End-to-end bandwidth measurement method considering effects on power-saving routers

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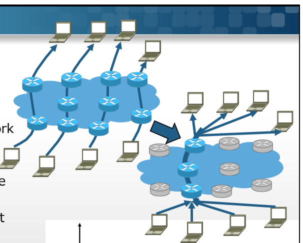
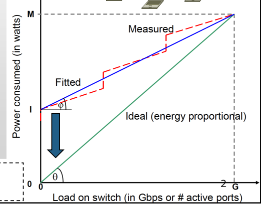
Energy efficiency in backbone networks



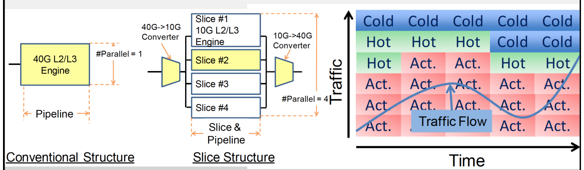
- Traditional method:
  - Change traffic routes so that the network paths are NOT distributed, but is concentrated on limited routes
  - Power-off unused switch ports/interface boards/routers/switches
  - Change in network topologies will affect the routing protocol (e.g. IP)
- Improving energy proportionality of routers and switches
  - Adjust link bandwidth/packet processing performance according to traffic load
  - The effect on routing protocols and applications is smaller due to no changes in network topology



P. Mahadevan, P. Sharma, S. Banerjee, and P. Ranganathan, ``A Power Benchmarking Framework for Network Devices,'' in Proceedings of IFIP Networking 2009, May 2009.

Power-saving router architecture

- A packet processing module in a router is implemented as ``slices''
  - e.g. 40Gbps engine is constructed by four 10Gbps engine slices
- The number of activated slices is controlled in the order of microseconds – milliseconds, according to the traffic load changes



[7] K. Zaitsu, K. Yamamoto, Y. Kuroda, K. Inoue, S. Ata, and I. Oka, "Hardware implementation of fast forwarding engine using standard memory and dedicated circuit," in Proceedings of IEEE ICECS 2010, pp. 379–382, December 2010.

Effect of power-saving routers on upper-layer protocols and applications

- Physical capacity of a router's output link changes dynamically, that may affect the performance of layer-4/7 protocols and applications
  - Existing protocols and applications are designed under the assumption that the physical capacity of a network path does not change except with route changes
  - Due to physical bandwidth changes, available bandwidth and round trip time of the network path will fluctuate due to other reasons than network congestion
  - Measurement accuracy of bandwidth and throughput may decrease significantly
    - Network applications such as peer/server selection in P2P/CDN, application-level routing, tree construction in application-level multicasting are based on accurate measurement of bandwidth and throughput
- Measurement traffic will affect the energy efficiency of power-saving routers
  - Measurement traffic may increase the network traffic load, that increase the power consumption of power-saving routers

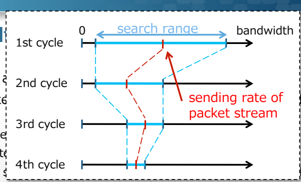
Research objectives

- End-to-end bandwidth measurement method that does not decrease the energy efficiency of power-saving routers
  - Simultaneous measurement of physical capacity and available bandwidth for monitoring the changes in physical capacity
  - Based on existing measurement tools
    - Pathload for available bandwidth [5]
    - CapProbe for physical capacity [8]
  - Parameter setting of Pathload based on the configuration of power-saving routers on the network path
  - Speeding up measurement tasks based on past measurement results

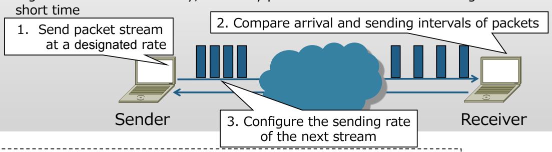
[5] M. Jain and C. Dovrolis, "End-to-End available bandwidth: Measurement methodology, dynamics, and relation with TCP throughput," in Proceedings of ACM SIGCOMM 2002, pp. 295–308, July 2002.

[8] R. Kapoor, L. jyh Chen, A. N, M. Gerla, and M. Y. Sanadidi, "CapProbe: a simple and accurate capacity estimation technique," in Proceedings of ACM SIGCOMM 2004, pp. 67–78, August 2004.

Available bandwid



- Packet streams are sent at a
- The receiver observes packe ing intervals
  - Intervals are **increased** -> se
    -> **decrease** the sending rat
  - Intervals are **unchanged** -> s n
    -> **increase** the sending rate of the next stream
- **Binary search** for estimating available bandwidth
- High measurement accuracy, but many packet streams are send with high rate in a short time

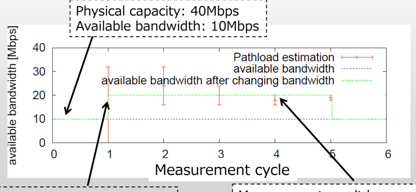


[5] M. Jain and C. Dovrolis, "End-to-End available bandwidth: Measurement methodology, dynamics, and relation with TCP throughput," in Proceedings of ACM SIGCOMM 2002, pp. 295–308, July 2002.

Effect of pathload on power-saving router

- Pathload's packet stream increases the load on the power-saving router
- Power-saving router increase the physical capacity to accommodate the increased traffic load
- Measurement accuracy degrades because the physical bandwidth increases during the measurement

Physical capacity: 40Mbps
Available bandwidth: 10Mbps



Physical capacity increased from 40Mbps to 50Mbps due to packet stream of Pathload

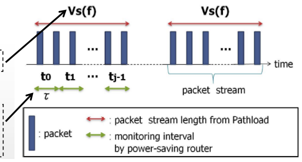
Measurement result becomes incorrect due to the increased physical capacity

Configuration of packet stream length

Packet stream length

V

Monitoring interval of link utilization of power saving router



$$U(t_{j-1}) = w\sum_{k=0}^{j-1}(1-w)^{j-1-k}\frac{R(f)}{C(t)} + \frac{R^C}{C(t)} \leq \lambda_u$$

threshold

Link utilization of power-saving router

Increased link utilization due to Pathload

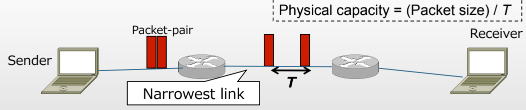
Link utilization due to cross traffic

Packet stream length of Pathload is configured with consideration of the monitoring interval of link utilization of power-saving router, so that we can avoid the increase in the physical capacity due to Pathload's packet stream

Physical capacity measurement by CapProbe

- Packet-pair based method
  - A sender sends two packets closely, and the increased interval is observed at a receiver to estimate the physical capacity of the narrowest link

Physical capacity = (Packet size) / T

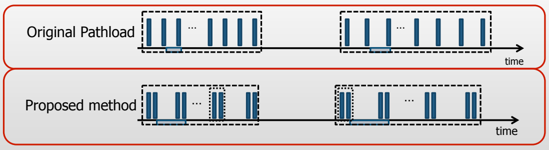


- CapProbe utilizes the result of the packet pair which has the minimum value of one-way delay from the sender to the receiver
  - Short measurement time and high-accuracy results are provided

[8] R. Kapoor, L. Jyh Chen, A. N, M. Gerla, and M. Y. Sanadidi, "CapProbe: a simple and accurate capacity estimation technique," in Proceedings of ACM SIGCOMM 2004, pp. 67–78, August 2004.

Simultaneous measurement of physical capacity and available bandwidth

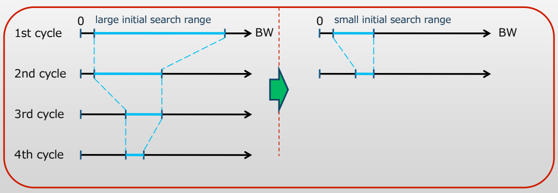
- Packet streams for Pathload are constructed by packet pairs, while preserving the average sending rate
  - Arrival interval of each packet pair is utilized for CapProbe's physical capacity measurement, and received rate of the whole stream is utilized for Pathload's available bandwidth measurement



- When the changes in the physical capacity is detected during a available bandwidth measurement, the measurement is cancelled and a new measurement is restarted after a significant interval
  - Discard incorrect measurement results

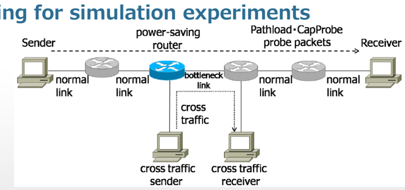
Speeding up of Pathload using measurement history

- Determine the initial search range of Pathload based on the past measurement results
  - Measurement time can be reduced especially when the network utilization is stable



[9] Le Thanh Man Cao, Go Hasegawa and Masayuki Murata, ImTCP: TCP with an Inline Measurement Mechanism for Available Bandwidth, Computer Communications Journal special issue of Monitoring and Measurements of IP Networks, Vol.29, Issue 10, pp. 1614-1626, June 2006.

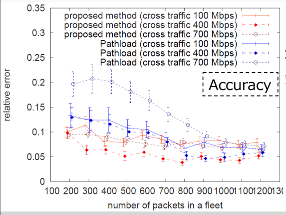
Setting for simulation experiments

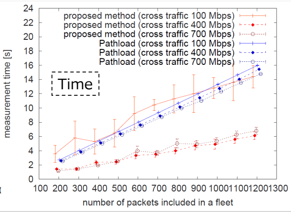


- Setting of power-saving router
  - Maximum physical capacity: 1Gbps
  - 10 slices of 100Mbps capacity
  - Thresholds for capacity tuning: 0.8 for increasing, 0.3 for decreasing
  - Monitoring interval of link utilization: 1msec
- Evaluation metrics
  - Measurement accuracy of available bandwidth
  - Required measurement time for a single measurement task
  - Changes in physical capacity setting of power-saving routers
- Performance comparison with the original Pathload

Simulation results (1): measurement performance

- Measurement accuracy and measurement time as a function of the total number of packets for each measurement task
  - Red lines: proposed method, blue lines: original Pathload

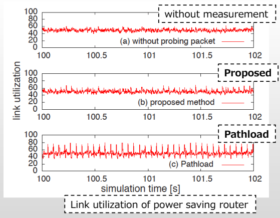


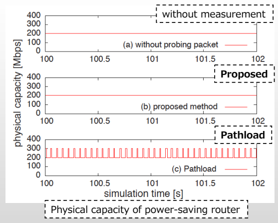


Proposed method shows better measurement accuracy and smaller measurement time

Simulation results (2): effect of power-saving router

- Changes in link utilization and physical capacity setting of power-saving router





- Proposed method has a smaller impact on the link utilization and no increase in physical capacity setting of power-saving router
  - Energy efficiency of power-saving router is preserved

Summary and future work

- Summary
  - End-to-end bandwidth measurement method was proposed, which does not affect the energy-efficiency of power-saving router
    - Simultaneous measurement of physical capacity and available bandwidth
    - Parameter tuning of bandwidth measurement is conducted based on the settings of power-saving router and past measurement results
    - Simulation experiment results showed the effectiveness of the proposed method
- Future work
  - Implementation experiments with the actual power-saving router prototype
  - Design of transport-layer protocols with bandwidth measurement under the existence of power-saving routers