Available Bandwidth Estimation in IEEE 802.11-Based Wireless Networks

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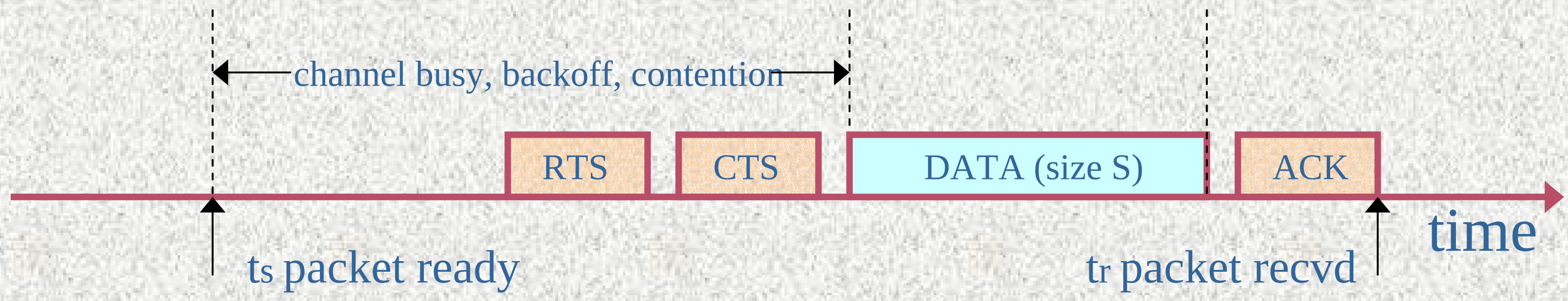
Introduction

- Theoretical channel capacity depends on the physical layer
  - 1, 2, 5.5 or 11 Mbps for IEEE 802.11
- Bandwidth actually available to the application is less due to:
  - Protocol overhead
  - MAC layer contention
    - » Location-dependent in multi-hop or multi-cell environments
  - Location-dependent channel errors
    - » Signal fading, bit-errors due to physical objects such as walls, doors, etc.

IEEE 802.11 MAC and Our Scheme

- IEEE 802.11 MAC:
  - Carrier sense:
    - Medium idle? Send RTS
    - Medium busy? Wait until medium idle, backoff for collision avoidance, send RTS
  - RTS-CTS-DATA-ACK
  - Collision? Increase backoff interval exponentially
- Our scheme:
  - Does not modify IEEE 802.11 in any way
  - Uses data transmissions for bandwidth estimation
    - No separate probing packets, etc.
  - Performed in the device driver of the wireless interface
    - Device driver loaded as a module under Linux

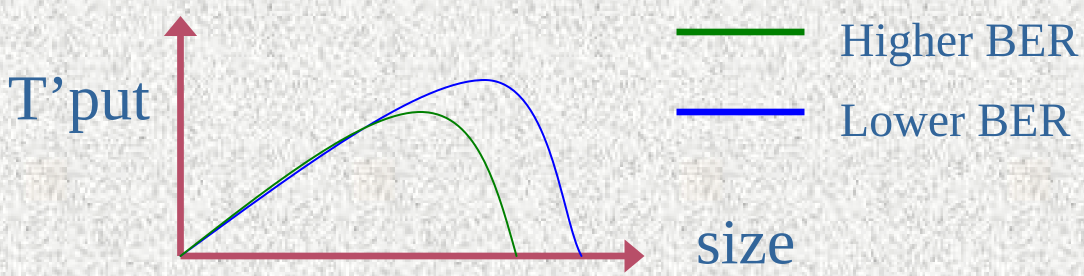
Bandwidth Estimation



- Measured BW = $S/(t_r - t_s)$
  - Running average with decay/Average over an interval
  - More contention? More time channel sensed as busy, more RTS/CTS collisions, higher backoffs => BW estimate smaller
  - More channel errors? Bit-errors in RTS/DATA cause RTS/DATA retransmission => BW estimate smaller
  - Only successfully transmitted MAC frames used in estimate

Packet Size

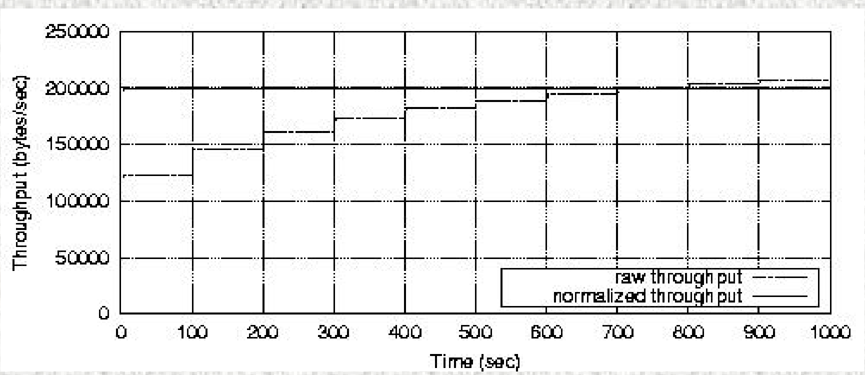
- Packet size affects BW estimate
  - Low channel bit-error rate (BER)? Larger packet size => higher throughput
  - High BER? Larger packet size => Larger probability of bit-error => lower throughput



- Indexed table of BW estimates for different packet size ranges
  - Separate estimation for data and acks (i.e., higher-layer acks) at source and destination respectively

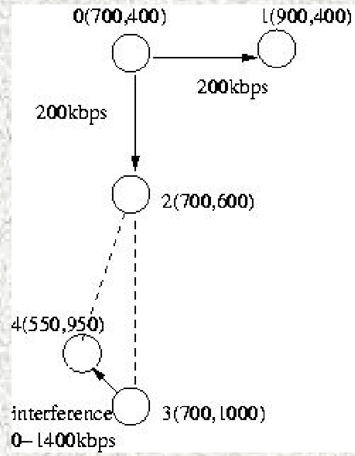
Normalization

- For low BERs
  - Scenarios used in our simulation and testbed experiments
  - Linear part of BER-packet size-throughput curve
- Packet size from 64B to 640B
- We can have a *single* estimate *normalized* to a reference packet size (512B)

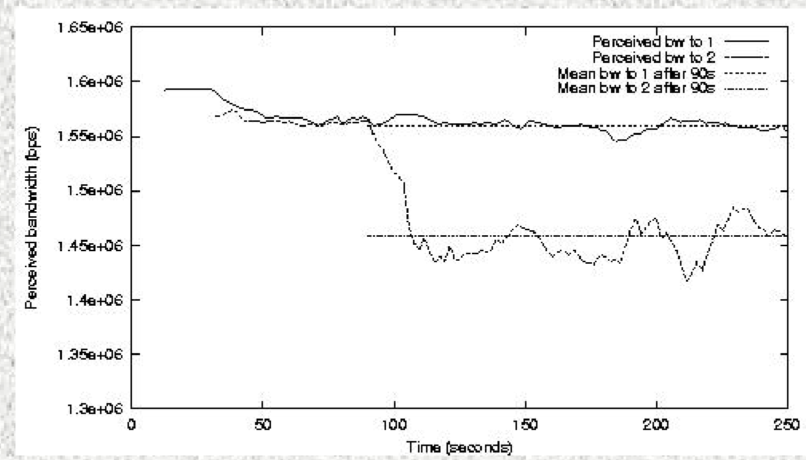


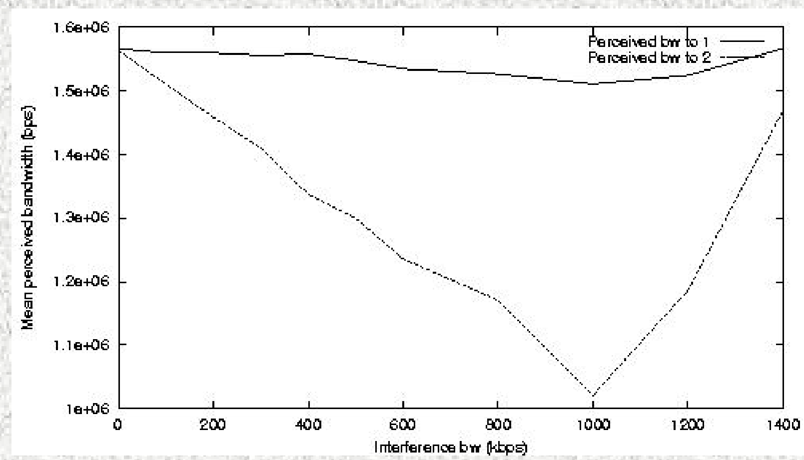
- Key observations for normalization:
  - Channel busy + backoff + RTS/CTS + ACK overhead same for packets of all sizes
  - Once channel captured, DATA is transmitted at physical channel rate, for all packet sizes
- Normalization enables estimation at source for both data and acks

Simulation Results



- CBR Contention experiments:
  - Running average with decay





- Variable contention experiments (for predictability):
  - %age difference between successive 2 sec. intervals
  - 1 contending TCP flow: >97% of the time <= 20% difference
  - 7 contending TCP flows: >80% of the time <= 20% difference

Application

- *Channel Time Proportion* (CTP)
  - A link has bandwidth estimate *k* bps, a flow over it requires *j* bps => it requires a fraction *j*/*k* of the channel shared by nodes in its neighborhood
- Use this in admission control for both single- and multi-hop IEEE 802.11 networks
- Admission control inaccurate
  - Admitting new traffic increases contention in the shared channel
  - Changes bandwidth estimate of flows
- Dynamic bandwidth management
- For more see:
  - S. Shah, K. Chen and K. Nahrstedt, **Dynamic Bandwidth Management in Single-hop Ad hoc Wireless Networks**, MONET journal special issue on Algorithmic Solutions for Wireless, Mobile, Ad Hoc and Sensor Networks (eds. Bar-Noy, Bertossi, Pinotti and Raghavendra), 2004.
  - K. Chen and K. Nahrstedt, **EXACT: An Explicit Rate-based Flow Control Framework in MANET**, Technical Report UIUCDCS-R-2002-2286/UILU-ENG-2002-1730, Department of Computer Science, University of Illinois at Urbana-Champaign, updated December, 2002.