Performance Evaluation and Improvement of Hybrid TCP Congestion Control Mechanisms in Wireless LAN Environment

Masafumi Hashimoto, Go Hasegawa, Masayuki Murata
Osaka University, Japan
m-hasimt@ist.osaka-u.ac.jp

TCP for high-speed and long-delay network

- TCP congestion control mechanisms for high-speed and long-delay network have been proposed
  - Categorized into three types from viewpoint of network congestion indications
    - Loss-based TCP variants: utilize packet loss events
      - HighSpeed TCP, Scalable TCP, etc
    - Delay-based TCP variants: utilize increase/decrease of RTT
      - TCP Vegas, FAST TCP, etc
    - Hybrid TCP variants: combine loss- and delay-based behaviors
      - Compound TCP, TCP-Adaptive Reno, etc

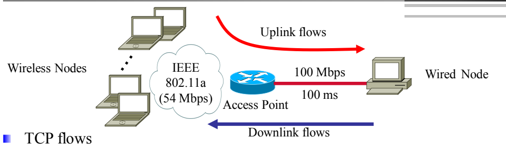
Wireless LAN environments

- Accessing the Internet through WLANs is becoming common situation
- Several wireless technologies will increase WLAN bandwidth
  - IEEE 802.11g, IEEE 802.11n etc…
- TCP variants for high-speed and long-delay networks would be transparently utilized in high-speed wireless networks
- It is important to evaluate the performance of the TCP variants in WLAN environments

Objectives of this work

- Evaluate the performance of delay-based and hybrid TCP variants in WLAN environment
- Propose a transport-layer solution to TCP unfairness problems in WLAN environment
  - We focus on numerous drops of ACK packets at an access point buffer

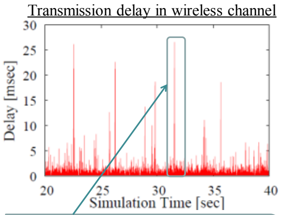
Simulation setting

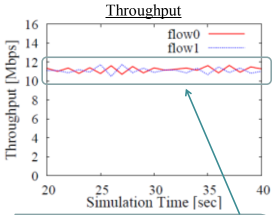


- TCP flows
  - Only one flow is generated for each wireless node
  - FAST TCP and Compound TCP are used for the simulation
- Access point: 100 packets buffer for WLAN interface
- Sender buffer size and advertised receiver window are set to large enough
- Simulation time: 200 seconds
  - Data transmissions of all flows start simultaneously when the simulation begins
- Performance metrics
  - Impact of transmission delay in wireless channel
  - TCP throughput unfairness among uplink flows
  - TCP throughput unfairness between uplink and downlink flows
- Fairness means that each flow obtain the same wireless bandwidth even if uplink and downlink flows coexist

Simulation results: Impact of transmission delay in wireless channel (1/2)

- FAST TCP: 2 uplink flows



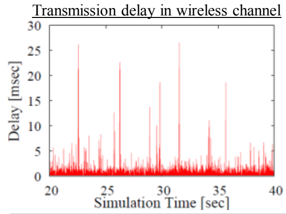


- Maximum delay fluctuations are about 25 ms
- The throughput is stable within 1 Mbps fluctuation
  - this is comparable with that of TCP Reno

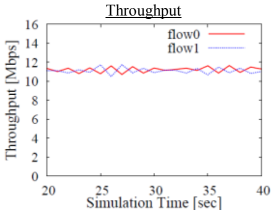
Simulation results: Impact of transmission delay in wireless channel (2/2)

- FAST TCP: 2 uplink flows

Transmission delay in wireless channel



Throughput

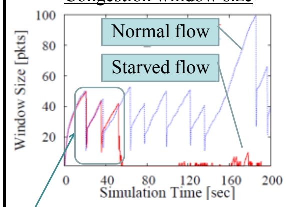


- The throughput of FAST TCP is not affected by the delay fluctuation
  - The main reason of this is that delay fluctuation in wireless channel would be absorbed at the send buffer of the WLAN interface of the wireless nodes.
- We confirmed that delay fluctuation in wireless channel have little effect on performance of other delay-based and hybrid TCP variants

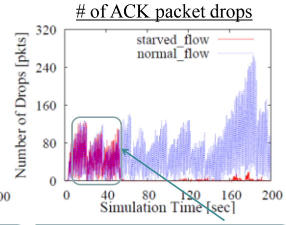
Simulation results: TCP unfairness among uplink flows (1/3)

- Compound TCP: 16 uplink flows

Congestion window size



# of ACK packet drops

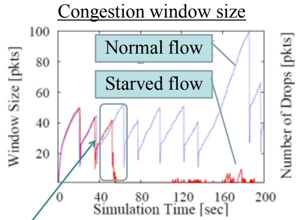


- The starved flow increase/decrease its congestion window as well as the normal flow
- TCP ACK packets of both flow are numerously discarded at the buffer of the access point

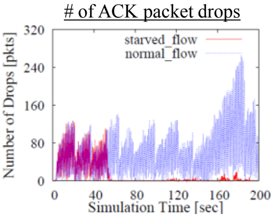
Simulation results: TCP unfairness among uplink flows (2/3)

- Compound TCP: 16 uplink flows

Congestion window size



# of ACK packet drops

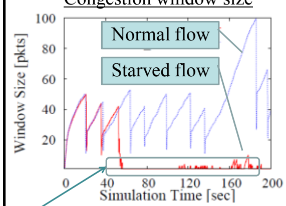


- The congestion window size of starved flow is set to one packet because of occurrence of RTO when *all* ACK packets in a window are discarded
  - Note that the buffer of the access point is still fully-utilized since the congestion is not resolved

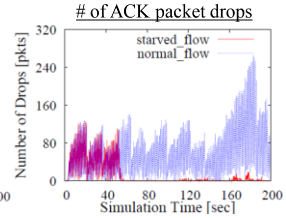
Simulation results: TCP unfairness among uplink flows (3/3)

- Compound TCP: 16 uplink flows

Congestion window size



# of ACK packet drops



- The starved flow transmits almost no data
  - Once RTO occurred at a certain flow, the flow cannot increase its congestion window for a long time

⇨ **TCP unfairness among uplink flows**

Summary of TCP throughput unfairness

- TCP throughput unfairness caused by the congestion at the access point
  - Transmission opportunity of the access point is equal to that of the wireless station
- Two kinds of TCP unfairness occurred in WLAN;
  - Among uplink flows
  - Between uplink and downlink flows
- These unfairness problems are due to numerous ACK packet losses at the access point buffer
  - Note that TCP activates the congestion control when a data packet is discarded but DOES NOT activate the congestion control when an ACK packet is discarded
- It is important to improve these unfairness because uplink and downlink flows share the same wireless bandwidth

Existing methods for unfairness in WLANs

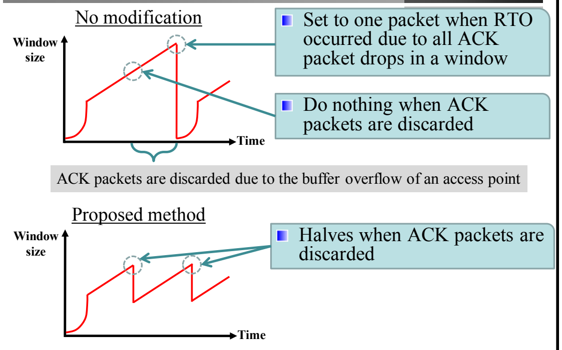
- A solution by modifying MAC protocol parameters [12]
  - Gives preference to transmission of an access point over that of stations
  - It takes large cost to change MAC protocols of access points because they are generally implemented in hardware
- A solution by modifying queue management mechanisms in an access point [13]
  - Divides the buffer into for data packets and for ACK packets.
  - It is not considered TCP unfairness among uplink flows
- IEEE 802.11e
  - Realizes different QoS requirements among flows which are generated from the station by utilizing per-flow queuing
    - It does not contribute to per-station fairness
  - Parameter settings are difficult

[12] Y. Fukuda and Y. Oie, "Unfair and inefficient share of wireless LAN resource among uplink and downlink data traffic and its solution," *IEICE Transactions on Communications, vol. E88-B, pp. 1577–1585, Apr.*2005.
[13] J. Ha and C.-H. Choi, "TCP fairness for uplink and downlink flows in WLANs," in *Proceedings of IEEE Global Telecommunications Conference 2006, pp. 1–5, Nov. 2006.*

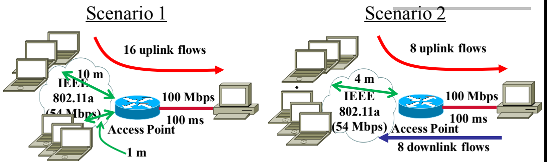
Proposed method (1/2)

- Propose a transport-layer solution to alleviate TCP unfairness problems
  - We focus on numerous TCP ACK packet losses when an access point is congested
- Proposed mechanism
  - Detecting ACK packet losses by monitoring the sequence number of received ACK packets
    - When it observes abnormal jumps of its number, it is regarded as ACK packet losses in the network
  - Activates the congestion control when number of ACK packet drops in a RTT exceeds pre-determined threshold
    - Halves the congestion window

Proposed method (2/2)



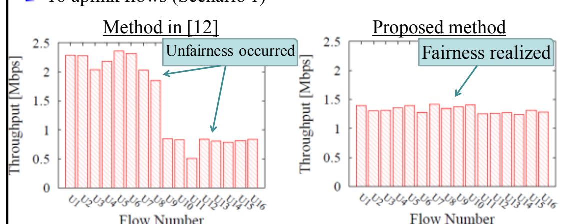
Simulation evaluations: Settings



- Two kinds of simulation scenarios
  - Scenario 1
    - 16 uplink flows
    - the eight stations and the other eight stations are located at 1 m and 10 m from the access point
  - Scenario 2
    - 8 uplink flows and 8 downlink flows
    - All stations are located at 4 m from the access point
- The other simulation settings are the same as the previous simulations

Simulation results: Improvement of TCP fairness among uplink flows

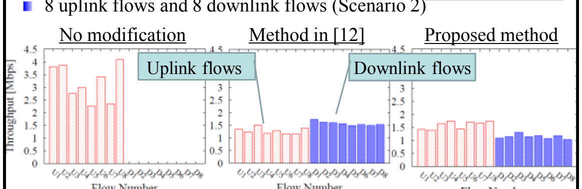
- 16 uplink flows (Scenario 1)



- The method in [12] causes significant unfairness between flows dependently on the distance of the stations
  - It is sensitive to the wireless channel environment
- The proposed method provides good fairness regardless of the location of the stations

Simulation results: Improvement of TCP fairness between uplink and downlink flows

- 8 uplink flows and 8 downlink flows (Scenario 2)



- When we do not apply any modification, there exists two kinds of unfairness
  - Unfairness among uplink flows
  - Unfairness between uplink and downlink flows
- The method in [12] and proposed method improve fairness between uplink and downlink flows
  - The throughput of downlink flows is slightly lower than that of uplink flows when the proposed method is applied

Conclusion and future work

Conclusion

- We evaluated the performance of TCP variants for high-speed and long-delay networks in WLAN environment
  - Delay fluctuations in wireless channel have little impact on the throughput of delay-based and hybrid TCP variants
  - Loss-based and hybrid TCP variants experience significant unfairness among uplink flows and between uplink and downlink flows
- We proposed the transport-layer solution against unfairness among TCP flows
  - The proposed method is effective not only for TCP fairness among uplink flows but also for fairness between uplink and downlink flows

Future work

- Investigation of the performance of the proposed method in the lossy network
- Evaluations of the proposed method in the actual WLAN environment