Performance Study for End-point Links of Networks

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***Abstract*—The rapid deployment of networks in various environments demands accurate, efficient measurement in order to estimate path links. In this work, we considered the challenges posed by broadband networks for available bandwidth capacity evaluation. We focused on rate, using token bucket in cable modem end link with non-FIFO scheduling, and on burstiness type of traffic applied by multi-rate end-links in wireless network that follows the IEEE 802.11 protocol. We used a software tool for estimating the path rate capacity and we found that raw links and the corresponding token bucket rates were calculated in a quick and accurate manner. The accurate prediction of the available bandwidth in an end-point network link can help to avoid traffic bottlenecks, server choice, and overlay networks.**

Keywords - end-point links; cable links; wireless links; throughput; performance evaluation.

I. INTRODUCTION

As the Internet grows in size and connection complexity, new application and services requirements necessitate the performance analysis of network paths using either some estimation techniques or developing appropriate software tools for monitoring and measuring the properties of end-to-end paths. In the context of performance evaluation the *available bandwidth* of a point-to-point path is a metric of crucial interest in packet switched networks and is therefore the key in studying network management, server selection, routing, and other network issues.

At previous works in literature, some performance metrics which referred to end-to-end paths have already been estimated. Some papers assume simple models of network links [1]. For example, Strauss et al. [1] admits that the narrow links -the links with the minimum capacity among all links- and the tight links –the links with the minimum available bandwidth among all links- along a specific path have a well-defined raw bandwidth that shows the rate at which bits can be traversed via the link. However, some of these assumptions used by the traditional model do not work with access networks like cable modem and wireless 802.11 [15], [16]. This discrepancy may be happen due to any of the following reasons:

(a) A network end link is likely to appear as variable values of row bandwidth because of the token-bucket rate regulation (like cable modem links). A similar behaviour can be noticed in wireless 802.11 end links, which appear as various multi-rates schemas.

(b) The packets may not be delivered via first input first output (FIFO) policy.

(c) Wireless 802.11 links may experience interference from high cross-traffic.

By this work, the challenges posed by broadband networks to existing capacity estimation techniques were identified. Many experiments for *available bandwidth* estimation of end-point links were done. The experiments demonstrated the impact of packet size on the maximum *achievable throughput* in wireless links. Finally, quantitative results revealed the effect of the multirate environment on the *available bandwidth*.

The paper has the following structure. In Section II, the basic performance definitions are presented and some related work is overviewed. In Section III, different types of network access and their characteristics of end-points are explained, while in Section IV the methodology of our experiments is outlined. Subsequently, in Section V the results of our experimental testbeds are reported, while Section VI provides the concluding remarks and outlines the future work.

II. BASIC DEFINITIONS- PREVIOUS WORK

A. Basic Definitions

Network path can be defined as any sequence of links, where a store-and-forward routing mechanism is used in order to transfer packets from one point (sender) to the other point (receiver). In our case study, each path is considered to be fixed and unique that implies no routing changes are applied in this path.

Link capacity (C_i in bps) at a specific link (i) is considered the maximum constant rate of bits that can be applied on this link when it is empty.

End-to-end link capacity (C in bps) of a path p is defined as the maximum rate of bits that can be applied at the path p when no other traffic is concurrently applied on this path C is therefore assumed the maximum rate that path p

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can provide to a flow. Consequently, the *end-to-end link capacity* of a path *p* can be estimated as:

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

where *v* is the total number of links at the sequence of store-and-forward links of path *p*.

Available link bandwidth [$A_i^{\Delta t}(t_0)$ in bps] of a link (*i*) at the time interval ($t_0, t_0 + \Delta t$) is defined as a fraction of the *link capacity* that has not been utilized during this time interval. Denoting the average utilization of a link (i) during the time interval ($t_0, t_0 + \Delta t$) as $u_i^{(\Delta t)}(t_0)$ the corresponding available bandwidth of link can be expressed as:

$$A_i^{(\Delta t)}(t_0) = C_i[1 - u_i^{(\Delta t)}(t_0)] \quad (2)$$

In the same manner, the *end-to-end available bandwidth* $A^{(\Delta t)}(t_0)$ of a path *p* can be considered as the minimum available rate among all links in this path. Thus, the *end-to-end available bandwidth* of a path *p* expresses the maximum rate that can be provided to a flow, without shortening the bandwidth of the rest of the traffic in this path. Formally, it can be estimated as:

$$A^{(\Delta t)}(t_0) = \min_{i=1..v}\{C_i[1 - u_i^{(\Delta t)}(t_0)]\} \quad (3)$$

Finally, another two significant metrics in performance analysis are the following:

Narrow link is the link with the minimum capacity among all links in a path, expressing thus the capacity of the whole path.

Tight link denotes the minimum available bandwidth among all links of path, which is therefore an indicator of the path's available capacity.

B. *Previous Work*

In the last two decades many efforts have been devoted by researches for estimating the network capacity of access links. The performance calculations in [2],[3] were based on the packet pair principle. Thus, various techniques have been designed to avoid interference; e.g., in [4] in order to transmit a packet subsequence with variable packet sizes like trains' wagons have been proposed. Efforts like [5], [6] and [7] based on packet/train approach have also been addressed; all these efforts investigated the relationship among packet sizes and packet delays, as well.

Nowadays, the *available bandwidth* estimations are distinguished into two main approach classes. The first bandwidth estimation class addresses the packet rate methods, while the other class concerns the packet gap methodology. Regarding the related work the first estimation class methodologies were applied by [8][9][10][11], while studies as [1], [12] conducted the second one class.

A time based and per nodes approach for *available bandwidth* is presented by Sarr *et al.* in [14]. The analytical approach is based on some controversial assumptions. Moreover another new effort for *available bandwidth* estimation in IEEE 802.11 networks is presented in [19].

The first class of estimations (based on packet rate) watches the sequence packets' probes. When the packet transmitted rate exceeds the *available bandwidth* then the receiver rate became lower (in comparison with sender rate) and the probe packets tend to queue up, causing an increment in one way delay.

On the other side the second method of estimation's class (based on packet gap) transmit probes with equal-sized packets which are spaced apart depending the transmission time of the probes on the specific link. The increment of the packets' spacing is used for make approaching the volume of cross-traffic. In this case the spacing say the cross-traffic is subtracted from the capacity obtained by the yielded *available bandwidth*.

III. Types And Basic Characteristics Of Under Study Network Access

We chose two typical cases of network access for study. One was the case of cable modems; the other was the wireless 802.11 case. Both extensively use typical access links. In the following paragraphs, we present four basic characteristics that are observed in broadband network access.

(1) *Link's Bandwidth.* Reversers consider that the link's bandwidth is the parameter that shows the bit rates that can be transmitted down to the link. Nevertheless, that is not true when a traffic regulation schema is used. The Internet service provider (ISP) can distribute a physical access link into smaller separate parts corresponding to the customers. So, the bandwidth divisions reveal that the traffic regulation schema is applied by ISP. With a cable modem, the token bucket technique is used; thus, the mean packet rate and maximum burst size in bytes is determined. It is noteworthy to distinguish the raw link bandwidth from maximum achievable packet rate.

(2*) Service order.* In classic performance studies, all packets have FIFO order for service distribution. As a result, the packets suffer from queuing, which increases delay. Nevertheless, in 802.11 accesses link, the stations access to broadband in a distributed fashion. Also, in cable modem case, the Cable Modem Termination System (the cable head) periodically distributes control messages assigned to various stations, inviting them to earn in unused slots. Hence, in both cases, the packet waiting among various stations would not be serviced in FIFO order.

(3) *Links with variable values of rates.* The wireless 802.11b employee radio links can operate at 1, 2, 5.5 end 11Mbps relative to the environmental conditions. Similarly, the 802.11a network operates between 6 and 54 Mbps. Different stations belonging to the same network can operate at different rates, although all stations share the same spectrum. This situation may cause cross-traffic to each station.

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For the IEEE 802.11 [15], [16] distributed medium access protocol used in ad hoc networks the distributed functions are based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) principles. When an emitter gains access to the medium, the whole frame is transmitted. Collision detection by the sender is impossible in radio networks. Emitters are notified of good frame reception by the corresponding acknowledgment packet.

Network behavior may have an impact on the *available bandwidth* estimation technique. The estimation model works well when the cross-traffic matches the fluid model, which happens when the traffic is interspersed uniformly with the probe packets.

The address hidden nodes situation, an optional RTS/CTS mechanism, can be triggered. RTS/CTS exchange prior to transmission provokes a mechanism reservation in a one hop neighborhood of both peers. When receiving such a packet, a node considers the medium busy for the duration of the subsequent transmission. This technique is named *virtual carrier sense*.

A. Available Bandwidth Estimation

The *available bandwidth* depicts the rates at which a packet flow can be climbed without disturbing the existing traffic. Thus, the quantity of interest remains the *available bandwidth*. In the next Section we describe the methodology and the experimental testbeds.

IV. Methodology Of Experiments

A. Networks' Cases of Study

For our experiments, we chose two special networks. The first was the cable modem testbed and the other was the 802.11 a/b/g wireless access network.

- In the case of the cable modem as head-point, we used a CISCO universal broadband router 7200 series; as 'cable modem' on the other side, a ZyXEL Prestige 971M – external Cable modem was used [17]. On the head-point side we were able to obtain the link's values of traffic.
- The second testbed equipment had seven 802.11a/b/g stations working ad hoc in the same building area. The wireless configuration consisted of 6 PCs (2.8GHz Pentium 4 with 1024 MB RAM). All PCs were equipped wtth a Linksys WPC55AG 802.11a/g/b Wireless Adapter [18]. PC1 and PC6 ran the Pathrate tool in order to estimate the bandwidth metrics, while the other four nodes were used for generating cross-traffic.

  All the nodes were arranged to work in 802.11a and the link was set at 6 and 54 Mbps. We chose two of them for obtaining our measurements, as the other two produced cross-traffic.

B. Estimation Tools

We downloaded the source code from the Pathrate's site [13], along with the relevant documentation.

Pathrate is a measurement tool used for estimating the capacity of Internet paths. An important feature of Pathrate is that it is robust to cross traffic effects, meaning that it can measure the path capacity even when the path is significantly loaded. This is crucial, since the hardest paths to measure the heavily loaded ones. By this software tool the two most significant bandwidth metrics associated with end-to-end paths namely capacity and available bandwidth can be quickly estimated. Pathrate is publicly available with source code, documentation, and installation instructions.

We studied the available source code after making some small changes for better adaptation. We used this software for our experiments.

V. Experimental Results

Here we demonstrate the results. The first figure shows the results of data transmitted over the cable modem, while the second and the third depict the results concerning the 802.11 wireless access networks.

A. Results of Cable Link Access

In Fig. 1, the *available bandwidth* versus various levels of cross-traffic, which was estimated for cable modem downlink, is illustrated. We ran the Pathrate software, trying various values of cross traffic. For each value of cross traffic, the software returned two values of capacity, low and high.

By performing various experiments, we obtained values of *available bandwidth* (Fig. 1).

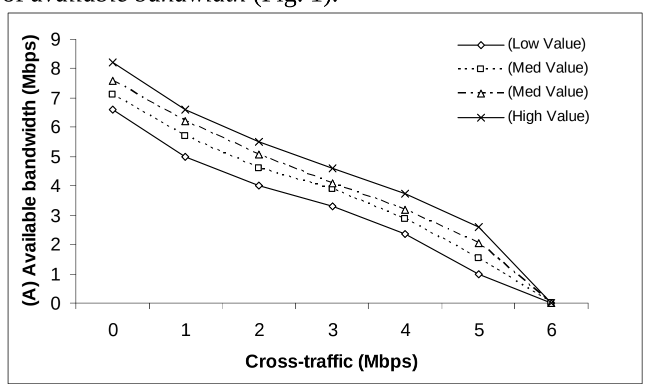

Figure 1. *Available bandwidth* versus *cross-traffic* in cable modem downlink in Mbps

According to Fig. 1, when the cross-traffic was absent, the bandwidth oscillated among the 6.6 and 8.2 Mbps. As the cross-traffic increased, the values of *available bandwidth* gradually decreased. In the limiting case of 6Mbps cross-traffic, the available traffic decreased to zero values.

B. Results of IEEE 802.11 Wireless Network

Like the packet transmission in 802.11, networks suffer when operations are significantly affected by the overhead of the packets. The minimum spacing among successive packets is considered overhead.

Experiments revealed that the packet size affected the maximum achievable *throughput*. Thus, the cumulative *throughput* was a little different when the payload used 300-bytes probe packets as opposed to 1000-bytes probe packets. As packets became bigger, we obtained higher values of cumulative bandwidth. We then created a series of experiments with small-value sized packets (small probes) and another one with high value packets.

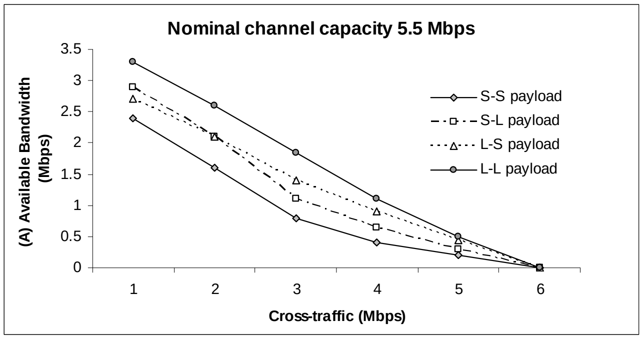

Figure 2. *Available bandwidth* versus *cross-traffic* in 802.11 access link with nominal channel capacity 5.5 Mbps

In Fig. 2, the *available bandwidth* versus various levels of cross-traffic, estimated for IEEE 802.11b wireless network access link runs at 5.5 Mbps, is illustrated.

The ‘S-S payload’ (‘Small-Small payload’) curve depicts the *available bandwidth* when the two nodes with determined *available bandwidth* used packages with 300-bytes probe size, while the cross-traffic was created (by the remaining nodes) by packages with 300-bytes probe size.

The ‘S-L payload’ (‘Small-Large payload’) curve depicts the *available bandwidth* when the two communicating nodes used packages of 300-bytes probe size, while the cross-traffic was created by a larger size probe package (here 1000-bytes probe size).

Similarly, the ‘L-S payload’ (‘Large-Small payload’) curve depicts the *available bandwidth* when the two measured nodes communicated using packages with a large size probe, while the cross traffic was created by a load consisting of packages with small size probes (for our experiment, 300-bytes probe).

Finally, the ‘L-L payload’ (‘Large-Large payload’) curve shows results when both loads of a pair of communicating nodes and their environmental traffic were created by packages with large size probes.

Fig. 2 shows how two communicating nodes were affected by the size of packets. As the packet size increased, the *available bandwidth* also increases. The cross-traffic of 2 Mbps was a focal point for our experiments. When the cross traffic created by packages with small probes exceeded this point of 2 Mbps and the communicating nodes used packages with large size probes, then the *available bandwidth* was higher compared to the corresponding case created by a smaller package size.

In all cases, when the cross-traffic increased, the *available bandwidth* was gradually reduced. Hence, in the limiting case of 5.5 Mbps cross-traffic, the available traffic decreased to zero values.

In Fig. 3, the quantitative results reveal the effect of the multirate environment in two nodes communicating at 54 Mbps.

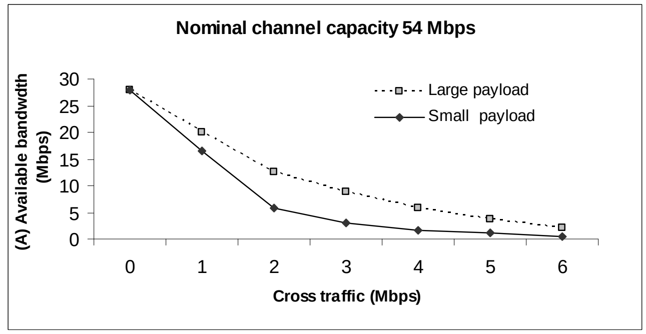

Figure 3. *Available bandwidth* versus *cross-traffic* in 802.11 access link with nominal channel capacity 54 Mbps

More specifically, in Fig. 3, the *available bandwidth* versus various levels of cross-traffic is appeared. The available bandwidth was estimated for IEEE 802.11 wireless network access link which was working at 54 Mbps.

The solid curve (‘Small payload’) depicts results obtained when the packages with 300-bytes probe were used; the two measured nodes ran at 54 Mbps, while cross traffic was generated by a pair of nodes running at 6 Mbps.

On the other hand, the dotted curve (‘Large payload’) depicts results obtained when the packages used 1000-byte probes and the node system worked in the same pattern of running.

In both cases, the available bandwidth gradually decreased as the cross traffic increased.

VI. Conclusion

The effective evaluation and measurements of capacities along end paths are of realistic interest, especially to activities such as capacity planning, protocol design, performance analysis, and system deployment.

We investigated broadband access networks. Focus was placed on the case of cable modem and the wireless 802.11 networks. The under study links could employ mechanisms such as token bucket rate regulation. The packets were scheduled in a non-FIFO manner, and the networks were available to support multiple distinct rates. All experiments were based on actual 802.11a and cable modems links. Our experiments quantitatively demonstrated how the *available bandwidth* was reduced when the cross-traffic increased.

Our future work will focus on several points. One idea is to study in detail the backoff periods in the estimation technique; another idea involves making cross traffic appear bursty for faster links, forcing the problem to be more complex.

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REFERENCES

[1] J. Strauss, D. Katabi, and F. Kaashoek, "A Measurement Study of Available Bandwidth Estimation Tools," In Proc. of of ACM Internet Measurement Conference (IMC), pp. 27-35, 2003.

[2] V. Jacobson and M. J. Karels, "Congestion Avoidance and Control". In Proc. of ACM SIGCOMM, pp. 314, 1988.

[3] S. Keshav, "A Control-Theoretic Approach to Flow Control," In Proc. of ACM SIGCOMM, pp. 191-201, 1991

[4] R. L. Carter and M. E. Crovella, "Measuring Bottleneck Link Speed in Packet Swicthed Networks," Performance Evaluation, Volumes 27-28, pp. 297-318, October 1996.

[5] A. Downey, "Clink: a Tool for Estimating Internet Link Characteristics," 1999. http://allendowney.com/research/clink/ (2010)

[6] A. B. Downey, "Using pathchar to Estimate Link Characteristics," In Proc. of ACM SIGCOMM, pp. 241-250, 1999.

[7] B. Mah. "pchar: A Tool for Measuring Internet Path Charateristics", 1999. http://www.employees.org/˜bmah/software/pchar (2011)

[8] M. Jain and C. Dovrolis, "End-to-End Available Bandwidth: Measurement Methodology, Dynamics, and Relation with TCP Throughput," In Proc. of ACM SIGCOMM, pp. 295-308, 2002.

[9] Vinay J. Ribeiro, Rudolf H. Riedi, Richard G. Baraniuk, Jiri Navratil and Les Cottrell, "pathChirp: Efficient Available Bandwidth Estimation for Network Paths," In Proc. of PAM Workshop, pp. 14–25, 2003.

[10] N. Hu and P. Steenkiste, "Evaluation and Characterization of Available Bandwidth probing Techniques," IEEE J.Selected Areas in Communications, Special Issue in Interet and WWW Measurement, Mapping and Modeling, Volume: 21 Issue:6, pp. 879-894 , 2003.

[11] B. Malander, M. Bjorkman and P. Gunningberg, "A New End-to-End Probing and Analysis Method for Estimating Bandwidth Bottlenecks," In Proc. of Global Telecommunications Conference, vol.1, pp. 415-420, 2000.

[12] V. Ribeiro, M. Coates, R. Riedi, S. Sarvotham, B. Hendricks, and R. Baraniuk "Multifractal Cross-traffic Estimation," In ITC, pp. 481–492, 2000.

[13] http://www.pathrate.org (2011)

[14] Chaikh Sarr, Claude Chaudet, Guillaume Chelius and Isabelle Guerin Lassous, "A node-based available bandwidth evaluation in IEEE 802.11 ad hoc networks," International Journal of Parallel Emergent and Distributed Systems Volume 21, Number 6; pp. 423-440, December 2006.

[15] Jian Ni and R. Srikant, "Distributed CSMA/CA algorithms for achieving maximum throughput in wireless networks," Conf. Proc. of Information Theory and Applications Workshop, 8-13 Feb 2009, ISBN: 978-1-4244-3990-4 , pp. 250 – 250, San Diego, CA .

[16] M.Durvy, O.Dousse and P. Thiran, "Self-Organization Properties of CSMA/CA Systems and Their Consequences on Fairness," IEEE Transactions On Information Theory, Issue Date: March 2009 , Volume: 55 Issue:3 pp. 931 – 943, ISSN: 0018-9448.

[17] http://us.zyxel.com/upload/download_library/P971M_v1_QuickStart Guide.pdf (2010)

[18] http://www.linksysbycisco.com/UK/en/support/WPC55AG/download (2011)

[19] Haitao Zhao, Emiliano Garcia-Palacios, Jibo Wei and Yong Xi., "Accurate available bandwidth estimation in IEEE 802.11-based ad hoc networks," Elsevier Computer Communications, Volume 32, Issue 6, pp. 1050-1057, 27 April 2009..

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