Using Packet Probes for Available Bandwidth Estimation: A Wireless Testbed Experience

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ABSTRACT

Evaluating available bandwidth estimation methods requires a malleable MAC protocol implementation, precise MAC layer packet timing measurements, and the ability to create control topologies in laboratory setups so that not all nodes are within communication range. To address these challenges, we have exploited IEEE 802.11e-derived features to obtain more control over the MAC layer operation of off-the-shelf radios and implemented a measurement-system that uses CPU timestamp counter and radio hardware timestamps to monitor MAC activity with microsecond resolution. In addition to presenting performance of our available bandwidth estimation method using packet probes, we also discuss solutions and open issues to provide useful information for other testbed cross-layer protocol evaluations, which are likely to face similar challenges.

Categories and Subject Descriptors: C.4 [Performance of Systems]: Design studies, Measurement techniques, Performance attributes

General Terms: Design, Measurement, Experimentation

Keywords: Wireless testbeds, Bandwidth estimation, Real-world evaluation

1. INTRODUCTION

The increasing use of wireless networks for real-time multimedia data calls for improved quality-of-service (QoS) support. QoS mechanisms such as admission control depend on accurate available bandwidth estimation. Admission control rejects new data flows if their bandwidth requirement exceeds available bandwidth on the network path. To our knowledge only passive monitoring of received packets, has to date been evaluated on wireless testbeds for available bandwidth estimation. While many other solutions exist for wired networks [1], these do not address the specific challenges of wireless networks. Most notably, due to the open and shared nature of wireless links, available bandwidth may be affected by interfering transmissions, even if the signal level is too low for data packets to be received. Methods have been proposed to address these challenges, but the simulation results have yet to be validated through testbed experiments.

This poster paper reports on our design, implementation, and preliminary testbed evaluation of an advanced available bandwidth estimation technique for commodity 802.11 hardware. Specifically, our contributions include:

- A novel packet probing method for available bandwidth estimation that can be implemented on off-the-shelf 802.11 radios using some 802.11e derived features.
- A method for MAC-level timing measurements at a sending station through CPU timestamp counters.

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2. MOTIVATION AND RELATED WORK

Many active and passive techniques for local and end-to-end available or achievable bandwidth estimation have been proposed for wired networks. These passive techniques benefit from the *observable* traffic in the past to estimate the near future. Active techniques, on the other hand, try to make use of minimally intrusive techniques (e.g., different kinds of probe packets) to infer the current state of the network. However, many of the wired bandwidth estimation methods are not equally-well applicable to wireless. Shared nature of the wireless medium makes bandwidth estimation a challenging task. Particularly in CSMA-based wireless MAC protocols, such as IEEE 802.11, exposed terminals are unable to initiate a concurrent transmission because they sense the channel busy. Therefore, any kind of bandwidth allocation decision at exposed terminals requires bandwidth usage information from nodes out of its communication range. In other words, accuracy of a passive traffic monitoring approach for available bandwidth estimation at such exposed terminals would be limited.

We define *available bandwidth* (AB) as the rate of *additional traffic* that can be transmitted from a node (towards a certain destination) without causing a significant degradation in service to other ongoing flows using this node. We define *maximum achievable bandwidth* (MAB) is defined as the maximum attainable rate of traffic that can be transmitted from a node (towards a certain destination), when no other competing traffic exists in the network.

Our presentation in this paper investigates experimental performance of packet probes in an ad-hoc network for AB estimation, where interference from CSNs are accounted for in the tests. Although packet probe approach has been used for MAB estimation in ad hoc networks previously [2], our approach targets estimating AB. We also use a novel approach in augmenting packet probe measurement accuracy through the use of IEEE 802.11e priority access mechanisms.

3. PACKET PROBING (PP) METHOD

The key idea of the packet probing (PP) method is sending two back-to-back probe packets (i.e., a probe pair) to an immediate neighbor node to measure their dispersion. Since dispersion between probes should be strongly correlated with channel utilization, the algorithm can derive AB from the dispersion information. Note that any activity that is keeping the channel busy, including transmissions from CSN's of a given node, will have an effect towards increasing probe packet dispersion. For this reason, the PP method is expected to provide accurate information on available bandwidth when exposed terminals exist in the network.

Success of PP method in estimating current channel utilization heavily depends on a particular implementations ability to delimit significant enough channel activity in between two probe packets. For this reason, inserting artificial delay between probe packets at source (forcing an initial gap) and using more than two back-to-back probe packets were investigated in wired network PP studies. To boost our probe packet's traffic delimiting ability, we propose a novel mechanism through the use of Wi-Fi Multimedia (WMM) extensions as follows. Relative to the regular traffic priority queue (WME_AC[BE]), we tailor the first probe packet queue to become a high priority queue (WME_AC[VO]), and the second probe packet queue to become a low priority queue (WME_AC[BK]). Such an assignment of queues to probe packets ensures that whenever the first probe packet is attempted to be sent out, it will have the highest priority to access the medium. The second probe packet goes out from the lowest priority queue, so that any regular traffic packet that is trying to contend for the medium at that time is given higher chances of going out before the second probe packet.

4. EXPERIMENTS AND RESULTS

We conducted most experiments on the ORBIT testbed [3], which provides access to a 400-node wireless radio grid inside a well isolated experiment environment together with support services for experiment handling, measurement collection etc.

To measure inter-packet transmission times, we record the time between the network device interrupts using the CPU Time Stamp Counter available on Pentium-compatible CPUs. Upon transmission of a packet, the network hardware informs the driver if an ACK packet is received or if all maximum retransmission count has been reached without receiving an ACK. Thus, assuming successful packet transmissions, the inter-packet transmission time can obtained by taking the difference between the CPU Time Stamp Counters recorded for each interrupt.

In our experiments, we have first verified that a simple "decodable-packets" based approach performs poorly on exposed terminals. The topologies in this study are obtained by injecting AWGN noise on to the testbed [4]. We have then implemented and tested an AB estimator using PP method in Linux. We have observed a strong correlation between PP dispersion and traffic present in air for all topologies we have tested. Dispersion behavior kept unchanged even though the traffic source moved out of the reception range (but still in CS range) of probing node. Figure 1 gives results from two of the topologies we have tested.

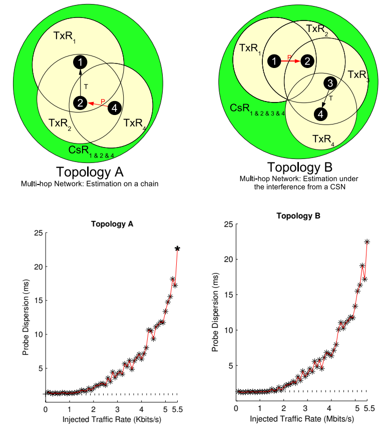

Figure 1: PP dispersion vs. injected traffic rate in two of the test topologies.

5. CONCLUSION AND DISCUSSION

In this study, we carried out an experimental testbed evaluation of a packet probing method to measure channel utilization on commodity 802.11 hardware. Through our experiments, we learned that:

- A strong correlation exists between probe dispersion and interference traffic. Thus, packet probing appears promising as a bandwidth estimation technique in wireless networks that can account for interference.
- Using CPU timestamp counters, radio clock timestamps and the interrupts provided by the WiFi adapter, packet dispersion and packet arrival times can be measured with accuracy on the order of microseconds.

These experiments are expected to serve as a useful case study for evaluation of cross-layer protocols with similar challenges.

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7. REFERENCES

[1] N. Hu and P. Steenkiste. Evaluation and Characterization of Available Bandwidth Probing Techniques. *IEEE JSAC Special Issue in Internet and WWW Measurement, Mapping, and Modeling*, 21(6), pages 879–894, August 2003.

[2] T. Sun, G. Yang, L.-J. Chen, M. Y. Sanadidi, and M. Gerla. A Measurement Study of Path Capacity in 802.11b Based Wireless Networks. In *Proc. of International Conference On Mobile Systems, Applications And Services*, pages 31–37, June 2005.

[3] D. Raychaudhuri, I. Seskar, M. Ott, S. Ganu, K. Ramachandran, H. Kremo, R. Siracusa, H. Liu, and M. Singh. Overview of the ORBIT Radio Grid Testbed for Evaluation of Next-Generation Wireless Network Protocols. In *Proc. of IEEE WCNC 2005*, pages 1664–1669, March 2005.

[4] S. K. Kaul, M. Gruteser, and I. Seskar. Creating Wireless Multi-hop Topologies on Space-Constrained Indoor Testbeds Through Noise Injection. In *Proc. of IEEE Tridentcom 2005*, pages 512–521, March 2006.