# Intelligent Probing Technique for Bandwidth Estimation in Wireless Network

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## Abstract

*With the development of broadband systems, multimedia communication in wireless networks has become very common. However, supporting multimedia applications over multiple users either require high bandwidth or a dynamic bandwidth utilization mechanism. This in turn calls for an efficient technique, that can estimate the available bandwidth in the network accurately over real-time. In this paper, the different estimation algorithms are analyzed and the performance of state-of-the-art estimation algorithm, 'Spruce', is evaluated by comparing with the actual measured bandwidth. The key characteristic found was that all the bandwidth estimation techniques themselves take up some amount of bandwidth, which not only results in inaccurate estimation, but also takes up precious bandwidth resource. This brings about the necessity for an intelligent probing technique that would not only offset the inaccuracy resulting from the self-use of the bandwidth, but also minimize the bandwidth used by the probing mechanism.*

## I. Introduction

In the recent years, there has been rapid growth of Internet-based services over the wireless network. With this, more and more demands are being placed on the performance of the network. The end-users demand that consistent monitoring of the performance is carried out, in order to both detect faults quickly and predict and provision for the growth of the network.

Measuring the performance of the Internet over wireless network is extremely difficult. Even with the complete support of the different Internet service providers (ISP), the complexity of the network means that normally multiple providers are involved in the end-to-end connection between hosts. This situation makes the monitoring of end-to-end performance by any one ISP nearly impossible. In addition, the inability of the users to be confident in the performance in the wireless network causes a great demand for new tools that would enable the end-users and the service providers to assess the performance of the wireless network, especially the network bandwidth, without any external assistance. There are significant constraints in the development of such tools. Importantly, these tools need to rapidly and easily measure the end-to-end performance of the network, while not placing any additional load on the network than is absolutely necessary. It should be noted that any extra load would restrict the times that the measurement could be made, and depending on the topology of the wireless network, it could create large extra traffic charges.

A large amount of time and energy is currently being spent for researching on high speed, next generation networks. These networks are being constructed in-order to support the large growth in the Internet, as well as enabling high bandwidth services to run over the network to more people. There is an increasing demand in the industry to find out whether the performance obtained from these networks is what is expected from them. With this regard, there has been much work on developing techniques for estimating the capacity and available bandwidth of network paths based on end-point measurements. Bandwidth is a key factor in several network technologies. Several applications can benefit from knowing bandwidth characteristics of their network paths. the motivation behind bandwidth estimation has been the potential for applications and end-host-based protocols to take advantage of bandwidth information in making intelligent choices on server selection, TCP ramp-up, streaming media adaptation, etc [JD02].

In this paper, the different bandwidth estimation techniques that have been proposed and used for wireless networks have been analyzed, and its advantages and shortcomings are discussed. In addition, a novel intelligent estimation technique is discussed, especially the characteristics required to make it an efficient method.

The paper is organized as follows. Section II describes the related work, whereas Section III reviews the performance of the state-of-the-art bandwidth estimation methods, and its characteristics. Section IV describes the experimental set-up that has been built, while Section V describes the simulation results. Finally, Section VI provides the conclusions and the future work in this direction.

## II. Related Work

Recently, bandwidth estimation techniques have drawn widespread interests in network management arena. A couple of bandwidth estimation techniques have been based on the packet-pair principle [JK98, K91]. However, the initial versions of such techniques did not consider the problem of cross-traffic interference. In order to alleviate this problem, various refinements have been proposed, that includes - sending trains of packets of various sizes (e.g., bprobe [CC96]) and better filtering techniques to discard incorrect samples: for example, nettimer [LB00]. However, the filtering technique is made complex by the multi-modality of the distribution of packet-pair spacing [P971] and with the observation that the dominant mode might not correspond to the actual network bandwidth [DDR01]. There are several other bandwidth estimation techniques, that were proposed in the early years of research in wireless networks - such as cprobe [CC96], symptotic dispersion rate [DDR01] etc. Many of the recently proposed techniques fall into two categories: packet rate method (PRM) and packet gap method (PGM). PRM-based tools, such as pathload [JD02], PTR [HS03], pathchirp [RRBNC], and TOPP [MBG00], are based on the observation that a train of probe packets sent at a rate lower than the available bandwidth

The current research on bandwidth estimation algorithms could be classified into three categories [SYCSG05], [ABPV06]: *packet dispersion measurement* (PDM), *probe gap model* (PGM) and *probe rate model* (PRM). The PDM techniques, such as the packet pair or packet train, estimates network capacity by recording the packet inter-arrival time. However, the main disadvantage of PDM-based technique is that they have very low accuracy when applied to the wireless networks. The basic principle of PGM is that the server sends a probe packet pair with time dispersion, $T_{in}$, and after successful transmission, the receiver records a changed dispersion time, $T_{out}$. The value, $T_{out}$ - $T_{in}$ is then the time for transmitting crossing traffics under the condition that a single bottleneck link is assumed. The crossing traffic rate, $BW_c$, could be written as $BW_c = (T_{out} - T_{in}) \times C/T_{in}$, where $C$ is the capacity of the network. Hence, the estimated available bandwidth would be $C – BW_c$. However, the main disadvantage of PGM is that it assumes that the network capacity is known, and that this would supply fast as well as a certain accuracy of estimation. In reality, however, the network capacity is not always known beforehand. The PRM techniques estimate bandwidth using three kinds of traffic rates: sender-side probing rate ($C_s$), receiver-side probing rate ($C_r$) and available bandwidth ($BW$).

## III. State-of-the-art Bandwidth Estimation

In terms of measuring the kind of bandwidth in the network, most of the proposed techniques concentrate on measuring one of two values - either the individual link bandwidths of a path, or the capacity of a path. In general, these techniques can be classified into two groups: *Single packet and packet pair techniques*. The names refer to the number of packets that are used in a single probe. A measurement of a link or path will consist of multiple probes, in the case of some implementations [J97] this can be in the order of 10MB of data (14400 individual probes) to measure a 10 hop path. The following sections will detail the theory of these techniques, improvements suggested and example implementations.

a. **Single packet techniques:** This method concentrates on estimating the individual link bandwidths as opposed to end-to-end properties. These techniques are based on the observation that slower links will take longer to transmit a packet than faster links. If it is known how long a packet takes to cross each link, the bandwidth of that link can be calculated.

**b. Packet pair technique**: This method attempt to estimate the path capacity not the link capacity discovered by single packet techniques. These techniques have been in use since at least 1993, when Bolot [B93] used them to estimate the path capacity between France and the USA. He was able to quite accurately measure the transatlantic capacity, which at that time was 128kbps. Packet pair techniques are often referred to as packet dispersion techniques. This name is perhaps more descriptive. A packet experiences a serialization delay across each link due to the bandwidth of the link. Packet pair techniques send two identically sized packets back-to-back, and measure the difference in the time between the packets when they arrive at the destination.

**Spruce:** Spruce has been one of the most successful bandwidth estimation techniques under the packet pair technique. Spruce has been found to be significantly superior to other methods like Pathload and IGI [Spruce ref]. The technique of Spruce is explained, in detail, followed by the experimental results in the next section.

Spruce (Spread PaiR Unused Capacity Estimate) is a tool for end hosts to measure available bandwidth. It samples the arrival rate at the bottleneck by sending pairs of packets spaced so that the second probe packet arrives at a bottle-neck queue before the first packet departs the queue. Spruce then calculates the number of bytes that arrived at the queue between the two probes from the inter-probe spacing at the receiver. Spruce computes the available bandwidth as the distance between the path capacity and the arrival rate at the bottleneck. Spruce is based on PGM. Like other PGM tools [21, 9], Spruce assumes a single bottleneck that is both the narrow and tight link along the path.

Some of the characteristics of Spruce that distinguishes it from other bandwidth estimation tools are explained below [ref].

1. Spruce uses a Poisson process of packet pairs instead of packet trains (or chirps). This form of sampling done by Spruce makes it both non-intrusive and robust.

2. With the help of a careful parameter selection, Spruce ensures that the bottleneck queue is not empties between the two probes in a pair, which is a prerequisite for having the correctness of gap model.

3. Spruce distinguishes capacity measurement clearly from available bandwidth measurement. Spruce considers that the capacity can be measured without any difficulty with one of the capacity measurement tools. In addition, it assumes that the capacity remains stable when measuring the available bandwidth. This assumption holds for all scenarios for which Spruce has been designed for estimating the bandwidth of the paths in overlay networks.

In the next section, the performance of Spruce is analyzed for computing the available bandwidth in real network settings.

## IV. Experimental Setup

Fig. 1 shows the simulation topology where multimedia applications send multimedia and crossing traffics to clients via a wired network as well as a last hop WLAN. Traffic servers send crossing traffics to share the bottleneck from AP to clients.

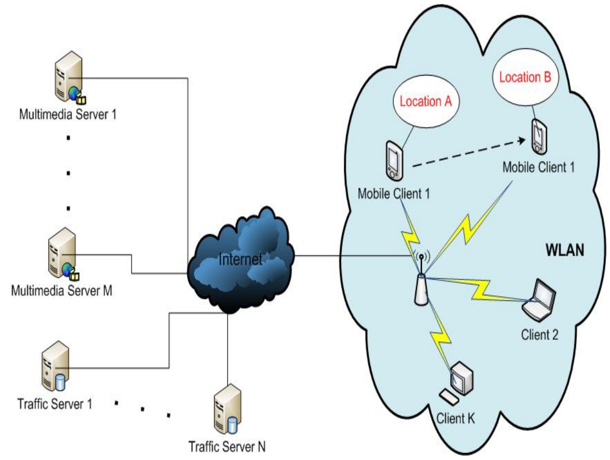


**Fig. 1 Simulation Topology**

In the experiment, it is assumed that IEEE 802.11b WLAN is the bottleneck link on the end-to-end path. The WLAN has the smallest available bandwidth which is also the end-to-end available bandwidth.

Table 1 summarizes the configuration setup in NS. Two additional wireless update package are introduced, NOAH[1] and Marco Fiero Package[2]. NOAH package (No Ad-Hoc) is used for simulating infrastructure WLAN and Marco Fiero Package provides a more realistic wireless network environment. As a result, in our experiment, there are four degrees of bandwidth - 1, 2, 5.5 and 11Mbps, depending on the distance from AP. Fig. 2 shows the characteristic of the real IEEE 802.11b network.

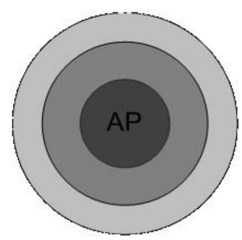


**Fig. 2 Signal Strength Around Access Point**

$W_{min}$ and $W_{max}$ are the minimum and maximum values of contention window. Basic rate, sending rate of control packets (*ACK*, *RTS*, *CTS*), is set as 1Mbps.

[1]http://icapeople.epfl.ch/widmer/uwb/ns-2/noah/
[2]http://www.telematica.polito.it/fiore/ns2_wireless_update_patch.tgz

| | |
|---|---|
| Transport Protocol | UDP |
| Wireless protocol | 802.11b |
| Routing protocol | NOAH |
| Error Model | Marco Fiero package |
| Wired Bandwidth | 100Mbps LAN |
| MAC header | 52 bytes |
| Wmin | 31 |
| Wmax | 1023 |
| ACK | 38 bytes |
| CTS | 38 bytes |
| RTS | 44 bytes |
| SIFS | 10μsec |
| DIFS | 50μsec |
| Basic rate | 1Mbps |

**Table 1. Simulation Setup in NS-2.29**

In our experiment, six separate tests were conducted. Each test consists of one to three unicast video traffics and one client starts moving from 5s at the speed of 1m/s. Variable network conditions were also introduced and realized by varying current traffic loads. This is done by generating CBR/UDP crossing traffics using 1500 bytes packet. Additionally, the number of video traffics increases in each separate test. Along with the increasing loads of traffics, the network becomes congested. This set is to verify how the performance of Spruce works under heavy network condition.

## V. Experimental Results

This section studies the performance of Spruce by comparing it with *Measured Bandwidth*. *Measured Bandwidth* is based on the concept of maximum throughput that an application can obtain. It depends on the transmission mechanism like TCP, UDP.

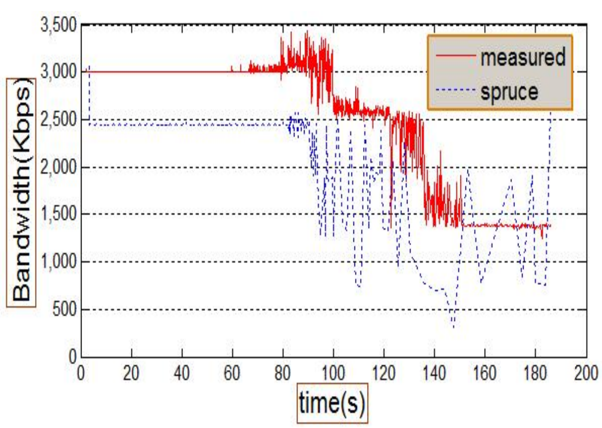


**Fig. 3 Comparison of bandwidth calculated from measured and spruce with no crossing traffic. (One server and one client)**

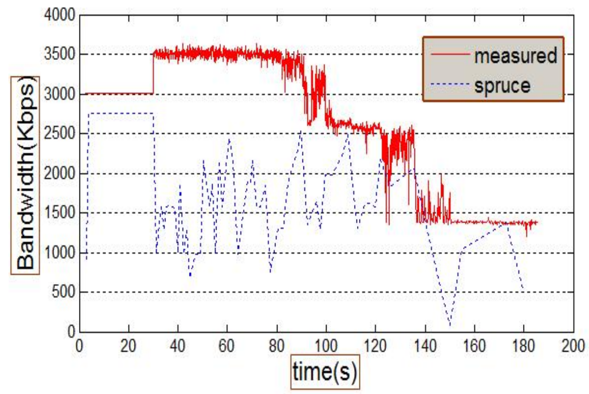


**Fig. 4 comparison of bandwidth calculated from measured and spruce without crossing traffic. (One server and two clients)**

Fig. 3 and 4 shows the comparison results of *Measured Bandwidth* (calculated from trace result of NS-2) and *Estimated Bandwidth* (Spruce) for periods of 0 and 200 seconds without cross traffics. The Spruce traffic was started from 3s. Spruce probing traffic used CBR/UDP flow to send packets of 1500 bytes with the rate of 0.15Mbps. The first test consisted of one server and one client as provided in Fig. 3. A video clip of two hundred seconds was transmitted to client via high speed (100Mbps) wired network and IEEE 802.11b WLAN. The client started moving away from AP from 2s at the speed of 1m/s. Since Marco Fiero package was implemented, bandwidth dropped when the distance between mobile client and AP increased. As seen in both Fig. 3 and Fig. 4, both the measured and estimated bandwidth fluctuated considerably at around 80s and 130s due to interference of incoming cross traffics. In order to discover the performance of bandwidth estimation, average bandwidth is introduced. In Fig. 3, the average bandwidth estimated by Spruce was 1.51Mbps, notably different from the measured bandwidth of 2.96Mbps. Thus, an error of 1.45 (47%) was observed with Spruce. However, it was observed that Spruce better during the initial time duration (the first 80 seconds). For the same configuration as for Test 1, another multimedia server and client pair were added in Test 2, and the results could be seen in Fig. 4. Two video clips with the same size were transmitted to clients in terms of unicast traffic streams. The error in case of Spruce was 1.63 (25%). Hence, Spruce performed considerably in case of heavy traffic condition (two clients).

Fig. 5, 6, 7, 8 provide the simulation results with the participation of crossing traffics. In order to have fair comparison, the Spruce probing traffic was added as in Test 1 and 2. The results in Fig. 5 were obtained with two video traffics and one crossing traffic. The video traffics were scheduled to start transmission at

2s and 30s, and the crossing traffic began at 50s. The incoming of traffics resulted in changes of estimated bandwidth as shown in the figure. Fig. 6, 7 and 8 show the results when the number of crossing traffic and video traffic increased.

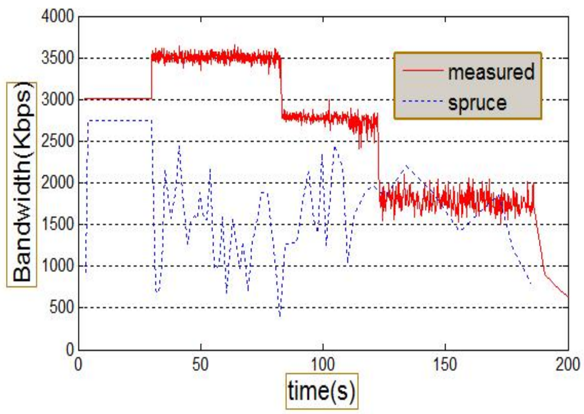


**Fig. 5 Comparison of bandwidth calculated from measured and spruce without crossing traffic. (Two clients and one cross traffic)**

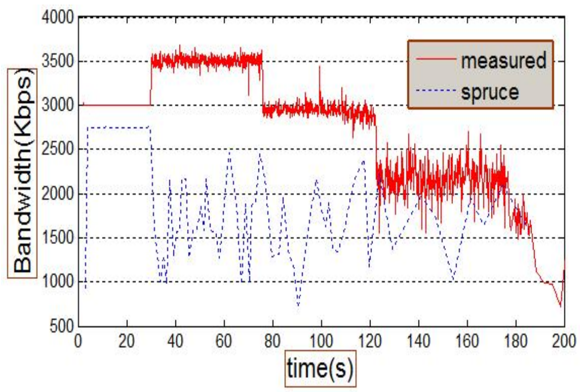


**Fig. 6 Comparison of bandwidth calculated from measured and spruce without crossing traffic. (Two clients and three cross traffics)**

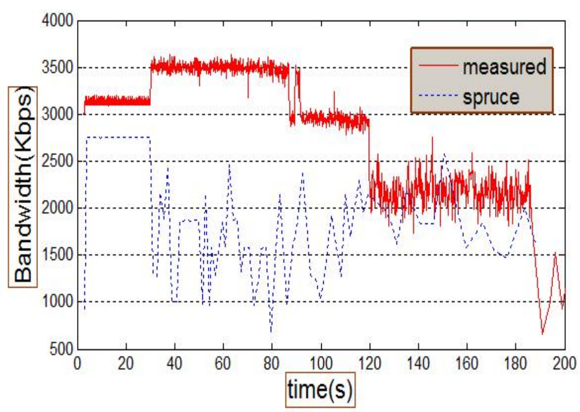


**Fig. 7 Comparison of bandwidth calculated from measured and spruce without crossing traffic. (Two clients and two cross traffics)**

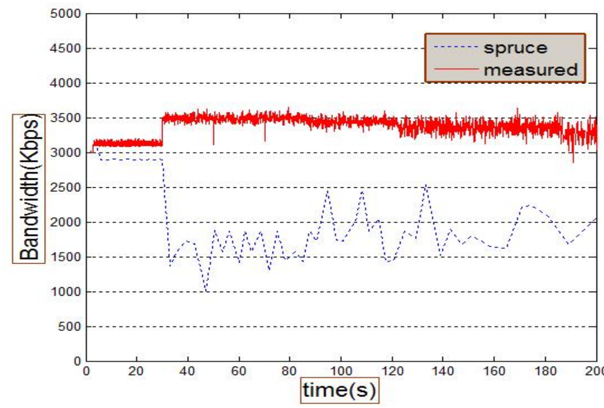


**Fig. 8 Comparison of bandwidth calculated from measured and spruce without crossing traffic. (Three clients and three cross traffic)**

## VI. Necessity for Intelligent Estimation Method

It can be observed from the experimental results in Section V that the performance of Spruce, can be offset by up to 50% as compared to the actual measured bandwidth, In practice, the performance of Spruce could be offset by 30% on average.

As the demand for performance on the Internet grows, so does the requirement for tools to accurately measure performance. This growing demand also means that solutions that place a large load on the network would not be able to scale. This infact creates an urgent need for having tools that can accurately estimate various types of bandwidths. Also, such techniques need to estimate the bandwidth accurately without creating large volumes of traffic.

An intelligent bandwidth estimation (iBE) technique is being researched by our team that would reduce the error between the measured and the estimated bandwidth. The basic idea of iBE is to use the difference between the packet's transmission time and reception time at MAC layer. The actual algorithm and the mechanism of iBE is not explained here completely; as it is still under research. The initial results are shown in Table II. It can be observed from Table II that for CBR/UDP traffic of 0.5 and 1.0 Mbps data rate for different video clients, the iBE shows significantly less error with respect to the actual measured bandwidth, as compared to Spruce.

## 6. Conclusion and Future Work

This paper reviews the different categories of bandwidth estimation techniques for wireless networks. Single pair and packet pair were the two prominent kinds of estimating bandwidth for such networks. A state-of-the-art packet-pair estimation technique, "Spruce" was described and analyzed for different kinds of Internet-based multimedia traffics. It was found over different conditions that the performance of "Spruce" though satisfactory at most of the times, was found to give high errors, as much as even 50%.

A new intelligent bandwidth estimation algorithm for multimedia delivery over wireless networks has been researched in the recent years. The initial results have shown the intelligent technique to give results much closer to the actual measured bandwidth. Further work in this direction is to fully develop the intelligent bandwidth estimation method, and to test its performance against different multimedia based applications.

## Acknowledgments

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| i | Video clients | Cross Traffic | Bandwidth (median, Mbps) | | | | |
|---|---|---|---|---|---|---|---|
| | | | measured | iBE | Spruce | error | |
| | | | | | | iBE | Spruce |
| 1 | 1 | None | 2.96 | 3.52 | 1.51 | 0.56 | 1.45 |
| 2 | 2 | None | 3.12 | 3.41 | 1.49 | 0.29 | 1.63 |
| 3 | 2 | CBR/UDP 0.5Mb/s | 2.72 | 2.67 | 1.62 | 0.05 | 1.1 |
| 4 | 2 | CBR/UDP 0.5Mb/s<br>CBR/UDP 1.0Mb/s | 2.63 | 2.25 | 1.58 | 0.38 | 1.05 |
| 5 | 2 | CBR/UDP 0.5Mb/s<br>CBR/UDP 1.0Mb/s<br>CBR/UDP 1.0Mb/s | 2.48 | 2.23 | 1.51 | 0.25 | 0.97 |
| 6 | 3 | CBR/UDP 1.0Mb/s<br>CBR/UDP 1.0Mb/s<br>CBR/UDP 1.0Mb/s | 2.45 | 2.31 | 1.26 | 0.14 | 1.19 |

**Table II. Bandwidth Estimation Performance of iBE, Spruce and comparison with actual Measurement**