TCP Behavior across Multihop Wireless Networks and the Wired Internet

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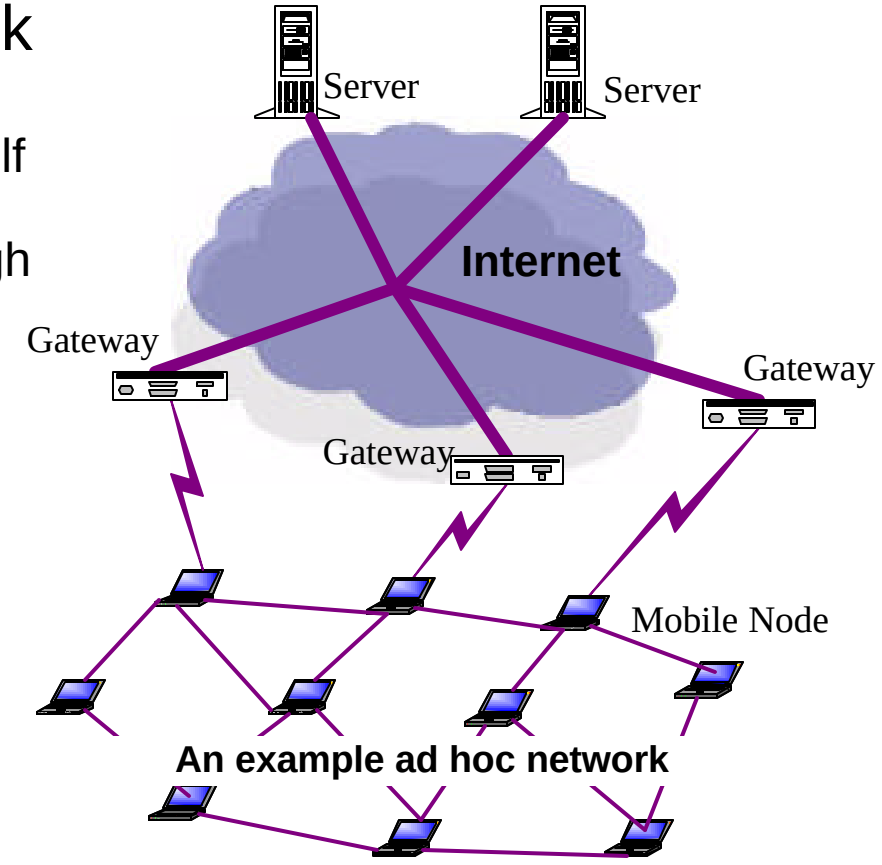
Motivation

- **Connecting ad hoc networks to the Internet**
  - Access web, download files, upload data, multimedia streaming etc.
  - TCP efficiency critical

- **New challenge:TCP performance on wired + multihop wireless path**
  - Different from “last hop” wireless networks (e.g. wireless LAN)
  - Different from “pure ad hoc” networks; the wired part introduces high propagation delays

Target Scenario

- Connecting an ad hoc network to the Internet
  - Wireless part is an independent, self managed network
  - Mobile node Internet access through multiple gateways
  - Web access, file download, multimedia streaming
- Multimedia Challenges :
  - **TCP**: Long propagation delay -> large congestion window; error vs congestion loss
  - **Video Streaming**: congestion control; friendly to TCP



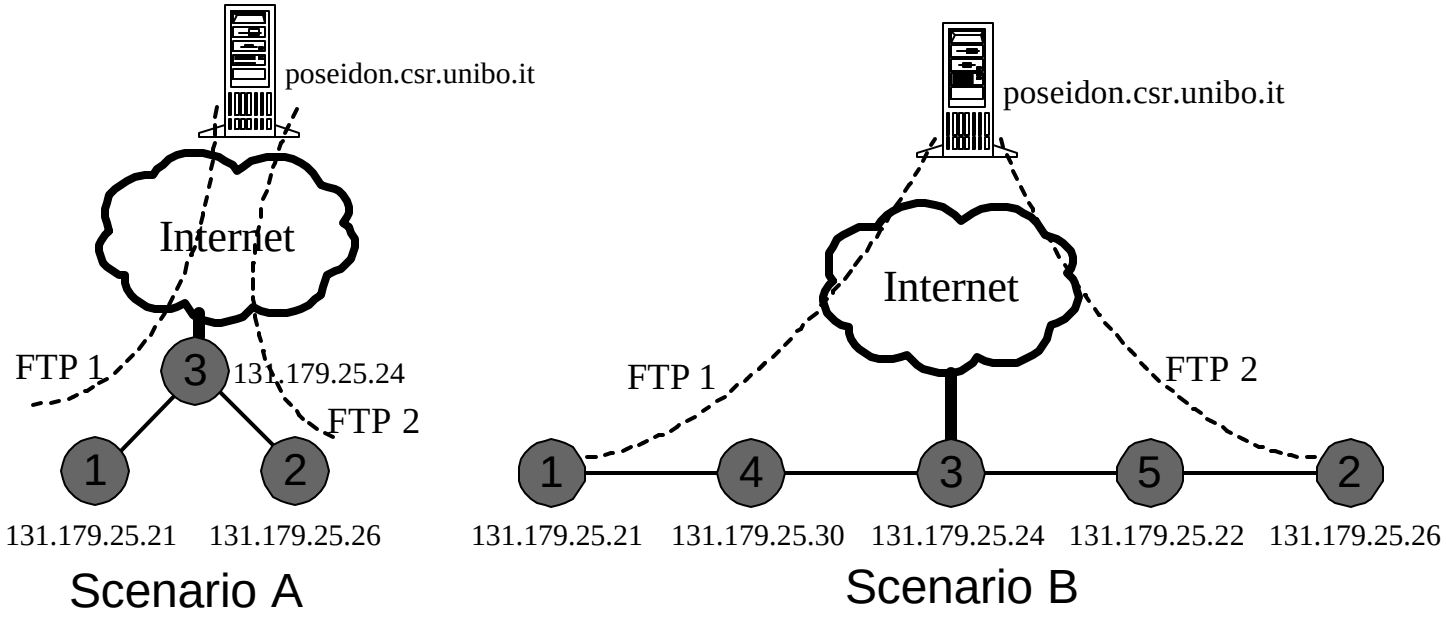
Testbed Measurements

- Testbed Configuration
  - Dell 1 GHz Pentium III Inspiron 4000 laptops
  - Lucent Orinoco 802.11 wireless card, 2M bps
  - FTP server : Located in the Internet, Running RedHat Linux 6.0
  - Wireless client : Mandrake Linux 8.1
  - TCP : TCP New Reno, MSS=1460 bytes
- Performance metrics
  - throughput; fairness

Testbed Measurements

Two Scenarios

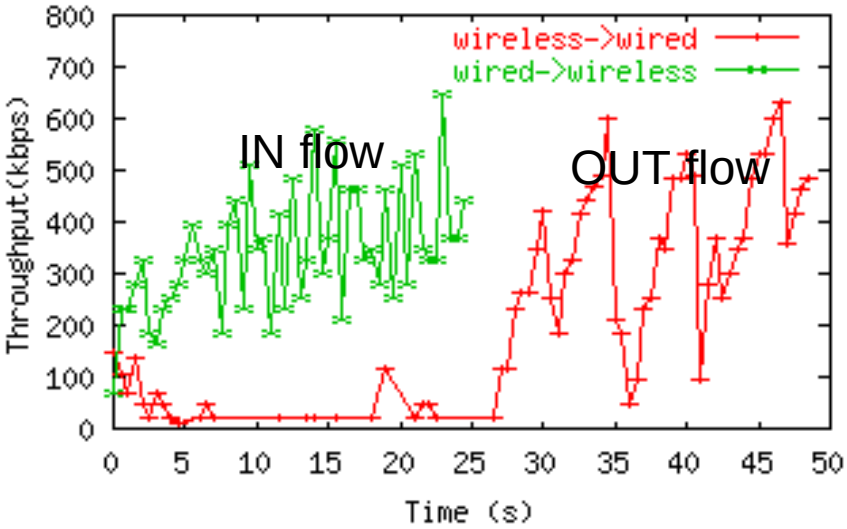
- Scenario A: “last hop” wireless network (wireless LAN)
- Scenario B: multihop ad hoc wireless network
- FTP flows in different directions are investigated
- Each FTP transmits a 1MB or 8MB file



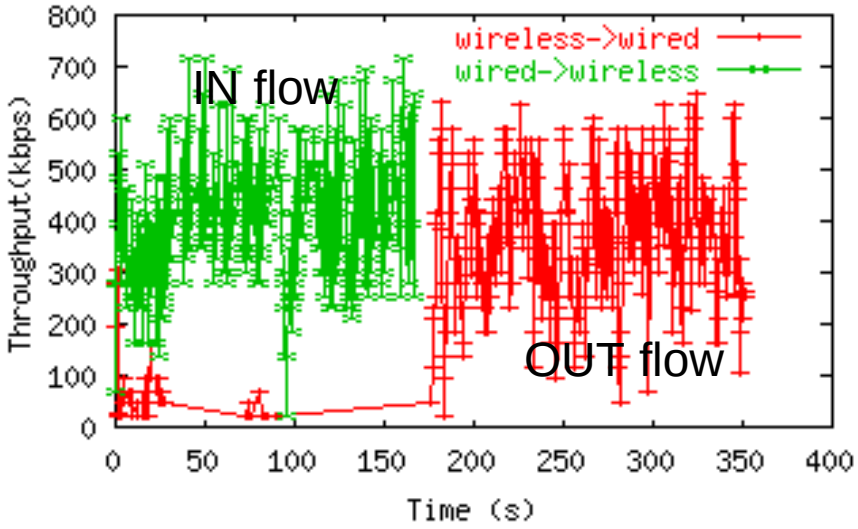
Fairness among Multiple TCP Flows

- Scenario A (W-LAN): No significant unfairness (not shown here)
- Scenario B : Significant capture/unfairness when there are OUT flows

  (OUT flow : wireless->wired, IN flow : wired->wireless)



Both flows transmit a 1M file

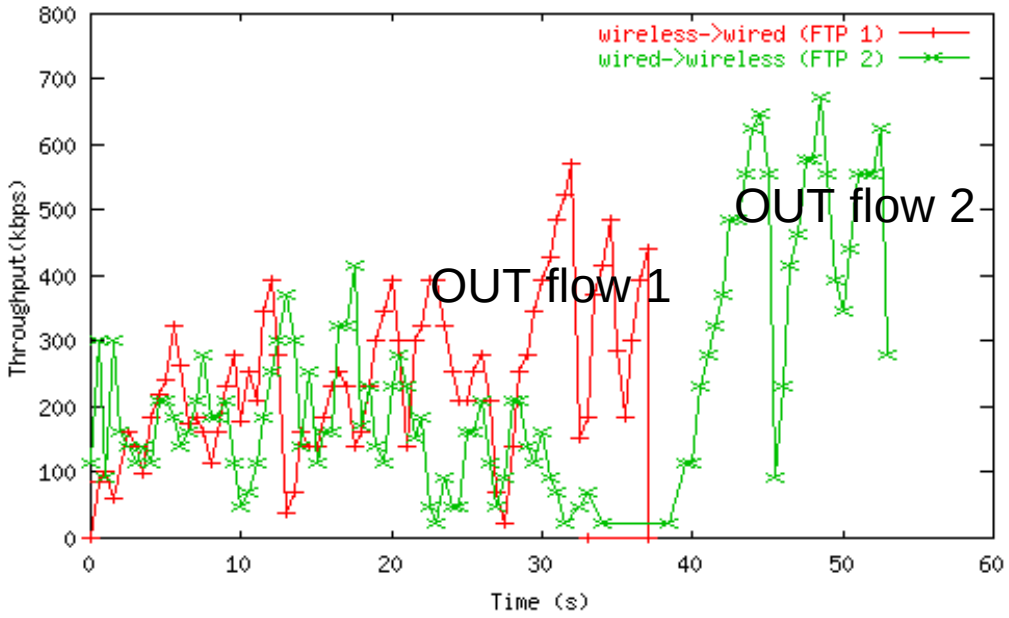


Both flows transmit a 8M file

Scenario B : Mixed flows (IN flow captures the channel; OUT flow starts after it)

Fairness (cont)

- Unfairness is observed even when there are only OUT flows (OUT flow : wireless->wired)



Both flows transmit a 1M file

Scenario B : Only OUT flows (Significant unfairness observed)

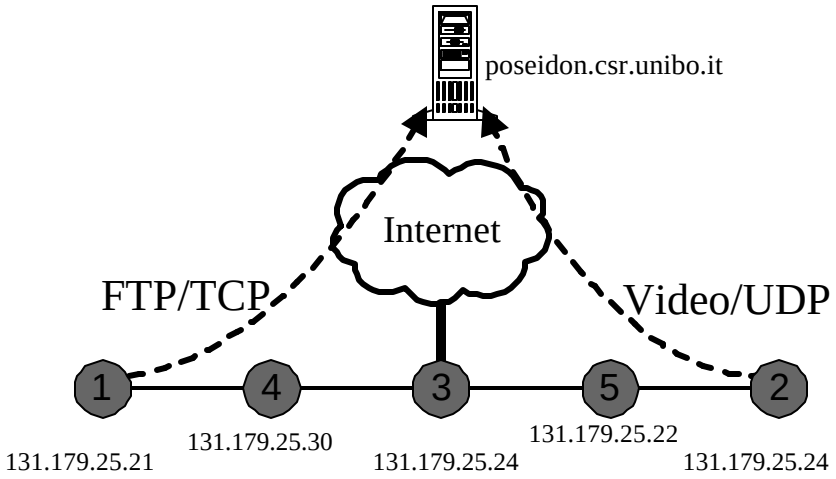
Lessons learned with TCP

TCP Unfairness:

- TCP flows from wired to wireless tend to capture the channel from flows in other direction
- Even when all TCP flows originate from wireless, they cannot share the bandwidth in a fair way
- TCP flows from wired to wireless can share the bandwidth equally

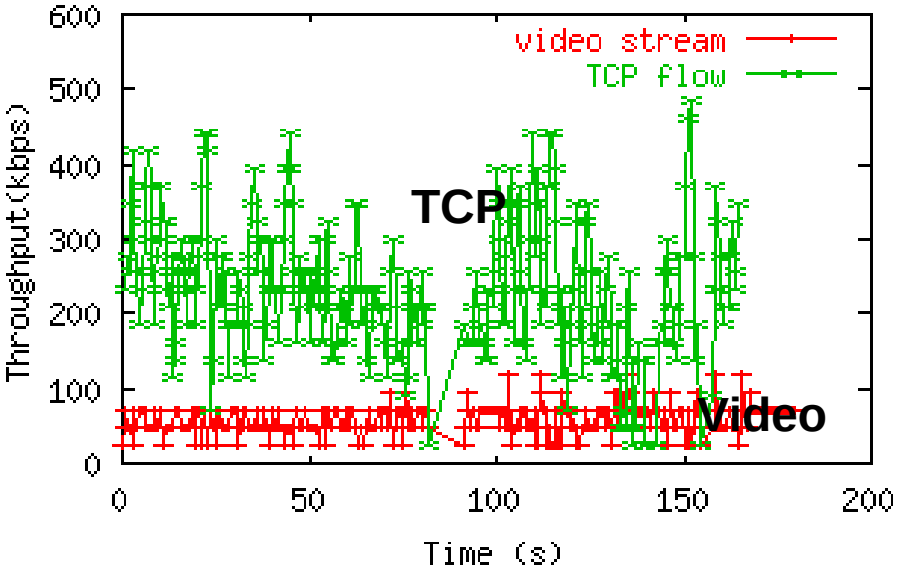
TCP Coexistence with Video Streams

- Video streams: CBR/UDP flows with various rates
- Scenario B (multihop)
- TCP flow: from node 1 to the wired server, transmitting a 8M file
- Video stream: from node 2 to the wired server
- Different rates of the video streams: from 80Kbps to 800Kbps
- Packet size: 1460 Bytes

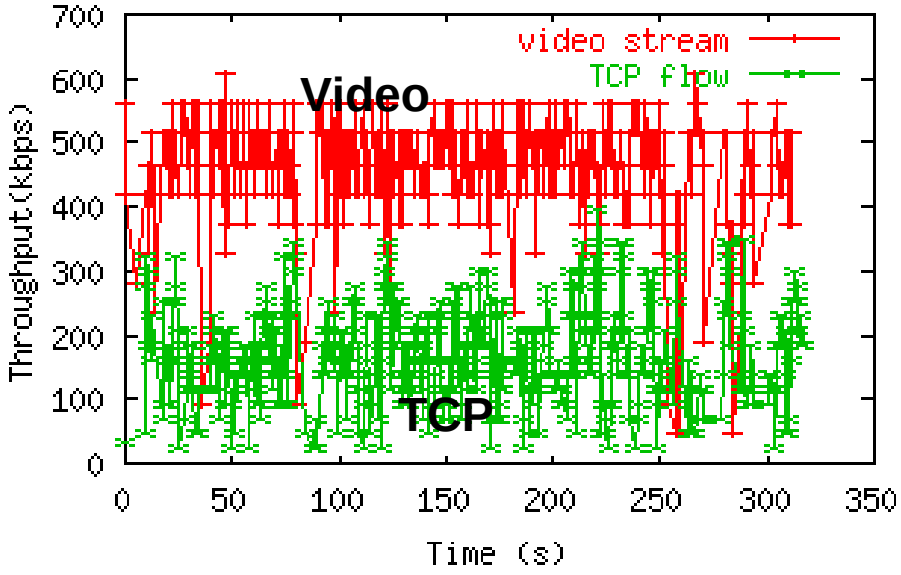


Coexistence of TCP/Video streams

- Low rate video (80Kbps) has minimal impact on TCP performance
- When the video rate increases (540Kbps), TCP throughput degrades, but no capture is observed



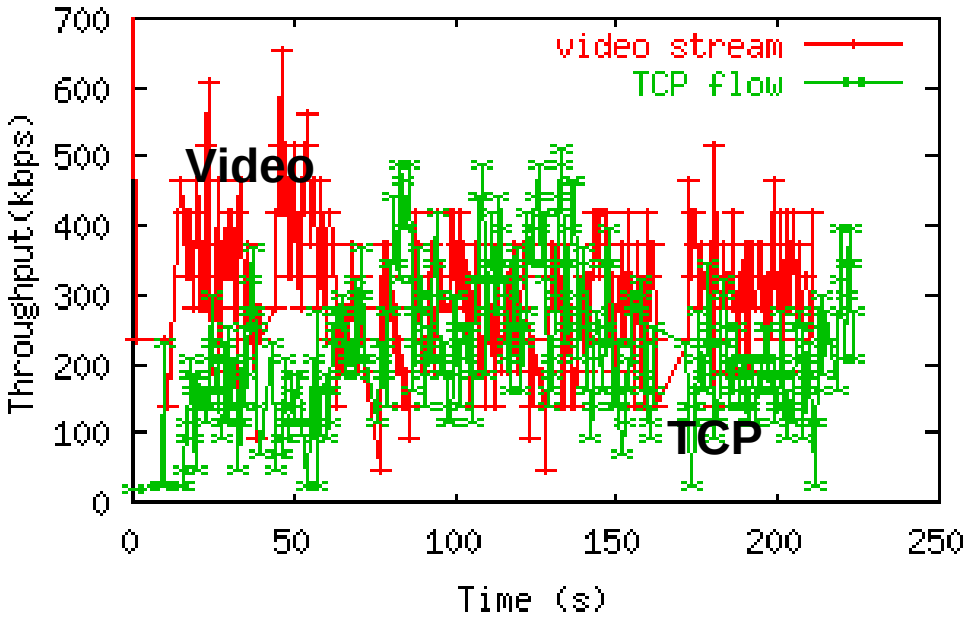
80Kbps video stream



540Kbps video stream

Coexistence of TCP/Video streams

- Surprisingly, when video rate is further increased to 800Kbps, TCP throughput gets better !
- High rate video streams block themselves at the source nodes
  - The source node and its next hop node compete for the same channel
  - High transmission rate from source blocks the next hop (heavy drops!)



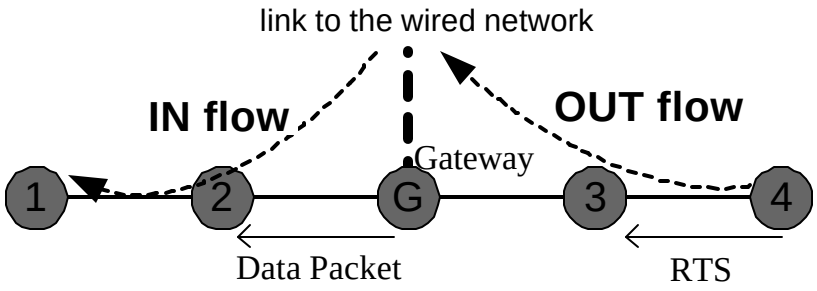
800Kbps video stream

Summary of the TCP/Video Experiments

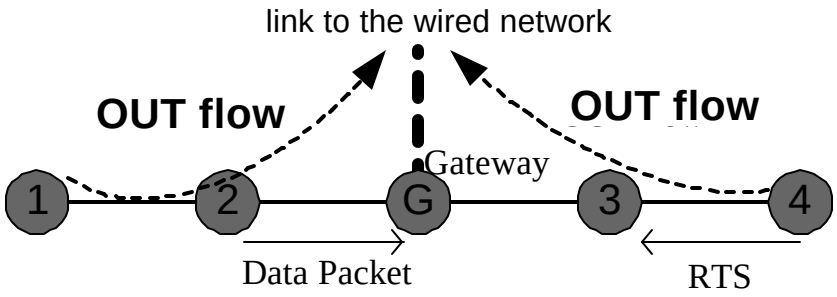
- TCP performance is affected by video streams. However, no capture problem is observed
- At high tx rate, video performs poorly due to source node and next hop interference
- For best performance, video rate must be carefully controlled in ad hoc networks (ideally, with feedback control like TCP)

Reasons of TCP Unfairness

- Hidden and Exposed Terminal Problems
- Binary Exponential Backoff (BEB) of 802.11 favors the last successful node
- TCP own timeout and backoff worsen the unfairness
- Lack of “cooperation” between TCP and MAC



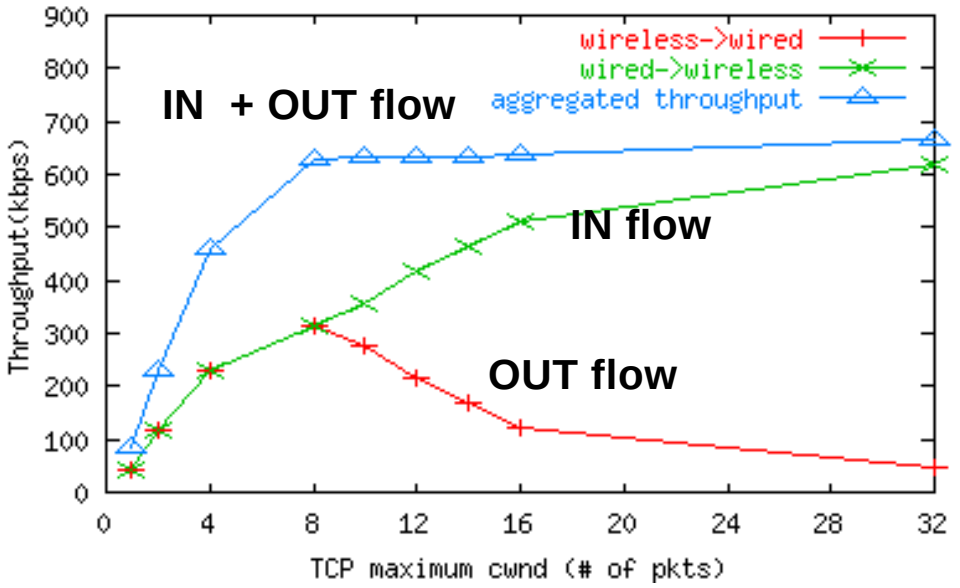
Hidden and exposed terminal problem with mixed flows



Hidden and exposed terminal problem with only OUT flows

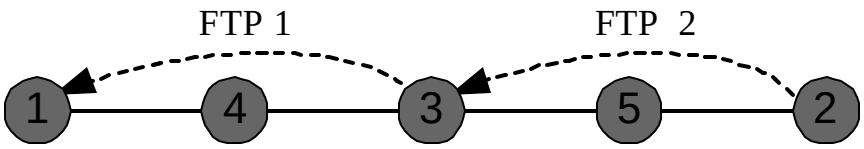
Optimal TCP Window Size

- Scenario B, IN + OUT traffic with varying **max TCP window size**
- There exists an **optimal TCP window size** (8 packet in our case): The aggregated throughput reaches upper limit; the two flows share the channel bandwidth fairly
- Unfortunately, the optimal max Window cannot be preconfigured
- And, TCP cannot independently stabilize at such optimal window => unfairness!!!

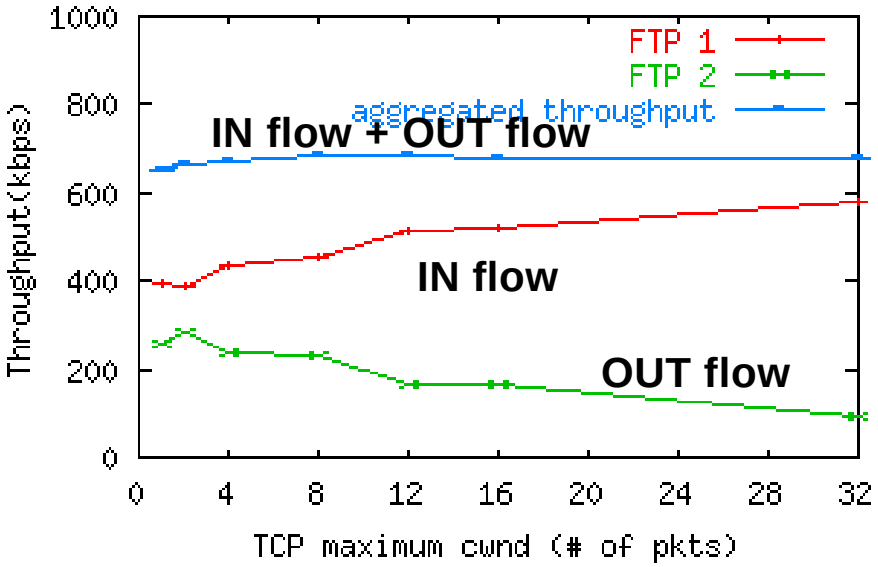


Problems Caused by Wired Part!!

- Repeat last experiment **without the wired part**
  - Can achieve reasonable fairness in a pure ad hoc network by **preconfiguring** the maximum TCP window to 1 or 2 packets (typically, performance peaks at W=2; no gain for W>2)
- Problem caused by wired part
  - Large window is needed (large RTT); cannot preconfigure W



Scenario B without wired part (mixed traffic)



Summary

- TCP across **wired/wireless networks** presents new problems (with respect to wired or wireless alone)
  - The wired part introduces long propagation delay and thus the need for large window (for efficiency)
  - TCP flows across wired/wireless experience significant capture/unfairness
  - Video streams also are vulnerable to congestion collapse
  - Fundamental causes rooted in MAC layer
  - 802.11 MAC modifications are investigated

Thank You!