Experimental evaluation of the TCP Simultaneous-Send Problem in 802.11 Wireless Local Area Networks

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Outline of talk

- Introduction
- NS results
- Testbed Experiments
- Results and analysis
- Conclusion

Introduction

IEEE 802.11 DCF mode

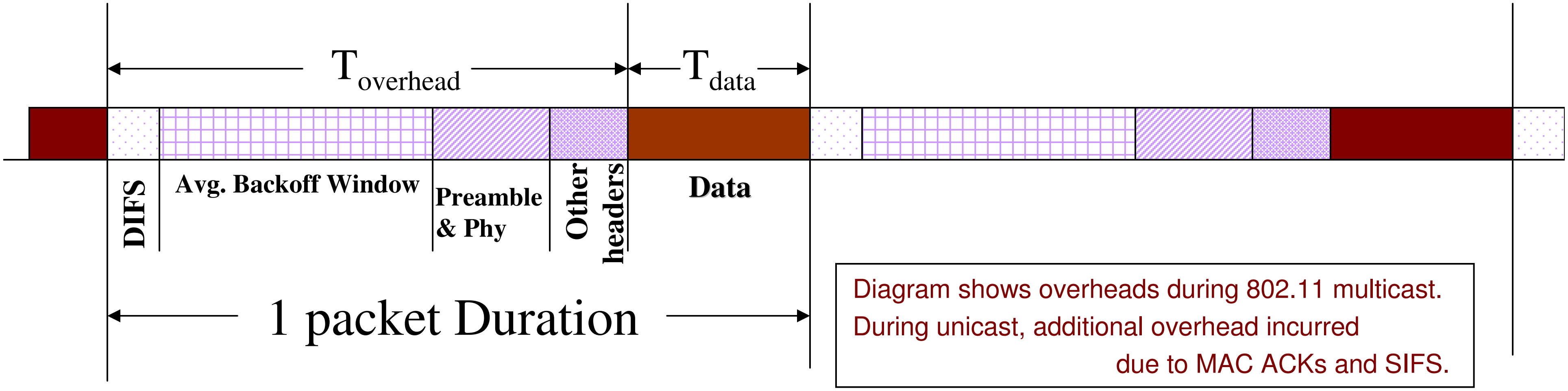


Diagram shows overheads during 802.11 multicast.
During unicast, additional overhead incurred due to MAC ACKs and SIFS.

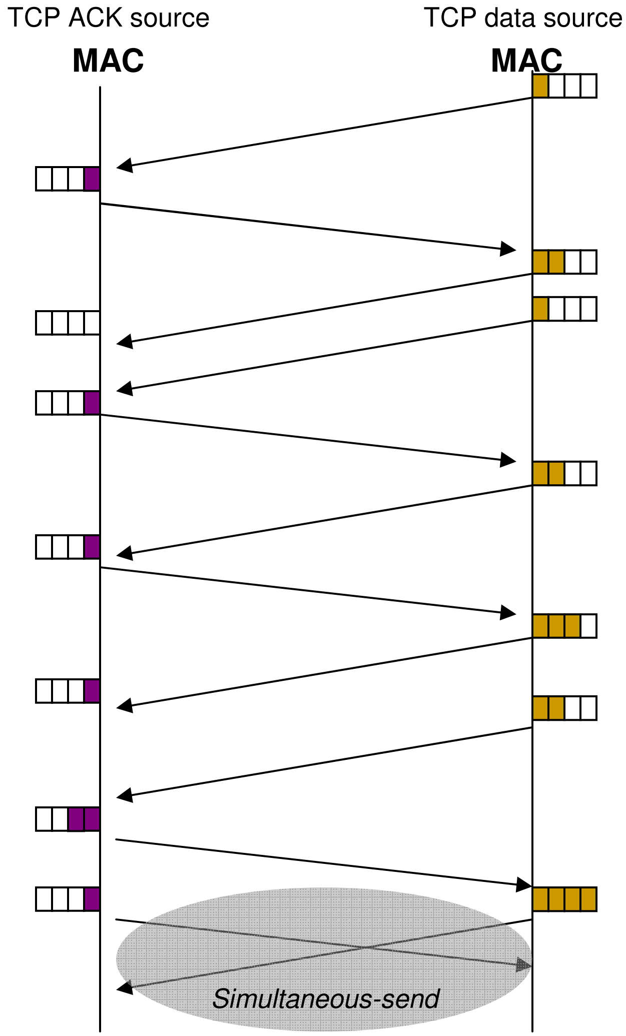
- Distributed access; equal priority for all nodes
- Large overhead per packet;
  - MAC contention (random backoff) primary contributor
  - Preamble and Phy headers transmitted at 1/2Mbps
  - DIFS
  - Other headers – LLC, IP, TCP
- For a 1kB packet, channel usage efficiency < 54%; < 2% for a 16Byte packet!

The TCP *simultaneous-send* problem

first reported in

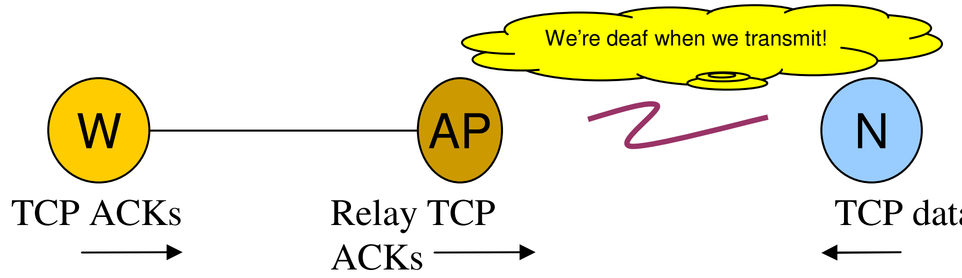
S Gopal, S Paul, D Raychaudhuri, "Investigation of the TCP Simultaneous-Send Problem in 802.11 wireless Local Area Networks", ICC May 2005, Seoul, South Korea

Persistent channel contention with TCP



- With TCP, packet arrival at 802.11 MAC is *not Poisson* and MAC contention happens far more often
- TCP slow-start causes a continuous supply of packets in the MAC queue
- Channel contention for every packet

TCP Simultaneous-send problem in 802.11 wireless networks



- TCP causes persistent MAC contention in 802.11 (Shown in previous slide)
- Hardware implementation – cannot send and receive at the same time
- Likelihood of at least 2 nodes of N nodes selecting the same backoff slot is:

$$1-\left(\frac{(CW-1)!}{(CW-N-1)!*(CW)^{N}}\right)$$

- ***Simultaneous-send*** problem occurs with a 3% likelihood
- TCP packet losses, and hence retransmission timeouts, reduce throughput

Alleviating simultaneous-send with *TCP ACK skipping*

- Assumptions:
  - Delayed ACK adaptation not enabled;
  - There is typically one ACK for every data packet
- TCP congestion window can tolerate skipping to some extent due to cumulative nature of TCP ACKs.
- ACK skipping reduces contention for data packets
  - 1 ACK skip reduces AP load by half
- However skipping too many ACKs is detrimental to TCP throughput due to constrained growth of the congestion window.

NS results

first reported in

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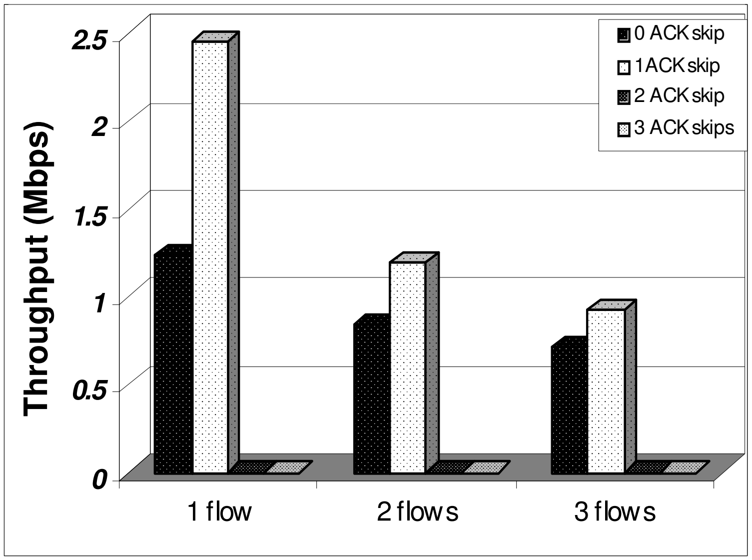
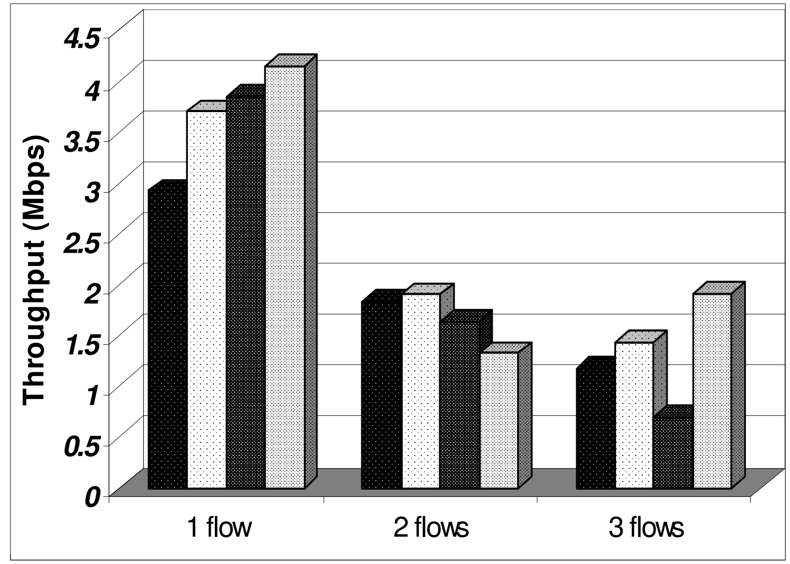
NS Results



Disabled MAC retries

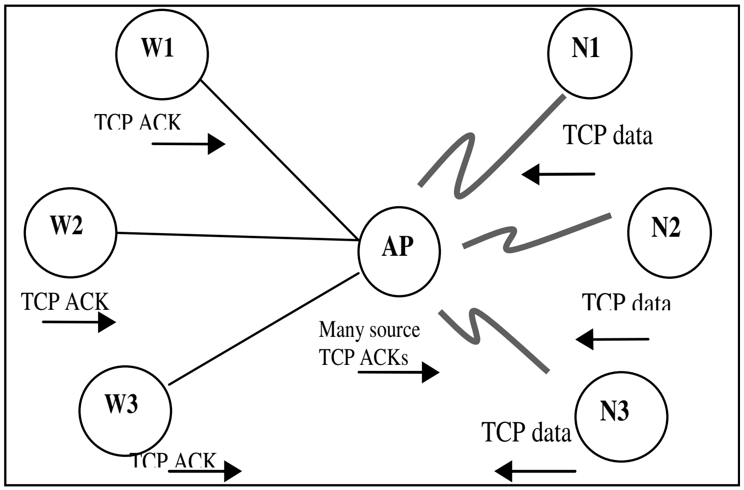


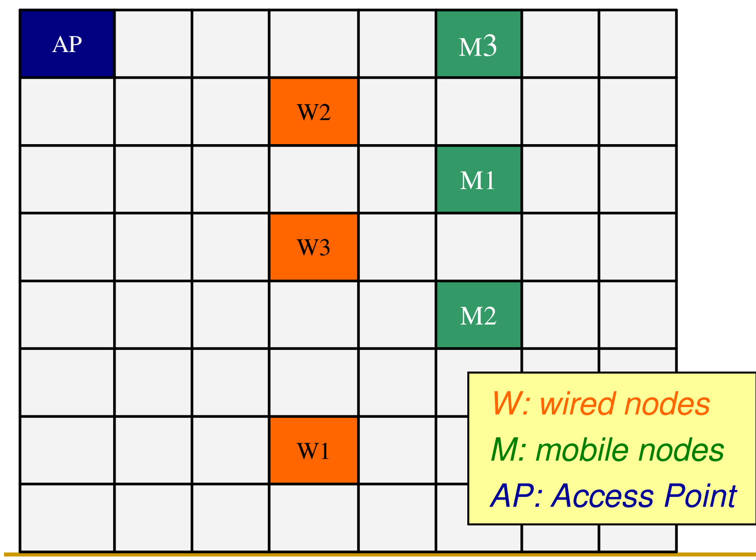
Enabled MAC retries

	Disabled MAC Retries	Enabled MAC Retries
Throughput Gain on 1 ACK skip	100 %	30%
Cause of gain with ACK skip	Reduced contention	Slower growth of cwnd during slow start
Higher ACK skips	Lost ACKs too costly; ACK starving degrades throughput	MAC retries compensate for ACK losses

ORBIT testbed experiments

Testbed Experiment setup





- Cisco and Atheros cards for wireless interfaces
- Configuration settings in Layer 2 and Layer 3
- All nodes in hearing range of each other
- No interfering traffic or noise, hence all packet losses due to MAC contention
- TCP code in kernel modified for ACK skipping

Some setup details..

- Only Atheros cards operated in “Master” and “Monitor” modes
- Only Cisco cards support MAC retry modification; Atheros cards do not.
- AP and Sniffer: Atheros cards; Wireless nodes: Cisco cards
- In the Disabled MAC Retries case: Retries disabled only for TCP data. Full retries for TCP ACKs.
- Cisco cards allow rate fixation; auto rate adaptation disabled
- Settings made with *iwconfig*

Setup details…

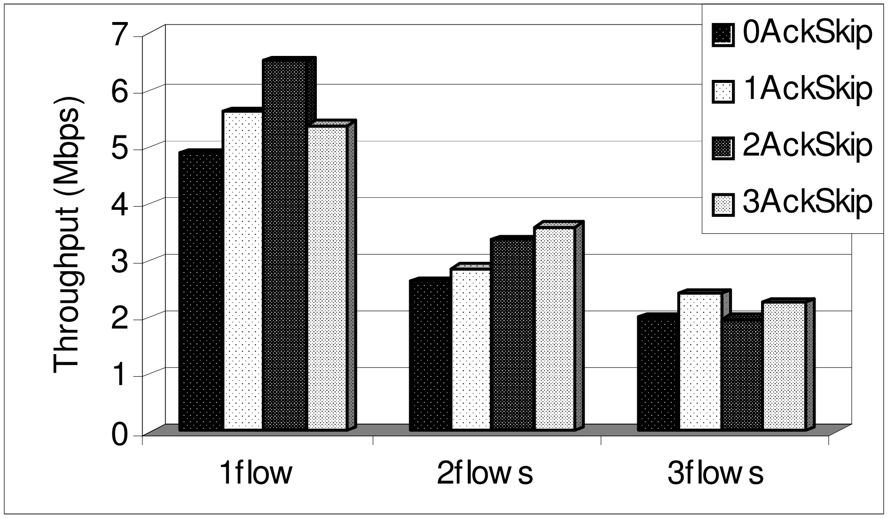
- Excellent TCP code in kernel 2.6.10 – well commented.
- Stevens “TCP/IP Illustrated” not useful. Code structure is very different
- Control plane of ORBIT testbed very handy for kernel modifications

Testbed Experiments

- Each throughput point in the graph is an average of 6 trials, and the simultaneous flows
- Short-lived flows - 100kB; Long-lived flows - 6MB file transfer
- Phy rate fixed at 11Mbps
- RTS/CTS disabled
- Maximum 16 MAC retries (default setting in Atheros cards)

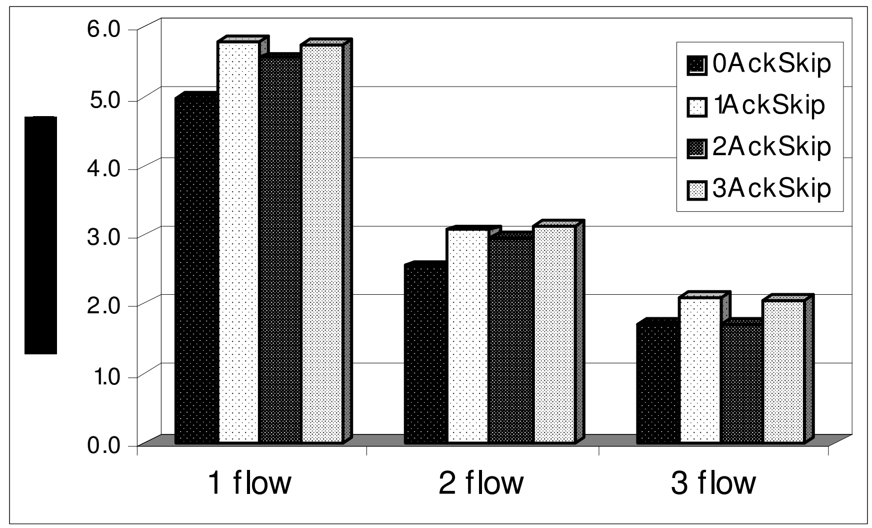
Testbed Results

Results (MAC Retries Enabled)



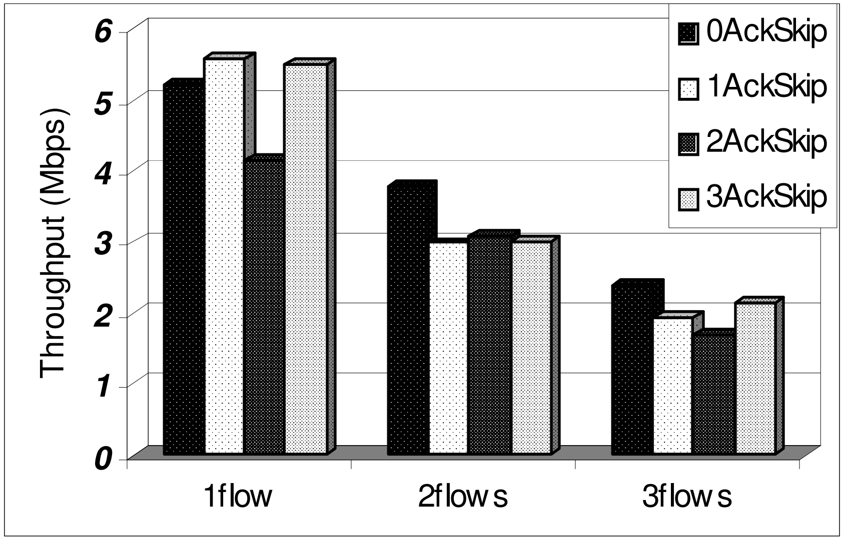
Short-lived flows

Consistent throughput gains with ACK Skipping



Long-lived flows

Results (Disabled MAC retries)

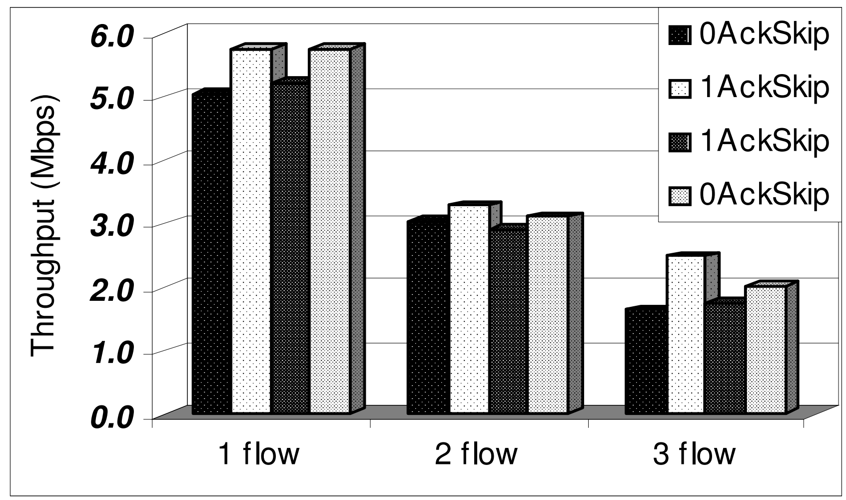


Short-lived flows

Wireless Nodes (TCP data) retry disabled

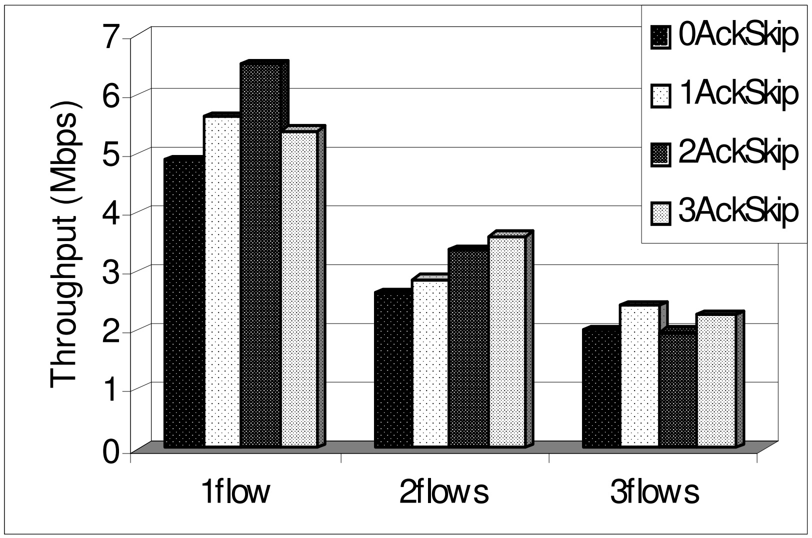
AP (TCP ACKs) retry NOT disabled

Sniffer showed TCP retx even with a single flow

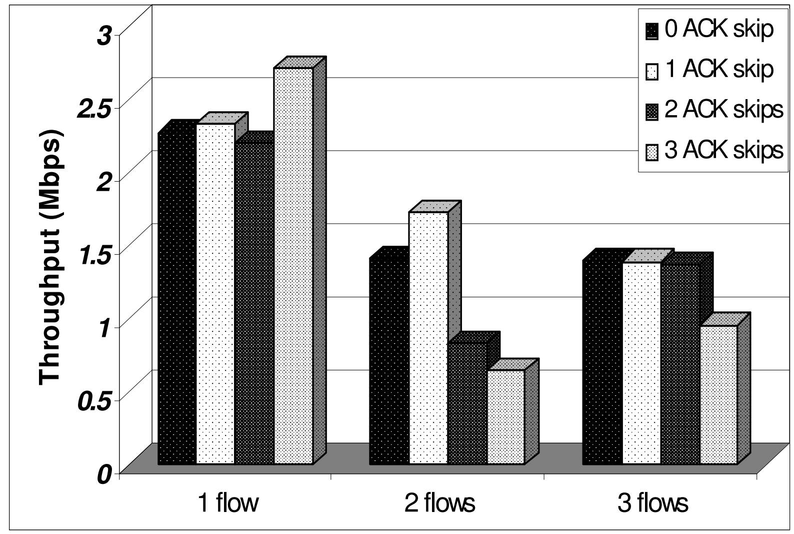


Long-lived flows

Comparing Testbed and NS results (Enabled MAC retries)



Testbed result



NS result

Testbed results:

- Much higher base throughput (4.8 vs. 2.2Mbps)
- Consistent gains with ACK skipping, although moderate.

Observations

- Testbed results confirm the TCP simultaneous-send problem
- Skipping 1 ACK consistently improves TCP throughput although for different reasons in different cases.
- Testbed results differ from NS results with respect to base throughputs and gains
- In the case with MAC retries: TCP slow start does not cause MAC queue overflows in real systems because of OS intervention.
- Status of variables hard to observe in real-time in testbed experiments; Sniffers used to observe packet flow

Conclusion

Conclusion

- Main insights:
  - Complex interaction of TCP with 802.11 MAC
  - TCP control packets interfere with transmission of data packets over 802.11 WLANs causing overall throughput degradation
  - Simple TCP adaptation of skipping alternate ACKs achieves significant gains
- NS simulations required to evaluate protocol correctness and observe status parameters in real-time
- Real-life evaluation of transport protocols essential to understand operation along with other layer protocols.
- ORBIT enables repeatability of wireless experiments
- Better instrumentation of the network stack required to observe real-time status.

Done! ☺

Questions… ?