"Busy Terminal Problem" and Implications for MAC protocols in Underwater Acoustic Networks

Yibo Zhu, Jun-Hong Cui, Zheng Peng, and Zhong Zhou

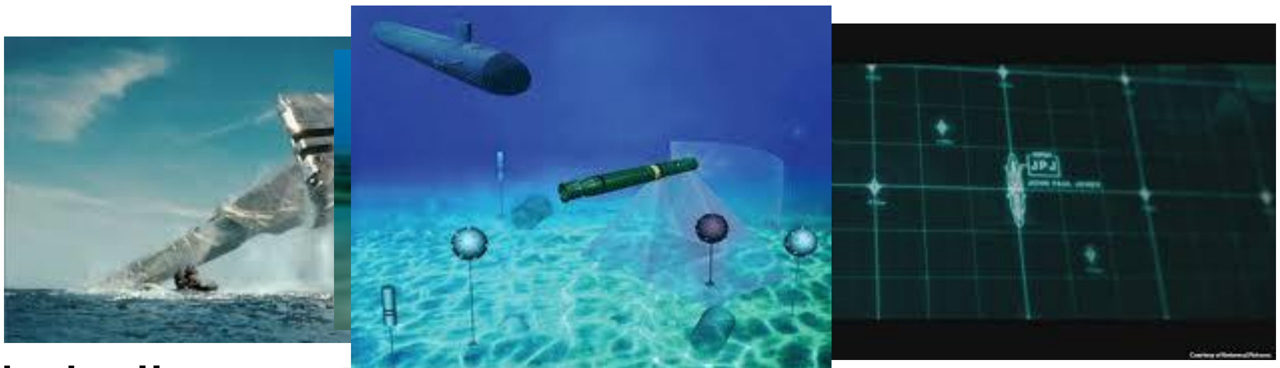
UWSN Lab @ University of Connecticut

Outline

- Background
- "Busy Terminal Problem" (BTP)
- Impact of BTP
- Modeling BTP
- Simulation Results
- Conclusion

Underwater Acoustic Networks (UANs)

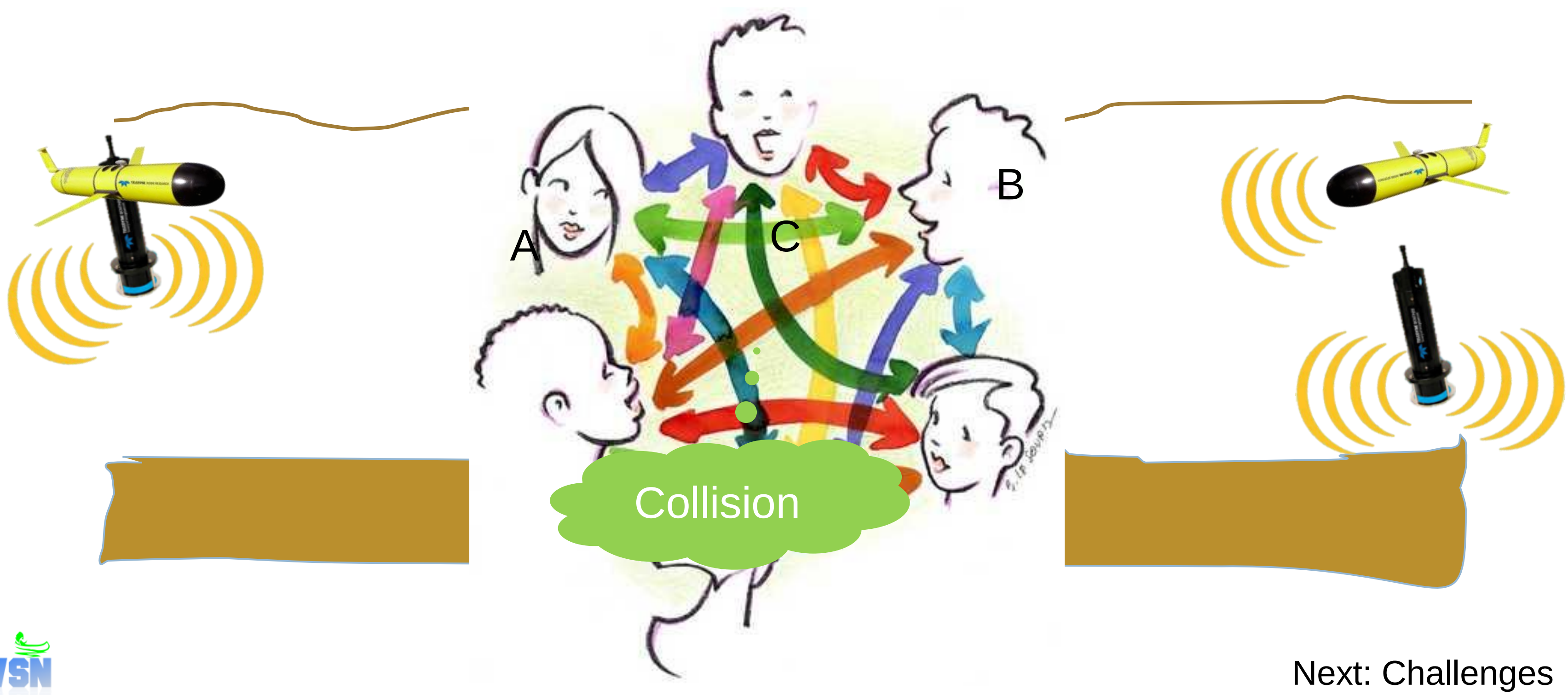
- Wide range of applications!



- 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 …

Media Access Control (MAC)

- What is Media Access Control?
  - Channel control mechanism that allows multiple nodes to communicate through a shared medium
  - Example: 802.11 (Wi-Fi)



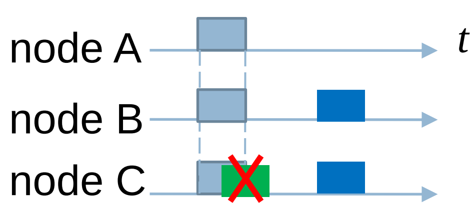
Challenges for Underwater MAC Design

- Slow propagation speed

  sound speed in water: ~ 1500m/s vs. radio speed: $2x10^8$

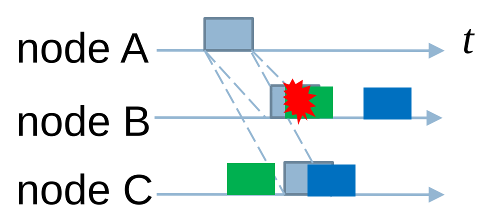
  ⇨ Long propagation delays

Radio Networks



Carrier sense in radio networks

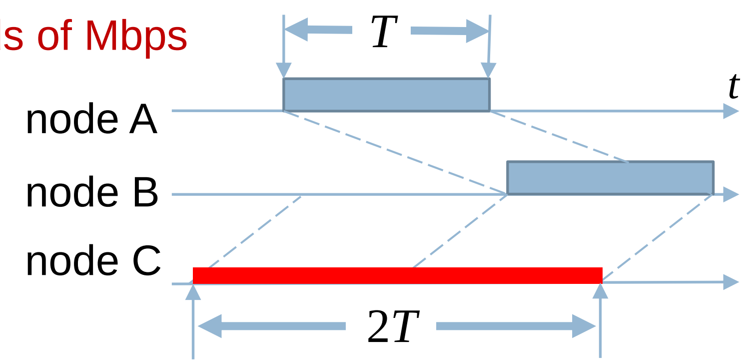
UANs



~~Carrier sense in UANs~~

- Low transmission rates ⇨ long transmission delays

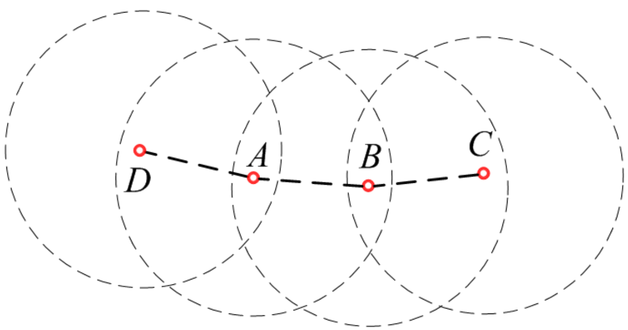
  acoustic: several kbps vs. radio: tens or hundreds of Mbps

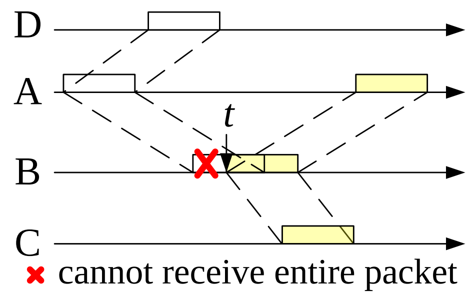


Much higher collision probability!

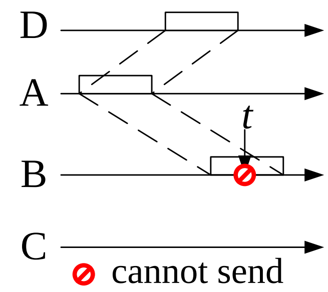
Motivation: behavior of acoustic modems

- A practical issue: non-interruptibility of acoustic modems





Interruptible scenario



Non-interruptible scenario

- Problem: How the non-interruptibility affects MAC performance?

- **Busy terminal problem (BTP)** : In half-duplex non-interruptible underwater acoustic networks, a node cannot interrupt reception/transmission to send another packet.
  - Significantly severe in underwater acoustic networks because of long transmission times

How BTP Affects Underwater MAC

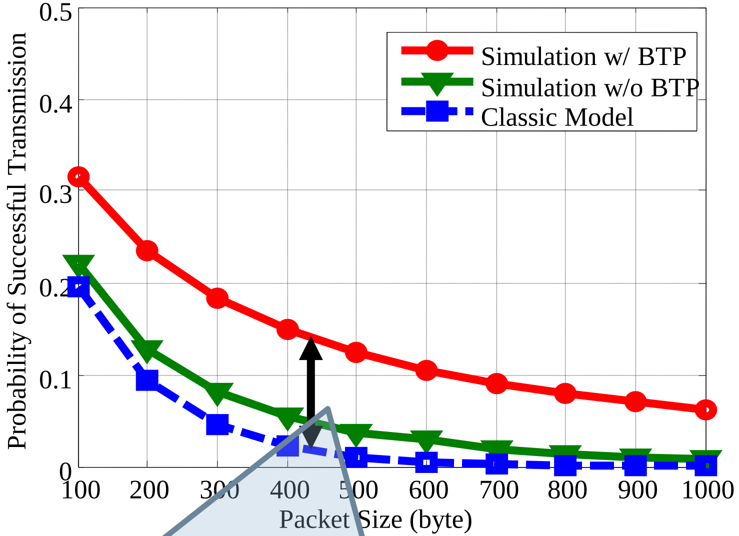
- Random access based MAC
  - Nodes cannot transmit at will
- Reservation based MAC
  - BTP disturbs the schedule and cause collisions
  - It is possible to avoid BTP for scheduled packets
    - Transmission does not conflict with any reception/overhearing
  - No intuitive way to avoid BTP for control packets

It is necessary to analytically study how BTP affects random access MAC (ALOHA-like approach).

ALOHA with BTP

Simulation settings:

- 500 nodes
- 5km x 5km x 3km
- Transmission range: 600m
- Transmission rate: 667bps
- Preamble length: 1.5s
- Poisson traffic rate: 0.05



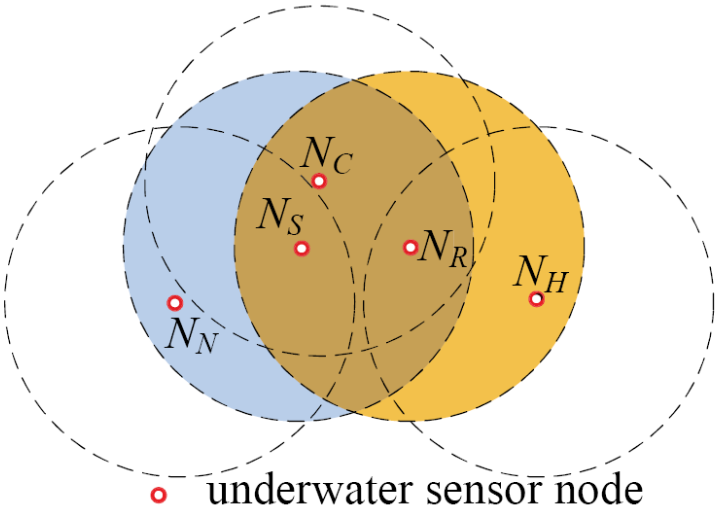
Classic model cannot capture the collision behavior in ALOHA underwater

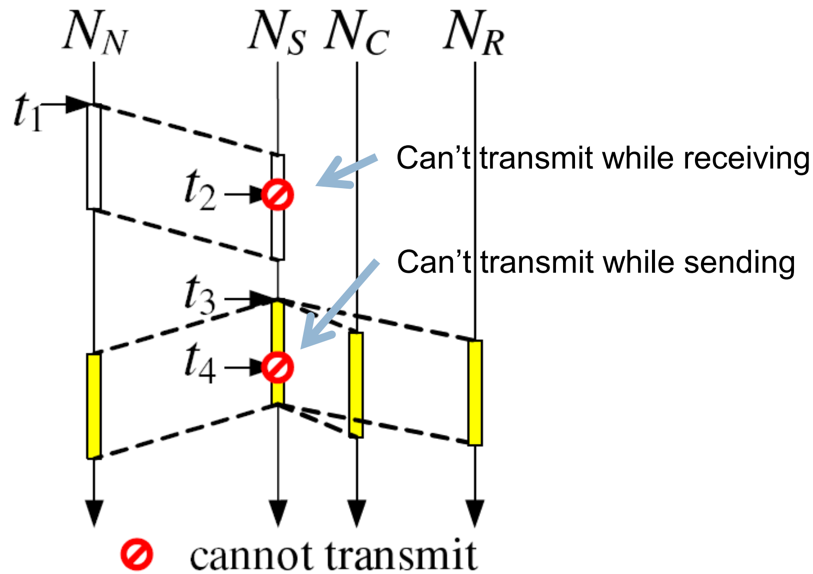
It is critical to model ALOHA with BTP!

Next: How to model?

Modeling ALOHA with BTP

- Possible conflicts



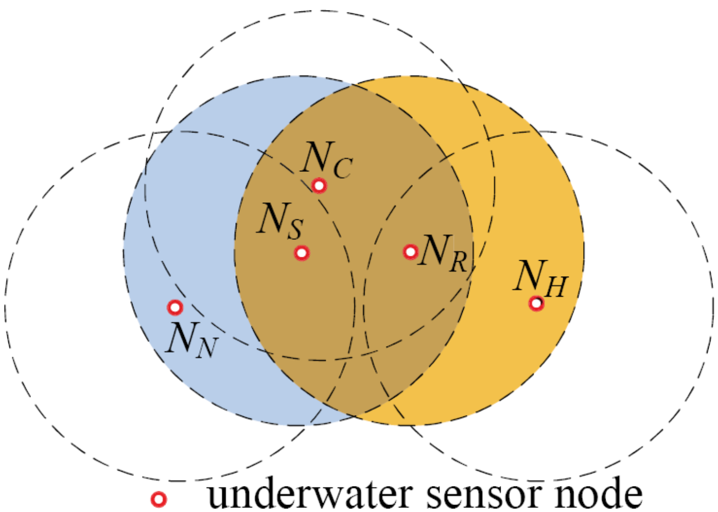


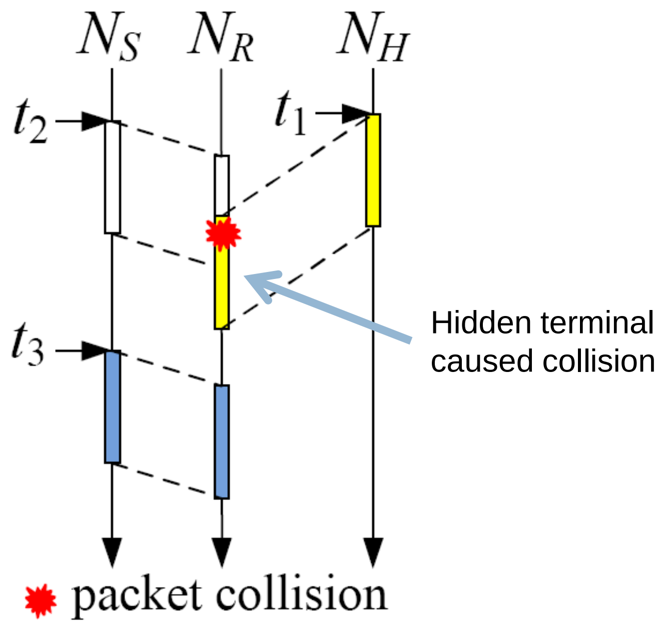
N_S: sender
N_R: receiver
N_C: a common neighbor of N_S and N_R
N_H: N_S's a hidden terminal
N_N: N_S's neighbor

① Rx/Tx and Tx/Tx conflicts at N_S

Modeling ALOHA with BTP

- Possible conflicts





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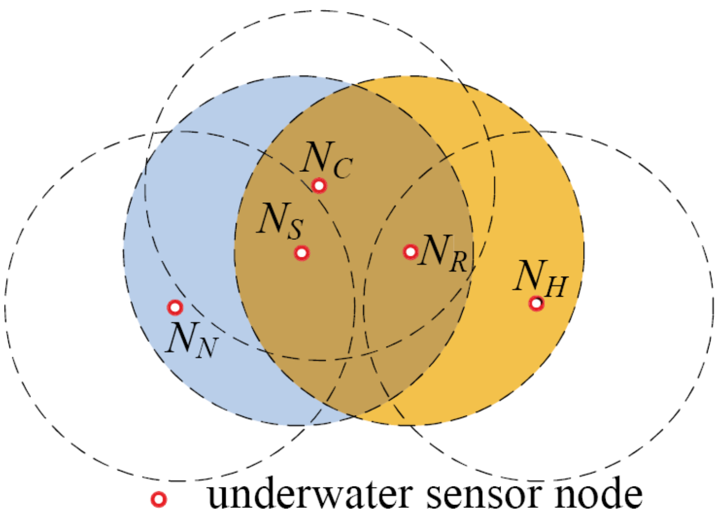
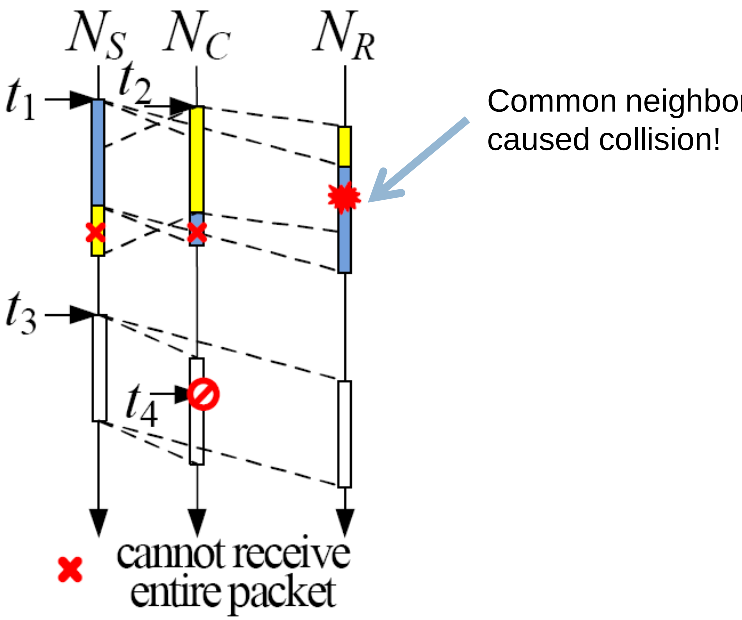
② Rx/Rx conflict at N_R by a hidden terminal

Modeling ALOHA with BTP

- Possible conflicts





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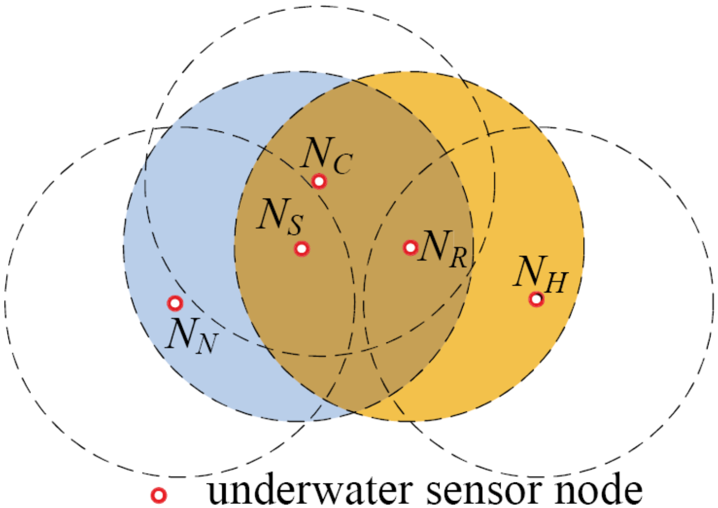
③ Rx/Rx conflict at N_R by a common neighbor

Modeling ALOHA with BTP

- Possible conflicts



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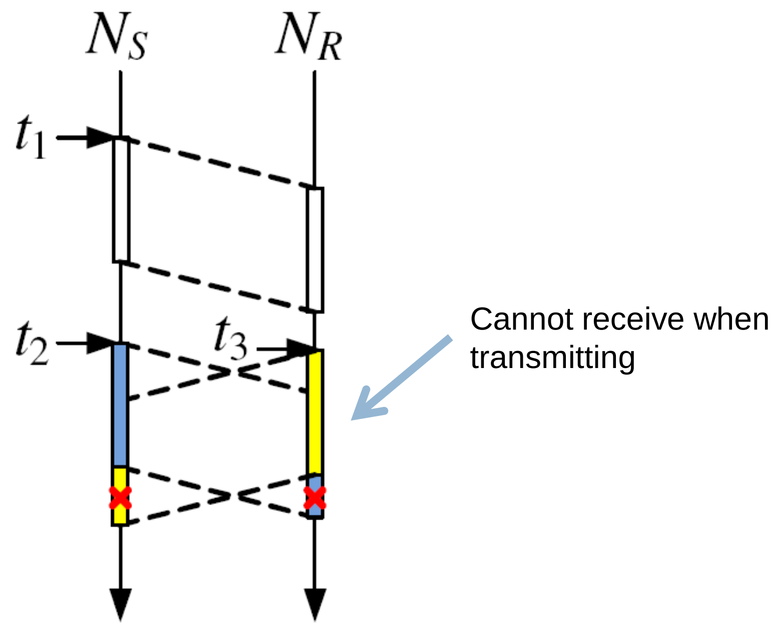


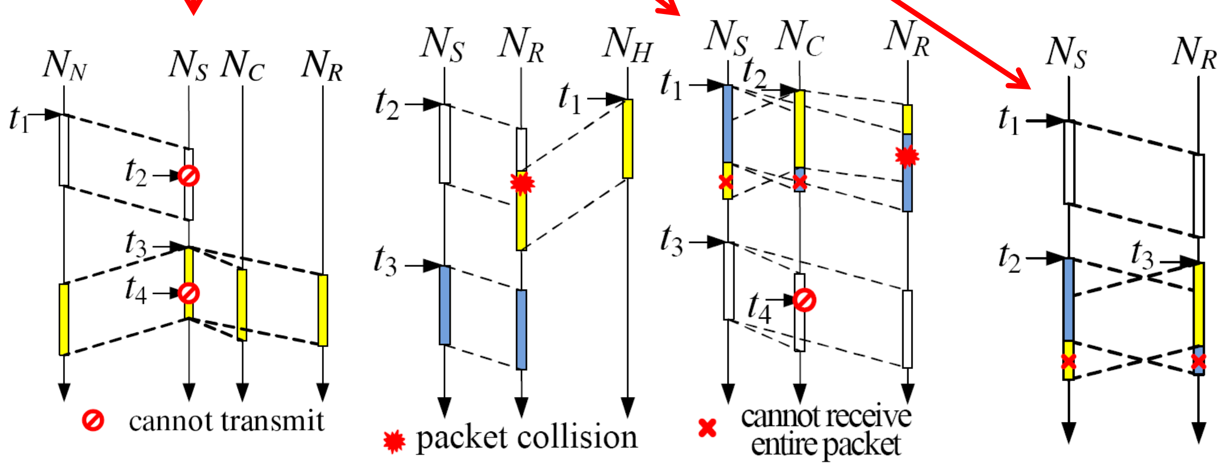
④ Tx/Rx conflict at N_R

Modeling Framework

- Probability of a successful transmission

$$P_s = \int_0^R \frac{3 d_{N_S N_R}^{\;2}}{R^3} \times P_{ne} P_{Tx}^{N_S} P_{RxRx}^{N_H} P_{RxRx}^{N_C} P_{TxRx}^{N_R} \, \mathrm{d}d_{N_S N_R}$$

- No channel error
- The sender can send
- No hidden terminal problem
- No collision caused by common neighbors
- The receiver can receive



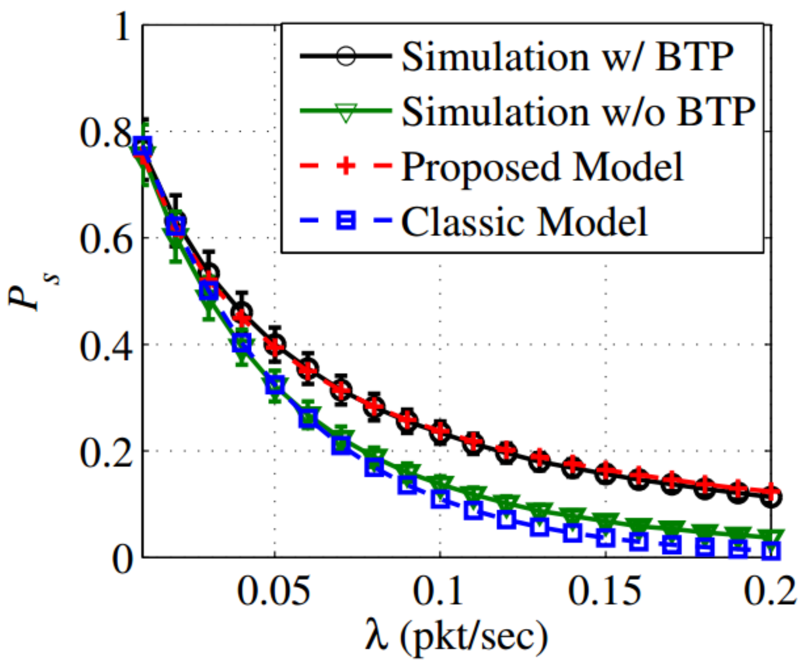
Next: Model validation

Model Validation

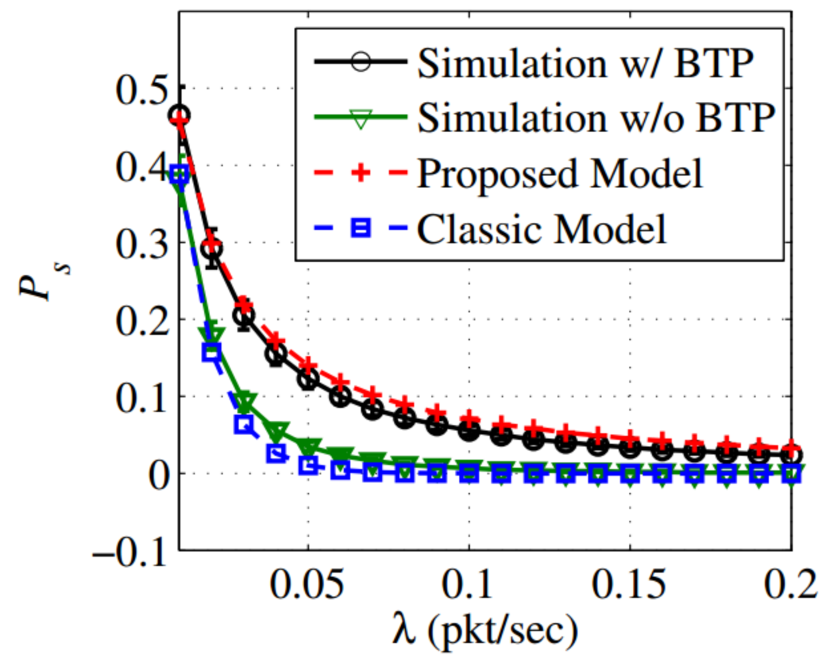
- Simulation platform: Aqua-Sim
- Default simulation settings:
  - 500 nodes randomly deployed in 5000m x 5000m x 3000m
  - Transmission range 600m
  - *BER*: 1e-5
  - Packet size: 500B
  - Traffic generation rate: 0.05 pkt/s
  - Teledyne Benthos modem:
    - Transmission rate: 667 bps;
    - Preamble:1.5 s
  - UCONN OFDM modem:
    - Transmission rate: 3045 bps;
    - Preamble: 0.486s

Next: Exp. results

Model validation with different packet generation rates



OFDM modem

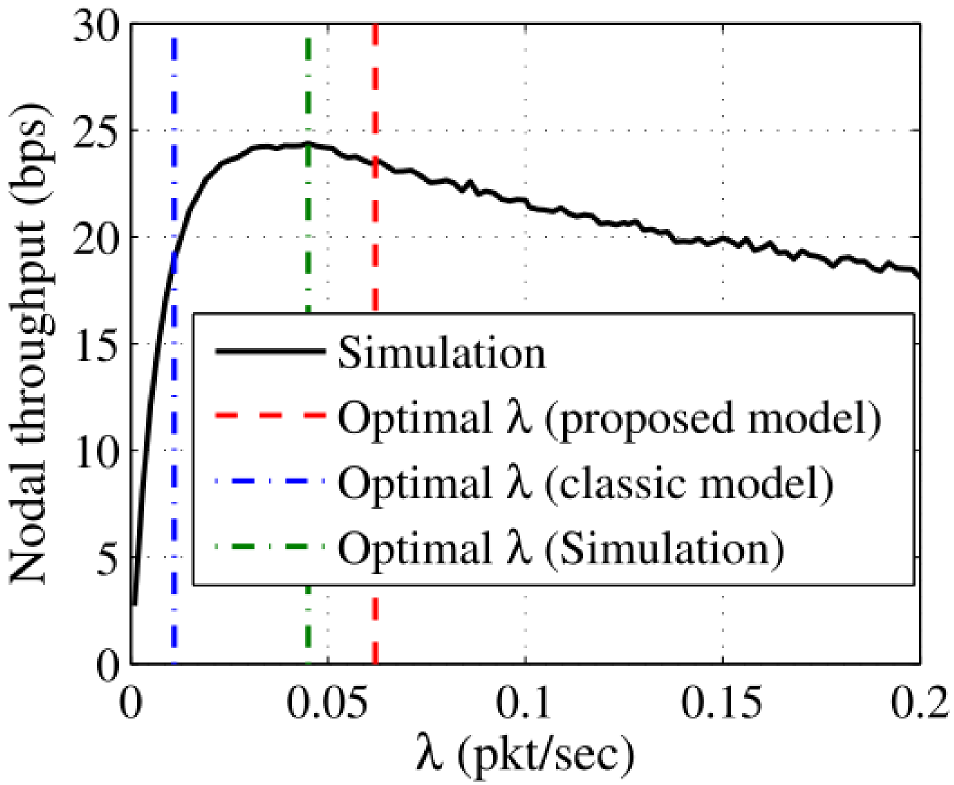


Benthos modem

The proposed model captures the behavior of ALOHA with BTP!

Throughput Optimization – A Case Study

- Maximize ALOHA's nodal throughput by finding the optimal packet generation rate λ



The optimal λ obtained through the proposed model is much closer to the simulation results!

Conclusion

- Identify the busy terminal problem and theoretically analyze its impact on MAC performance
  - Based on real acoustic modem characteristics
  - Can affect the performance of underwater MAC protocols
  - New model of ALOHA with the busy terminal problem
  - Guide the future MAC design and analysis
    - A case study on throughput optimization

- Future Work
  - Model reservation based MAC with BTP
  - Handle BTP in future MAC design

Thanks
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Questions?