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AVAILABLE BANDWIDTH ESTIMATION METRICS AS TOOLS TO EVALUATE NETWORK TRUNK LINKS

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ABSTRACT

Nowadays the platform par excellence for the development of all telecommunication activities is the Internet; and its infrastructure is facing new challenges every day due to the growth in demand for more content, such as streaming video, storage, and cloud processing. Also, to maintain optimal levels of service quality, network applications demand more telecommunication resources. Similarly, the network infrastructures that support these applications have evolved, and demand greater and more efficient management of the trunk links, which play a primary role in sustaining services. Therefore, this paper presents the performance evaluation of trunk, wired and wireless links in a heterogeneous computer network infrastructure, using available bandwidth estimation tools such as IGI, Pathload, and Traceband. Thus, for the experimental evaluation of the trunk links, two real network scenarios were implemented, where crosstraffic was generated in a synthetic way using the Mgen tool. Consequently, this study allowed verifying in other aspects; that the metrics of the estimation tools can be used to evaluate and know the performance of wired and wireless trunk links, which can be reliable up to 96% for network administrative tasks.

Keywords: available bandwidth; network trunk links; heterogeneous networks; quality of service.

INTRODUCTION

From Industry 3.0 to the recently launched 4.0, humanity has experienced many significant changes in various aspects; one of the most important being telecommunications, which has brought about different ways of relating, sharing information, having fun, and doing work (Weforum, 2020). Therefore, the platform par excellence for the development of all the experiences mentioned has been the Internet; and its infrastructure is facing new challenges every day due to the growth in demand for more content, such as streaming video, storage, and cloud processing (Ha & Xu, 2018), (Jain & Dovrolis, 2008).

Also, to maintain optimal levels of Quality of Service (QoS) network applications demand more telecommunications resources. Therefore, the network infrastructures that support these applications have evolved; and have progressively increased the data transfer speed, from 100 to 400 Mbps; likewise, the management and maintenance of the high-speed links of these networks play a primary role in the sustainability of the network services supported on a SDN a NFV networks infrastructures (Azevedo, Bonfim, Lima, & Fernandes, 2018), (Joshi, K., & Benson, T, 2016), (Aceto, Palumbo, Persico, Chen, & Pescape, 2018).

In relation to the above, to efficiently manage the network links, the most important technique is the real-time monitoring of the network traffic throughput, which allows to know the performance regarding metrics such as Capacity, Transmission Speed, Available Bandwidth (av_bw), Lost packets, among others; being for this work the av_bw the most important (Shi, Yang, Gou, & Xiong, 2020), (Salcedo, Guerrero, & Guérrero, 2017), (Kirova, Siemens, Kachan, Vasylenko, & Karpov, 2018).

Therefore, the most important metric in end-to-end links studies was the av_bw. Thus, the av_bw of a link refers to the unused part of the total capacity of the link for a certain period. Therefore, although it appears that the capacity of a connection depends on the transmission rate of the technology used and the propagation medium used, it furthermore depends on the traffic load on that link that will vary with time(Kapoor, Lao, Chen, Gerla, & Sanadidi, 2004), (Jain & Dovrolis., 2002),

Since at any point in time a new connection may arise within the link, to correctly measure this indicator, bandwidth measurements must be made in a time interval over which an average. This can be expressed by the following equation:

$$u_i(t, t+\tau) = \frac{1}{\tau}\int_t^{t+\tau} u_i(t)\, dt, \qquad (1)$$

where $u(x)$ is the av_bw at a given time instant x.

It is possible to calculate av_bw in a segment, so that if $C_i$is the capacity of segment i, $u_i$is the average utilization of that segment in a given time interval, the mean value of av_bw Ai can be expressed as follows:

$$\mathrm{A_i} = \mathrm{C_i}(1 - \mathrm{u_i}). \qquad (2)$$

In the same way as capacity, av_bw will be the minimum found along a link or several segments:

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$A = \min_{i=1..H} A_i$. (3)

The estimation of the end-to-end av_bw has been studied by several researchers around the world. Several works are aimed to describe the estimation techniques and related concepts (Chan, 2015). Other studies present comparative analysis of the estimation tools when tested in different network scenarios and under different types of cross traffic (Jain & Dovrolis, 2004).

However, the studies do not show a real analysis of the effects that cause the performance of the traffic flow in a network infrastructure with wireless trunk segments; such as, the real capacity of the link, lost packets, latency, av_bw, among others; because they only focus on evaluating the av_bw estimation tools in wireless network infrastructures based on IEEE 802.11, and 4G/LTE architectures, among others (Abolfazli, Sanaei, Wong, Tabassi, & Rosen, 2015), (Paul, Tachibana, & Hasegawa, 2016).

In relation to the above, there is a need to have studies to know the real state of the packet flow in heterogeneous networks, which contain wired segments, interconnected with wireless links (called trunks). Consequently, this work presents an evaluation of a heterogeneous network using tools for estimating av_bw, and performs a performance analysis of the network evaluated, which facilitates the optimization and management of network resources, and also would improve the QoS of network applications and QoE (Quality of Experience) of users accessing services (Salcedo, Guerrero, & Martinez, 2018).

Therefore, this study ran 270 experiments using a specialized and real network testbed. The crosstraffic used in the experiments was generated by MGEN tool (Adamson & Gallavan, 1997). The following Section presents the relative works and the reasons why this study was performed and the state of the art of similar studies of the av_bw estimation. In the next Sections, presents the methodology to design and the ran experiments. Finally, the analysis of the results and conclusions are presented at two last Sections.

RELATED WORKS

Currently the exponential growth of Internet traffic demand and the need to provide end users with better service performance to their applications. This makes between different metrics for network administrative services, the estimation of av_bw becomes very relevant; due to it is an important optimization QoS metric specifically Internet networks; this justifies the efforts of researchers worldwide, to make better comparative studies of the behavior of av_bw estimations tools, which appear in(Botta, Davy, Meskill, & Aceto, 2013), (Nguyen, Tran, & Nguyen, 2014), (Guerrero & Labrador., 2010), (Guerrero & Morillo, 2012) (Guerrero, Salcedo, & Lamos, 2013).

However, the study and measurement of the performance of type networks, being the Internet the most representative one, has had a great interest from the research community, focusing on an aspect called av_bw, due to multiple applications in different areas such as: Compliance with service level agreements, network management, traffic engineering and real time provisioning resources, flow control and congestion.

On the other hand, the studies found in the literature, do not show an analysis of the effects on network performance, with respect to the real capacity of the link, packet loss, latency, av_bw, among others; when the traffic flow passes through wireless networks; specifically in network infrastructures that have wireless trunks (Shiobara & Okamawari, 2017).

Among the studies that can be highlighted are (Azevedo, Bonfim, Lima, & Fernandes, 2018), which introduces a solution that reduces the impact of the new 802.11n arrangements in the av_bw estimation tools; and evaluates how the 802.11n MAC layer factors influence the estimates of four av_bw estimation tools: ASSOLO, PTR, PathChirp, and YAZ. Also, (Shiobara & Okamawari, 2017) evaluates a new estimation method called "TPG" that use a Train of Packet Groups as a probe of the av_bw estimation; this method (TPG) is implemented and evaluated by using a commercial FDD-LTE (frequency division duplex long term evolution) system. On the other hand (Paul, Tachibana, & Hasegawa, 2016) introduces a new Enhanced Available Bandwidth Estimation Technique (NEXT) by introducing a parameter-independent curve-fitting technique to detect the av_bw estimation toolsfrom a one-way queuing delay signature; and it was evaluated on a real test over a radio interface in a 4G/LTE mobile communication network.

In other hand, in (Hernandez & Insuasty, 2015), presents a new protocol approach to test active tools for av_bw in wireless networks environments. In addition, in (Abolfazli, Sanaei, Wong, Tabassi, & Rosen, 2015) introduces a methodology to accurately measure throughput of the 4G WiMAX data network in real wireless environment from end-users perspective; they suggest an intelligent monitoring system in corporation of both (A. Tirumala & Gibbs, 2006) and OOKLA (Abolfazli, Sanaei, Wong, Tabassi, & Rosen, 2015) that can measure the throughput, but also can predict the future throughput based on previous throughput data. Finally, in (Dely, *et al.*, 2014) proposes BEST-AP as a new mechanism for selecting the based on a novel av_bw estimation scheme. The av_bw provided by an AP depends mainly on the signal quality and the load on the wireless channel. Using the av_bw estimations, the system exploits the best AP for longer duration while probing the less good APs for shorter duration to update the bandwidth estimations.

The papers introduced, showing the efforts made by researchers to evaluate the most important av_bw estimation tools; likewise, they use av_bw metrics as a parameter to evaluate the performance of wireless network architectures; however, they do not present an evaluation of the traffic throughput in the wireless links as trunks, but as a complete network, and do not take into account the wired network infrastructure.

The above indicates that there are several reasons that make this work different from the previous ones. First, evaluates four av_bw estimations tools in wired scenario.

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Second, evaluates the same tools, but in a heterogeneous scenario, which has a wireless link, which works as a trunk between two wired networks. And third, we present a comparative analysis between the two scenarios, regarding latency, and av_bw.

PERFORMANCE EVALUATION

Evaluation Testbed

Essentially, at the hardware level for the experimental evaluation of the two network infrastructures, we built a specialized testbed for each scenario.

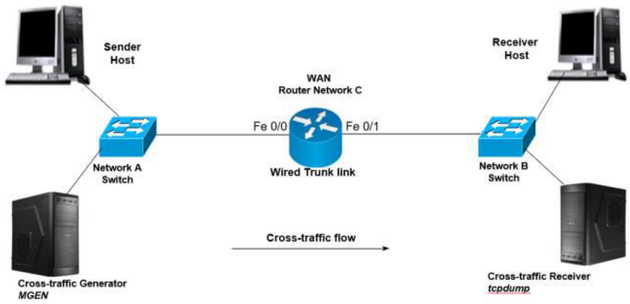

Figure-1. Specialized network testbed with wired trunk link.

The first testbedis completely controlled and configurable about packet size, and propagation delay environment, see Figure-1. The hardware testbed has the following components: four computers corresponding to the host, which allow you to interact with the network and perform all necessary tests, equipped with enough processing power to support the performance that experiments require the CPU speeds running up to 3.4GHz, and all of them with GNU-Linux, see Table-1. Also, for each host to communicate with the others, each network has Cisco Switch, which can operate on 100Mbps. Also, to interconnect the network A with the network B, each network has one CISCO Series Router (100Mbps). Each switch is connected to the interface (LAN) F00/0 of their respective router; also they are interconnected using the interface Fe0/1, thus simulating a wired trunklink, setting up the network C.

Table-1. Host features.

Hosts	Operating systems	Architecture	CPU-Clock (Mhz)
Crosstraffic generator	Ubuntu-Linux 18.04	X86_64	Intel Core i7 3.4 GHz
Cross-traffic receiver			
Sender host			
Receiver host			

The second testbed, is slightly different from the one presented above; because it presents a change in the C network, which is constituted by a wireless link, where two Cisco APs are connected to simulate a wireless trunklink, see Figure-2.

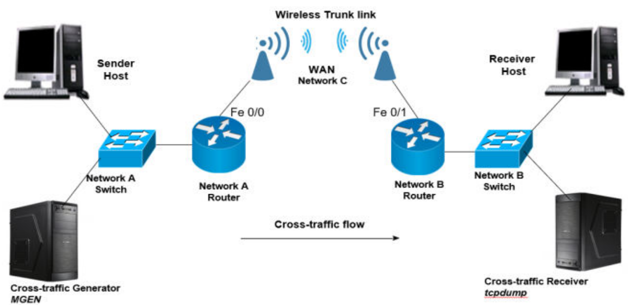

Figure-2. Specialized network testbed with wireless trunk link.

At the software level, the testbed has two main elements. First, theav_bw estimation tools selected to evaluate were installed and configured in the respective host, mainly in the Sender and the Receiver host.

On another hand, researchers in their evaluations have been forced to simulate a congestion link and crosstraffic control, to determine the link behaviors and performance. Therefore, generators used packets (synthetic traffic) for estimating. To select a packet generator synthetic traffic, three important aspects were analyzed. Initially, it is replicates traces (PCAP files), also allowing scale traffic transmission rate (0% to 50%) on the link used. Finally, it has been implemented in a real testbed and not a simulation (e.g. NS-3). Consequently, the tool for generating synthetic traffic is the one described below:

MGEN, it is easy to use, due to the flexibility of the parameters (*Protocol*, *Sender host* (Tx), *Receiver host*

(Rx), and *Events*, etc.) of each type of traffic generated. It also allows traffic to generate a trace previously captured in a *pcap* file. This makes using the *CLONE* parameter but cannot scale the amount that is to be introduced to the network. It is important to clarify that with other options such as POISSON or BURST, among others, *Mgen*canscale traffic.

To evaluate the functionality and performance of the tools selected a group of scenarios were designed with different types of traffic (escalate the trace), as the *tcpreplay* traffic generator tool has this capability. To scale the trace defined using the parameter *mbps* that allows flooding the channel to a controllable amount of data, reaching a precision of 1µs.

Given the above and according to the amount of traffic; scenarios to be evaluated are: Without traffic, with 0% and 50% of crosstraffic; with 30 experiments were performed for each scenario, to have 30 evaluations for each tool, and thus achieve a total of 90 experiments by stage and reaches an amount of 270 experiments, which are shown in Table-2.

Table-2. Hosts features.

Scenarios	CrossTraffic (mbps)	# Exp	# Tools	Total
1	0%	30	3	90
2	50%	30	3	90
			Total	270

Finally, the metrics selected to evaluate the performance of the links and the network are latency, and Av_bw, because they allow to determine the throughput links in relation to the purposes of this work.

Evaluated av_bw tools

All evaluated av_bw tools are active and intrusive; and they were carefully selected from the literature review, of which 26 pre-selected tools. Then those 23 filtered according to the following criteria as performed by Salcedo in (Salcedo, Guerrero, & Guérrero, 2017). Therefore, the selected tools for this studyare shown in Table-3.

Table-3. Evaluated Estimation tools.

Tools	Evaluated times by other authors
IGI	9
Pathload	22
Traceband	3

RESULTS AND ANALYSIS

The tools described in the previous section were evaluated using an actual 100Mbps bandwidth for the wired trunk link; and the wireless trunk link with 54 Mbps. Consequently, this evaluation allowed estimating the av_bw, and the estimation time used by each tool in each of the scenarios and experiments executed.

Wired Trunk Links

Initially, when analyzing the average results obtained from the three tools (IGI, Traceband, and Pathload) of the to evaluate the wired trunk link (See Figure-1); we found that when estimating av_bw with 0% cross traffic, the tools in the first 10 experiments show a low performance when estimating av_bw far from the real value, but that after experiment 12 it improves, although it continues approximately 28% of the expected real value.

On the other hand, when evaluating the trunk link with 50% cross traffic, the tools show until experiment 13 a non-ideal throughput, due to overestimating av_bw with respect to the expected value. However, then it can be observed that the estimation of av_bw keeps a stable throughputof 90%, because it is very close to the real expected value, see Figure-3.

In relation to the above, two things can be determined. First, when estimating av_bw on a wired trunk link with 0% cross traffic, it cannot be concluded that it is fully available, due to the fact that the tools present an error in the measure known as overhead; which is produced due todoes not compute into estimation the test traffic used to estimate the av_bw. However, when evaluating the wired trunk link with 50% of cross traffic, it can be determined that although the estimated value of av_bw presents a maximum average error of 20%, it is a measure that can be reliable for evaluating this type of scenario, because at a theoretical level it is inferred that a wired trunk link normally has at least 30% of cross traffic, which is associated with the burst behavior of Internet traffic.

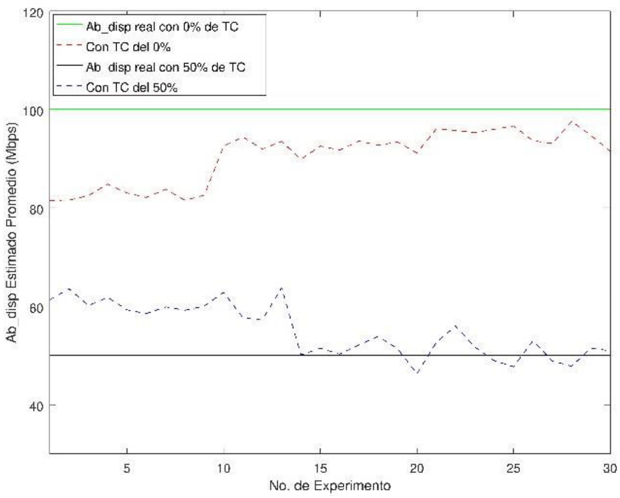

Figure-3. Estimated av_bwaverage on a wired trunk link with 0% and 50% cross traffic.

Now, when analyzing the average estimation time used by the tools to estimate av_bw, see Figure-4. It can be seen, that when the wired trunk link has 0% cross traffic the tools use less time to estimate av_bw, which ranges from 9s to 13s; while the same link with 50% cross

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traffic, the estimation time is higher. This is associated with the congestion of the evaluated link, because a link with more cross traffic, the test traffic used by the estimation tools interacts with the cross traffic, which causes the tools to be slower to obtain the results.

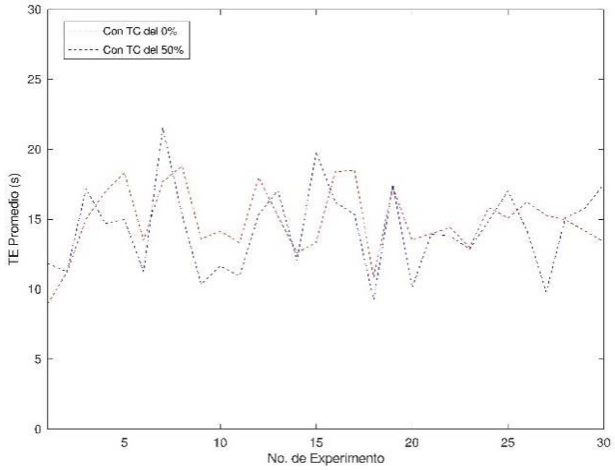

Figure-4. Estimation time averageto estimation on a wiredtrunk link with 0% and 50% cross traffic.

Wireless Trunk Link

The results obtained when evaluating the wireless trunk link (see Figure-5), using the estimation tools IGI, Traceband, and Pathload; show that when estimating the av_bw of the wireless trunk, with 0% cross traffic; the tools show low performance, because they underestimate and overestimate the av_bw with respect to the real value, with values of 8% and 12% respectively. However, when evaluating the same trunk with 50% cross traffic, the tools show a better performance; because they underestimate and overestimate av_bw with respect to the real value, with values of 4% and 7% respectively.

This allows us to state that for wireless trunk links the estimation tools allow us to know the throughput of the link, being more precise this result when the link has 50% of cross traffic approximately.

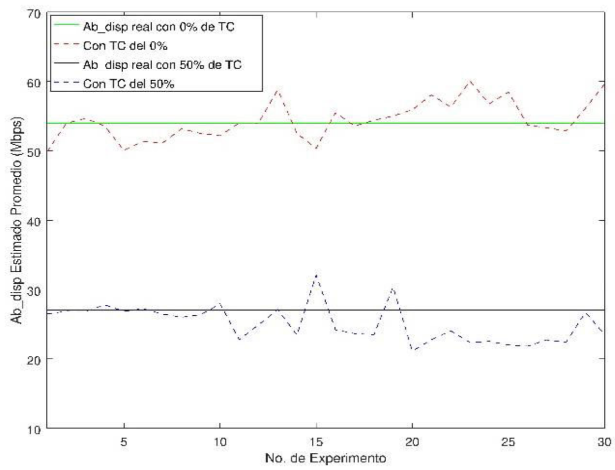

Figure-5. Average estimation time for estimation on a wired trunk link with 0% cross traffic.

On the other hand, for the average estimation time calculated when evaluating the wireless trunk link with the estimation tools, see Figure-6. It can be observed that for 0% and 50% of cross traffic the tools are slow compared to what is known in the literature for tools as (Guerrero & Labrador., 2010); because it reaches up to 17s and 24s, for 0% and 50% cross traffic respectively. Finally, these high estimation times for both cross traffic scenarios are related to the latency added by the wireless link in the transmission and reception processes of data in the physical layer of the network model.

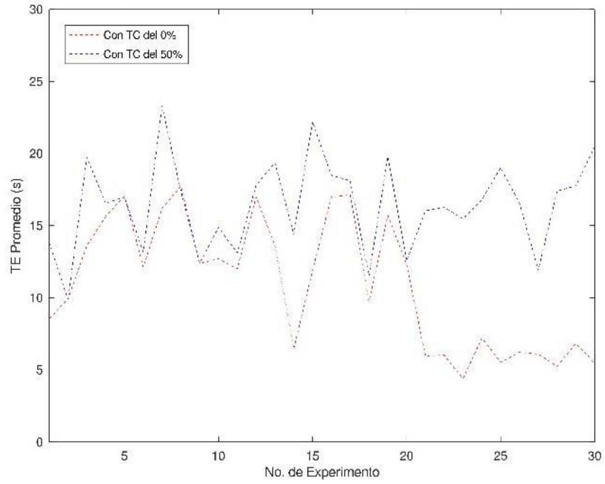

Figure-6. Average estimation time for estimation on a wired trunk link with 0% and 50% cross traffic.

Finally, when comparing the results obtained for the wired trunk link with the wireless one, two important aspects can be defined. Firstly, about av_bw, the tools presented better performance in the wireless trunk; because they reached 96% maximum accuracy, while for the wired link it was 90%, see Figures 3 and 4. Secondly, when observing the estimation time used by the tools (see Figures 5 and 6); the performance is slightly better in the wired trunk link scenario. So, although the estimation time reaches 20s in one of the estimations, it can be said that it is lower, compared to the time used by the tools when evaluating the wireless trunk link, which reaches between 15s and 23s.

CONCLUSIONS AND FUTURE WORKS

Finally, the development of this work made it possible to determine two important aspects. First, that when evaluating the wired and wireless trunk link, av_bw estimates showed that by evaluating these links with 50% traffic, values can be obtained with acceptable accuracy to make decisions regarding bandwidth resource management, which is an important metric in the performance of real-time services. On the other hand, it was validated that the estimate of av_bw with 0% cross traffic cannot be used to determine if a trunk link is fully available (100%).

Second, the estimation time found when evaluating the tools, showed that for wireless trunk links

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they add more latency to the link cross traffic; making wireless links a bottleneck for applications that base their QoS on high bit rates.

Finally, we proved that metrics of the av_bw estimation tools can be used to evaluate and know the performance of wired and wireless trunk links; thus, this work will allow start the evaluation of different types of network services that are today mostly used by mobile users. Additionally, it generates new challenges to improve or create estimation tools that allow the selection of wireless network access points with higher av_bw.

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REFERENCES

A. Tirumala J. D. & Gibbs K. 2006. Iperf. Iperf.

Abolfazli S., Sanaei Z., Wong S. Y., Tabassi A. & Rosen S. 2015. Throughput measurement in 4G wireless data networks: Performance evaluation and validation. Computer Applications & Industrial Electronics (ISCAIE), 2015 IEEE Symposium on, (pp. 27-32). doi:10.1109/ISCAIE.2015.7298322

Aceto G., Palumbo F., Persico V., Chen H. & Pescape A. 2018. Evaluation of SDN-based bandwidth estimation in Mobile Broad Band networks. 2018 24th Asia-Pacific Conference on Communications (APCC), (pp. 263-268). Retrieved from https://ieeexplore.ieee.org/abstract/document/8633562

Adamson B. & Gallavan S. 1997. Multi-Generator. Multi-Generator.

Azevedo D., Bonfim M., Lima L. & Fernandes S. 2018. Towards an Accurate Bandwidth Estimation Tool for 802.11 n Wireless Networks. 2018 IEEE Symposium on Computers and Communications (ISCC), (pp. 00486–00491). doi:10.1109/ISCC.2018.8538751

Botta A., Davy A., Meskill B. & Aceto G. 2013. Active Techniques for Available Bandwidth Estimation: Comparison and Application. In E. Biersack, C. Callegari, & M. Matijasevic (Eds.), Data Traffic Monitoring and Analysis (7754: 28-43). Springer Berlin Heidelberg. doi:10.1007/978-3-642-36784-7_2

Chan K. 2015. Testing and Measurement: Techniques and Applications: Proceedings of the 2015 International Conference on Testing and Measurement Techniques (TMTA 2015), 16-17 January 2015, Phuket Island, Thailand. CRC Press.

Dely Kassler A., Chow L., Bambos N., Bayer N., Einsiedler H. & PeyloC. 2014. BEST-AP: Non-intrusive Estimation of Available Bandwidth and its Application for Dynamic Access Point selection. Comuputer Comunicactions. 78-91.

Guerrero C. D. & Morillo D. S. 2012. On the reduction of the available bandwidth estimation error through clustering with k-means. 2012 IEEE Latin-America Conference on Communications, (pp. 1-5). doi:10.1109/LATINCOM.2012.6506020

Guerrero C. & Labrador. M. 2010. On the Applicability of Available Bandwidth Estimation Techniques and Tools. Computer Communications, 33, 11-22. doi:http://dx.doi.org/10.1016/j.comcom.2009.08.010

Guerrero C. & Labrador. M. 2010. Traceband: A Fast, Low Overhead and Accurate Tool for Available Bandwidth Estimation and Monitoring. Computer Networks, 54, 977-990. doi:http://dx.doi.org/10.1016/j.comnet.2009.09.024

Guerrero C., Salcedo D. & Lamos H. 2013, 5. A Clustering Approach to Reduce the Available Bandwidth Estimation Error. Latin America Transactions, IEEE (Revista IEEE America Latina), 11, 927-932. doi:10.1109/TLA.2013.6568835

Ha P. & Xu L. 2018, 4. Available bandwidth estimation in public clouds. IEEE INFOCOM 2018 - IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), (pp. 238-243). doi:10.1109/INFCOMW.2018.8407010

Hernandez I. & Insuasty D. 2015. Protocol Approach to Test AVBW Tools in Wireless Environment. VII Congreso Iberoamericano de Telemática CITA2015, 7, 4. Retrieved from http://www.researchandinnovationbook.com/PROCEEDINGS/CITA2015/Archives/papers/paper51.pdf

Jain M. & Dovrolis C. 2004. Ten Fallacies and Pitfalls on End-to-end Available Bandwidth Estimation. Proceedings of the 4th ACM SIGCOMM Conference on Internet Measurement (pp. 272-277). New York, NY, USA: ACM. doi:10.1145/1028788.1028825

Jain M. & Dovrolis C. 2008, 8. Path Selection Using Available Bandwidth Estimation in Overlay-based Video Streaming. Computer Network., 52, 2411-2418. doi:10.1016/j.comnet.2008.04.019

Jain M. & Dovrolis. C. 2002. Pathload: A Measurement Tool for End-to-End Available Bandwidth. In Proceedings of Passive and Active Measurements (PAM) Workshop, (pp. 14-25). doi:10.1.1.17.4495

Joshi K. & Benson T. 2016, 11. Network Function Virtualization. IEEE Internet Computing, 20, 7-9. doi:10.1109/MIC.2016.112

Kapoor R., Lao C., Chen L., Gerla & Sanadidi Y. 2004, 8. CapProbe: A Simple and Accurate Capacity Estimation Technique. ACM SIGCOMM Computer Communication Review. 34, pp. 67-78. doi:10.1145/1015467.1015476

Kirova V., Siemens E., Kachan D., Vasylenko O. & Karpov K. 2018. Optimization of Probe Train Size for Available Bandwidth Estimation in High-speed Networks. MATEC Web of Conferences. 208, p. 02001.

Nguyen U., Tran D. & Nguyen G. 2014. A Taxonomy of Applying Filter Techniques to Improve the Available Bandwidth Estimations. Proceedings of the 8th International Conference on Ubiquitous Information Management and Communication (pp. 18:1-18:8). New York, NY, USA: ACM. doi:10.1145/2557977.2558004

Paul A. K., Tachibana A. & Hasegawa T. 2016. NEXT-FIT: Available Bandwidth Measurement over 4G/LTE Networks-A Curve-Fitting Approach. 2016 IEEE 30th International Conference on Advanced Information Networking and Applications (AINA), (pp. 25-32). doi:10.1109/AINA.2016.24

Salcedo D., Guerrero C. D. & Martinez R. 2018. Available Bandwidth Estimation Tools: Metrics, Approach and Performance. International Journal of Communication Networks and Information Security, 10, 580. Retrieved from http://www.ijcnis.org/index.php/ijcnis/article/view/3516/324

Salcedo D., Guerrero C. & Guérrero J. 2017, 12. Overhead in Available Bandwidth Estimation Tools: Evaluation and Analysis. International Journal of Communication Networks and Information Security (IJCNIS), 9, 393-402. Retrieved from http://www.ijcnis.org/index.php/ijcnis/article/view/2475

Shi J., Yang Q., Gou G. & Xiong G. 2020. An Quick Available-Bandwidth Measurement Method Based on Link Delay Growth Rate. Proceedings of the 2020 8th International Conference on Communications and Broadband Networking. 51-57.

Shiobara S. & Okamawari T. 2017. A Novel Available Bandwidth Estimation Method for Mobile Networks Using a Train of Packet Groups. Proceedings of the 11th International Conference on Ubiquitous Information Management and Communication (pp. 59: 1-59: 7). New York, NY, USA: ACM. doi:10.1145/3022227.3022285

Weforum. 2020, MArzo. Worl Economic Forum. Retrieved from https://www.weforum.org/