TRAMMS

Traffic Measurements and Models in Multi-Service Networks

TRAMMS Public newsletter n4, February 2009

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Estimating Available Bandwidth in Real Time

Abstract

The Celtic TRAMMS project (http://projects.celtic-initiative.org/tramms/) measures and analyzes IP traffic in European access networks. The public newsletters give a brief summary of the results. They are available to the public, by download from the project website.

One aspect of the TRAMMS project is to study methods and tools that measure the fraction of a network path not utilized by IP traffic; also known as the available bandwidth. BART (http://www.barttool.org/) is a method that can estimate the available bandwidth by analyzing probe traffic transferred between two network nodes. *BART has several important features; for example the method does not require access to or information from any intermediate network nodes and hence does not rely on deep-packet inspection or other passive monitoring techniques, the available bandwidth estimate is updated in real time for each probe traffic sample, BART requires low CPU and network overhead.* This combination of features is powerful and gives BART a wide range of applicability.

This Newsletter reports on the BART standardization and validation process performed as part of the TRAMMS project. The BART method complements the passive measurement methods and the results reported on in earlier Newsletters.

BART in a nutshell

BART ("Bandwidth Available in Real Time") is a method for estimating path available bandwidth and tight link capacity in real time over packet-switched network paths. The BART method relies on actively sending probe traffic over a network path, in order to determine at which probe rate the path shows signs of congestion. This rate defines the available bandwidth – the fraction of the capacity not utilized by IP traffic.

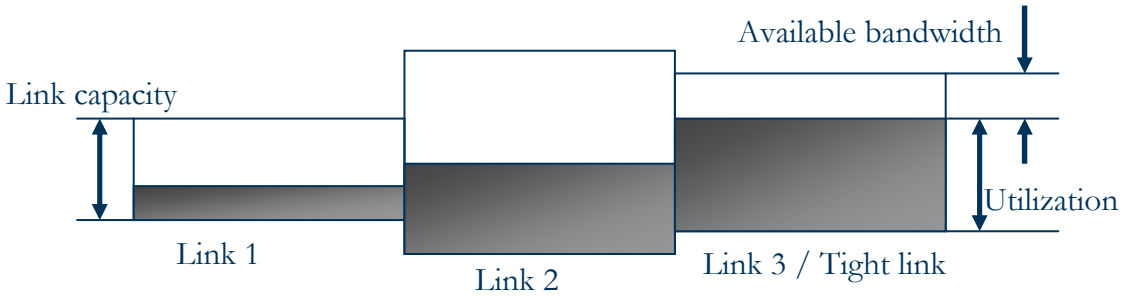

Figure 1: The concepts of link capacity, utilization and available bandwidth in IP networks.

The capability of measuring the available bandwidth between two nodes is useful in several contexts; including network monitoring of inter-operator paths, call-admission control and server selection. For example, measurement of available bandwidth in real time opens up for adaptation based on available bandwidth in congestion control and streaming of audio and video.

One additional important application of BART is to use the available bandwidth estimates for service level agreement (SLA) verification. Operators offering for example mobile broadband using HSPA technology traditionally state a theoretical maximum limit of the offered IP-layer bandwidth, often 7.2 Mbps. The available bandwidth between the mobile device and a test server will describe one parameter of the SLA offered by the operator. Having means to measure it gives customers a way to test the "selling facts" given by their operator. In the case of testing HSPA connections, the available bandwidth may change depending on where the user is located in relation to base stations, the weather conditions as well as the number of users in the cell.

The concepts of the performance parameters capacity, utilization and available bandwidth are shown in Figure 1 which illustrates three links that are part of a network path. Each link has a constant capacity that defines the maximum rate at which IP traffic can be sent. At any given point in time the links are utilized to some degree by IP traffic, this is exemplified by the shaded area in each box. Then, for each link the

available bandwidth is calculated as the difference between the link capacity and the utilization.

BART estimates the available bandwidth of the link with the least available bandwidth of the path. This defines the path available bandwidth. Further, BART estimates the tight link capacity which is the capacity of the link defining the path available bandwidth. The path available bandwidth and tight link capacity is illustrated as Link 3 in the Figure 1.

By analysing probe traffic being transferred from one node to another node BART can estimate the available bandwidth. The so called "probing" is illustrated in the figure below.

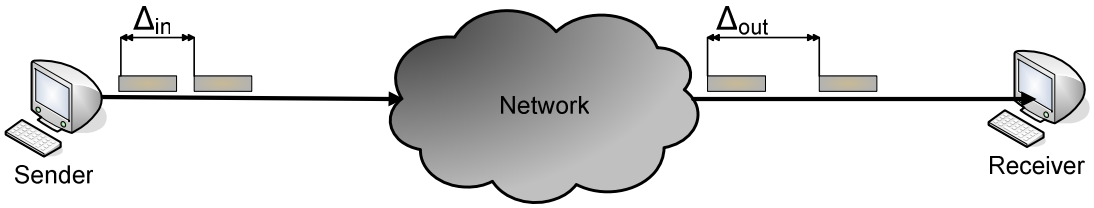

Figure 2: The concept of IP network probing.

A BART sender is transmitting IP packets at randomized inter-packet separations towards a receiver; the separation is affected by other IP traffic sharing the network. The receiver timestamps each incoming IP packet and calculates the new inter-packet separation. The inter-packet separation at the sender and receiver are analyzed by the BART Kalman filter, a statistical method for tracking properties in real time that are not directly observable, and the output from that analysis is the path available bandwidth and the tight link capacity. *Observe that BART only needs access to the sender and receiver node. The network in-between is unknown and hence no access to intermediate nodes is required. Also, the overhead of the IP probe traffic is low; in the current implementation the overhead is in the order of 2% of the tight link capacity.*

The BART method is owned by Ericsson, but the development has been done in cooperation with academia for several years. Currently, BART is developed, validated and/or being deployed as part of several academic projects; the Celtic TRAMMS project, the EU FP7 MOMENT project and the Vinnova BARTAP project. Past BART-related projects are the Vinnova EvaluNet, KKS EvaluNet II and the EU FP6 EVERGROW projects.

BART evaluation

As part of the TRAMMS project, BART has been validated in a multitude of scenarios; for example in a testbed at Ericsson Research in Sweden, in a wireless 802.11 network at Mälardalen University and in a vehicle-industry network at a company located in Sweden. BART has also been successfully demonstrated to Celtic reviewers in December 2008 where BART measured the available bandwidth in real time between Stockholm and Bilbao.

As a result of earlier validation it has been shown that BART provides available bandwidth estimates of better quality compared to similar methods developed in academia. This is for example discussed in the paper "Real-Time Measurement of End-to-End Available Bandwidth using Kalman Filtering" published in the proceedings of IEEE Network Operations and Management Symposium (NOMS) 2006.

Snapshots of the research results related to validation of the BART method obtained in TRAMMS are discussed below.

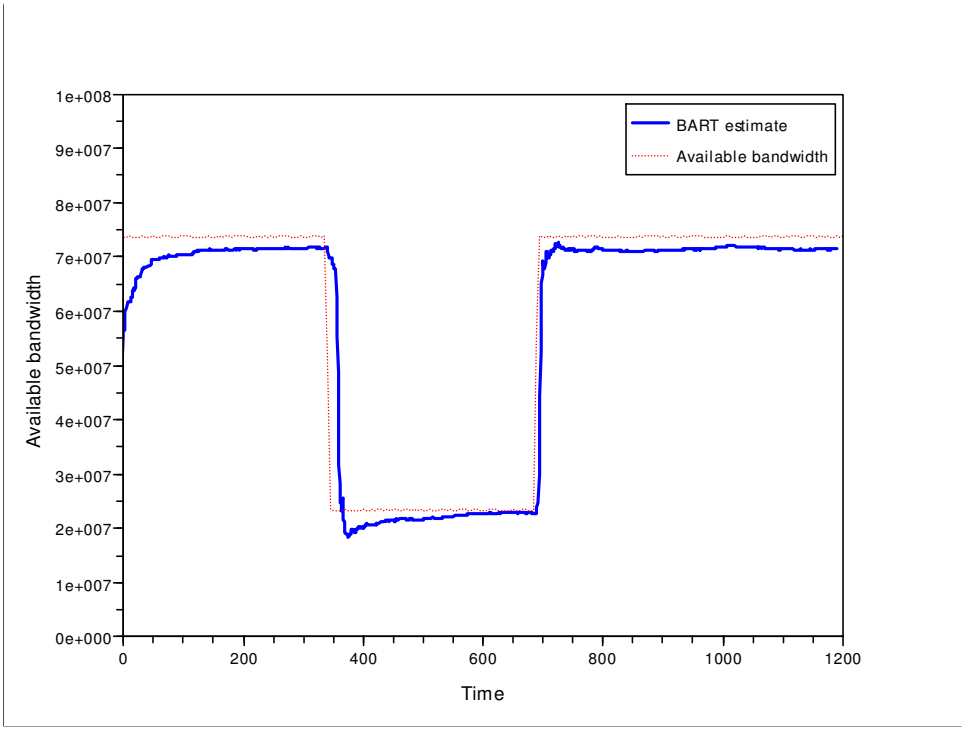

Figure 3: BART estimate from a measurement session at the Ericsson testbed.

In Figure 3 above, the available bandwidth estimate in bits per second reported by BART is shown as the blue curve over time (seconds). The red curve is the correct value of the available bandwidth; that is what BART is trying to estimate. As can be seen, the BART estimate tracks the correct values accurately even in the case when the available bandwidth abruptly changes at times 350 and 700. This particular graph

comes from a measurement conducted in the Ericsson testbed where all IP traffic parameters can be modified and hence are known beforehand. Further, the basic BART method is in this case enhanced with a statistical method called change detection that enables the quick reaction to sudden changes in available bandwidth.

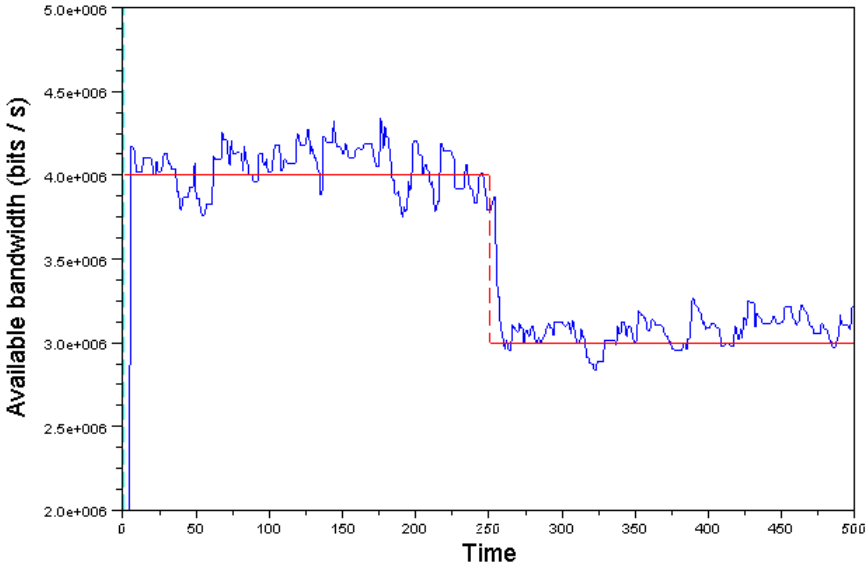

Figure 4: The blue curve is the BART estimate from a measurement session in an 802.11b wireless network. The red curve is what BART is trying to measure.

In Figure 4 the available bandwidth estimate reported by BART is again shown as the blue curve over time. The red curve is what BART is trying to estimate. This graph comes from a measurement session within a wireless 802.11b network. In such networks the actual IP available bandwidth varies due to for example radio quality, thus it is hard to state the correct value at a given time. The red curve is in this case an approximation of the available bandwidth obtained by measuring the maximum achievable UDP throughput (such a test requires in contrast to BART heavy "probing" overhead). As can be seen in the figure, the BART estimate tracks the red curve values within reasonable error margins, also when the available bandwidth abruptly changes at time 250.

Results related to BART measurements in 802.11 networks were published in 2008 as part of the proceedings of the IEEE Local Computer Networking Conference (LCN). The paper is entitled "On Measuring Available Bandwidth in Wireless Networks".

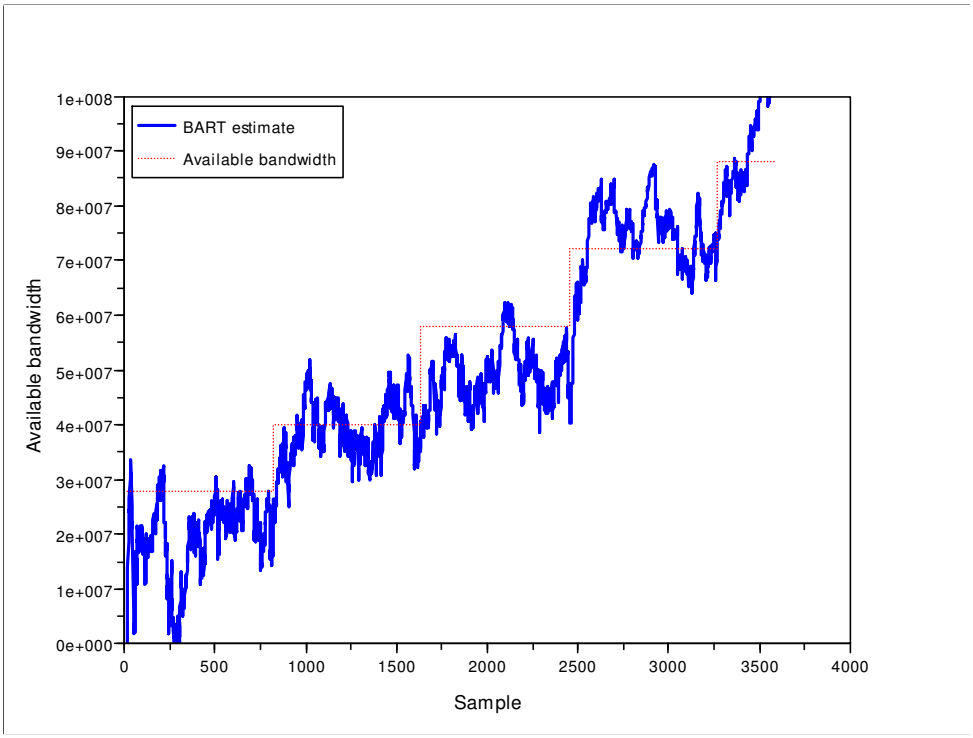

Figure 5: BART estimate from a measurement session in a vehicle-industry network at a company located in Sweden.

Figure 5 comes from a measurement trial in a vehicle-industry network. The company where this trial was made can not be made official. The blue curve is the BART estimate and the red-dashed curve is an approximation of the correct available bandwidth value (bits per second). The BART estimate captures the general trend of increasing available bandwidth throughout the measurement session. The BART estimate fluctuates but are within reasonable error margins compared to results from similar measurement methods. Other methods in this area of research often also have a tendency to systematically over- or underestimate the available bandwidth. BART has no such problem in this case.

BART standardization

As part of the TRAMMS project Ericsson is also working on standardizing a performance-parameter framework of which the two parameters estimated by BART are included, as well as pushing for standardizing the BART method itself. The standardization body of interest is the International Telecommunication Union (ITU-T). However, there are no restrictions or limitations on developing BART standards in for example the Internet Engineering Task Force (IETF) or the Third generation Partnership Project: Long Term Evolution (3GPP LTE).

About these Measurements

The measurements reported above are performed with the Ericsson implementation of BART. It is not available to the general public but can under certain circumstances be used for evaluation purposes within the TRAMMS project.

If you would like to receive the public reports about TRAMMS results, please indicate this in an email to tramms-info@celtic-initiative.org.