bandwidth in an industrial application

Martin Nilsson
Swedish Institute of Computer Science (SICS)
POB 1263,164 29 KISTA, Sweden

Andreas Johnsson
Ericsson Research
164 80 KISTA, Sweden

Peter Brander
Bombardier Transportation AB
721 73 VÄSTERÅS, Sweden

***Abstract*—We report results from a field study using the BART method for measuring available bandwidth in a local IP-network for use in train cars. The test was performed on physical hardware in a laboratory environment for a set of two cars. Test results indicate that BART measurement is viable.**

***Keywords and phrases:* Available bandwidth, real time, end-to-end measurement, Internet, layer-2, network, Kalman filter, BART, application.**

I. Introduction

Internet protocol (IP) technology is well established for consumer applications, but is still relatively new in industrial applications. However, there is an industry trend of moving away from the diversity of field buses towards IP-based communication. Inexpensive, reliable hardware and software for IP-based communication is available generally, and standards are well established. This can mean large savings from a number of perspectives, including development, manufacturing, operation, and maintenance. A problem holding back IP-communication in industrial applications is the absence of built-in measurements of such important engineering parameters as available bandwidth and link capacity.

BART is a measurement method intended to help out in this situation. By sending probe trains of time-stamped packets over an end-to-end path (fig. 1), BART estimates the available bandwidth and capacity of the narrowest link using Kalman filtering. This paper is a field study describing the result of testing the BART method on genuine hardware, setup in a laboratory environment. The test successfully indicates that BART may indeed be useful for measurement tasks in this kind of network. This marks the first time BART has been tested in a commercial application, completely independent from any influence by BART developers. For these measurements, packet data was collected by software developed at Ericsson Research, and results computed by an implementation of the BART algorithm developed at SICS.

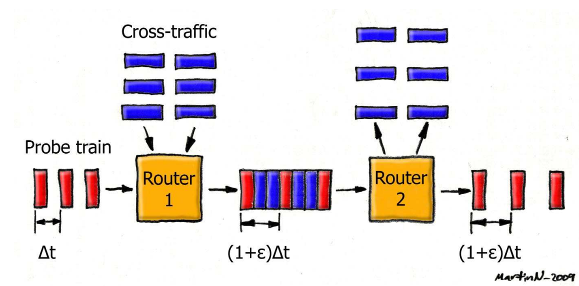

Fig. 1. BART estimates available bandwidth from the inter-packet strain ε.

A. Related work

Computing available bandwidth from passive monitoring of an end-to-end path is be possible with the cooperation of all nodes in the path. However, this is rarely possible in practice. Instead, by sending trains of probe packets, the available bandwidth can be estimated from the timing of the probe train packets. Such measurements only require access to the sender and receiver.

Although there are a large number of methods for measuring available bandwidth using active probing [3], most cannot measure available bandwidth effectively in real-time. BART, first proposed in [1] and subsequently elaborated in [2], and pathChirp [4], are exceptions. For the application reported on here, BART has the attractive feature that it can be easily retrofitted and executed, without requiring any modifications or detailed knowledge of the system to be measured. Having said this, we emphasize that the primary purpose of this study is to specifically investigate the behavior of BART on an industrial use case, rather than comparing BART with other measurement methods.

II. The setup

Measurements were performed over the nominally 100 Mbit/s switch (TS) backbone link in a set of two cars.

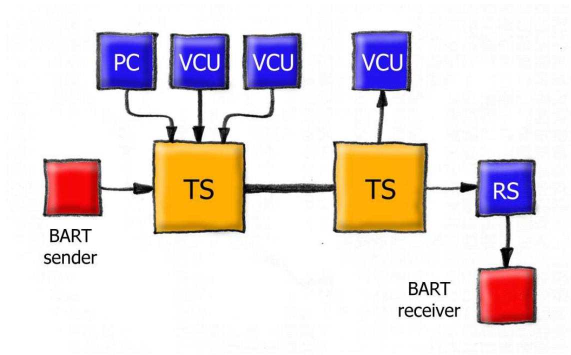

Fig. 2. Topology of the measured network.

A Linux laptop with a 1Gbit/s Ethernet interface was connected directly to one TS, while another laptop with the same capacity was connected to a ring switch (RS) on the other TS. The first laptop was used as probe train generator and the other as a receiver.

One PC and two control units (VCU) connected to the first TS were used as cross-traffic generators in order to mimic a deployed situation. These nodes all had 100 Mbit/s Ethernet interfaces. Varying degrees of cross-traffic was generated by these different sources over the same TS-TS link in parallel with the probe traffic. The receiver of the cross traffic was a VCU on the second TS. The cross-traffic was set to 72, 60, 42, 28, and 12 Mbit/s, leaving a nominal available bandwidth of approximately 28, 40, 58, 72, and 88 Mbit/s, respectively. Here, we say "nominal", because separate instrumentation showed some degree of stochastic variation of the rate, which was approximately constant bit-rate, could not be controlled in detail. It is this cross-traffic that determines the available bandwidth, which is measured by the BART probes.

Each cross-traffic setting was allowed to run for approximately 5 minutes at 2.85 probe trains/s, generating 855 probe trains for each setting, for a total of approximately 3600 probe trains.

A distinguishing feature of the network is its being a layer-2 network, where traffic is transmitted in different priority classes. An important question was in what way this affects the measurements.

Testing proceeded smoothly for all values of cross traffic. Each car in a train forms its own ring network in addition to the TS-TS backbone, but for this measurement setup, such a ring network was unavailable. No problem was observed with the BART measurement procedure, which produced clean measurements throughout.

III. Measurements

The set of measurements data points is shown in figure 3. Each dot represents a probe train.

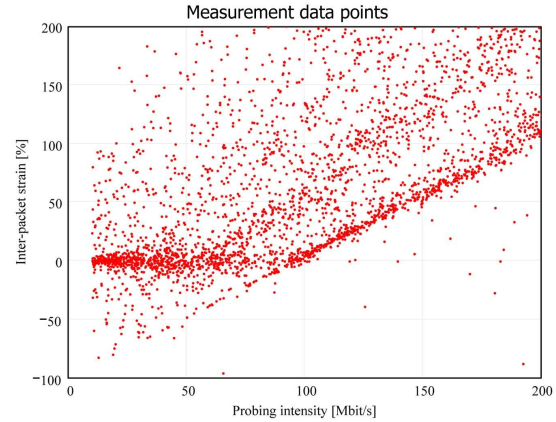

Fig. 3. Each point in the diagram corresponds to one probe train measurement.

The horizontal axis gives the probe intensity, and the vertical axis the average *inter-packet strain*, i.e. how much the inter-packet distances have grown when the packets arriving at the receiver, compared to when they were sent by the sender. Negative strains imply that packets appear more closely spaced at the receiver than at the sender. This may seem counter-intuitive, but happens because packets may "pile-up" and concentrate at a congested router. Such negative strains can occasionally reach large values.

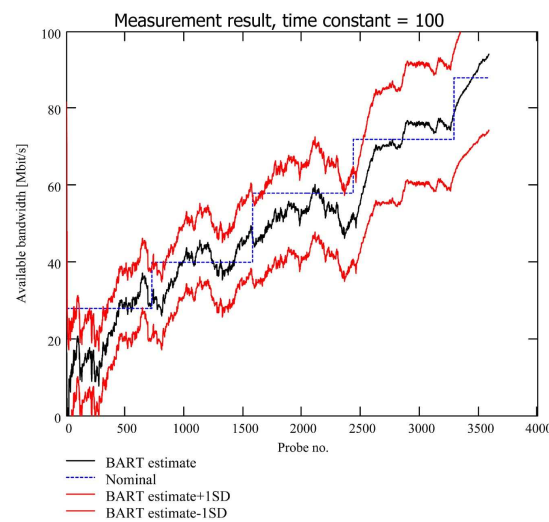

Fig. 4. Measurement result using a medium time constant.

From the clusterings of the points in figure 3, BART incrementally estimates the available bandwidth and the standard deviation of this estimate. The result is shown in figure 4. The top and bottom curves indicate one standard deviation (+1SD and -1SD, respectively), representing the error in the estimate.

The BART implementation used for this measurement offers a single, user-tunable parameter, “tuning knob”. This parameter is a time constant, analogous to the time constant of a low-pass filter. A large value of the time constant will give smoother estimates, but slower reaction to changes. The optimal value of this parameter is subjective, and depends on what/how the user wants to measure. For the measurement reported in this paper, we used a time constant of 100 samples. A smaller time constant will give a curve that is more jagged, but that more quickly adjusts to changes (fig. 5).

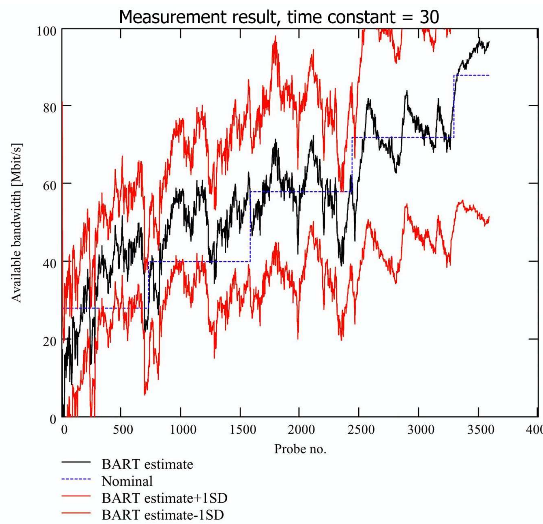

Fig. 5. Measurement results using a short time constant.

A larger time constant gives a smoother curve, which adapts more slowly (fig. 6).

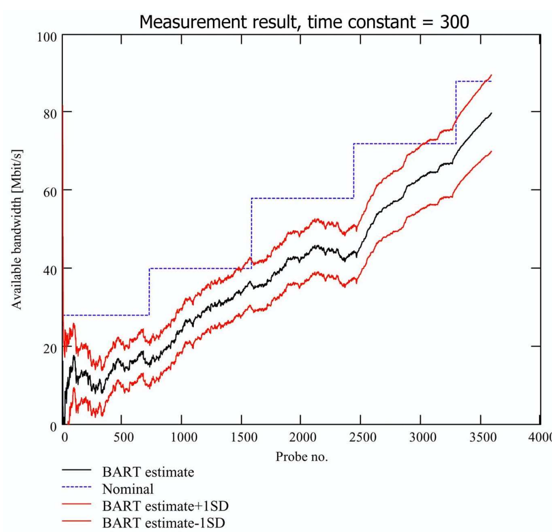

Fig. 6. Measurement results with a long time constant.

As can be seen from the diagrams, the estimate is “jagged”. One may ask why this curve is not more similar to the nominal available bandwidth. The answer is that the nominal value is not the “real” value. The actual available bandwidth on a link is not a smooth value. It depends on the measurement time frame. For the extreme case of intervals shorter than a packet, the available bandwidth must be 0% or 100%, since either there is a packet traveling on the link or there is not. For larger intervals, the available bandwidth is averaged over the interval, and the smoothness depends on the interval size. The measurement interval size is given by BART’s time constant. Accurate measurements require many samples, and for short intervals, this means high sampling frequency. For the test reported here, the 100Mbit/s-link was sampled 2.85 times/s, using 17 packets of 1500 bytes each, meaning a measurement overhead of approximately 0.6%.

During testing, the layer-2 nature of the network became apparent in the following way: Without cross-traffic, the available bandwidth was measured to be close to 100%. However, for a small increase (1 Mbit/s) in cross-traffic, the measured available bandwidth was immediately reduced by more than 10 Mbit/s. This appears to be due to the fact that in this setup, cross-traffic is given higher priority than probe traffic. Consequently, as soon as cross-traffic appears at the TS, it is reserved a fixed bandwidth at that TS, instantly reducing the bandwidth available to probe traffic by the same amount. This can be seen as a confirmation that BART measures available bandwidth *in the same traffic class as the probe traffic*. Beyond this, no negative effects of the layer-2 properties of the network were observed.

IV. Conclusions

Measurement results suggest that BART is indeed a viable method for available bandwidth measurements. We found no difficulties in measuring the network, despite its layer-2 features. It needs to be kept in mind that the BART estimate is an instantaneous extrapolation of the available bandwidth. This does not necessarily mean that this bandwidth can be utilized in practice. An attempt to fill the estimated available bandwidth may affect the network in ways that change the network properties indirectly, e.g. causing reallocation of capacity to certain priority classes. A basic rule for BART is that available bandwidth is measured for the same type of traffic as is used by the probe trains. This test was performed in a limited laboratory setup. For future full-scale testing, the test should be applied to a system comprising a full ring network.

V. Acknowledgments

When a new algorithm is developed in an academic environment, a common procedure is to test it only in a simu-

lator. Testing an algorithm in an industrial environment can be challenging, because critical parts of the system may be unknown, unaccessible, proprietary, or confidential. Perhaps this is the main reason for the scarcity of such studies. This one was made possible thanks to the generous support and cooperation by Bombardier Transportation AB.

This work has been performed within the SICS Center for Networked Systems funded by VINNOVA, SSF, KKS, ABB, Ericsson, Saab Systems, TeliaSonera and T2Data.

This paper was prepared using TeXmacs.

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