Distributed On-demand MAC Scheduling for Underwater Acoustic Networks

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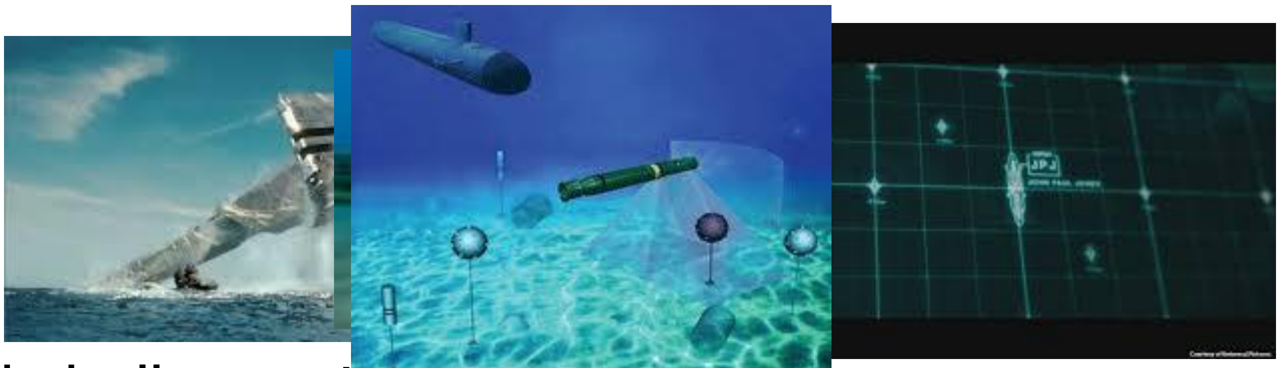
Outline

- Background
- Motivation: Heavy Collisions
- Implication for Practical MAC Design
- Proposed Solution: Distributed On-demand Scheduling
- Simulation Results
- Conclusion

Underwater Acoustic Networks (UANs)

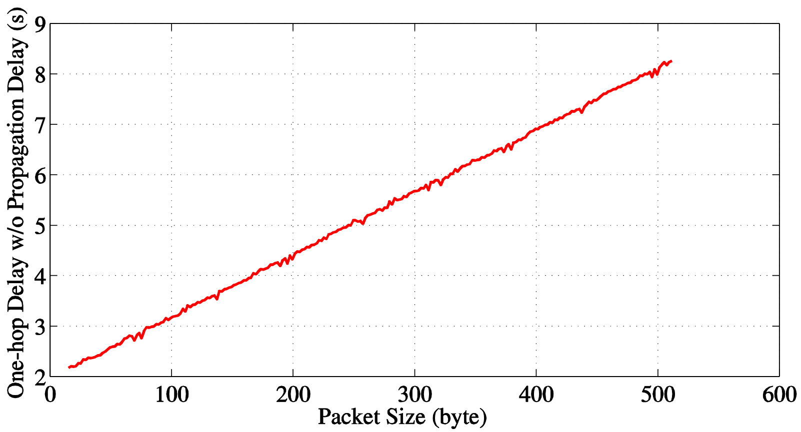
- Wide range of applications!



- Grand challenges!
  - Acoustic communication
    - Slow propagation speed
      - sound speed in water: ~ 1500m/s vs. radio speed: $2x10^8$
    - Low available bandwidth
      - acoustic: several kbps vs. radio: tens or hundreds of Mbps
  - Dynamic environment
    - Water current …

Motivation – Acoustic Modem Characteristics

- One-hop delay with Benthos Modem



$$D = \frac{L}{667} + 1.9615$$

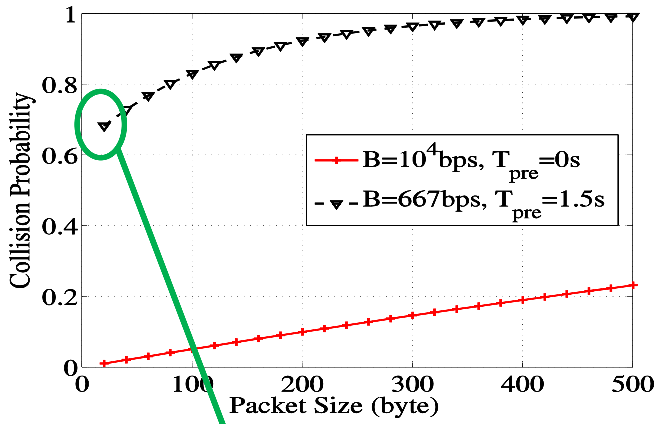
D: one-hop delay without propagation delay, in second

L: The size of packet, in bits

- Observed characteristics
  - Extremely low effective transmission rate (conventionally 10 kbps)
  - Long preamble : 1.5 s (conventionally ignored)

Impact on collision probability

- Collision probability P_c of ALOHA with varying packet size:



- Observation
  - Significantly heavier collisions when considering the real modem characteristics
  - Even short packet of 20 bytes collide with probability 0.68

Are control packets still effective for collision avoidance?

Implication for practical MAC design

- Contention is costly!
  - Random access-based MAC
    - Long transmission time cause severe collisions
  - Reservation-based MAC
    - Principle:

      Control packet is very short and thus effective for collision avoidance
    - Radio Networks: works well
    - Underwater Acoustic Networks:
      - Control packet is very long

- Key feature of practical MAC design:

  COLLISOION FREE, even for control packets

Distributed On-demand Scheduling (DOS)

- Both control and data packets are collision-free
  - Guarantees a high performance (contentions are costly)
- Distributed
  - Expensive to collect required information for a centralized scheduling algorithm
- On-demand
  - Nodes' traffic requirements are dynamic
- Pure scheduling only
  - Not modem-specific:
    - No CDMA
    - No power adjustment
    - No multi-user receiver system or multi-channel

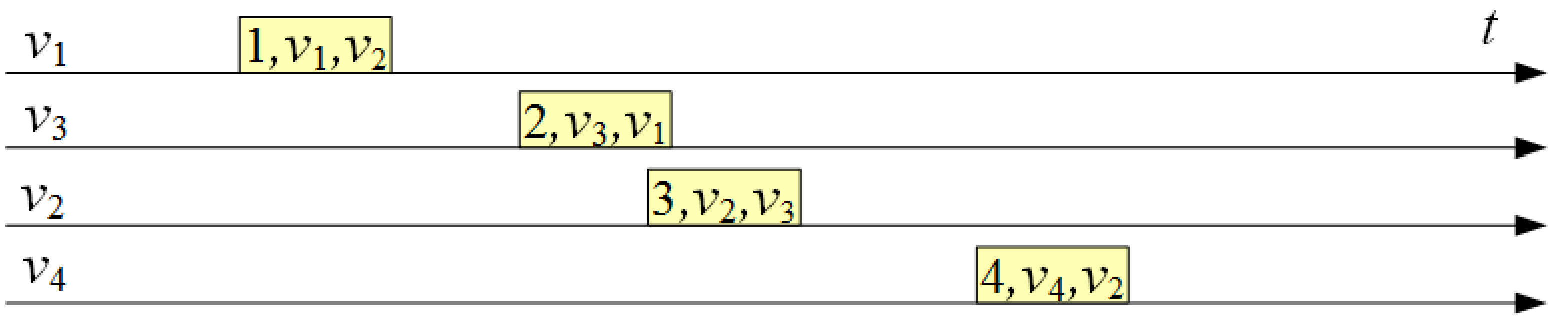
Basic Ideas

- Cluster based network structure
  - Group the nodes into clusters, using existing clustering algorithms
- The data transmissions within a cluster are scheduled by cluster heads
  - Cluster members contact the cluster head to request data transmissions
- Schedule exchanges between neighboring cluster heads
  - Every cluster head aware of what's going on in the neighboring cluster
- Two hop neighbors' up-to-date tx schedule is enough for a node's new collision-free schedule

How to schedule a packet transmission?

- Example:

Schedule $5, v_1, v_2$

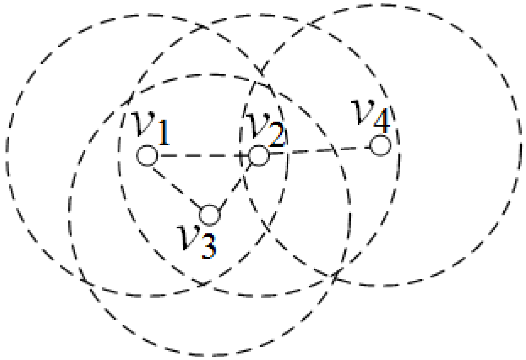


$1, v_1, v_2$ Event of transmitting a packet from v_1 to v_2

$1, v_1, v_2$ Event of receiving a packet from v_1 to v_2

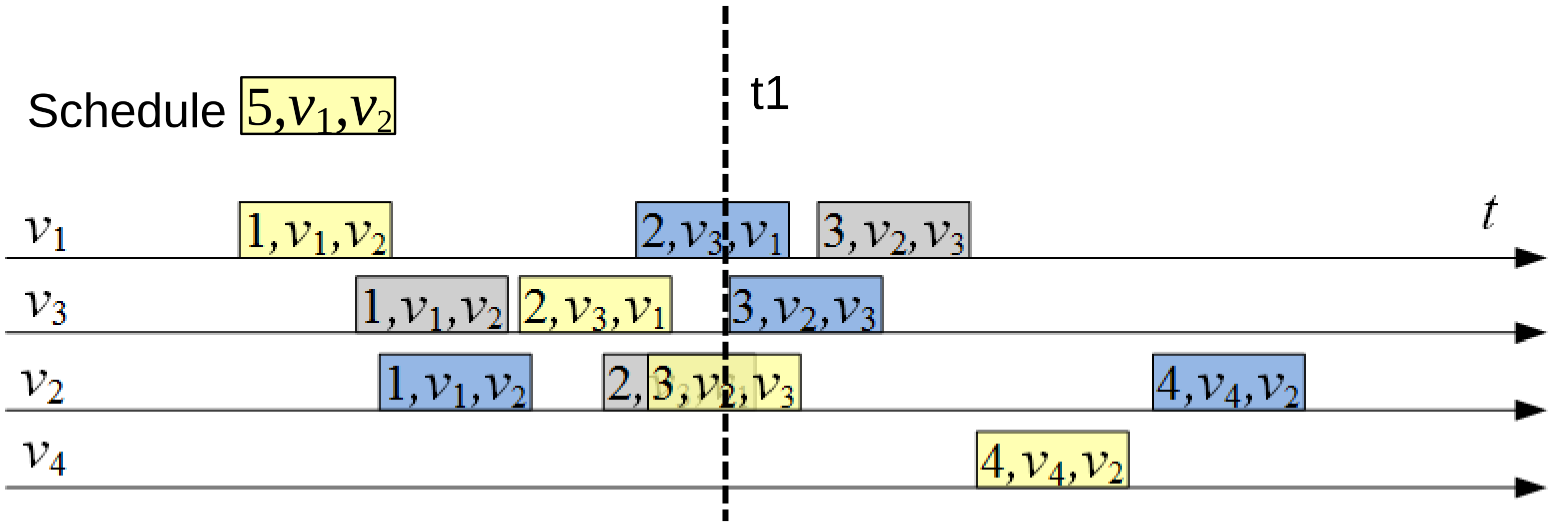
$1, v_1, v_2$ Event of overhearing a packet from v_1 to v_2

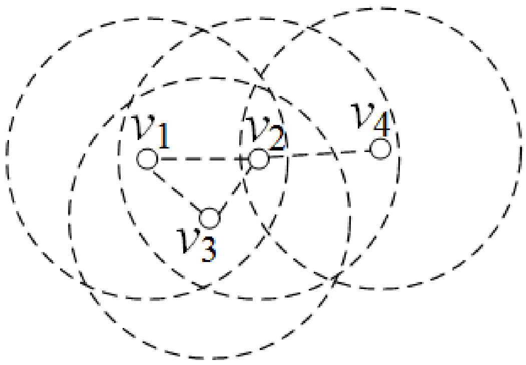
Newly scheduled TX slot



How to schedule a packet transmission?

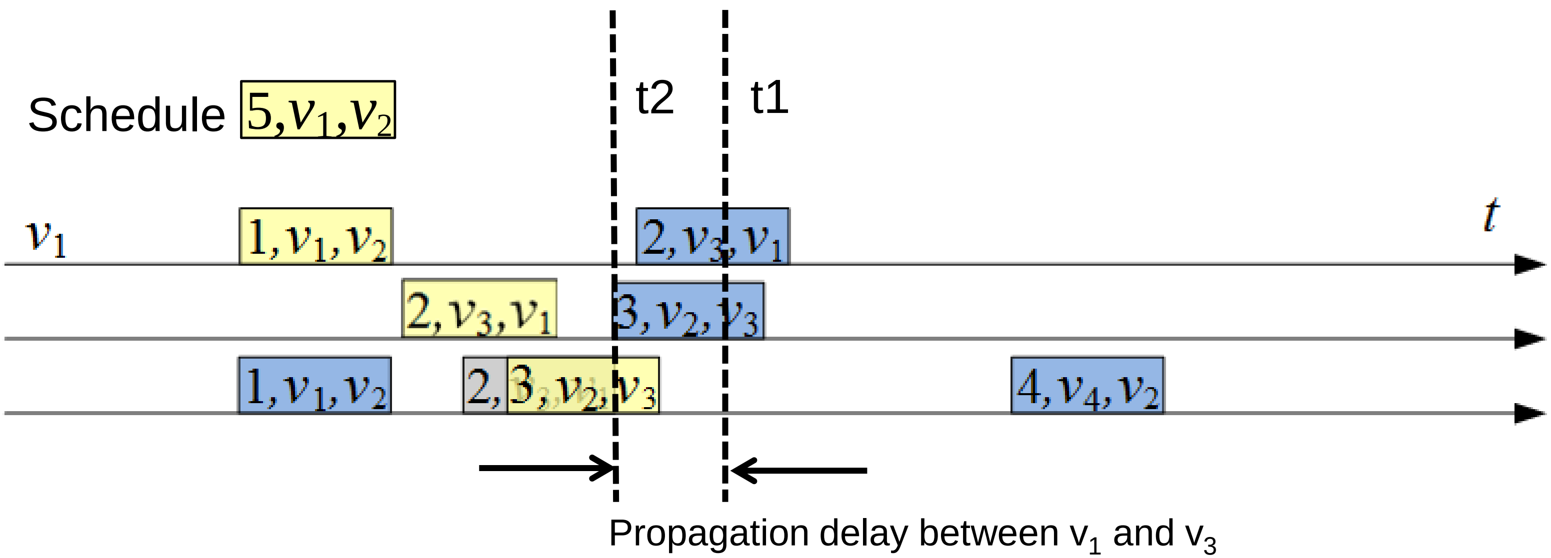
- Corresponding events and sequence





How to schedule a packet transmission?

- Time alignment and mapping



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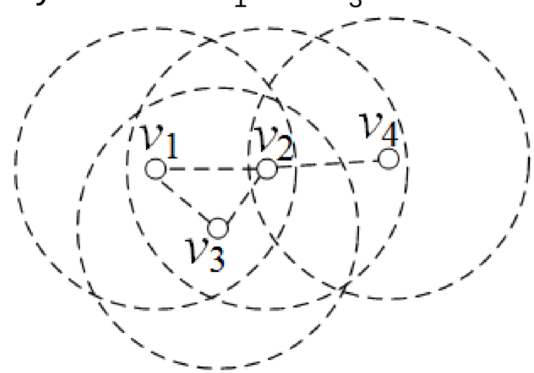
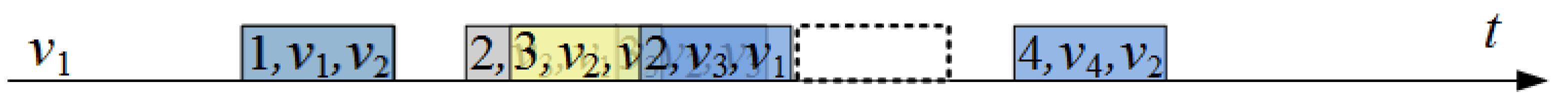
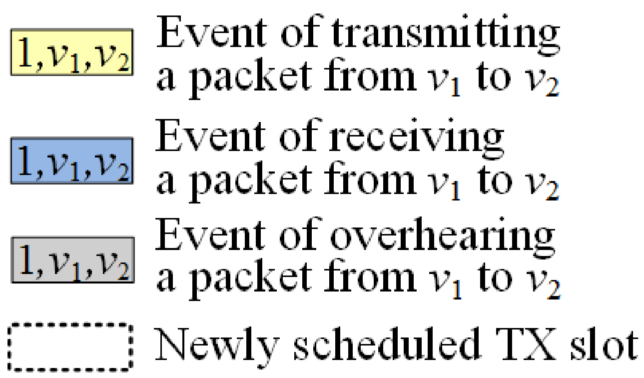


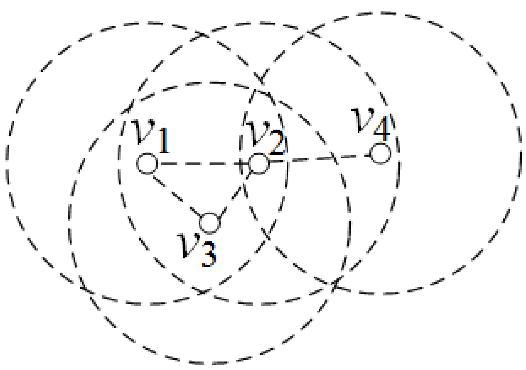
How to schedule a packet transmission?

- Combine all events to v_1's timeline and find a time slot for packet #5

Schedule $5, v_1, v_2$

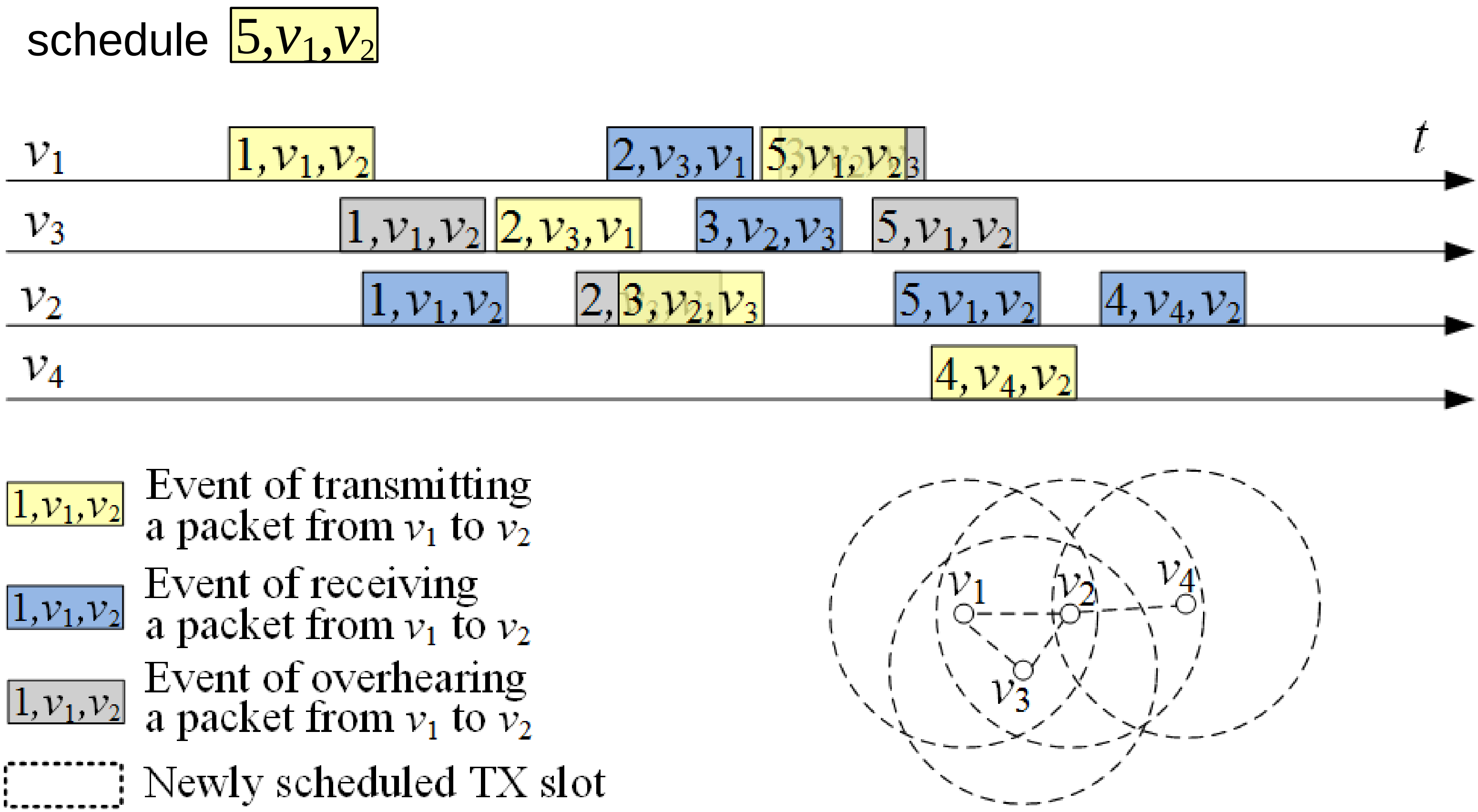






How to schedule a packet transmission?

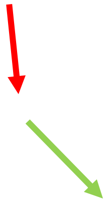
- Collision free for packet #5



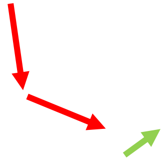
One-hop cluster based solution

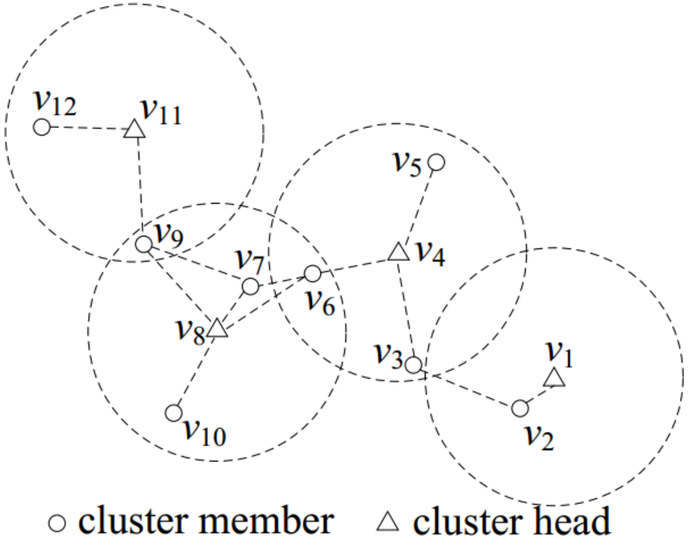
- Cluster head schedules all members’ tx slots
- Neighboring Cluster Heads (NCH) collaboratively generate collision-free schedules

2-hop NCH

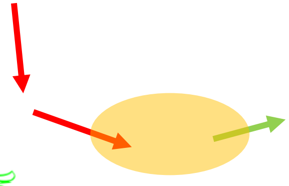


3-hop NCH





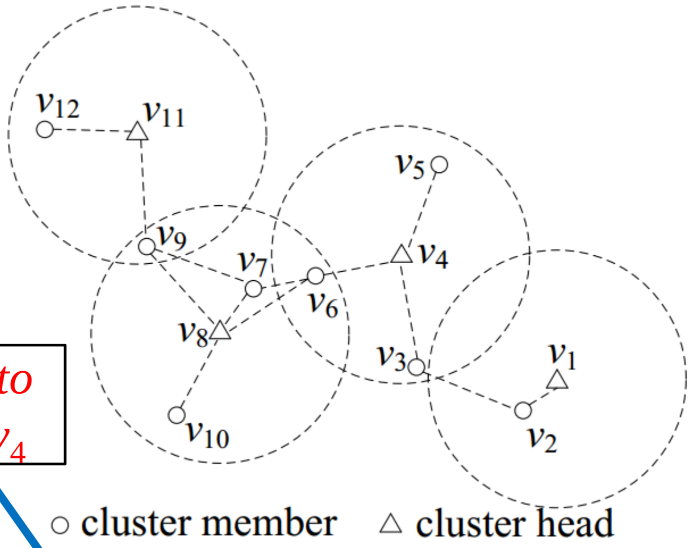
4-hop NCH

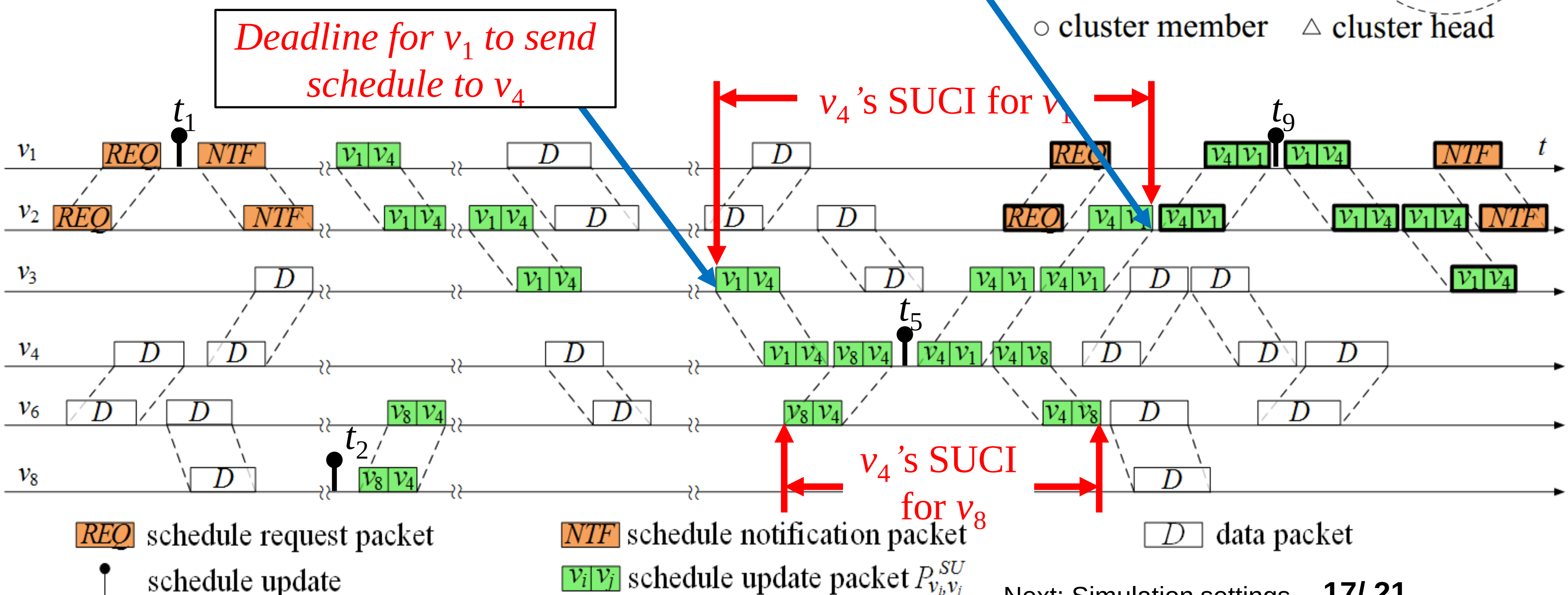


Ferry hop

Scheduling in DOS

- Schedule update time
- Schedule update conflict interval (SUCI)
- Schedule notification packet
- Request packet
- Notification packet

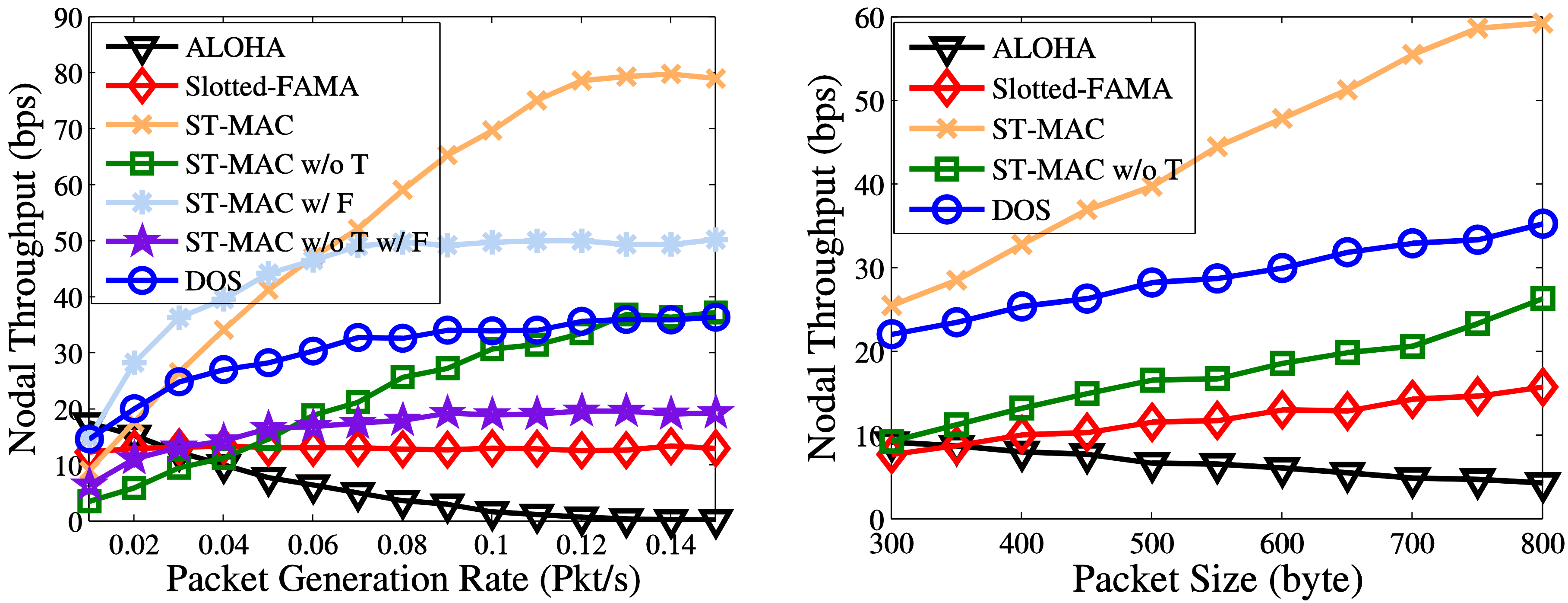




Simulation results

- Simulation settings
  - Platform: Aqua-Sim
  - Protocol comparison
    - ST-MAC and its three variants
    - Slotted-ALOHA
    - Slotted-FAMA
  - Poisson traffic pattern
  - Maximum transmission range 1100m
  - Teledyne Benthos modem:
    - Transmission rate: 667 bps;
    - Preamble:1.5 s
  - Network deployment: 80 nodes randomly distributed in 6000m × 6000m × 20m area; 80 sender/receiver pairs

Simulation results



DOS achieves comparable throughput to ST-MAC, a centralized solution, far outperforms others.

Summary

- Propose a distributed on-demand scheduling MAC
  - Collision-free: both data and control packets
  - Distributed: schedules locally, no global information required
  - On-demand: adapt to nodes' dynamic traffic
  - Pure-scheduling: No special requirement on modem device: CDMA, multi-channel, multi-user
  - Achieves high performance

- Future Work
  - Integrate DOS with a clustering algorithm capable to manage dynamic topology
  - Explore a cross-layer design approach to couple DOS with cluster-based routing

Thanks
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Questions?