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

Jingpu Shi
Theodoros Salonidis
Edward Knightly

Rice Networks Group
ECE, Rice University
Simulation in single-channel multi-hop CSMA networks

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

- Imbalanced throughput distribution in CSMA networks.
Using multi-channels to solve starvation

- 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)

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)

- 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

- 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

- Starvation due to uncoordinated transmissions.

Example

Channel view of A:

Long data packets make the interval even smaller.
Multi-channel coordination: missed channel reservation

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

Example

(First identified by Junmin So etc, Mobihoc 04)
Multi-channel coordination: receiver on different channel

- Receiver is missing (on a different channel)

**Example**

- Hard to synchronize channel hopping schedule.
Challenges in solving all the problems

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

- Asynchronous
- One common control channel, multiple data channels.
  - Separate control exchange from data transmission.
  - Provide a common frequency reference for nodes.
AMCP principle 1

- Reserve common channel and data channel differently.
- Improve efficiency, avoid collision on data channels.
AMCP principle 2

- Only contend for channels clear of traffic
AMCP principle 3

- Self-learning channel hopping
  - Stick to the channel given successful transmission
  - Contend for a different channel given collision
Lower throughput bound analysis
step 1

- Construct a worst-case low throughput scenario with $N$ interferers: A cannot sense the activity of the interferers
Lower throughput bound analysis
step 2

- 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.

\[ T_P(A) = \frac{[1 - \tau(B)]x}{\tau(B)T_e + [1 - \tau(B)](1 - x)\sigma + [1 - \tau(B)]xT_b} \]

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)

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

AMCP achieves higher throughput than MMAC
Protocol Analysis
(multi-hop flows with mobility)

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.
Thank you!
Channel switching overhead

![Graph showing the relationship between aggregate throughput (pkt/s) and channel switching time (us). The curve indicates a decrease in throughput as channel switching time increases.]
Protocol Analysis (Multi-hop flows, download scenario)

20 nodes, 19 flows, download traffic from the root
Protocol Analysis (starvation scenarios)

Two data channels, one control channel
50 flows topology
Inefficiency due to channel switching constraints

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

Example