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

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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 scare 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

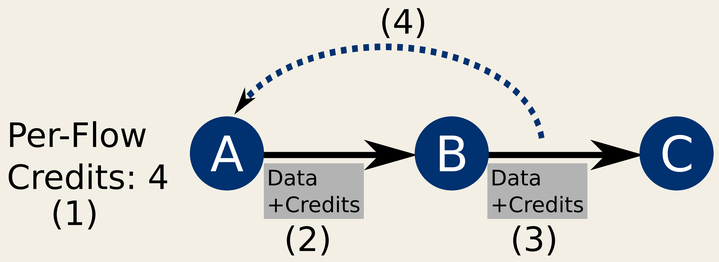
Hop-by-Hop Transport

- 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

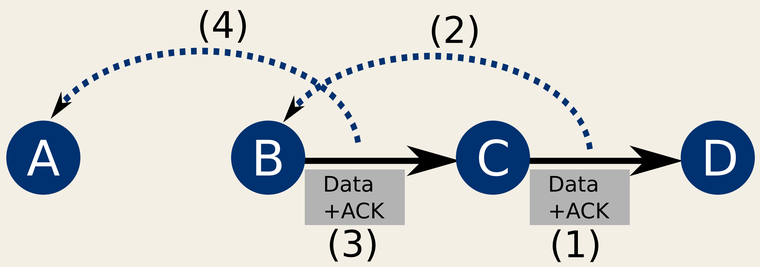
- compatible with existing 802.11 MAC
- per-flow state built on-demand, deleted when unused
  - state automatically re-built whenever a route changes
  - nodes on the old route continue to transmit so packets are not lost
- per-flow packet scheduling at each node
  - fair-queueing provides fairness among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

Credit-Based Congestion Control



(1) A initializes the pool of credits
(2) A sends data to B and decrements the available credits for the flow
(3) B sends data to C, and includes the available credits in a shim header
(4) A overhears a frame sent by B and synchronizes the available credits for the flow, using the shim header

Reverse ACKs



(1) C sends data to D, and includes the current ACK value in a shim header
(2) B overhears a frame sent by C and learns the ACK value for this flow
(3) B sends data to C, and includes the current ACK value in a shim header
(4) A overhears a frame sent by B and learns the ACK value for this flow

Multiple Radio Networks

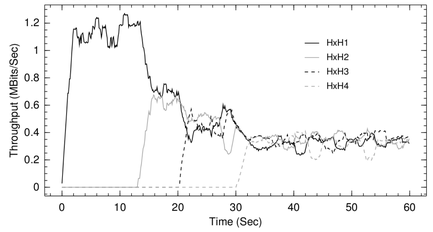
- use explicit messages to pass credit and ACK values to previous hop
  - send often enough to avoid stopping the flow
  - limit the rate to avoid excessive overhead
  - remains compatible with existing 802.11 MAC
- modify the MAC to pass information to previous hop
  - send flow identifier in DATA frame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

Simulation Results

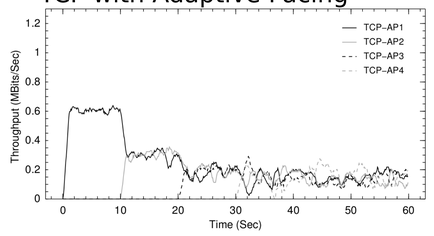
Better Throughput, Excellent Fairness

Dumbbell Topology

HxH



TCP with Adaptive Pacing

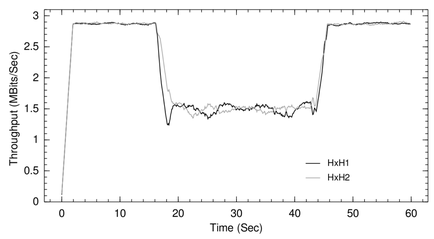


	HxH	TCP-AP	ATP	Vegas	NewReno
Flow 1	1.21	0.55	1.04	0.61	0.38
Flow 2	1.33	0.52	0.93	0.50	0.72
Flow 3	1.31	0.51	0.99	0.73	0.59
Flow 4	1.20	0.57	0.82	0.32	0.57
Total	5.05	2.15	3.79	2.17	2.26
Fairness	0.998	0.998	0.993	0.928	0.956

Faster Reaction to Mobility

Sudden Congestion Topology

HxH



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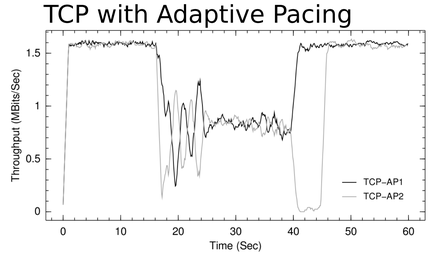

Higher Throughput in Mesh and Ad Hoc Networks

	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