Starvation Mitigation Through Multi-Channel Coordination in CSMA Multi-hop Wireless Networks

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Jingpu Shi
Theodoros Salonidis
Edward Knightly

Rice Networks Group
ECE, Rice University

Simulation in single-channel multi-hop CSMA networks

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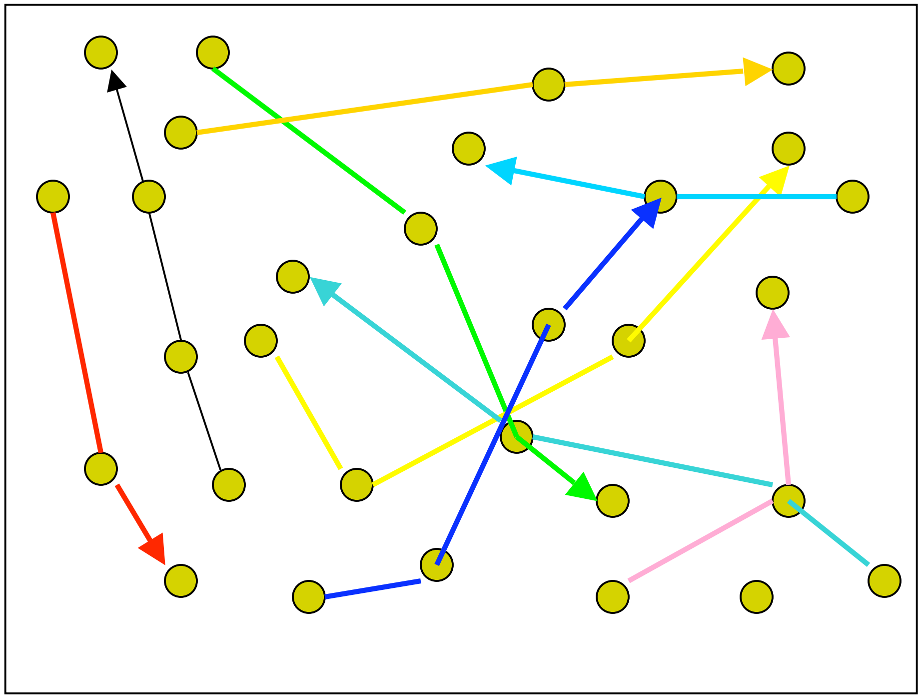

IEEE 802.11 networks, Ns 2, 50 nodes, 10 flows, 1m/s, 1000x1000m UDP load: 30 pkts/s

Starvation in single-channel multi-hop CSMA networks

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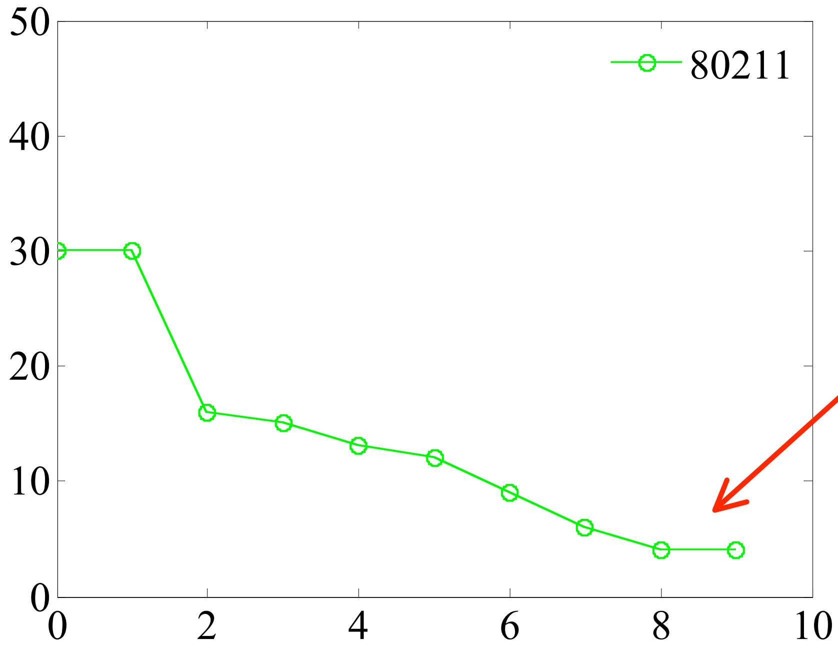

"starve"

- Imbalanced throughput distribution in CSMA networks.

Using multi-channels to solve starvation

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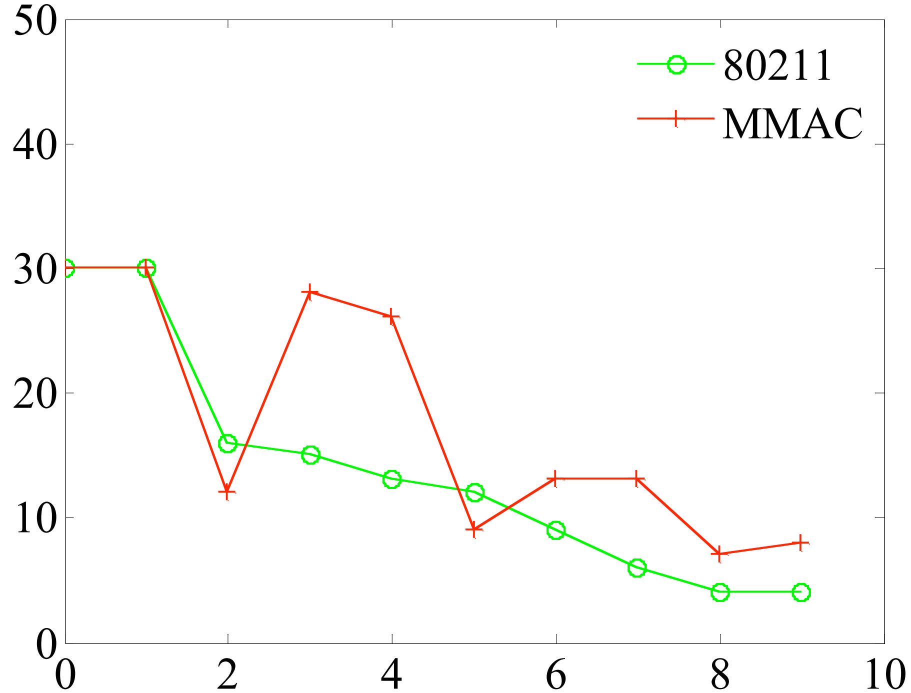
- Solved with sufficient number of channels and radios, and global information.
- In practice, resources are limited, global information is not available.
- Some multi-channel protocols can efficiently increase aggregate throughout, given practical constraints.

Multi-channel MAC (MMAC)

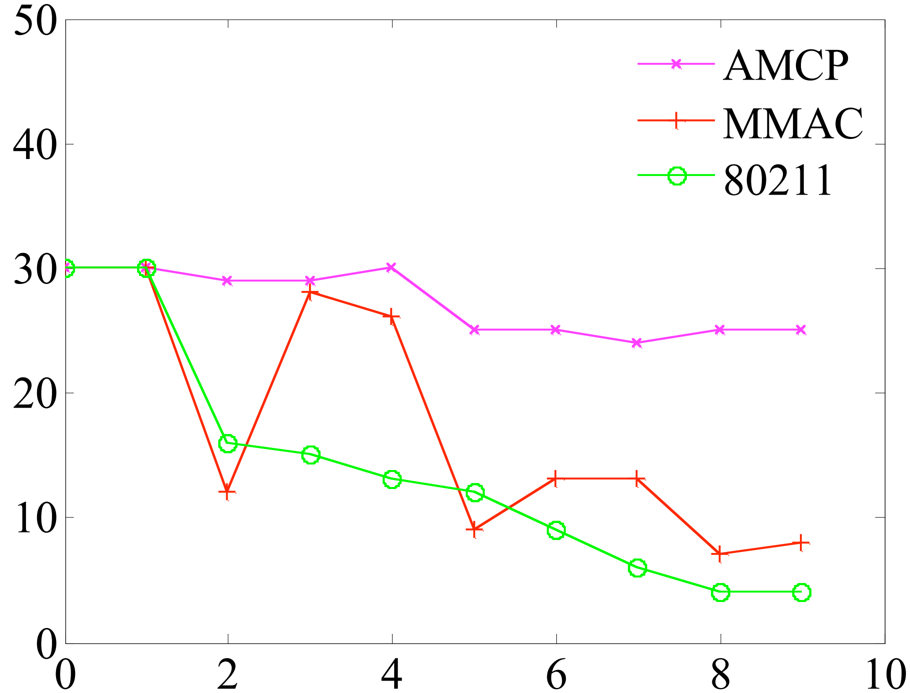
J. So and N. Vaidya. Multi-Channel MAC for Ad Hoc Networks: Handling Multi-Channel Hidden Terminals Using A Single Transceiver . In Proc. ACM MobiHoc, Tokyo, Japan, May 2004.

Using multi-channels to solve starvation, multi-hop flows



- Multi-channel protocols do not necessarily address starvation.

Performance of our protocol



- Other protocols increase aggregate throughput.
- Our protocol significantly improves ***per-flow throughput.***

Our assumptions (system model)

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- Single radio, multiple channels.
  - Can only listen to or transmit on one channel.
  - Can only receive, or transmit, but not both.
- Channels are completely orthogonal.
- Multi-hop CSMA networks.

Challenges in solving starvation in multi-hop network

- Single channel starvation problem
  - Several transmissions can occur on one channel, thus inherit single-channel starvation problems.
- Multi-channel coordination problem
  - Separate transmissions to reduce interference.
  - Coordinate their transmission.
  - How to achieve these two goals.

Single-channel problems: asymmetric channel state

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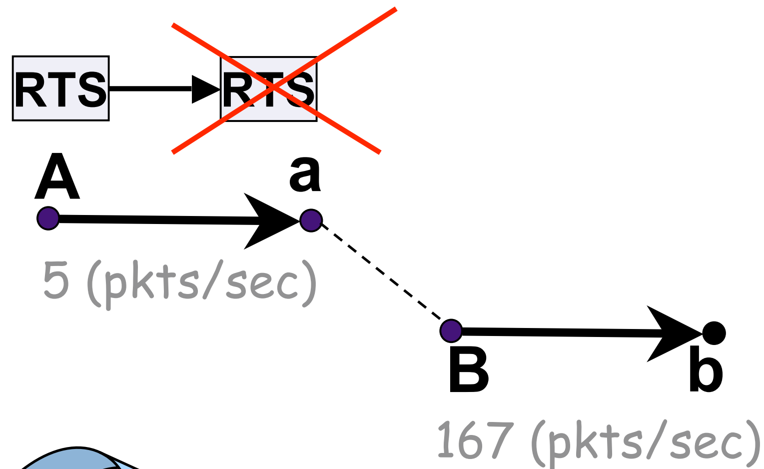
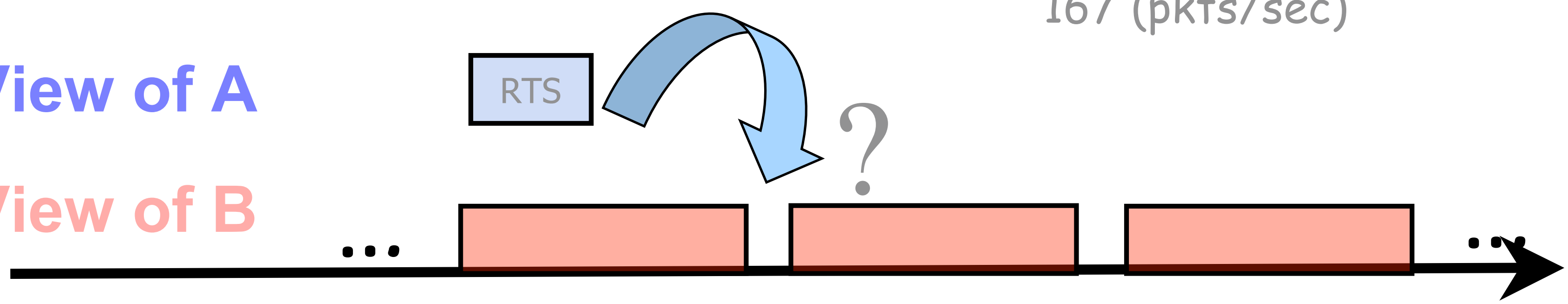
- Starvation due to asymmetric view of channel state.

Example



View of A

View of B



Long data packets make the interval even smaller.

Single-channel problems: uncoordinated transmissions

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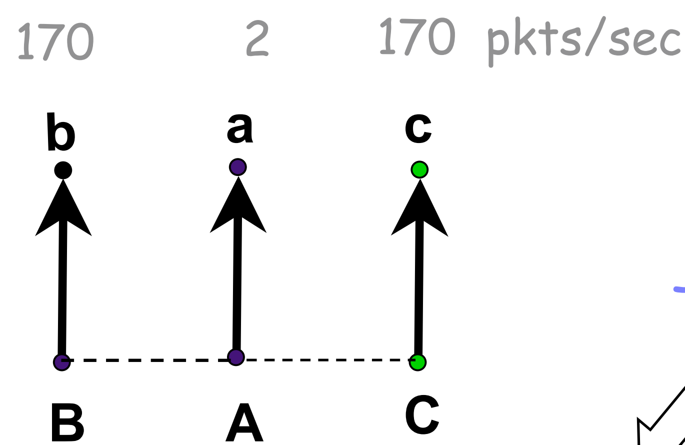
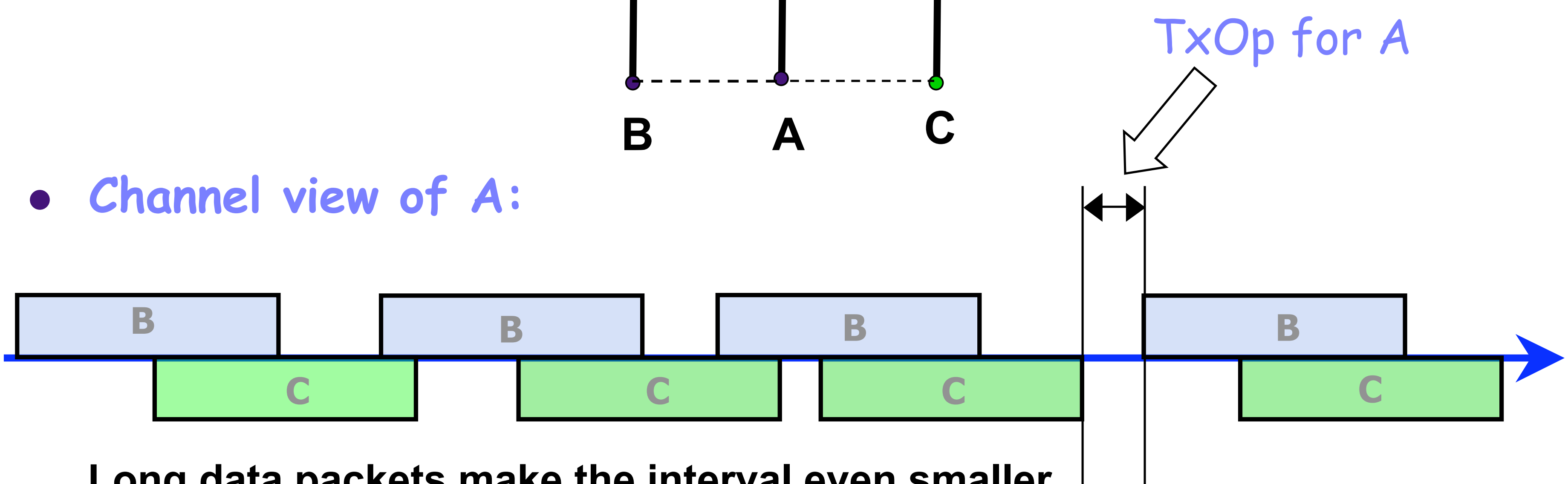
- Starvation due to uncoordinated transmissions.

Example



- *Channel view of A:*



Long data packets make the interval even smaller.

Multi-channel coordination: missed channel reservation

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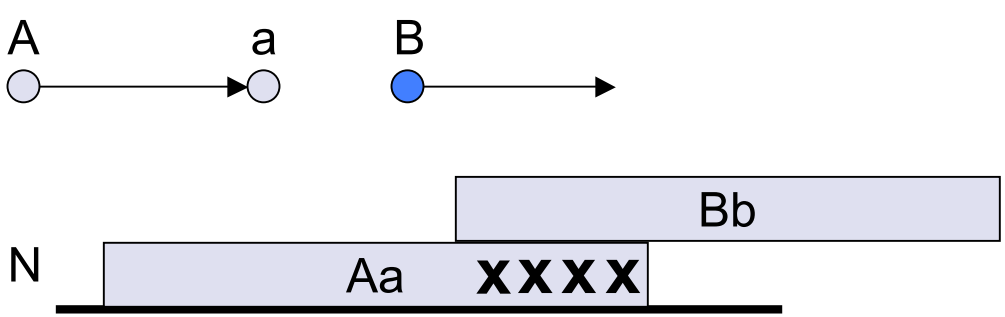
- Channel reservation of one flow may not heard by its neighbors on different channel.

Example

Channel N



(First identified by *Junmin So etc, Mobihoc 04*)

Multi-channel coordination: receiver on different channel

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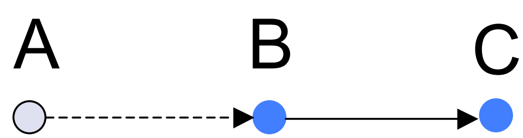
- Receiver is missing (on a different channel)

Example



- Hard to synchronize channel hopping schedule.

Challenges in solving all the problems

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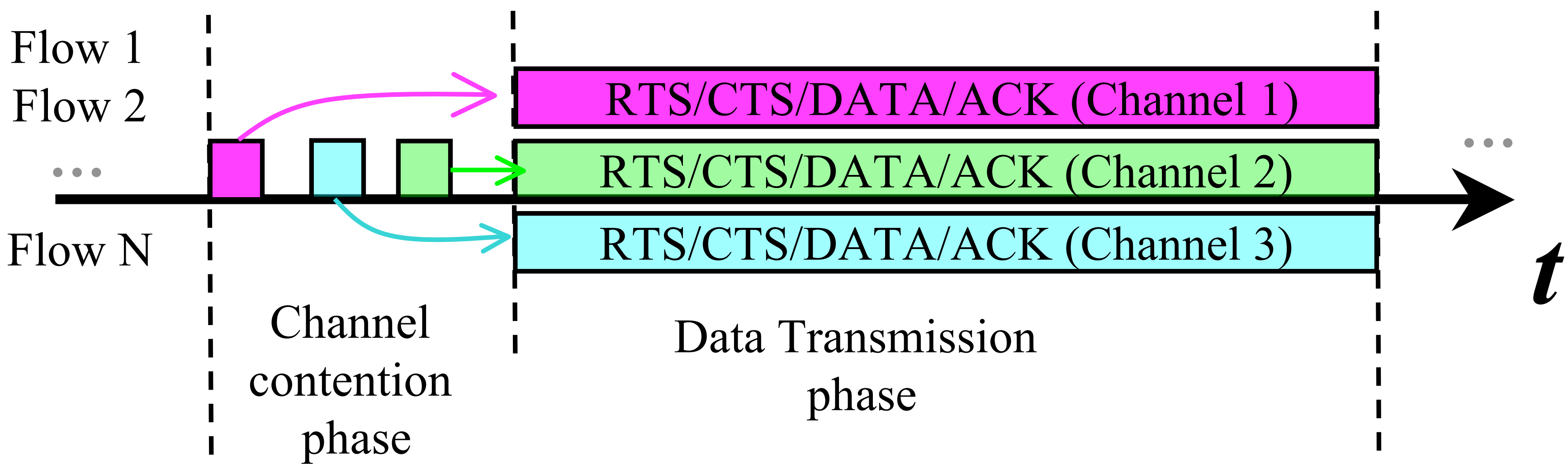
MMAC (Junmin So, Mobihoc 2004)

Common time reference, infrastructure supported



Problems

1) Duration of negotiation phase
2) Receiver missing
3) Single channel starvation problems

AMCP (Asynchronous Multi-channel Coordination Protocol) general description

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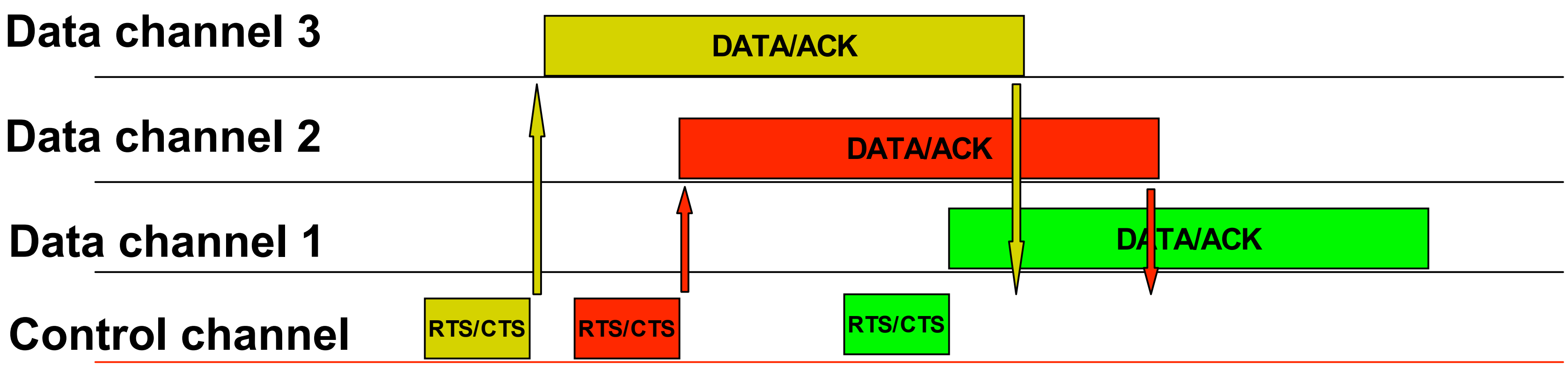
- Asynchronous
- One common control channel, multiple data channels.
  - Separate control exchange from data transmission.
  - Provide a common frequency reference for nodes.



AMCP principle 1

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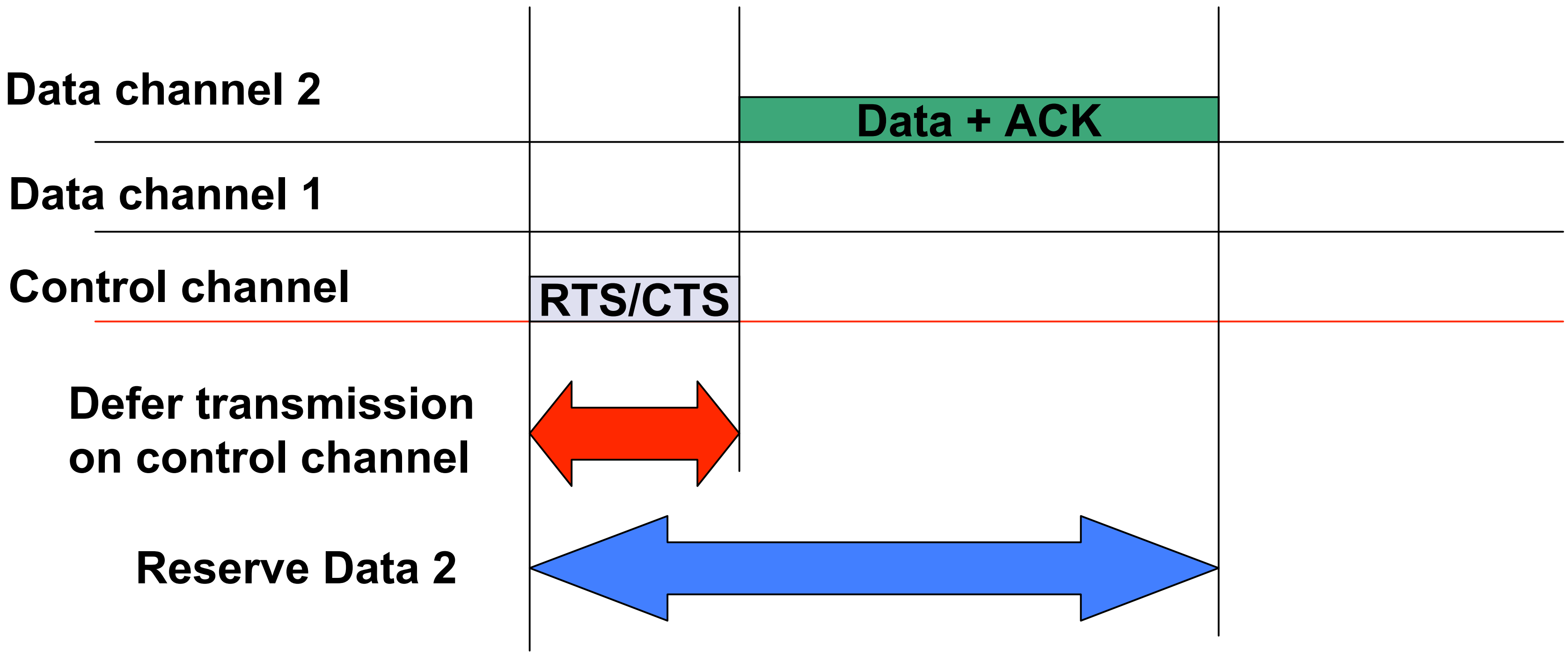
- Reserve common channel and data channel differently.
  - Improve efficiency, avoid collision on data channels.



AMCP principle 2

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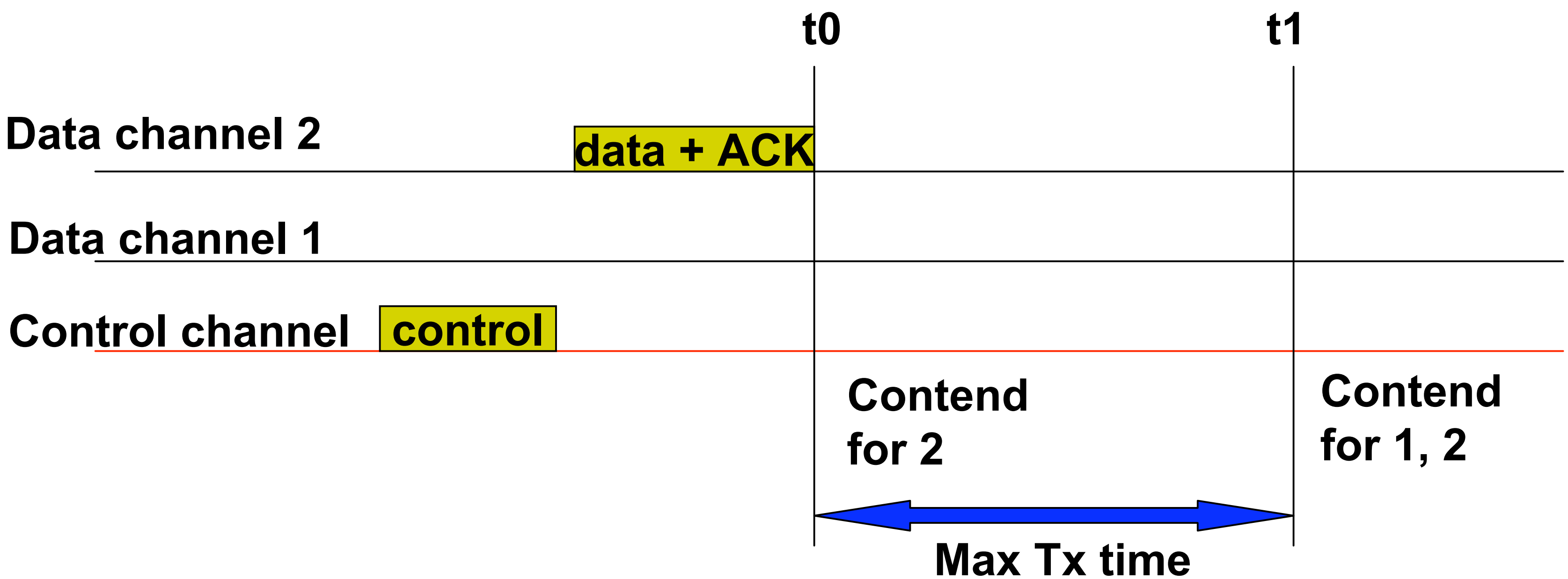

- Only contend for channels clear of traffic

AMCP principle 3

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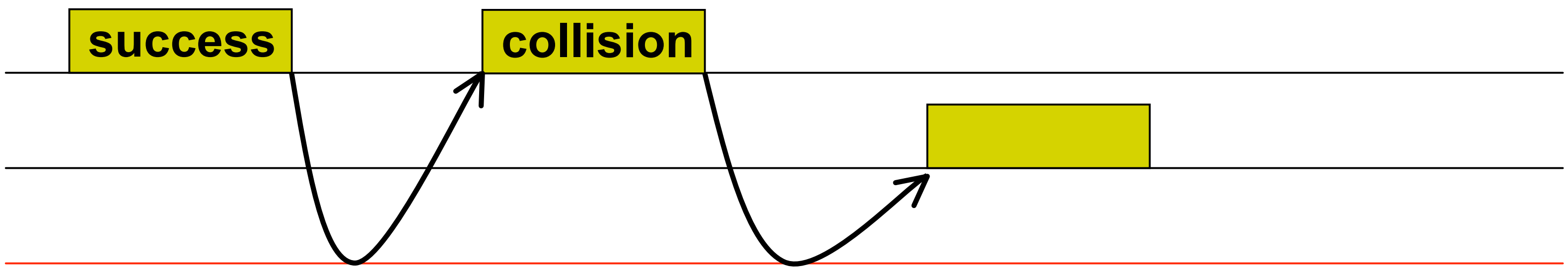

- Self-learning channel hopping
  - Stick to the channel given successful transmission
  - Contend for a different channel given collision

Lower throughput bound analysis step 1

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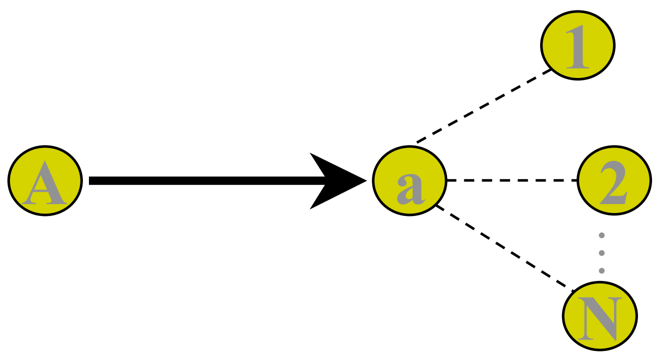
- Construct a worst-case low throughput scenario with N interferers: A cannot sense the activity of the interferers



Lower throughput bound analysis step 2

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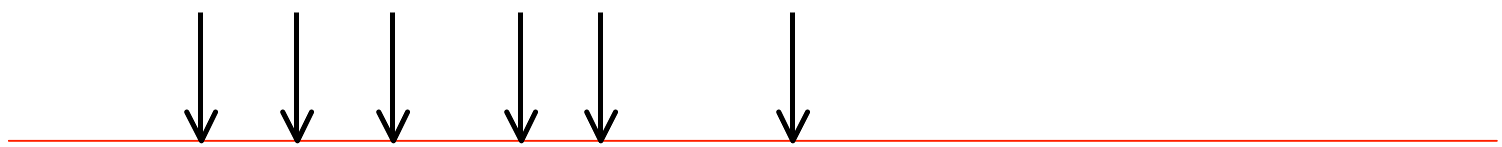
- Assume aggregate transmission attempt distribution is poisson.



- Compute conditional collision probability perceived by this flow.

$$p = 1 - e^{-\frac{2T_{RTS} + T_{CTS}}{T_{RTS} + T_{CTS} + T_{DATA}} N}$$

Lower throughput bound analysis step 3

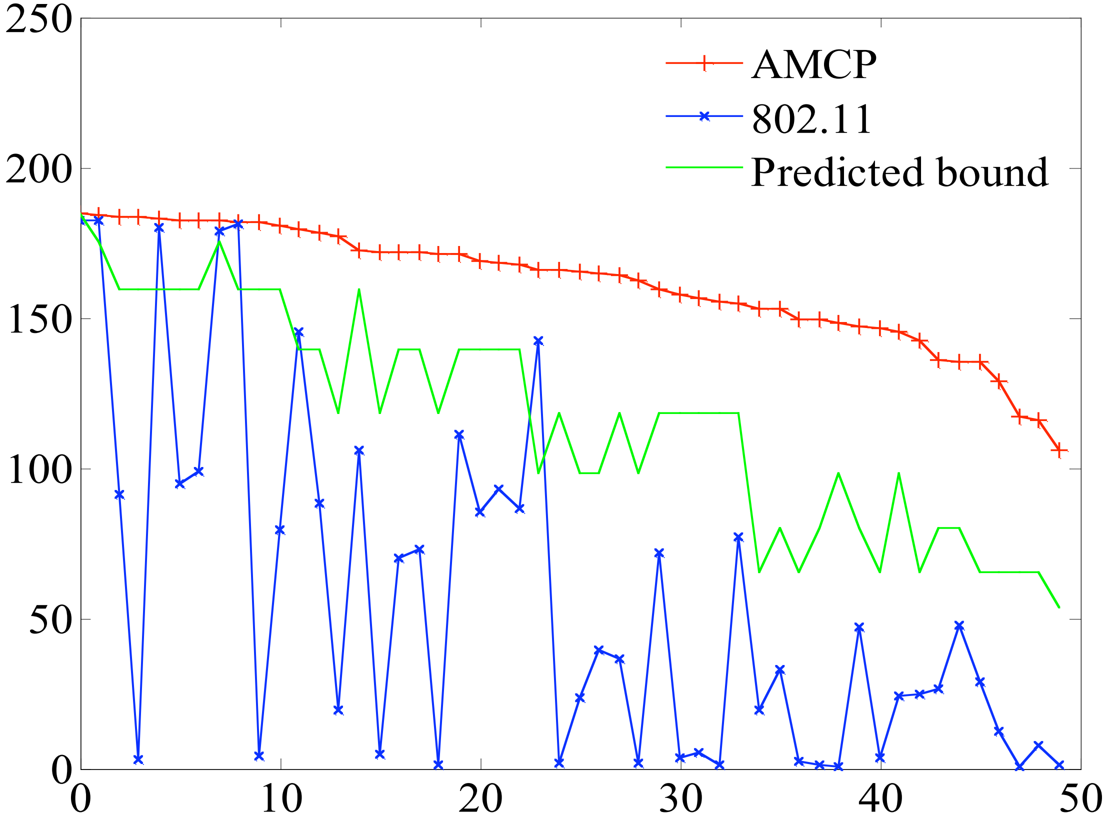
- Use our single-channel CSMA analytical model to compute the (minimum) throughput of this flow.

M. Garetto, J. Shi, and E. Knightly. Modeling Media Access in Embedded Two-Flow Topologies of Multi-hop Wireless Networks. In Proc. ACM MobiCom, Cologne, Germany, August 2005.

$$T_P(A) = \frac{[1-\tau(B)]x}{\tau(B)\bar{T}_s + [1-\tau(B)](1-x)\sigma + [1-\tau(B)]x\bar{T}_b}$$

Protocol Analysis (Arbitrary topology, single-hop flows)

12 data channels, 100 nodes, 50 one-hop flows 1000mx1000m area



Flows starve with 80211

Lower bound is much higher than 802.11

AMCP throughput higher than lower bound

Protocol Analysis (Arbitrary topology, single-hop flows)

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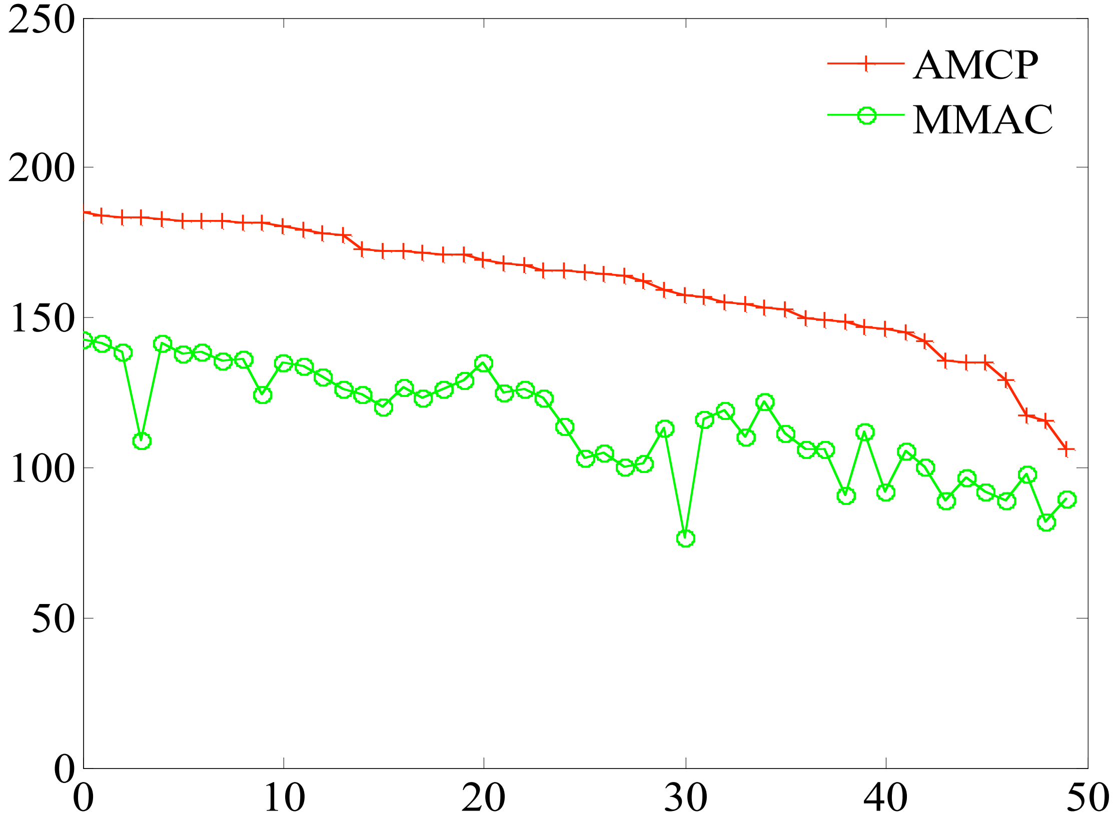
12 data channels, 100 nodes, 50 single-hop flows, 1000mx1000m area



AMCP achieves higher throughput than MMAC

Protocol Analysis (multi-hop flows with mobility)

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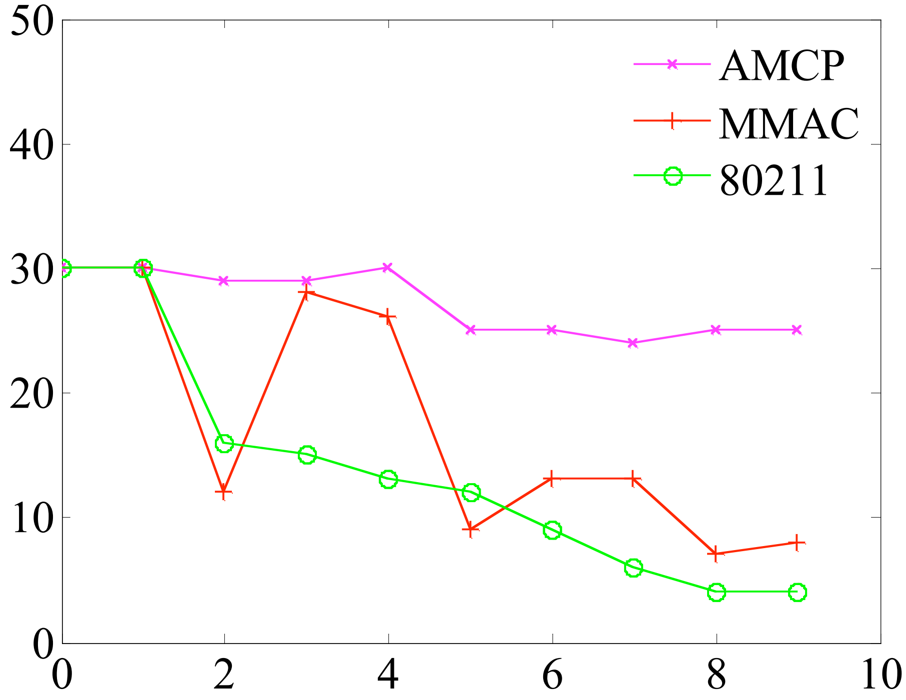
50 nodes, 10 flows, 1m/s, UDP traffic: 30 pkts/s



AMCP outperforms 802.11 and MMAC

Summary of contributions

- Addressed both single-channel starvation and multi-channel coordination problems.
- AMCP significantly increases per-flow throughput.
- Derived approximate lower-bound.
- All these are achieved with single radio, without global synchronization.

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Thank you !

Channel switching overhead

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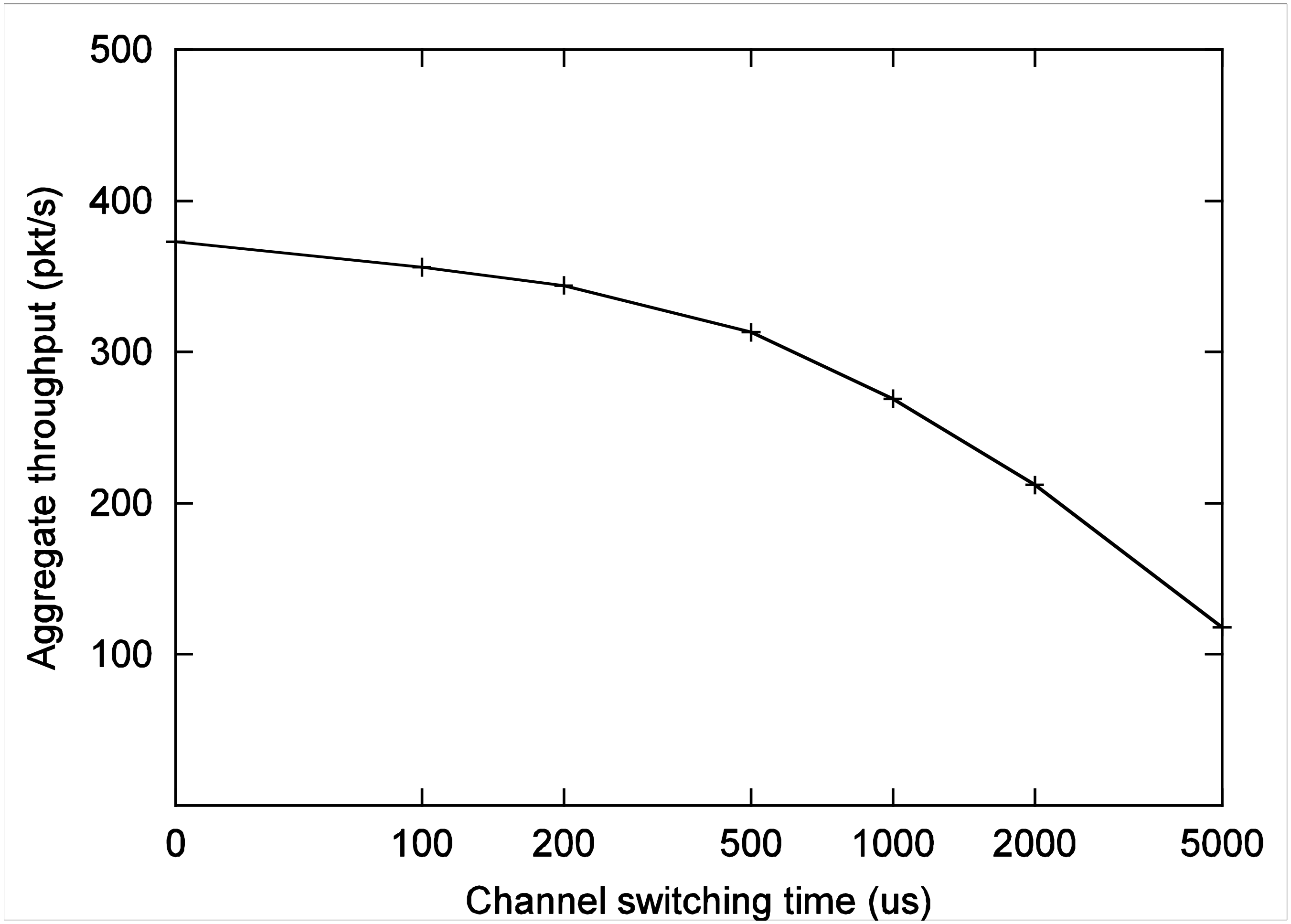

Protocol Analysis (Multi-hop flows, download scenario)

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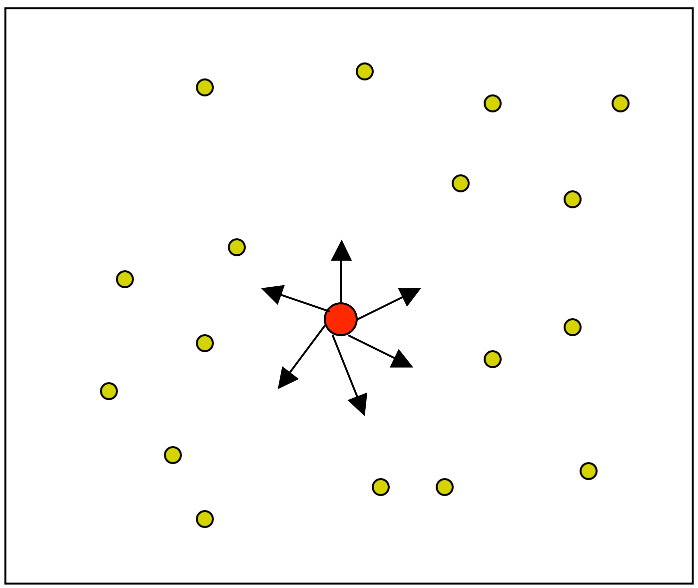
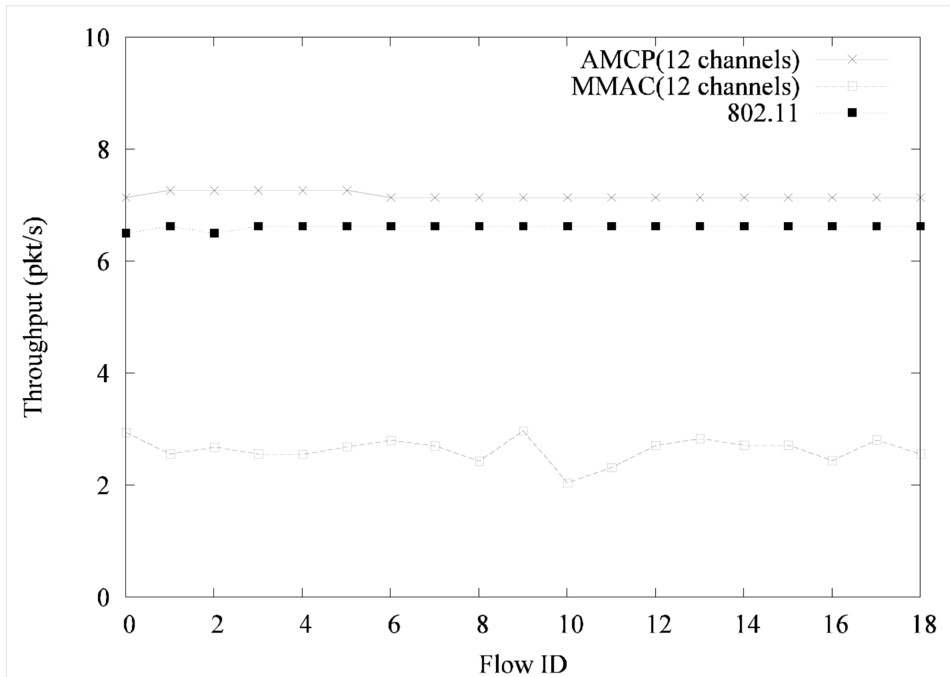
20 nodes, 19 flows, download traffic from the root





Protocol Analysis (starvation scenarios)

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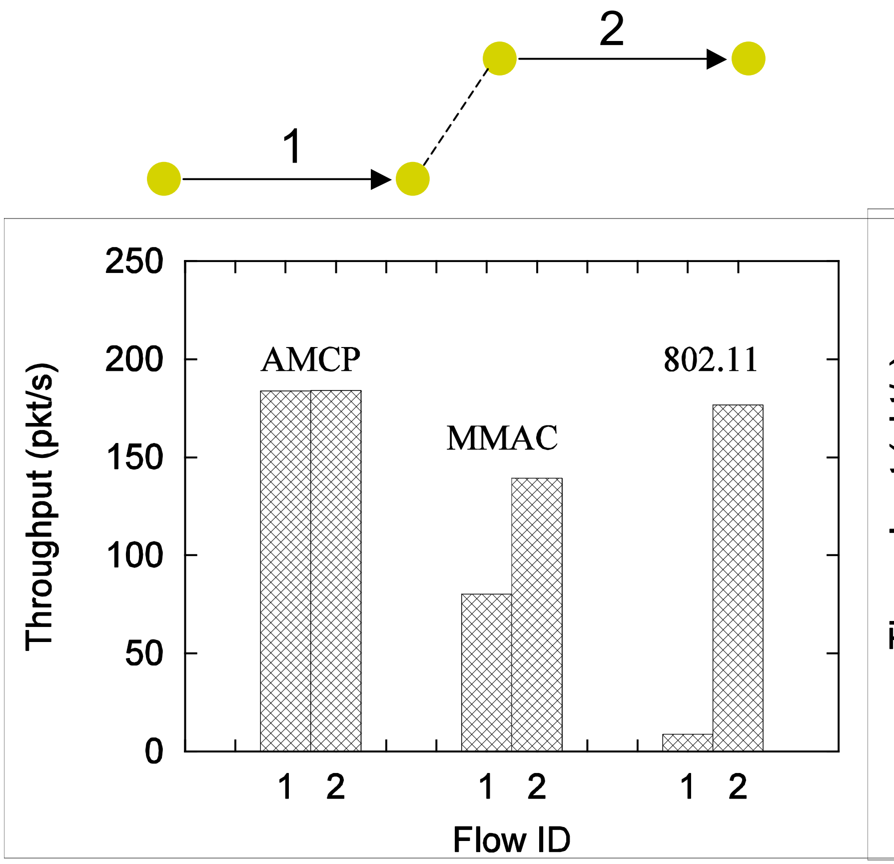
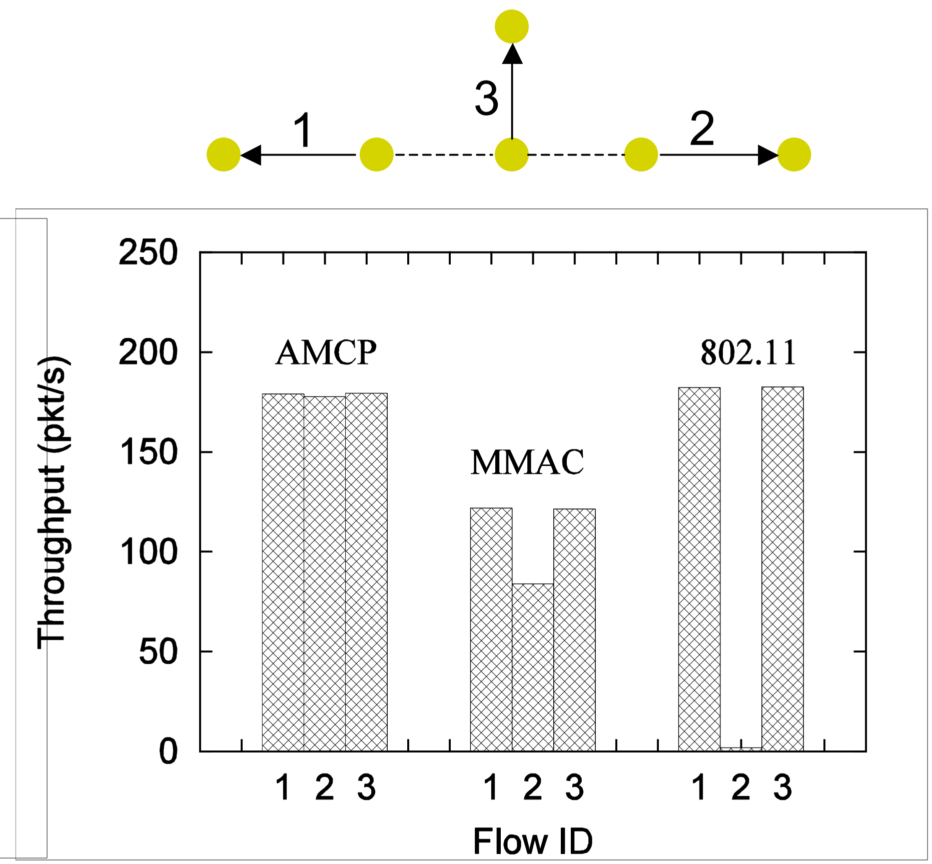
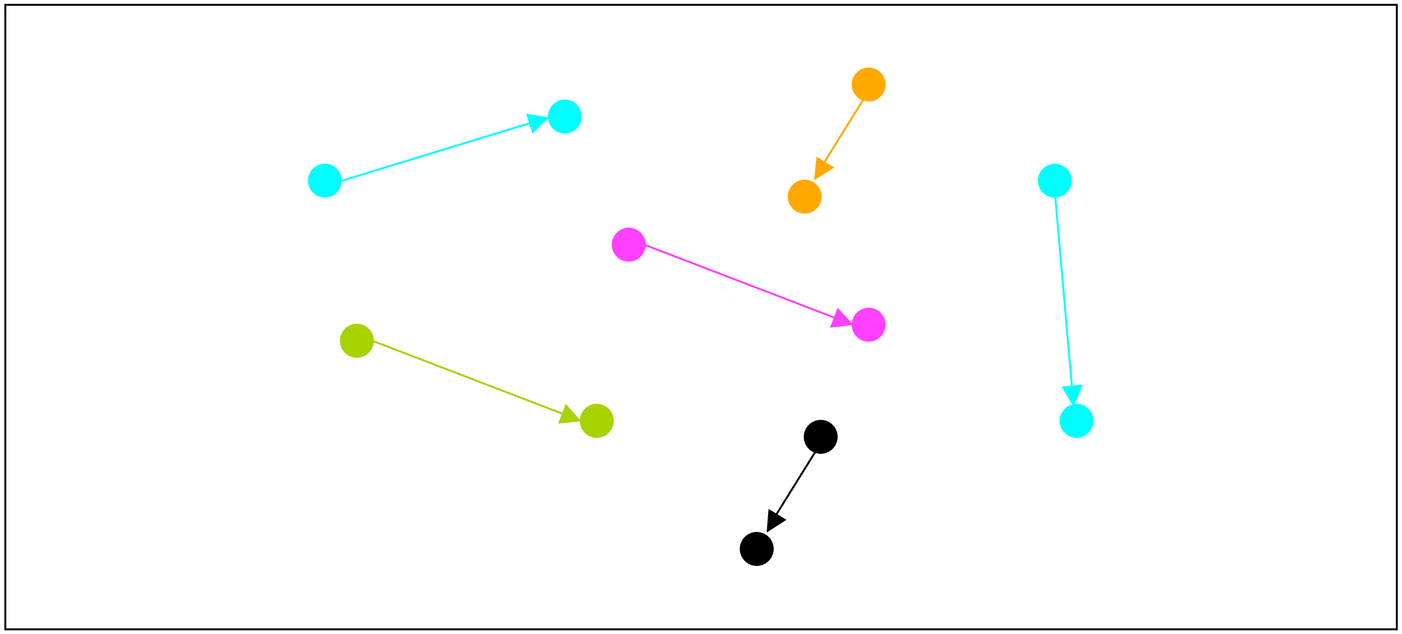




Two data channels, one control channel

50 flows topology



Inefficiency due to channel switching constraints

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Some packets may be stuck in the queue due to in capabilities of swift channel switching

Example