Available Bandwidth Estimation Tools: Metrics, Approach and Performance

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Abstract: The estimation of the available bandwidth (av_bw) between two end nodes through the Internet, is an area that has motivated researchers around the world in the last twenty years, to have faster and more accurate tools; Due to the utility it has in various network applications; Such as routing management, intrusion detection systems and the performance of transport protocols. Different tools use different estimation techniques but generally only analyze the three most used metrics as av_bw, relative error and estimation time. This work expands the information regarding the evaluation literature of the current Available Bandwidth Estimation Tools (ABET's), where they analyze the estimation techniques, metrics, different generation tools of cross-traffic and evaluation testbed; Concentrating on the techniques and estimation methodologies used, as well as the challenges faced by open-source tools in high-performance networks of 10 Gbps or higher.

Keywords: Internet measurement tools, Available bandwidth estimation, Network throughput.

1. Introduction

The last years have brought a great change in the increase in the consumption of multi-content and it is becoming more frequent for the user to choose the moment, place and format to visualize information of his preference. This phenomenon implies, for example; The migration of traditional television to multimedia consumption on the Internet, among other changes of paradigms.

In the new century has seen an increasing and continuous number of Internet users and network applications. Internet users have grown more than 900% from 2000 to 2017 [1] and as well as the use of network applications such as e-mail, voice over IP (VoIP), Peer to Peer (P2P) and video Streaming. For some of these, information on available bandwidth can be used to monitor and improve performance.

The concept of bandwidth is essential for digital communications, and specifically the data packet network, which refers to the amount of data that a route can support per link or which can transmit per unit time. For many applications with high data load, such as file transfer or multimedia streaming; Managing real-time av_bw can positively impact application performance as well as interactive performance, which are more sensitive to low latencies than to high network performance, which can benefit from lower end-to-end delays associated to high bandwidth links with low latencies of data transmission [2].

The correct estimation of av_bw as a metric is important for both users and providers. For the former, estimation techniques facilitate the optimization of end-to-end transmission behavior. For the latter is taken advantage of by the administration tools can accurately monitor the use of one or more links; Internet service providers, can monitor and verify levels of quality of service; Transport protocols can determine the best transmission rate according to the amount of bandwidth available in the network; Intrusion detection systems can generate alerts based on an unexpected increase in network utilization; Which has been studied widely [3], [4], [5], [6], [7], [8], [9]. These and other applications require an end-to-end estimate of the av_bw, because there is no control over the intermediate links through which the communication channel is established.

Table 1. ABET's developed to date

Year	Tool	Author
2016	NEXT-FT	Kumar, Tachibana and Hasegawa
2014	BEST-AP	Dely, Kassler, Chow, Bambos, Bayer and Einsiedler
	Brandshape	Low and Alias
2009	ASSOLO	Goldoni, Rossi and Torelli
	Traceband	César Guerrero
2008	DCSPT	Ergin, Gruteser, Luo, Raychaudhuri and Liu
	Wbest	Li, Claypool and Kinicki
2007	YAZ	Sommers, Barford and Willinge
2006	ImTCP	Man, Hasegawa and Murata
	BART	Hartikainen, Ekelin and Karlsson
2005	BET	Botta, D'Antonio, Pescapé, Ventre
	Owamp	Shanlunov, Teitelbaum, Karp, Boote and Zekauskas
2004	DietTopp	Johnsson, Melander and Björkman
2003	PTR	Hu and Steenkiste
	Iperf	The Iperf team
	PathChirp	Vinay Ribeiro
	Spruce	Strauss, Katabi and Kaashoek
	Wren	Zangrilli and Lowekamp
	Abing	Navratil and Cottrell
	Pathrate	Dovrolis and Prasad
2002	IGI - PTR	Ningning Hu
	Pathload	Jain and Dovrolis
2001	Pipechar	Jin Guojun
2000	TOPP	Bob Melander
1997	Pathchar	Van Jacobson
1996	Cprobe	Carter and Crovella

The main av_bw estimation tools developed so far, are based on the two approaches. The first one, called Probe Rate Model [10], whose most representative tools are Pathload [11], Pathchirp [12], BART - Bandwidth Available in Real-Time [13] and Yaz [14]. And the second one, Probe Gap Model [15], with Traceband [16], Spruce [17], Abing [18] and Initial Gap Increasing (IGI) and Packet Transmission Rate (PTR) [19]. Based on one or another approach, trying to improve the different authors have developed techniques and methods of estimation, which in turn have been implemented in estimation tools, to refine the estimation. Therefore, tools like Assolo [20], Pathload and Pathchirp use SLoPs (Self-Loading Periodic Streams) [21]; In contrast, estimators as Traceband, Abing, IGI, PTR and Wbest [22], use PP/TD (Packet Pair/Train Dispersion), and TOPP (Trains of Packet Pairs) used by the Diettopp tool. Table 1 shows and expands the tools developed to date, with their respective authors.

Table 2. Tools evaluated by comparison studies

No	Author	Publication year	Evaluated tools
1	Downey	1999	Pathchar
2	Zangrilli	2003	Wren
3	Strauss	2003	IGI, Pathload, Spruce
4	Prasad	2003	Pathchar, Pathload, Iperf, Cprobe
5	Jain	2003	Pathload
6	Hu	2003	IGI, PTR, Pathload, Iperf
7	Shriram	2005	Pathload, PathChirp, Spruce
8	Michaut	2005	PTR, Pathload, Cprobe, PathChirp, Spruce, Pipechar, TOPP
9	Botta	2005	Pathload, PathChirp, BET
10	Man	2006	ImTCP, Pathrate
11	Johnsson	2006	DietTopp, Pathload
12	Guerrero	2006	IGI, Pathload, PathChirp
13	Angrisani	2006	IGI, Pathload, PathChirp
14	Sommers	2007	Pathload, Spruce, YAZ
15	Ali	2007	IGI, Pathload, PathChirp, Spruce
16	Urvoy	2008	Pathload, Spruce
17	Mingzhe	2008	Pathload, Iperf, PathChirp, Wbest
18	Ergin	2008	DCSPT
19	Gupta	2009	PTR, Pathload, PathChirp, Spruce
20	Cabanas	2009	Pathload, Iperf
21	Guerrero	2010	IGI, Pathload, PathChirp, Abing, Spruce, Traceband
22	Goldoni	2010	IGI, PTR, Pathload, PathChirp, Spruce, DietTopp, YAZ, Wbest, ASSOLO
23	Botta	2013	IGI, Pathload, PathChirp, Spruce, Abing, ASSOLO, Wbest, DietTopp
24	Xiaodan	2014	IGI, Pathload, Spruce, Abing, YAZ
25	Nguyen	2014	Abing, TOPP, BART, ASSOLO
26	Low	2014	Pathload, Brandshaper,
27	Hernández	2014	PTR, Pathload, ASSOLO, Owamp
28	Salcedo	2017	Abing, Diettopp, Pathload, PathChirp, Traceband, IGI, PTR, ASSOLO, Wbest

Due to the number of techniques and tools in the current literature, in the area of av_bw estimation, there are many attempts by different authors to collect useful information, which servers in two ways. One is as general information about the area of estimation of estimation of av_bw and second as reference for specific specialized consultation od basic concepts, functionality of estimation approaches, characteristics of the techniques developed and performance of certain tools. In [23], [24], [25], [26], [27], [28],, treats the basic concepts of the av_bw estimation area, such as *capacity*, *availablebandwidth* and the behavior of Internet traffic *Self-similar and Burst traffic*. Also authors in [29], [2], [17], broaden the previous basic concepts of the area of the estimation and measurement of av_bw. more used and important but concentrate on new elements like *Narrow link*, *cross-traffic*, *tight link* and add concepts like bulk transfer capacity (BTC), among others. Studies such as [30], [10], [31], [32], [33], [9], [34], [35], [36], [20], [37], [38], [39], [40], [41], concentrate on analyzing the techniques developed, because each author, based on one of the two approaches, creates a technique to optimize the variables of the av_bw metric, such as estimation time, prediction, and relative error. When developing a technique, it is implemented, evaluated and compared with studies such as [42], [11], [12], [43], [44], [45], [46], [47], [22], [48], [20], [49], [16], [50], [51], [13], [52], [53], [54], [55], show the comparative performance between two or more tools evaluated in simulated environments such as using NS-2 or NS-3, and in real network testbed Evaluate protocols, control certain network parameters, see Table 3.

All studies presented and reviewed, are important and at the time offered a relevant content according to the subject addressed, covering the needs of the area of the estimation of av_bw. This area is constantly changing, and information is growing rapidly. Due to this, our work will focus on a complete and updated summary of the av_bw concepts, metrics, variables, approaches, techniques and tools found in the current literature, concentrating on the analysis of the behavior of each estimation technique, and also; In the successes and failures offered by the most representative tools developed under these techniques.

The rest of the document is distributed as follows. In section II, we discuss the concepts of metrics related to the estimation of av_bw. Next in section II, a summary of all the estimation techniques used by the most representative tools of the area appears. In section IV, the main characteristics or differentiating elements of the av_bw estimation tools are discussed, which have been evaluated and compared by different authors. Finally, we find as conclusions, a summary and observations.

2. Metrics related to av_bw

This section introduces four metrics related to bandwidth: capacity, available bandwidth, One-Way Delay, and Bulk-Transfer Capacity (BTC). The first two are defined for both individual links and end-to-end links, while the BTC is generally defined only by an end-to-end path.

2.1 Capacity

The capacity of a link can be defined as the lowest bit rate that it is possible to transmit along the individual segments that are found in its route. The speed at which a network segment can transfer the data is usually the transmission rate or segment capacity. Thus, the link that determines the lowest capacity in the path is the one that will determine the capacity of the entire link [2], [11].

$$C = min_{i=1..H} C_i, \quad (1)$$

On the other hand, in a segment or link, the link layer can transmit data at a constant rate, for example, the rate of a 10-Gigabit Ethernet segment, it can handle transfer rates up to 10Gbps or less. However, in the network layer (IP), this rate is always lower because of the number of headers that are introduced. If the transmission time for an IP packet is:

$$T_{L3} = \frac{P_{L3} + O_{L2}}{C_{L2}}, \quad (2)$$

where P_{L3} is the size of the IP packet, O_{L2} the size of the Layer 2 protocol header (Ethernet, PPP, among others) and C_{L2} is the capacity of the link At the link level. If the capacity at level 3 is:

$$C_{L3} = \frac{P_{L3}}{T_{L2}} = \frac{P_{L3}}{\frac{P_{L3} + O_{L2}}{C_{L2}}} = C_{L2} = \frac{1}{1 + \frac{O_{L2}}{P_{L3}}}, \quad (3)$$

$$C_{L3}C_{L2} = \frac{1}{1+\frac{O_{L2}}{P_{L3}}}. \quad (4)$$

In this way, two protocols of the link layer can be compared, such as PPP and Ethernet. The PPP protocol has a header that occupies 8 bytes and the Ethernet header occupies 38 bytes.

It is important highlight that, there are other level 2 technologies that do not transmit at a constant rate, as is the case of networks that use IEEE 802.11n Wireless technology. In this case, transmissions are used between (54-300) Mbps, depending on the error rate found in said transmission. The first definition of capacity that was used in Equation 1 can be applied in these technologies as long as it is used in a time interval in which it is transmitting at a constant rate.

2.2Available Bandwidth

The most important indicator in this study is an end-to-end link. The av_bw of a link refers to the unused part of the total capacity of the link for a certain period of time. 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 [17], [27], [29].

Since at any point in time a new connection may arise within the link, in order 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:

$$\bar{u}_i(t, t+\tau) = \frac{1}{\tau}\int_t^{t+\tau} u_i\,(t)dt, (5)$$

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 A_i can be expressed as follows:

$$A_i = C_i(1-u_i), (6)$$

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

$$A = min_{i=1..H}A_i, (7)$$

2.3 TCP y Bulk transfer capacity (BTC)

TCP is the most important transport protocol that exists on the Internet, its use is almost 90% of traffic. Therefore, getting a measure of your performance would be of great interest to end users. Unfortunately, it is not easy to get the performance of a TCP connection. There are several factors that can influence TCP performance, such as the size of the transfers, the type of cross-traffic (UDP or TCP), the number of TCP connections that compete, the size of the initial window, etc. For example, transfers such as a typical web page depend mainly on the first congestion window, round trip time (RTT), and the TCP Slow-Start boot mechanism, instead of taking into account the bandwidth Of the route. In addition, TCP transfer performance can vary significantly when using different versions of TCP, even if the av_bw is the same [44], [56].

The BTC defines an indicator that represents the achievable performance for a TCP connection, ie, the BTC is when the maximum performance is obtained by a single TCP connection. In the connection, all TCP congestion control algorithms must be able to be applied as specified in RFC-2581 . However, this RFC leaves some implementation details open, so a measure must also specify in detail other Important parameters about the application (or emulation) of TCP. It should be noted that av_bw and BTC are different parameters. BTC is specific for a TCP connection, whereas the av_bw does not depend on a transport protocol. The BTC depends on how the bandwidth is shared with other TCP connections, while the av_bw assumes that the average traffic load is kept constant and estimates the available bandwidth on the link.

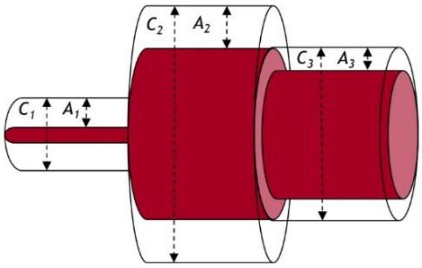

Figure 1. Minimum av_bw in 3 different capacities network segments.

3. Bandwidth Estimation Techniques

Within the active methods two groups can be distinguished. On the one hand those dedicated to the study of capacity and bandwidth available and on the other those that analyze the delay, its variation and the rate of packet loss. Within this group stand out the following set of techniques: Variable Packet Size Probing (VPS) estimates the ability of individual jumps. Packet Pair/Train Dispersion (PPTD) which estimates end-to-end capacity. Periodic Streams (SLoPS) which estimates the bandwidth available end-to-end. Trains Of Packet Pairs (TOPP) which estimates the end-to-end available bandwidth [29], [57].

3.1 Variable Packet Size (VPS)

The VPS method is based on the single packet delay model; You can measure the capacity of each jump or section along a link. Typical tools that are based on the VPS technique include pathchar, clink, pchar, etc. The key element of the VPS technique is to measure the RTT method from the source to each hop of the link depending on the size of the bundle \cite{Li2008}. Specifically, it is expected that the minimum RTT $T_i(L)$ for a given packet of size L to the jump i is:

$$T_i(L) = \alpha + \sum_{k=1}^{i}\frac{L}{C_k} + \alpha + \beta_i L, (8)$$

where C_k is the capacity of the corresponding k jumps, α is the delay of the packet up to the i jump that does not depend on the size of the L polling package, and β_i is the slope of the minimum RTT until the jump i against the size of the poll package L, given by

$$\beta_i = \sum_{k=1}^{i}\frac{1}{C_k}, (9)$$

Repeating the minimum RTT measurement for each jump i = 1,..,H, and by linear interpolation, the estimate of the capacity at each jump i along the link is

$$C_i = \frac{1}{\beta_i - \beta_{k-1}}, (10)$$

3.2 Packet Pair/Train Dispersion (PPTD)

The PPTD technique consists of sending bursts of consecutive *k* consecutive packets of constant size (*S*) ($k >= 2$) from source to destination. The dispersion (temporal separation between packets) measured at the destination, which these packets undergo, allows to estimate the maximum rate that can be reached in the traversed network. Therefore, capacity is estimated using the following equation:

$$C = \frac{(k-1) * S}{t_k - t_1}, (11)$$

where t_k is the arrival time of the packet i, and t_1 is the arrival time of packet 1.

Table 3. Analysis of available bandwidth studies

Author	Evaluated metric	Type of traffic	Utilized testbed
Downey [60]	Accuracy, Av_bw, latency	ICMP packets	Internet infraestructure
Zangrilli and Lowekamp [61]	Av_bw, overhead, accuracy, estimation time, Latency	TCP and UDP packets	Real Testbed
Strauss et al. [17]	Accuracy, failure patterns, overhead,	UDP packets	Internet infraestructure
Prasad et al. [2]	Capacity, Av_bw, Bulk-Transfer Capacity)	Variable Packet Size (VPS) probing, TCP and UDP packets.	Real testbed
Jain and Dovrolis [21]	Relative Error, Accuracy, Estimatio0 Time, Packett Size and Latency	Use TCP Packetand real cross traffic	Real testdbed
Hu and Steenkiste [19]	Accuracy, Relative Error, Estimation Time, Av_bw	TCP and UDP packets	NS2
Shriram et al. [62]	Accuracy, Overhead	Accuracy, Overhead	Real testbed
Michaut and Lepage [63]	OWD, Delay variation, RTT, Packet loss	TCP packets	Real testbed
Botta et.al. [44]	Accuracy, Relative error, Av_bw,	TCP and UDP packets	Real testbed
Man et al. [46]	Capacity, PPS, bandwidth	Internet Traffic-TCP packets	NS2
Johnsson et al. [64]	Packet Delay	Sintetic traffic	Real testbed
Guerrero and Labrador [65]	Accuracy, overhead, relative error, convergence time	TCP and UDP packets	Real testbed
Angrisani et al.[66]	Capacity, Av_bw	UDP packets	Real testbed
Sommers et al. [14]	Accuracy, overhead, Relative error, Av_bw	TCP and UDP packets	Real testbed
Ali et al. [67]	Accuracy, overhead, response time	TCP and UDP packets	Real testbed
Urvoy-Keller et al. [68]	Av_bw and time-stamp	Data set.	Real testbed
Mingzhe Li et al. [69]	Av_bw, relative error, overhead, cross traffic, Estimation time	Sintetic traffic generated by MGEN and iperf tool	Real testbed
Ergin et al. [70]	Av_bw, dispersion, packed delay, throughput	TCP and UDP packets	Real testbed
Gupta et al. [71]	Data rate, number of hops, interference amount	Data set.	Real testbed
Cabanas et al.[72]	Av_bw, accuracy	No describes	Real testbed
Guerrero and Labrador [73]	Tight link capacity, crosstraffic, cross-traffic packet size, Av_bw, accuracy	TCP and UDP packets	Real testbed
Goldoni and Schivi [74]	Estimation time, overhead and accuracy	TCP and UDP packets	Real testbed
Botta et al. [6]	Accuracy, probing time, overhead, Av_bw	TCP and UDP packets	Real testbed
Xiaodan [75]	Av_bw, accuracy, estimation time	TCP packets	Real testbed
Nguyen et al. [?]	Av_bw, cross traffic, RTT, packet loss rate	TCP and UDP packets	Real testbed
Low and Alias [76]	Bandwidth, RTT, packet loss	TCP and UDP packets	Real testbed
Hernandez and Insuasty [77]	Av_bw, accuracy, estimation time	UDPpackets	Real testbed
Salcedo et, el. [78]	Av_bw, overhead, relative error, estimation time	TCP and UDP packets and cross-traffic	Real testbed

However, if there is traffic from another source simultaneously with the test, there is an underestimation of the capacity as Consequence of the fact that the packages of another origin are intermingled with the ones of test increasing the dispersion of the latter. This effect is more pronounced as greater than *k*, since it increases the probability that traffic from another source that circulates through the network is introduced between the test packets.

3.3 Self-Loading of Periodic Streams (SLoPS)

SLoPS measures the available \cite{Jain2003} capacity of a network path. The source sends a number of packets of the same size *S* (a periodic packet stream) to the receiver with a certain rate r_o and with arrival rate *r*, the period between packets is $T=S/r_o$. This methodology considers variations in the monitoring of the delays in a sense *D* one-way delay of the test packages. It assumes that if the flow rate r_o is greater than the available bandwidth av_bw, the flow will cause a temporary overload in the queue of the more congested node, that is, of the link that Determines the available bandwidth on the [59] path.

One-way delays (OWD's) will continue to increase as each packet of the stream is queued at the lowest av_bw (tight link) link. In the other case, if the flow rate *r* is less than the available bandwidth av_bw, the test packets will go through the path without causing any accumulation or agglomeration on the lowest av_bw and the delay will not increase. Based on this principle, an iterative algorithm is developed to measure and estimate av_bw. The source host (*SND*) sends a periodic stream *n* with rate $r(n)$ and the receiver (*RCV*) analyzes the variations of delays to determine if $r(n) > av_bw$or not and notifies the SND to increase or decrease the $r(n)$ rate.

The source examines the trajectory with successive packet streams of different transmission rates, while the receiver notifies the source about the trend of delays in one direction of each stream. Available bandwidth estimated Av_bw may fluctuate during the measurement. SLoPS identifies such variations when it detects that the OWD delays of a flow do not show a clear tendency to increase or decrease.

3.4 One-Way Delay (OWD)

In the Figure 1 can see how the last segment A_3 has the smallest av_bw and this will be the bottleneck of the transmission at that instant of time.

It is important to note that on many occasions it is assumed that the traffic load is stationary all the way. This is only reasonable taking a short time interval since it is an indicator that varies rapidly with time. This fact is the main difference that exists with respect to the capacity, since it does not change as fast as there are no modifications in the routes or the links.

One-Way Delay (OWD) is defined as the delay experienced by the packet on the outgoing route, ie the time a packet *k* uses to reach its destination. This delay depends on the transmission time, latency and queue delay. The transmission time is the time the router uses to transmit a packet, which is a function of the packet size and the connection capacity. Queue latency is the time the signal uses to traverse the link, determined by the physical characteristics of the link. Queue delay is the time that a packet has to wait in the router due to cross-traffic. The first two terms are deterministic while the latter is random. Therefore, the OWD can be expressed as:

$$\Omega_k^k = \sum_{s=0}^{i} (x_s + d_s + q_s) = \sum_{s=0}^{i} \left(\frac{P_k}{C_s} + d_s + q_s \right), (12)$$

where x_s is the transmission time of a packet of the size of P_k, d_s is the queue latency and q_s is the queue delay. To measure OWD, it is necessary to have timestamps, both at the origin and at the destination. For some applications, a single measure at the origin can be interesting using Round-Trip Time (RTT), which is the time it takes to go and return a packet along the link.

3.5 Trains Of Packet Pairs (TOPP)

The TOPP technique can estimate both the nominal capacity and the available capacity of several nodes in a network path [59]. The technique consists of two phases, the first consists of the technique of probing or sending trains of packet pairs, and the second, the analysis of the time stamps of the packet pairs.
In the first step or probing stage, several packet streams are sent, whose transmission rate increases linearly to a maximum rate that is greater than the available capacity of the narrowest node in the trajectory (tight link).

$$r_i = [r_{1,} r_{2,} r_{3,} \ldots\ldots, r_n], (13)$$

where

$$r_1 = r_{min}, r_2 = r_1 \Delta r, r_3 = r_2 \Delta r, \ldots, r_{n-1} \Delta r, (14)$$

The size of each probe packet is constant: $S_1 = S_2 ... = S_n$ Thus, there is a total set of packet streams that equals the number of transmission rate levels.
In the second step, from each pair of measurements (r, r'), we estimate the capacity values C and av_bw. If r is greater than the av_bw, *r>av_bw* of end-to-end path. The the second probe packet will be queued behind the first packet and the measured measure at the receiver will be $r'<r$. In the other case, if r <*av_bw*, then TOPP assumes that the packet pair arrives at the receiver at the same rate it had at the time it left the source. There are similarities between the SLoPS and TOPP techniques, since both are based on the self-congestion of the lower capacity node, the main differences between the two techniques are related to the statistical processing of the measurement to estimate the av_bw [2].

Table 4. Evaluated tools frequency by researches

Author	Tool	Frecuency
2002	IGI	9
2002	Pathload	22
2003	PTR	7
2003	PathChirp	12
2003	Spruce	11
2003	Abing	6
2004	DietTopp	3
2007	YAZ	3
2009	Assolo	4

4. ABET's performance analysis

At present, no complete comparative studies are included in the literature, which include the largest number of technical review and evaluation of evaluation tools. In 2015 [77], introduced a complete state of the art of available bandwidth, however, this work is only focused on a few databases and there are about 18 papers focused on evaluation of estimation tools.
For this review we analyze a little more than 30 works focused on the evaluation of tools of estimation of bandwidth, however, some works were discarded due to their present a greater publication boom for the years 2003-2007, where they are 14 of the 28 total documents. It should be noted that for the last 5 years the average number of tools evaluated per document is 6 tools, while for the other years.
It is important to clarify that in most works the evaluations were carried out, given that the document presented a new tool, or a technique to improve the accuracy, speed or other metric of the measure. The most evaluated tools are IGI, Pathload, PTR, PathChirp, Spruce, Abing, DietTopp, YAZ and ASSOLO, the other tools were evaluated in less than three documents. Certainly, the most evaluated tool is Pathload, with a total of 22 documents in which it was taken for comparisons, followed by PathChirp with 12 documents and Spruce with 11, see Table 4.
In terms of the environment in which the tools were evaluated, about 75% ie., about 20 documents made their measurements under a testbed test platform and a small percentage in a simulated environment, see Table 2 and Table 3. For traffic generation the most used packet generators are MGEN and D-ITG, mostly using synthetic Poisson and Bursty traffic with about 45% and 37% of the documents respectively.
The most evaluated metrics in the documents are capacity, available bandwidth, error, accuracy and estimation time, accounting for more than 75% of documents. In most works Pathload is considered as the tool that delivers the most successful results, that is to say with a minor error, but it is also considered one of the tools with the longest measurement and intrusive time. Likewise, contradictory results are presented between the performance of the tools, all of which are supported by the different measuring conditions and tests carried out, which vary considerably from one document to another.

5. Conclusions and perspectives

In the literature there were no papers focused on the revision of documentation of available bandwidth estimation tools, this being an initial work in the performance of a current evaluation work. This work is excepted to encourage more work in the area of available bandwidth to obtain greater developments in the area because in recent years the tools and techniques developed has been declining.
It was determined that the development of tools focused on the overhead caused in the estimation of available bandwidth are in an initial stage, the developments and characterizations realized in this work contribute to the generation of knowledge of later works focused on the estimation of av_bwof end-to-end network with zero overhead, which impacts on better packet transmission rates and traffic control, this makes telecommunication networks much more efficient which has been of great importance due to the great growth In their use given the new technologies.

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