

HxH: A Hop-by-Hop Transport Protocol for Multi-Hop Wireless Networks

Daniel Scofield, Lei Wang, and Daniel Zappala

Computer Science Department, Brigham Young University



Introduction

- TCP suffers from poor bandwidth utilization in multi-hop wireless networks

Multi-hop wireless networks include both mesh and ad hoc networks -- nodes have one or more WiFi interfaces, may be stationary or mobile

- Challenges: contention, hidden and exposed terminals, spatial reuse, mobility

Problems with End-to-End Transport

Improper Diagnosis of Loss

- wireless networks can lose packets due to contention, interference, congestion, and mobility
- end-to-end protocols have difficulty distinguishing which type of loss has occurred, then reacting properly
- the node that sends a frame is in the best position to determine what caused the loss

Slow Feedback Loop

- end-to-end protocols use some form of implicit or explicit signalling -- e.g. packet loss or ECN -- to control the rate
- in wireless networks, this feedback loop can become delayed or lossy, causing the transport protocol to make rate adjustments with imperfect knowledge of network conditions

Poor Response to Mobility

- route changes make it difficult to converge to the proper rate
- mobility can lead to sudden changes in available rate even without a route change
- slow feedback loop means loss or under-utilization

ACK Overhead

- channel access is a scarce resource, must be shared
- many flows are one-way; per-packet ACKs can't be piggybacked with data
- each end-to-end ACK wastes bandwidth
- can delay or aggregate ACKs, but it is hard to reduce feedback without hurting responsiveness

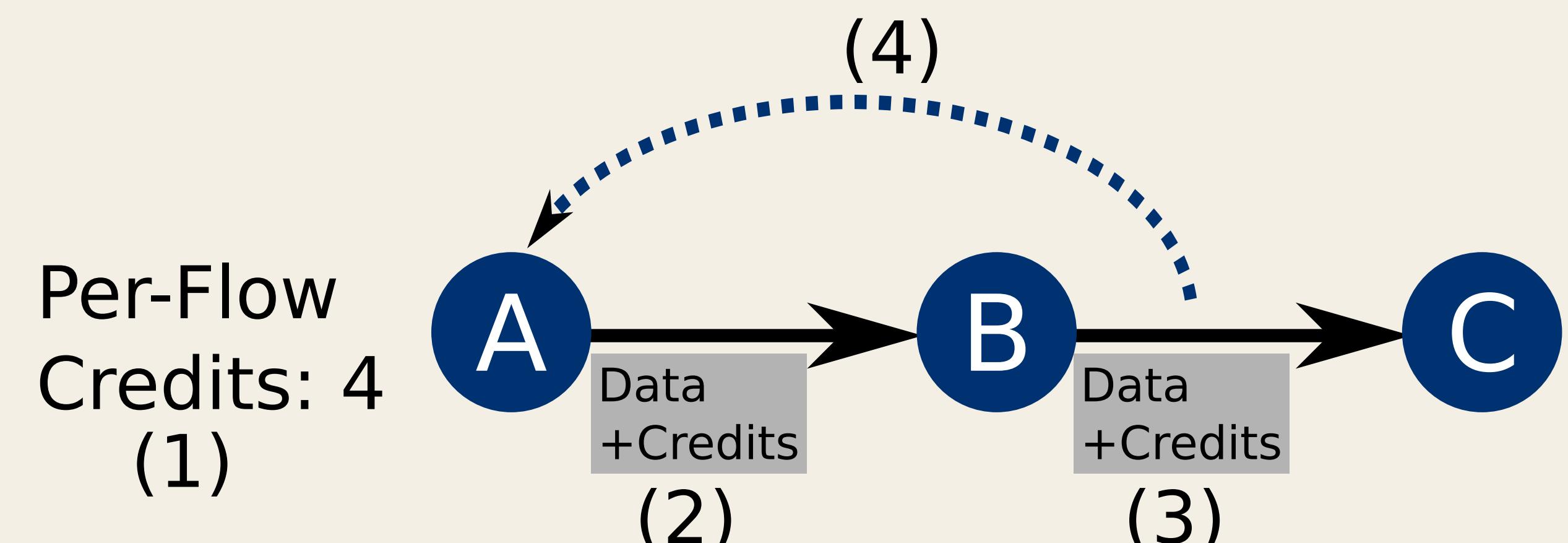
Hop-by-Hop Transport

- Each node controls the rate at which it sends to the next hop
- Intermediate nodes
 - are better positioned to diagnose the cause of packet loss
 - can have a shorter, faster feedback loop
 - are able to react more quickly to congestion and mobility
 - can help reduce the overhead of end-to-end ACKs
- Per-flow state is feasible in a wireless access network

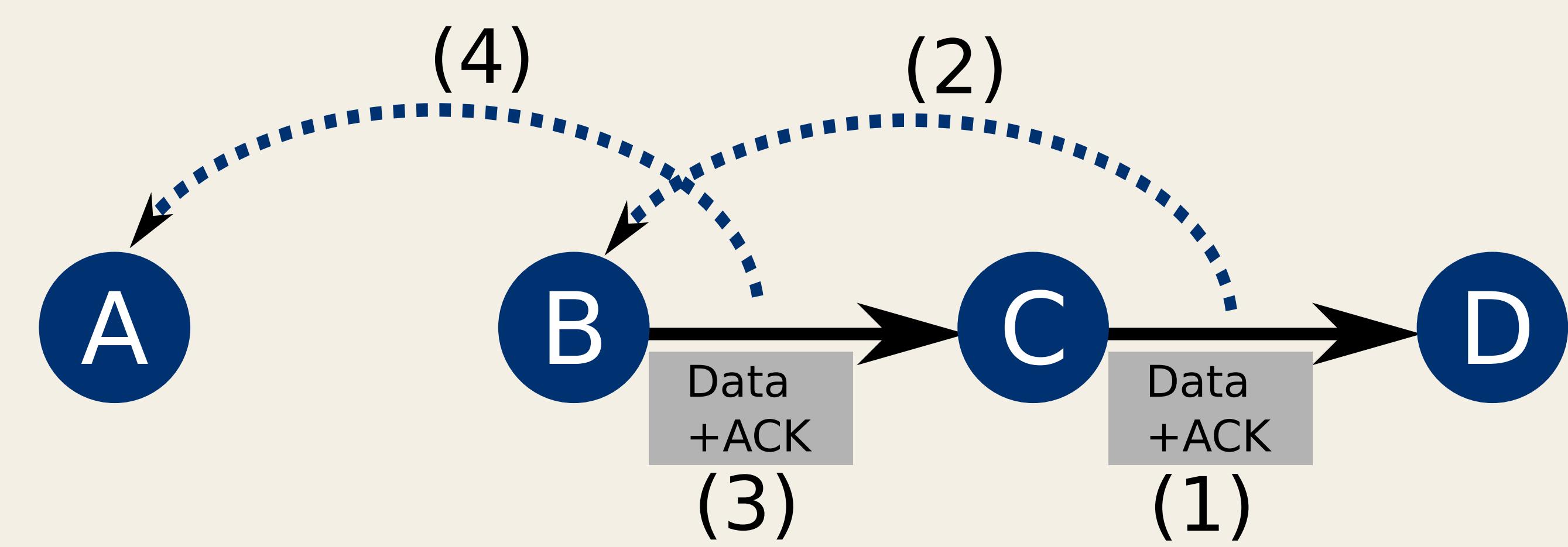
HxH Transport Protocol

- compatible with existing 802.11 MAC
- per-flow state built on-demand, deleted when unused
 - state automatically re-built whenever a route changes
 - nodes on the old route continue to transmit so packets are not lost
- per-flow packet scheduling at each node
 - fair-queueing provides fairness among flows traversing the same node
 - frames lost due to contention or interference are retransmitted locally

Credit-Based Congestion Control



Reverse ACKs



- C sends data to D, and includes the current ACK value in a shim header
- D sends data to B, and includes the current ACK value in a shim header
- B sends data to C, and includes the current ACK value in a shim header
- A overhears a frame sent by C and learns the ACK value for this flow

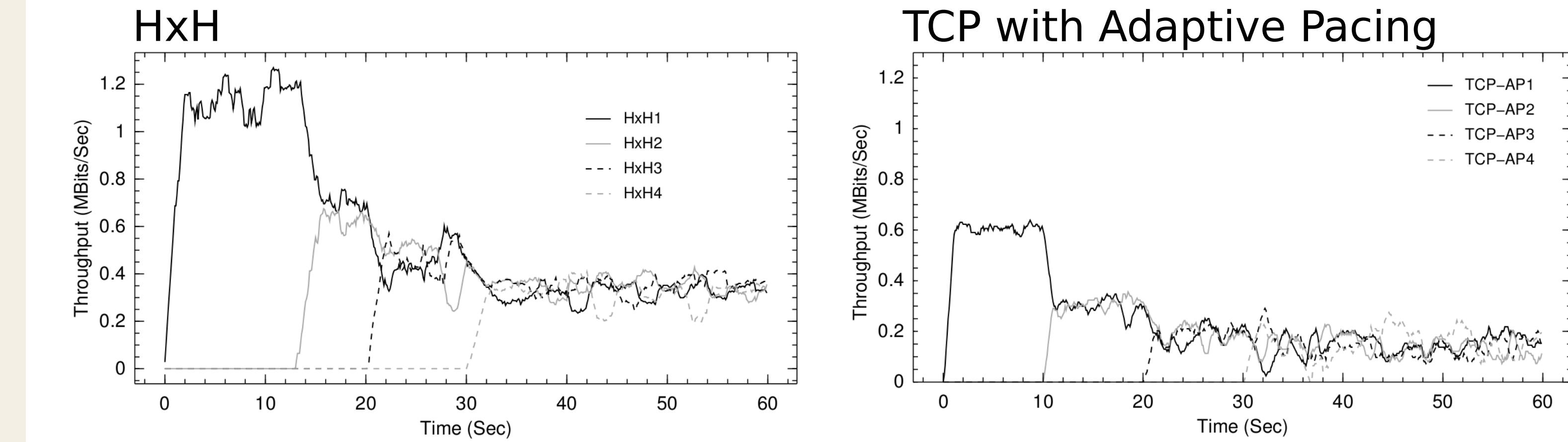
Multiple Radio Networks

- use explicit messages to pass credit and ACK values to previous hop
 - send often enough to avoid stopping the flow
 - limit the rate to avoid excessive overhead
 - remains compatible with existing 802.11 MAC
- modify the MAC to pass information to previous hop
 - send flow identifier in DATA frame
 - send flow's credit and ACK values in ACK frame

Simulation Results

Better Throughput, Excellent Fairness

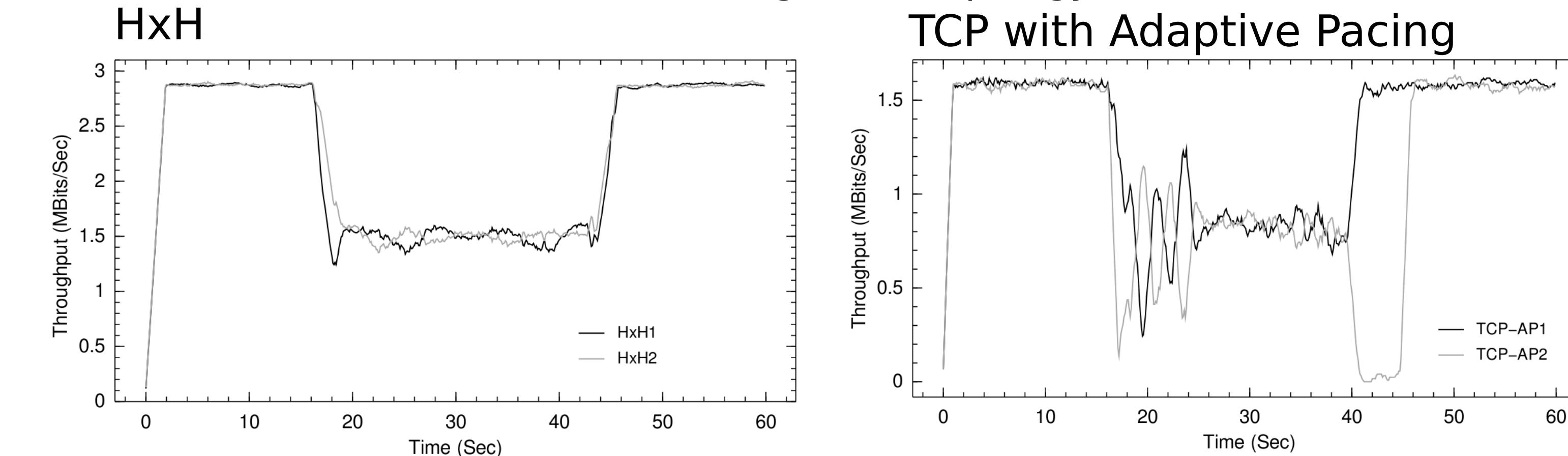
Dumbbell Topology



	HxH	TCP-AP	ATP	Vegas	NewReno
Flow 1	1.21	0.55	1.04	0.61	0.38
Flow 2	1.33	0.52	0.93	0.50	0.72
Flow 3	1.31	0.51	0.99	0.73	0.59
Flow 4	1.20	0.57	0.82	0.32	0.57
Total	5.05	2.15	3.79	2.17	2.26
Fairness	0.998	0.998	0.993	0.928	0.956

Faster Reaction to Mobility

Sudden Congestion Topology



Higher Throughput in Mesh and Ad Hoc Networks

	HxH	TCP-AP	ATP	Vegas	Reno
Mesh	14.25	6.85	11.75	7.02	6.03
AdHoc	20.07	7.69	8.02	11.16	10.67

Aggregate MB transferred in 60 seconds

Future Work

- Currently implementing HxH and conducting measurements on a wireless mesh testbed
- Comparison to other hop-by-hop approaches, including congestion pricing, rate-based control and backpressure
- Improved fairness in a mesh network, by adapting Neighborhood Red
- Transparency to TCP
- Combined wired and wireless paths