Revealing the problems with 802.11 medium access control protocol in multi-hop wireless ad hoc networks

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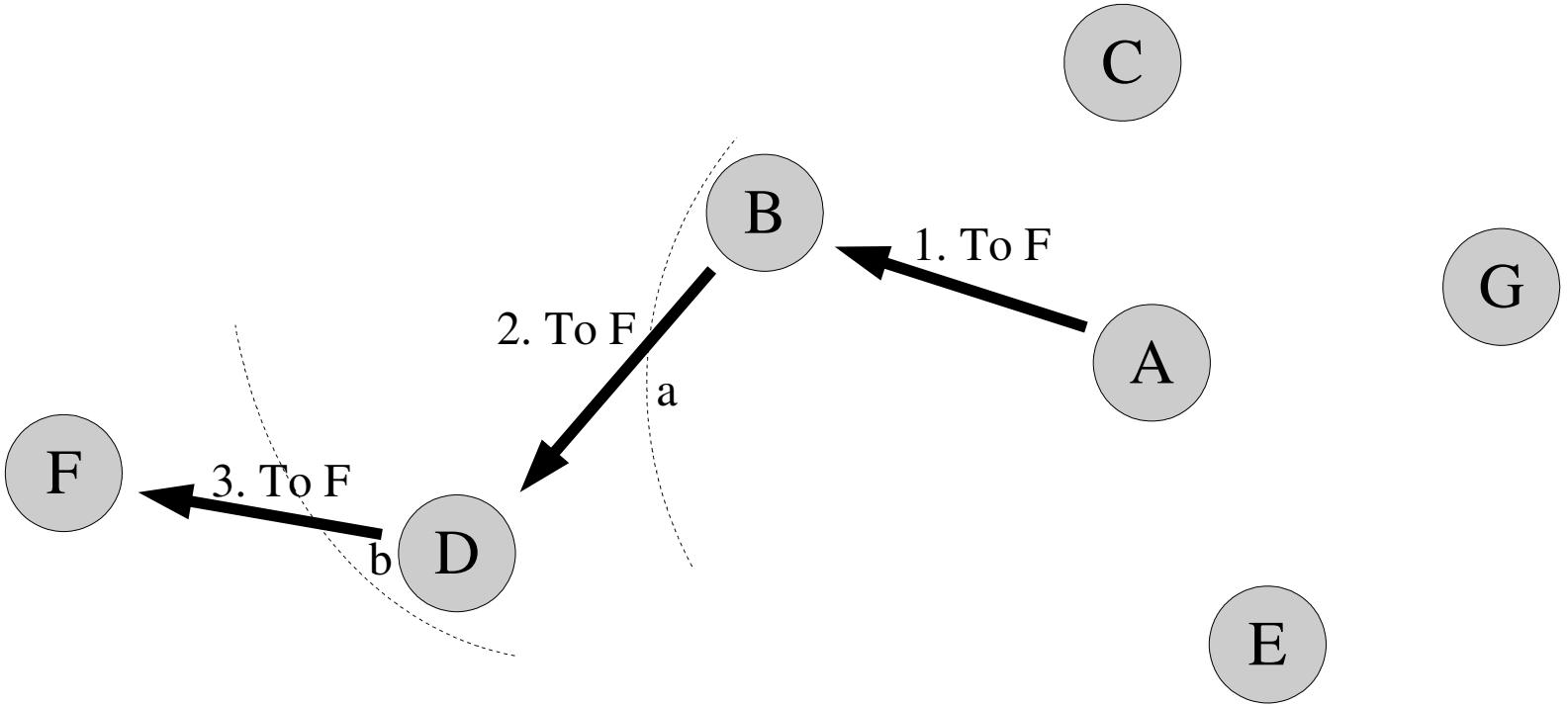
Content

- Introduction
- Overview of IEEE 802.11 standard
- Introduction to TCP
- Simulation environment
- Three discovered problems and analysis
- Conclusions

Introduction (1/2)

- What is a *multi-hop wireless ad hoc network*?



Introduction (2/2)

- IEEE 802.11 MAC layer protocol is a standard for wireless LANs.
- It was not designed for multi-hop networks.
- It is also widely used in almost all test beds and simulations for wireless ad hoc network research.
- Media is a scarce resource in a wireless networks.
  ⇒ The impact of MAC layer is emphasized.
- TCP doesn't work well with IEEE 802.11.

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Overview of 802.11 Standard (1/2)

- Covers the MAC and physical layer.
- Two access methods:
  - Distributed Coordination Function (DCF).
  - Point Coordination Function (PCF).
- DCF uses CSMA/CA:
  - Effective when the medium isn't heavily loaded.
  - Can handle *hidden node problem*.
  - Can't handle *exposed node problem*.

Overview of 802.11 Standard (2/2)

- Physical layer:
  - Three ranges: *Interfering range*, *sensing range* and *nominal range*.
  - Interfering range and sensing range are larger that the range at which the receivers are willing to accept packets (nominal range).
  - Tries to send RTS packet 7 times before declaring link breakage.

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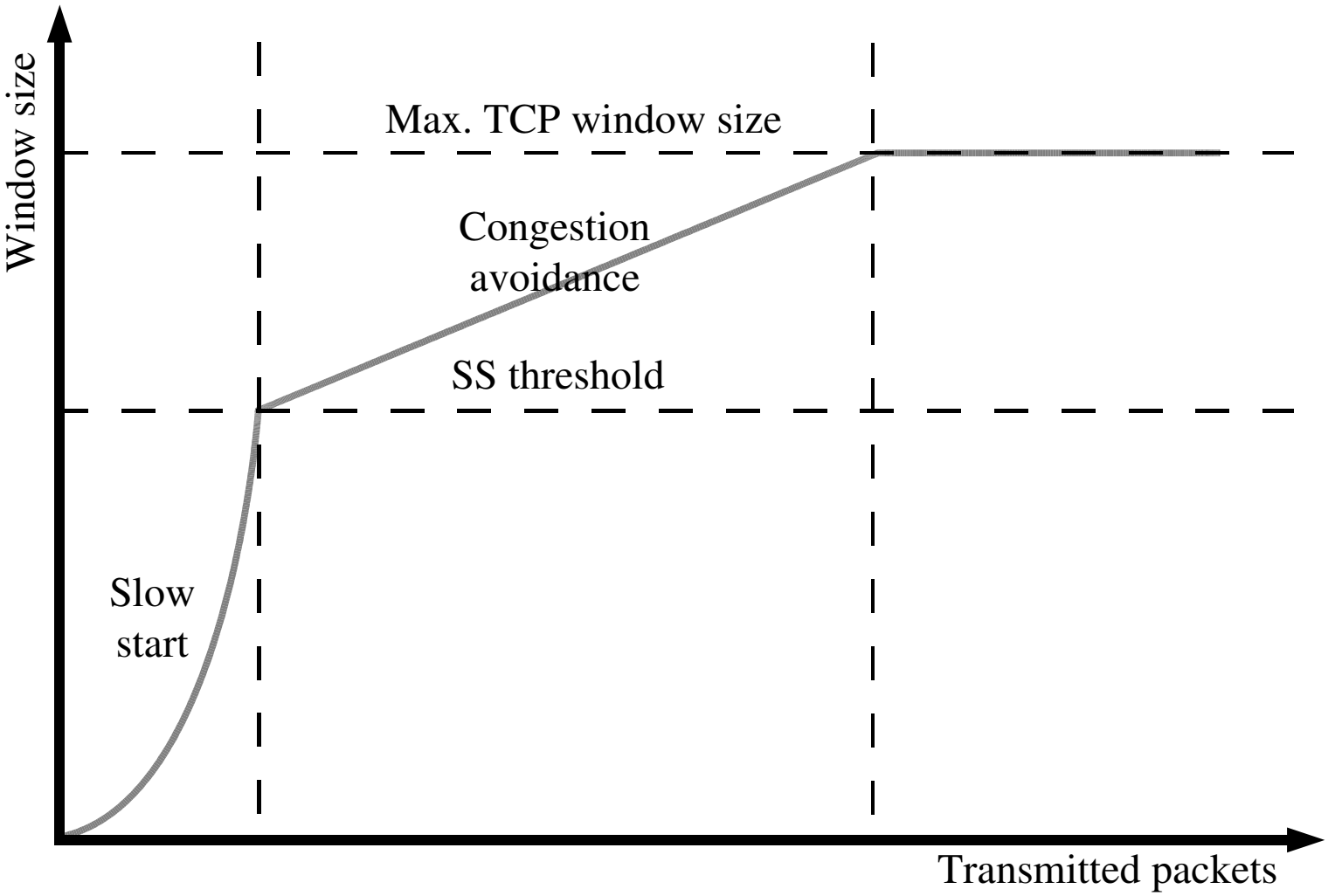
Introduction to TCP (1/2)

- Window-based transmission layer protocol.
- Includes flow-control.
- Uses ACK messages.
- Changes it's window size according the network conditions:
  - Slow start phase.
  - Congestion avoidance phase.

Introduction to TCP (2/2)



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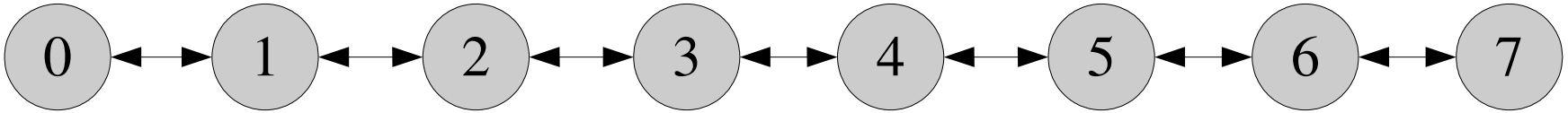
Simulation Environment (1/2)

- ns2 with extensions (DSR, BSD's ARP, ...).
- OPNET was used for validation.
- Single physical channel object.
- Radio is 802.11, 2Mbps, nominal range of 250m.
- Nodes have 50 packets queue for packets awaiting transmission.
- Nodes are statical and identical with each other.

Simulation Environment (2/2)

- String topology with 8 nodes.



- 200m distance from node to node.
- All nodes aren't involved in each experiment.
- TCP connections with large file transfers.
- TCP Reno variant used (has fast recovery).

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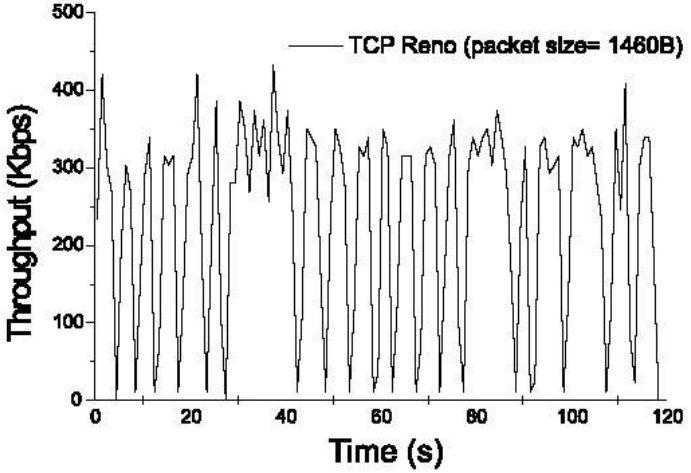
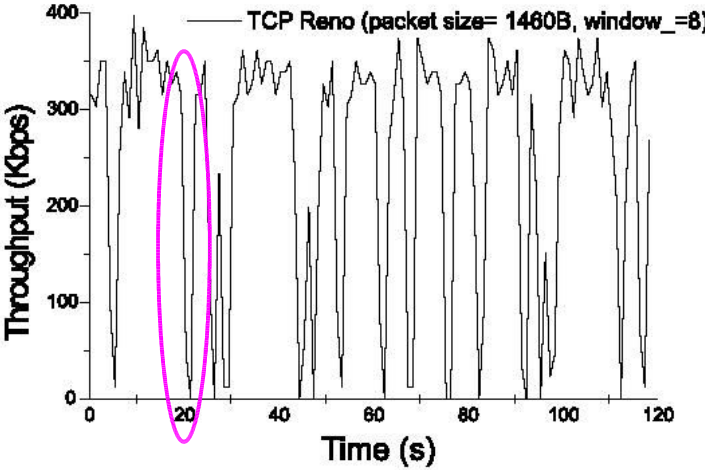
1st Problem – TCP Instability (1/4)

- Scenario:
  - Four-hop TCP connection from node 1 to node 5.
  - Throughput measures on 1.0 second intervals.
  - TCP maximum windows size varied (32, 8, 4).
- Conclusions:
  - TCP throughput doesn't stay in the same level.
  - TCP doesn't work well with IEEE 802.11.
  - Situation can be avoided by adjusting TCP parameters.

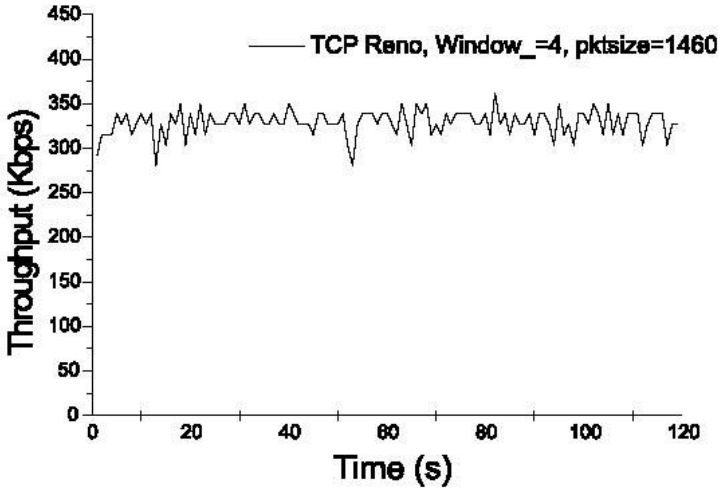
1st Problem – TCP Instability (2/4)



(a)



(b)



1st Problem – TCP Instability (3/4)

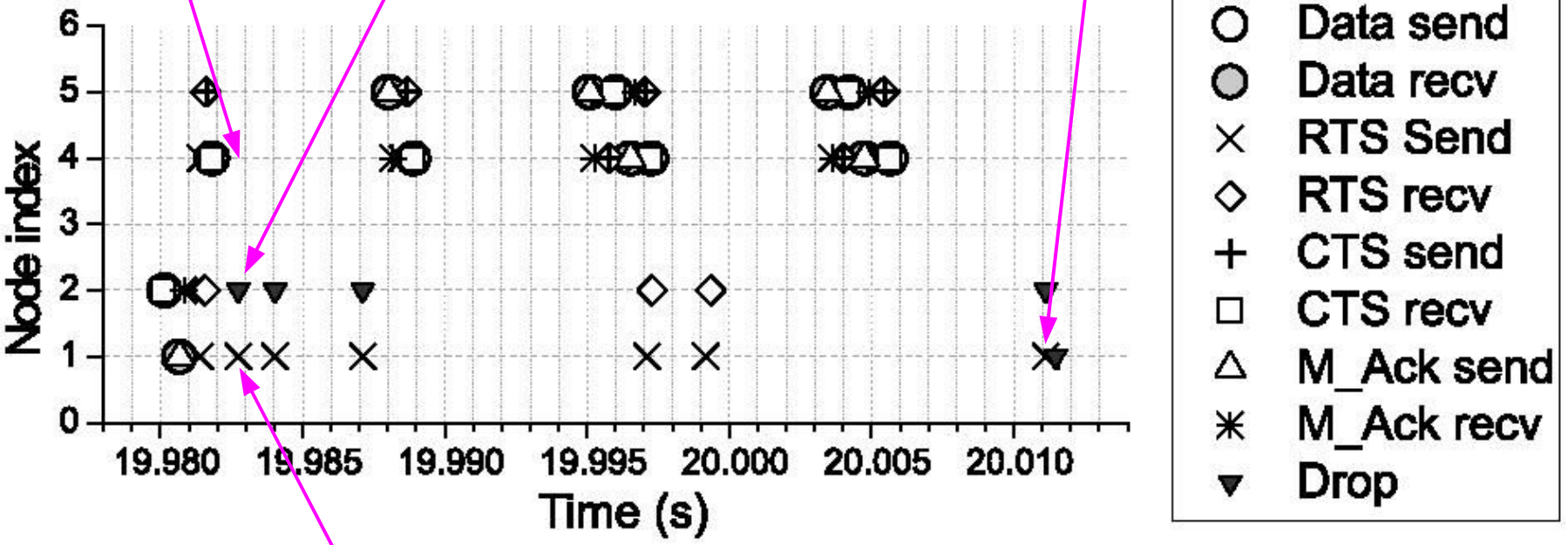
- Analysis:
  - 802.11 layers reports link breakage ⇒ Route failure.
  - In ns2, the interfering and sensing range are more than two times the size of the nominal range.
  - This scenario is suffering from the *exposed node problem*.
  - Route failure recovery takes longer than the TCP timeout threshold is ⇒ TCP window size becomes 1.
  - Also TCP retransmission needed.

1st Problem – TCP Instability (4/4)

Node 4 is sending TCP data to node 5

Link breakage reported

Node 2 is on the interfering range

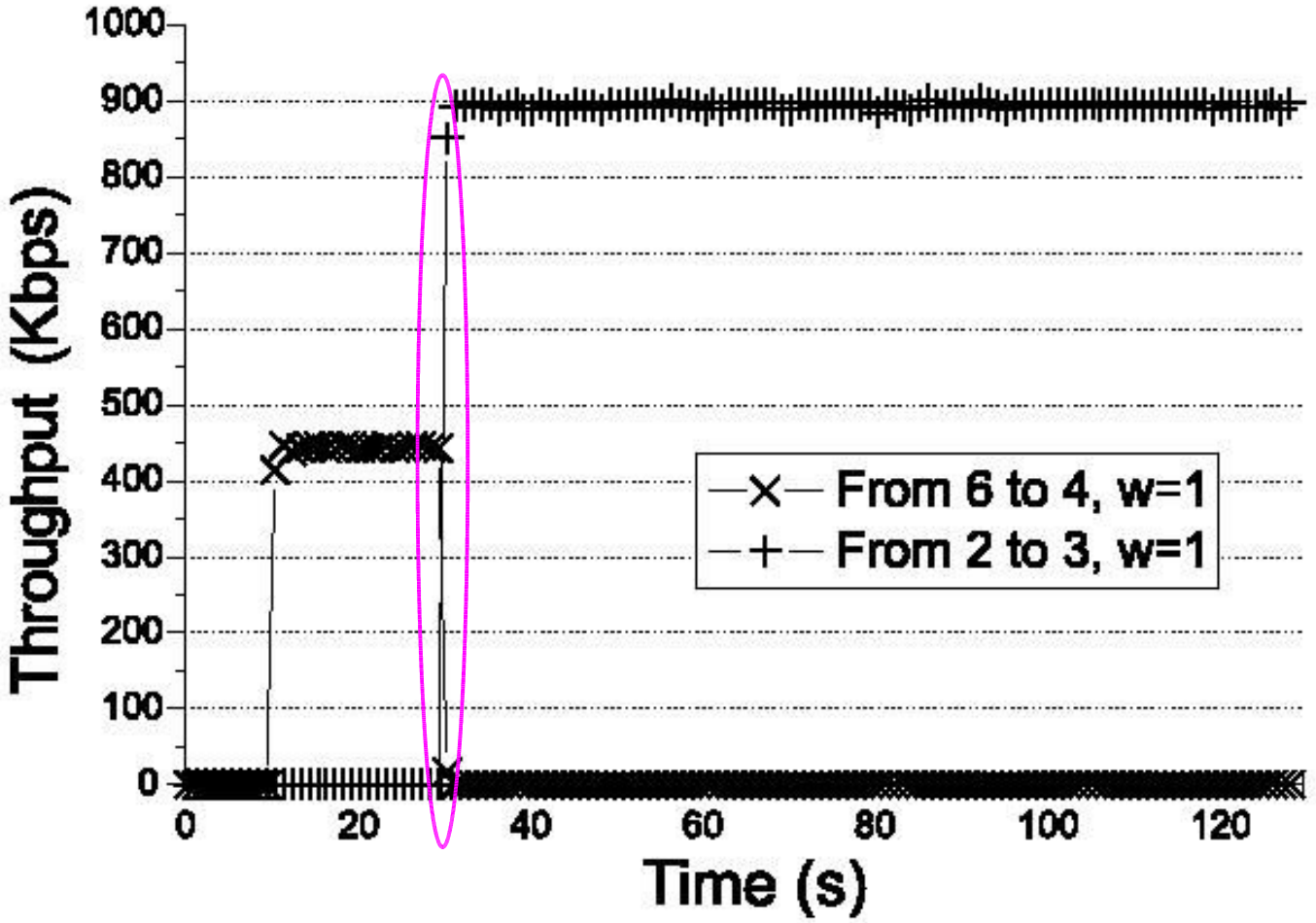


Node 1 is not on the sensing range

2nd Problem – Unfairness (1/4)

- Titled “Neighboring node one-hop unfairness”.
- Scenario:
  - Two TCP connections.
  - First session starts at 10s, and goes from 6 to 4.
  - Second session start at 30s, and goes from 2 to 3.
- Conclusions:
  - Second sessions displaces the first session completely.
  - TCP maximum window size doesn't matter.

2nd Problem – Unfairness (2/4)



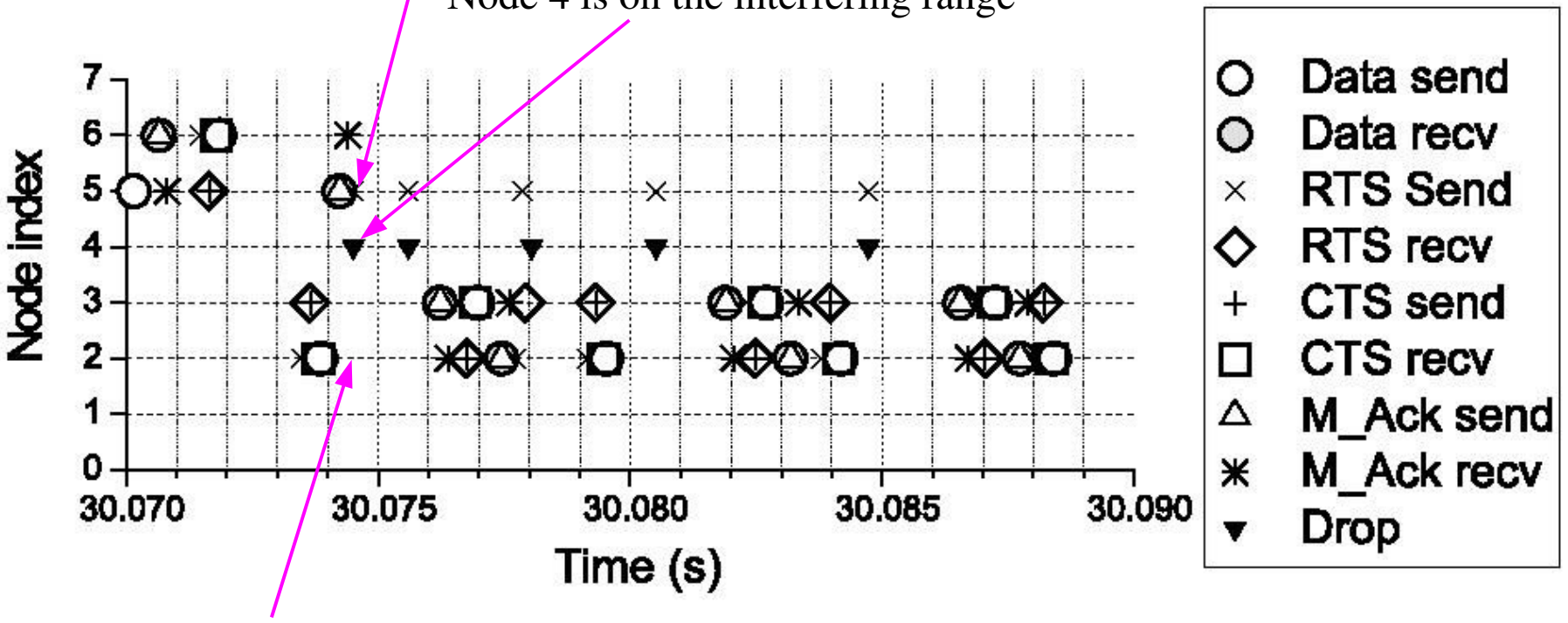
2nd Problem – Unfairness (3/4)

- Analysis:
  - Node 4 can't successfully receive RTS from node 5.
  - Also this scenario is suffering from the *exposed node problem*.
  - Node 5 doesn't get a change to deliver RTS to node 4, because node 2 is doing almost non-stop transmission.

2nd Problem – Unfairness (4/4)

Node 5 is not on the sensing range

Node 4 is on the interfering range

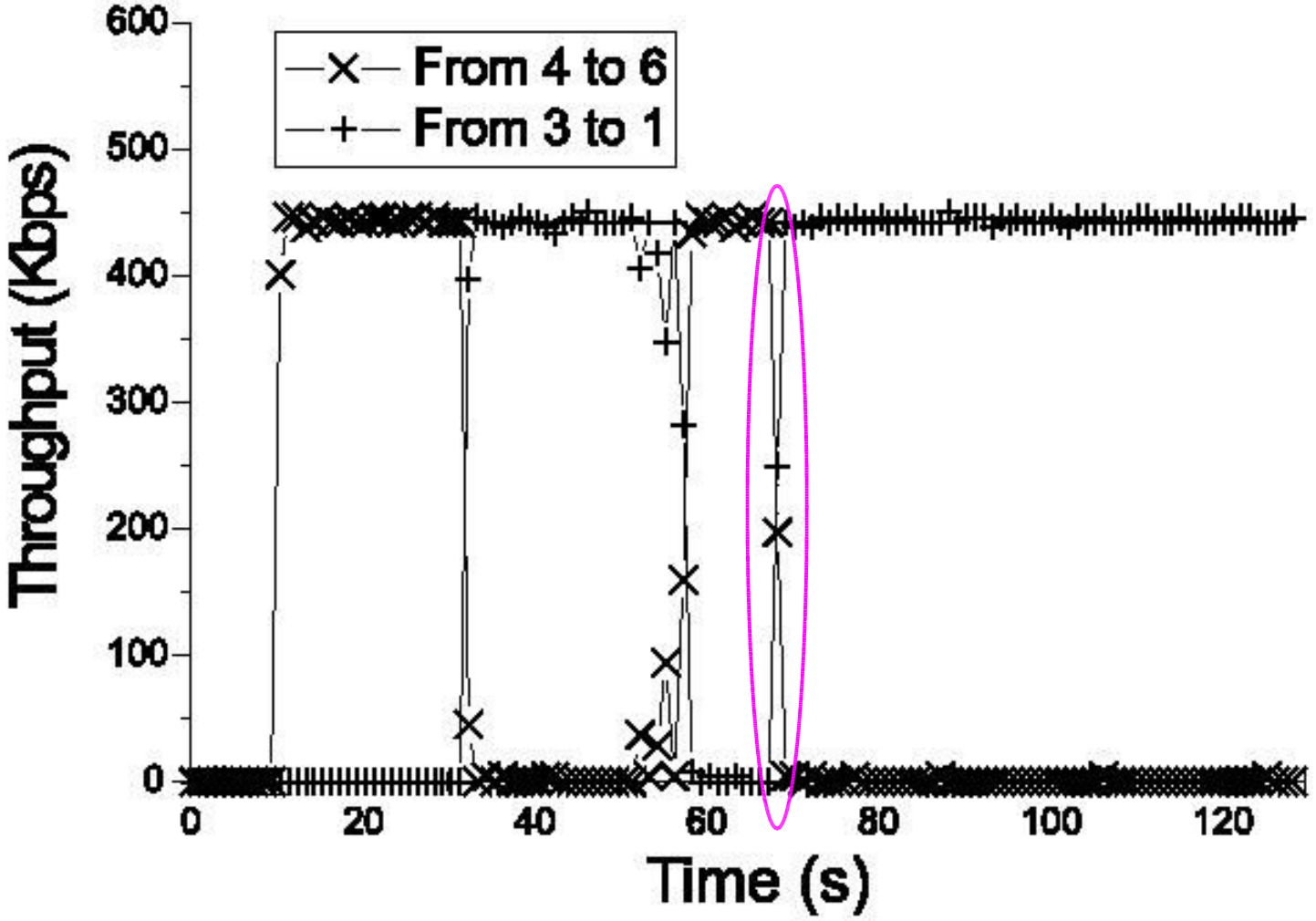


Node 2 is sending TCP data to node 3

3rd Problem – Incompatibility (1/4)

- Scenario:
  - Two TCP connections.
  - First session starts at 10s, and goes from 4 to 6.
  - Second session start at 30s, and goes from 3 to 1.
- Conclusions:
  - Two simultaneous TCP connection can't coexist in the 802.11 network at the same time.
  - TCP maximum window size doesn't matter.

3rd Problem – Incompatibility (2/4)



3rd Problem – Incompatibility (3/4)

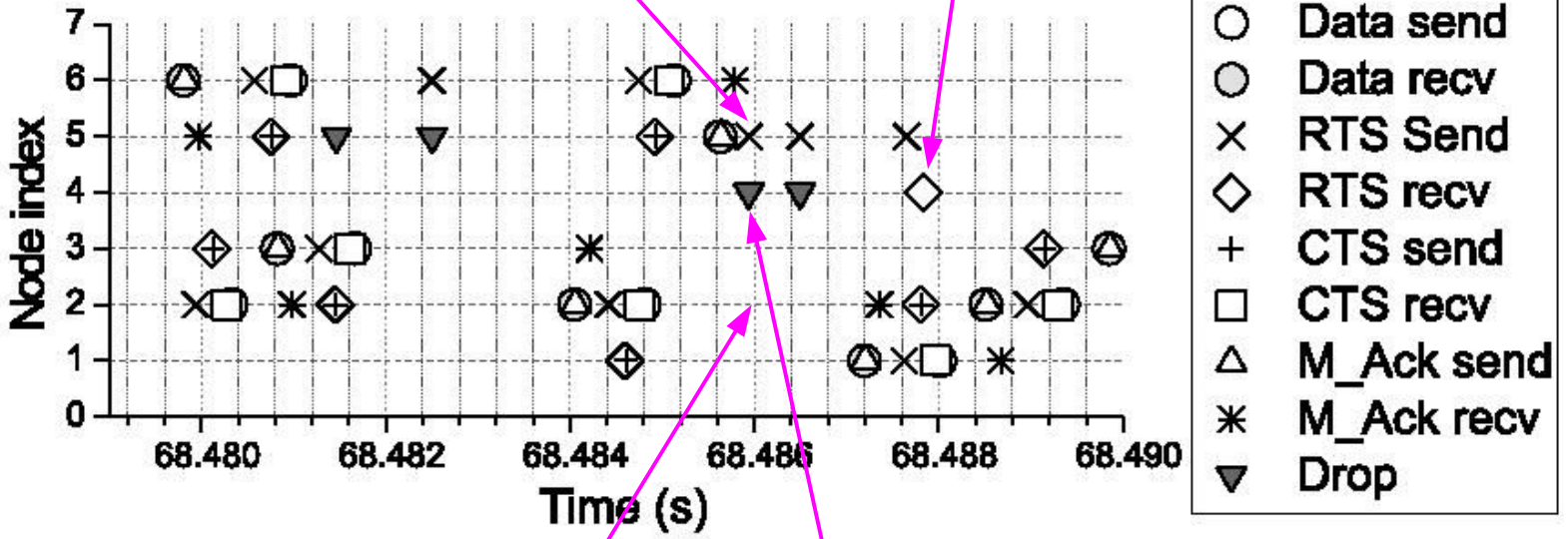
- Analysis:
  - Also this scenario is suffering from the *exposed node problem*.
  - Both TCP sessions have difficulties accessing the media.
  - Session turnover occurs in random time.

3rd Problem – Incompatibility (4/4)

Node 4 can't send CTS to node 5, because it can sense node 2 and 3

Node 5 is not on the sensing range

First session dominates



Second session dominates

Node 2 is sending TCP data to node 1

Node 4 is on the interfering range

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Conclusions

- Current 802.11 protocol doesn't work well in multi-hop ad-hoc networks, because of *exposed node problem*.
- Especially TCP protocol has serious problems with IEEE 802.11 networks.
- 802.11 protocol probably isn't suitable for mobile ad hoc test beds and simulations.
- More efforts on the MAC layer are needed to design a usable wireless mobile network.