurements Research Community

The perfSONAR nodes deployed in Kenya by KENET are part of a global network of nodes that are open to network engineers and researchers worldwide. Engineers or researchers can use the nodes to collect Internet measurement metrics for research purposes or policy advocacy if they have access to the Internet. For example, researchers could collect measurement metrics in areas of Internet policy and research which can be used to map intra-country, inter-country and continental connectivity as depicted in Table 5. It is also possible for graduate students to conduct Internet measurements research using the open perfSONAR platform.

Internet measurements researchers can conduct on-demand measurements whenever there is a specific event, and this allows for correlation between real-life events and internet measurement metrics. The resulting data can be used to better design networks or inform policy at the global or local level.

Table 5. Analysis of delay measurements from Nairobi, Kenya to other cities in the world

	Kampala, UG	Durban, ZA	Amsterdam, NL	London, UK	Washington, US
Nairobi, KE (Outbound)	172.22	33.57	81.20	93.61	120.39
Nairobi, KE (Inbound)	9.99	79.65	71.81	92.06	129.03
Nairobi, KE (RTT)	182.21	113.22	153.01	185.67	249.42

5 Conclusion and Future Work

This paper has highlighted the perfSONAR internet measurement infrastructure at KENET, with Kenya being one of the locations in Africa where perfSONAR has been deployed and in active use. Other African countries with perfSONAR measurement nodes include Nigeria, Senegal, South Africa and Uganda. The paper has also delved into the applications that support the perfSONAR measurement infrastructure at KENET. Finally, the paper has elaborated the use cases for the infrastructure within the community in Kenya and globally where the data archived by the infrastructure can be interrogated and used in making policy or design decisions by African researchers or regulators.

Internet measurements are important in providing a benchmark for testing the quality of experience of internet connectivity services. perfSONAR is very handy in providing a platform for both scheduled and on-demand network performance measurements. These measurements can equip network engineering teams with adequate visibility of the network performance and related archives of data that can be drilled down with the aim of identifying or correlating performance problems with actual events on mutli-domain networks in partnership with other stakeholders.

Deployment of the perfSONAR measurement platform has empowered the KENET NOC with data and tools for performance monitoring. More work should be done to test a GPS clock source for use in improving the time accuracy of the

measurement nodes and measure what percentage improvement is achieved by implementing a GPS clock in country. The second area that requires more work is the deployment of more perfSONAR measurement nodes in Kenya to foster more collaborative problem identification. In this regard, KENET will consider; in collaboration with partners, deployment of lower cost perfSONAR measurement nodes based on lower power consumption chipset computers like the Raspberry Pi. These will aid in having more crowdsourced data that will improve the accuracy of the measurements analyzed by researchers.

At the continental level, more perfSONAR nodes should be installed in African countries to enable measurements of network connectivity, interconnectivity and quality of experience; in addition to having reliable measurement results that will enhance future decision making.

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