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PERFORMANCE EVALUATION OF PRM-BASED AVAILABLE BANDWIDTH USING ESTIMATION TOOLS IN A HIGH-SPEED NETWORK ENVIRONMENT

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ОЦІНКА ЕФЕКТИВНОСТІ ВИМІРЮВАННЯ ДОСТУПНОЇ ПРОПУСКНОЇ ЗДАТНОСТІ PRM ІНСТРУМЕНТАМИ У СЕРЕДОВИЩІ ВИСОКОШВИДКІСНОЇ МЕРЕЖІ

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ОЦЕНКА ЭФФЕКТИВНОСТИ ИЗМЕРЕНИЯ ДОСТУПНОЙ ПРОПУСКНОЙ СПОСОБНОСТИ PRM ИНСТРУМЕНТАМИ В СРЕДЕ ВЫСОКОСКОРОСТНОЙ СЕТИ

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Abstract. Awareness regarding available bandwidth value between two terminal devices is applicable for solving a wide variety of networking issues. This value causes challenges for an accurate network monitoring and optimization of link capacity usage. Among the various metrics that belong to the traffic monitoring on a network path, this research is focused on available bandwidth estimation. The methodology of probe rate model for the available bandwidth estimation in wired networks is considered. Characteristics of the existent tools – Kite and Yaz are given and the prototype of a new developed tool Kite 2 is described. A comparison of tools for available bandwidth estimation performance in the high-speed environment is given.The optimized configuration of each tool in comparison to its default settings is proposed.

Keywords: available bandwidth, end-to-end measurements, link capacity, emulated networks,10 Gps networks, Kite, Yaz.

Анотація. Знання про величину доступної пропускної здатності каналу між двома кінцевими пристроями у мережі може бути застосовано для вирішення багатьох мережевих питань. Це приводить до нових викликів, пов`язаних з точним мережевим моніторингом та оптимізацією використання ємності каналу. Серед різноманітних метрик, що відносяться до моніторингу передачі даних по мережевому шляху, ця дослідницька робота спрямована на вивчення доступної пропускної здатності каналу. Розглядається методологія вимірювання доступної пропускної здатності високошвидкісного каналу за допомогою аналізу потоку з постійною швидкістю. Надані характеристики існуючих інструментів – Kite і Yaz та описується прототип нового інструмента Kite 2. Проведено порівняння ефективності інструментів вимірювання доступної пропускної здатності. Запропоновано оптимізовані налаштування кожного з іструментів на базі результатів вимірювання.

Ключові слова: доступна пропускна здатність, наскрізне вимірювання, ємність каналу, емульовані мережі , мережі 10 Гб/с, Kite, Yaz.

Аннотация. Знания о величине доступной пропускной способности канала между двумя оконечными устройствами в сети, может быть применено для решения многих сетевых задач. Это приводит к возникновению новых вызовов, связанных с точным сетевым мониторингом и оптимизацией использования ёмкости канала. Среди разнообразных метрик, относящимся к мониторингу передачи данных по сетевому пути, эта исследовательская работа направлена на изучение доступной пропускной способности. Рассматривается методология измерения доступной пропускной способности высокоскоростного канала с помощью анализа потока с постоянной скоростью. Описан прототип нового инструмента Kite 2. Приведено сравнение эффективности инструментов измерения доступной пропускной способности. Предложены оптимизированные настройки каждого из инструментов на основе результатов измерений.

Ключевые слова: доступная пропускная способность, сквозное измерение, ёмкость канала, эмулированные сети, сети 10 Гб/с, Kite, Yaz.

Introduction. Available bandwidth estimation–and the evaluation of link capacity and maximum achievable throughput are key processes in the context of packet networking as measurements of-network infrastructure performance. The available bandwidth (AvB) value relies on the amount of data which can be transferred through the link or the whole path (end-to-end measurement) in a given time period. It is crucial for audio- and video- streaming technologies, overlay and content distribution networks, greed applications, Big Data transmission and many others [1, 2].

Thus, the results of the measurements are required to be accurate, low latent, and resource intensive. Applications in high-speed networks especially refers to those which need measurement techniques and tools in order to monitor networks for their performance expectations.

Related works. Several software tools were developed in recent years which use different methods and models of network metrics estimation. These include: pathload [3] and pathChirp [4], which are based on evaluation of one-way-delay properties changes while sending periodic streams of packets; algorithm IGI [5], which detects proportional correlation of initial packet gaps changes and cross traffic in the path, thus detecting a tight link; Yaz [6, 15], which makes calculations based on difference of inter-packet intervals on the receiver and sender sides; Abing [7], which evaluates packet pair dispersion; ASSOLO [8], which is based on enhanced algorithm of pathChirp and increases the accuracy of measurement by increasing of the probing stream density; ttcp [9], which measures achievable TCP throughput; path rate which is based on packet pairs dispersion method; Netperf, which uses large TCP transfer [2]; and others which were described in [2, 10]. A summary and initial comparison of these tools were already given in papers such as [11] and [12].

It is important to separate which network metrics is measured by these tools – link capacity, available bandwidth or achievable TCP throughput – as each of these parameters defines at a different core characteristic. To explain their difference, the pipe model for a path with 3 links is shown in Fig. 1. It graphically represents that the width of each segment corresponds to the capacity of each link. The shaded area shows a spare capacity or available bandwidth.

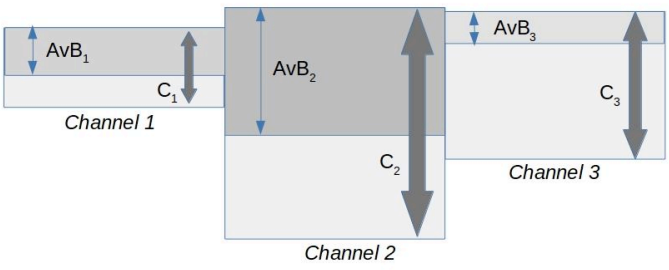

Figure 1 – Network model of interconnected links with variable bandwidth parameters

The lowest capacity among all network segments (in this case C1) at the same time defines the capacity of the whole end-to-end path, as well as the lowest value of available bandwidth (AvB3) corresponds to the end-to-end available bandwidth. As shown in Fig. 1, narrow and tight link can be different. Thus, each measurement algorithm should be properly used for a network performance evaluation and elicitation of its parameters.

For example, *Pathload*, *pathChirp*, and *IGI* applications measure end-to-end available bandwidth, *Pathrate* measures end-to-end capacity, *ttcp*, and *Netperf* software measure achievable TCP throughput.

The purpose of this article is to investigate measurements of end-to-end available bandwidth as it is the most comprehensive metric of explored network and provide performance evaluation for less examined tools in comparison to the explored and well-known ones.In this research, it was also decided to implement a new self-developed tool for a more comprehensive analysis of PRM-based tools.

Estimation approaches. In order to make the choice of the studied tools, two principles of available bandwidth measurement were explored: Probe Rate Model (PRM) and Probe Gap Model (PGM) [12]. The PGM-based technique relies on the dependency of transfer throughput in a link and gap dispersion between packets in the probing train or pair.-Hence, cross traffic is evaluated and further subtracted from the predefined path capacity. This technique assumes that the narrow link with the minimum capacity within the entire network path is equal to the tight link of the path [10]. As described in this article-tight link can be different from a narrow one in a multi-hop network, so the tool based on this model can significantly underestimate the available bandwidth. Also, this technique imposes restrictions on measurement if the value of path capacity is unknown beforehand. Such statements contradict the goal of our research, which is why we have referred to another technique – PRM – based on the self-induced congestion [13].

PRM model uses iterations of probing trains or pairs from source to receiver with increasing/decreasing transmission rates but with the constant rate within one iteration. The decision of send-rate variation is made after the evaluation of successfully transferred packets to the receiver side. If the rate of the packet train or train of packet pairs is higher than the available bandwidth – a new iteration with a specifically decreased rate is generated and this step continues until the probe rate is not equal to available bandwidth. This technique is characterized by a high accuracy and requires relatively less time for estimation opposed to the PGM model, despite the fact that the intrusiveness of the technique to the link or obtained data for the measurement is much higher. The balance of intrusiveness and accuracy is a keystone performance metric for the available bandwidth estimation tool used in the research described in this paper.

Investigated tools. The choice of measurement tools for their further comparison and investigation is based on compliance with such parameters:

1. Support for available end-to-end bandwidth measurements;
2. Probe Rate mode as a basis of the used algorithm;
3. Applicability in a 10 Gbps network;
4. GPL-licensing of a source code in order of its investigation and optimization for the high-speed environment;
5. Modernity and unexplored performance opposed to the well-known tools.

While conducting research,-measurement tools were chosen – Kite (also named Estimator) [14], developed in terms of study tool Kite 2, and a proven a high-performance measurement instrument – Yaz [15]. In Table 1 the main features of the listed tools are described.

Yaz, or calibrated pathload tool, is based on the Pathload algorithm of Self-load periodic streams but uses only one probe packets train opposed to fleets of trains in Pathload. It evaluates an inter-packet interval (and its corresponding constant bit rate – CBR) for each iteration of measurement as an increased value of the previous inter-packet interval on the sender side by its difference with the inter-packet interval on the receiver side. Yaz finalizes the process of measurements as soon as this difference of inter-packet intervals reaches predefined thresholds. The previous study of this tool shows high performance of this tool in networks up to 1 Gps. Thus, Yaz is used as a reference tool in terms of this research [15].

Table 1 – Explored available bandwidth estimation tools

Tool	Author	Measurement metric	Technique
Yaz	J. Sommers, P. Barford, W.Wilinger	End-to-end Available Bandwidth	SloPS of a CBR train
Kite (Estimator)	D. Kachan	End-to-end Available Bandwidth	SloPS of packet trains
Kite 2	V. Kirova	End-To-end Available Bandwidth	SloPS of packet pairs and trais

Kite (Estimator in this paper) uses the same technique but with enhanced features, such as the automatic adjustment of a number of samples which allows the use of Step Decreasing Factor in high-speed networks – the rule of increasing the probe send rate [5, 14]. This tool was previously compared to the Yaz in [14] and showed accurate estimations.

Kite 2 is based on an evaluation of the inter-packet interval of the probe of the packet train or train of packet pairs (dependable on the chosen mode) by the receiver. It consists of at least three iterations of probe sending while one measurement-analyzes the difference of inter-packet interval on the server and client side with the maximum possible sender probe rate and decreases till the appropriate rate is equal to the available bandwidth of the path.

Test environment. The results of the paper were gathered from experiments run on a testbed described in Fig.2. In order to provide test environment for the 10 G network, such equipment was used: 2 instances of Netropy 10 G WAN Emulators, 2 instances of end terminals one on which is sender with 12 x Intel(R) Xeon(R) CPUX5690 3.47 GHz processors, 32 GB RAM and equipped with with 10 G NIC, another one is receiver with 6 x Intel(R) Xeon(R) CPU X5690 3.47 GHz processors, 42GB of RAM and 10G NIC. Both machines run Linux distribution – Ubuntu 16.04 system with the 4.4.0 – 97-low-latency kernel. ExtremeNetworks Summit x650 – 10 Gbps switches were used for the network devices. In order to emulate fluidity of AvB in real conditions, one of the network emulators cyclically changes its capacity with such steps: 2 Gbps, 7 Gbps, 10 Gbps during the whole measurement.

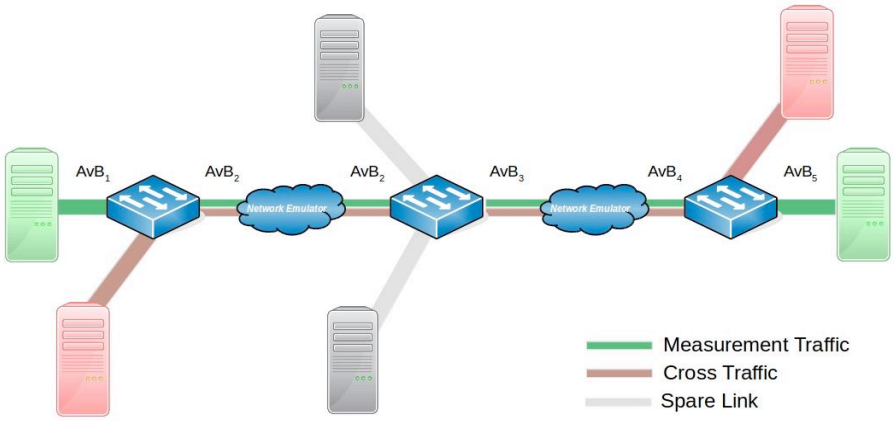

Figure 2 – Setup of the measurement testbed

As a test environment is configured for a high-networking, optimization of studied tools was provided. It included modification of the included input parameters, such as maximum segment size, packet stream lengths, and the number of packets in stream per measurement, in order to gain appropriate probe rate for the 10 Gbps transmission. Configuration of available bandwidth tools in comparison to its default settings is provided in Table 2.

Table 2 – Optimized and Default configurations of AvB tools

Tool	Default value	Optimized value
Yaz		
MTU, bytes	1500	9000
Minimum MTU, bytes	200	1500
Packet Stream Length	50	50
Streams per measurement	1	3
Kite (Estimator)		
MSS, bytes	1472	8972
Amount of samples for the initial measurement	20	100
Initial Send rate	Auto	1
Kite2		
Measure type	Train of pairs	Packet train
MSS, bytes	1472	8972 bytes
Send rate	100 Mbps	1 Gbps
Ratio of occupied bandwidth	0.01 %	1%

The results of the measurement with the duration of 60 sec are shown in Fig. 3. During the measurement, three iterations of capacity variation were performed. The light-blue graph corresponds to the reference bandwidth, the dark blue presents results of measurement by Kite 2 tool, the red – results by Estimator tool, and the yellow – by Yaz. Dots on each graph show the number of evaluated values by each tool per iteration.

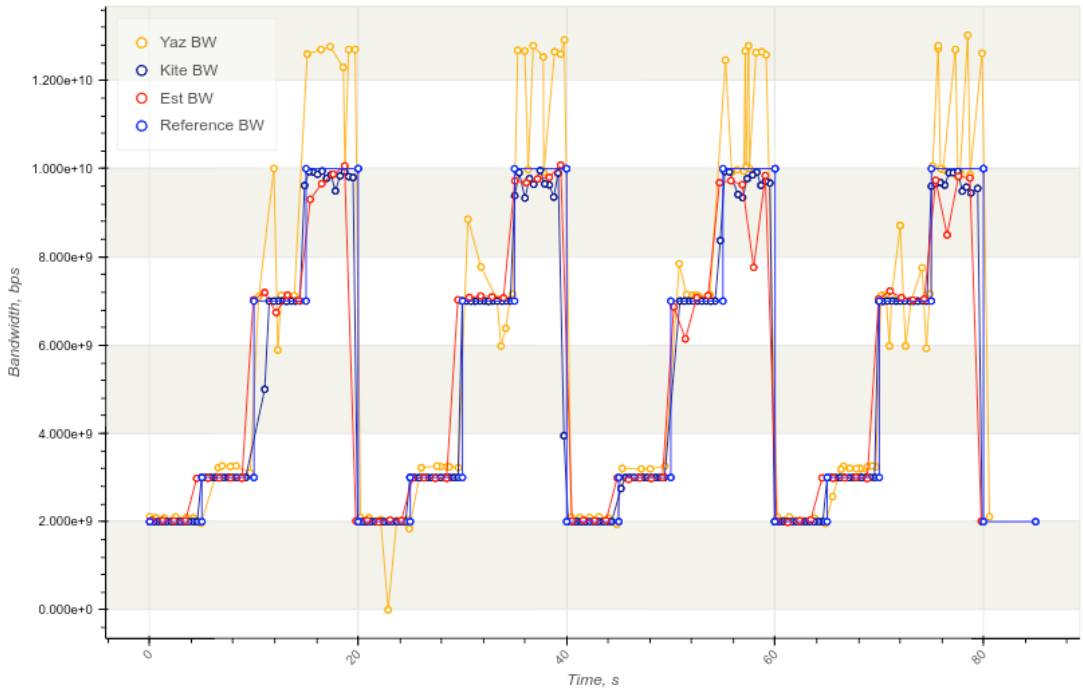

Figure 3 – Accuracy of the measurement tools idle link with variable capacity

On the IDLE link when the capacity is limited only by emulators, all three tools show low overhead for the estimation of AvB up to 4 Gbps. With the increase of capacity overheads of tools grows constantly, as well as the number of estimation outliers.

The most precise estimation for the range 4 – 10 Gbps is shown by Kite 2, despite the fact that it tends to overestimate the AvB at high speeds. It might be related to the amount of occupied capacity by this tool while estimation. For the link with 10 Gbps capacity, it consumes approx. 1.6 Gbps to calculate each finite AvB value in a contradiction to 300 Mbps consumed by Estimator tool.

Estimation overhead is shown in the Fig. 4. As it is represented by the boxplots for each examined tool, the lowest range of error values corresponds to Kite 2 measurement with a tendency of underestimation up to 100 Mbps for the 10G network Kite (Estimator) show tend to both – overestimation and underestimation of the evaluated available bandwidth value. Bursty outliers of Yaz measurements in the Fig. 3 are detected in the wide range of boxplot, which are spread among 400 Mbps of overestimation.

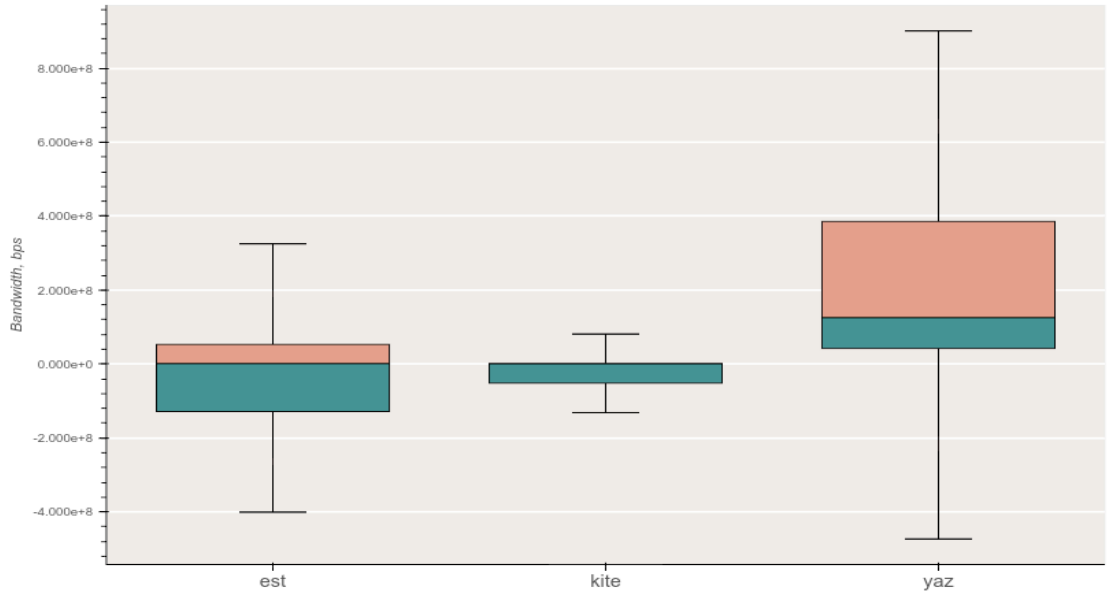

Figure 4 – Overhead of the measurement tools in idle link with variable capacity

In order to track the changes of measurement accuracy dependable on the deterioration of conditions by the network, we have configured the network emulator to inject Packet Losses or Delay. We gradually increased the value of delay or losses in order to detect the threshold at which any of the tools-would not continue to handle-measurements. The results of experiments are shown in the Fig. 5. and Fig. 6.

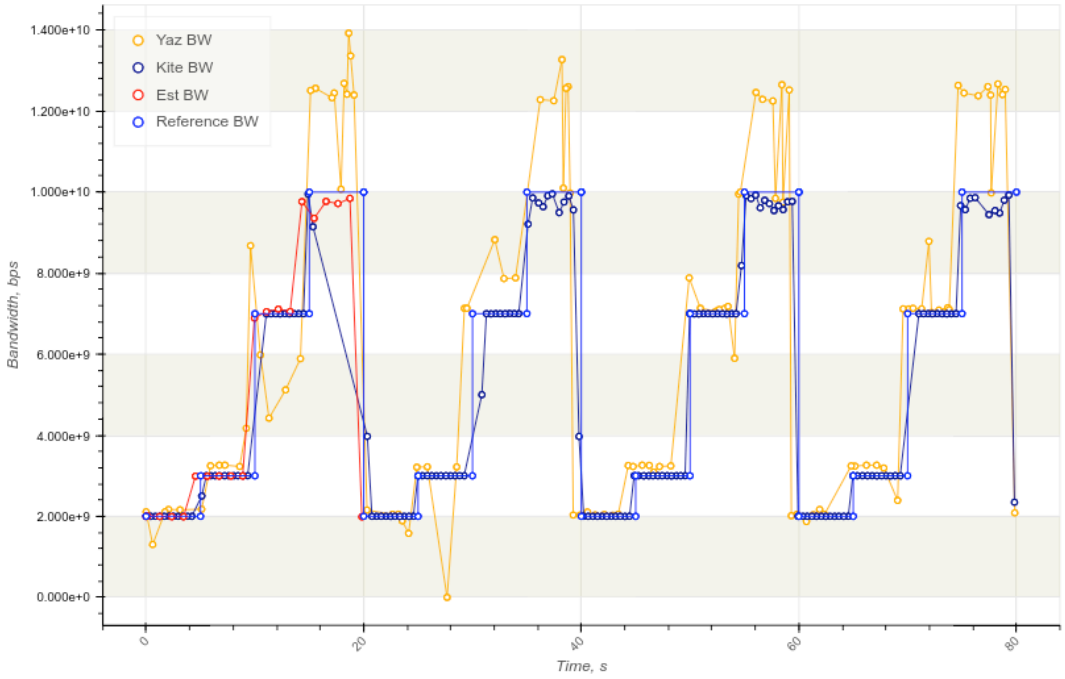

Figure 5 – Accuracy of the measurement tools in link with variable capacity and 0,5 ms of delay

The investigation showed that the performance of measurement tools suffered mostly from packet delay than from losses and all examined tools successfully measured AvB metric with 1% of Packet Losses.

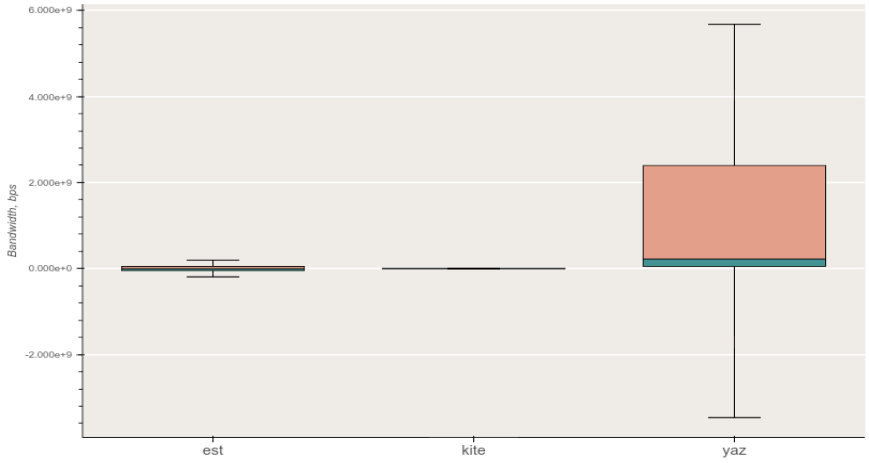

Figure 6 – Accuracy of the measurement tools in link with 0,5 ms of delay

In conclusion, we would like to emphasize that an initial comparative evaluation of the available bandwidth estimation tool performance is presented in this paper. One of the research purposes was to study unfamiliar and previously non-compared tools, so three were chosen: Yaz (as a reference algorithm), Kite (Estimator) and Kite 2 – a self-developed, enhanced algorithm. These tools were evaluated under their optimized runtime configurations. Accordingly, for the accuracy and overhead evaluation at different values of link capacity, a testbed was built with commercial

high-speed hardware components. The results which were obtained can be used for the fine tuning of the considered tools and showing competitiveness of the developed tool Kite 2 as opposed to the known and investigated one. Further research into tool behavior under stressful network conditions is indicated.

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