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

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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: $\sim 1500\text{m/s}$ vs. radio speed: $2\times10^8$
    - 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: \(~1500\text{m/s}\) vs. radio speed: \(2\times10^8\)
  - Long propagation delays

- **Low transmission rates** ➔ long transmission delays
  - acoustic: several kbps vs. radio: tens or hundreds of Mbps

Radio Networks

- node A
- node B
- node C

Carrier sense in radio networks

UANs

- node A
- node B
- node C

Carrier sense in UANs

Much higher collision probability!

Next: Acoustic modems
Motivation: behavior of acoustic modems

A practical issue: non-interruptibility of acoustic modems

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

It is critical to model ALOHA with BTP!

Classic model cannot capture the collision behavior in ALOHA underwater
Modeling ALOHA with BTP

Possible conflicts

- **Rx/Tx** and **Tx/Tx** conflicts at $N_S$

$N_S$: 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
Modeling ALOHA with BTP

- Possible conflicts

\[ N_S: \text{sender} \]
\[ N_R: \text{receiver} \]
\[ N_C: \text{a common neighbor of } N_S \text{ and } N_R \]
\[ N_H: N_S \text{'s a hidden terminal} \]
\[ N_N: N_S \text{'s neighbor} \]

② Rx/Rx conflict at \( N_R \) by a hidden terminal
Modeling ALOHA with BTP

 vigorously

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

③ Rx/Rx conflict at $N_R$

by a common neighbor

Common neighbor caused collision!

cannot receive entire packet

Next: Collision type 4
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

\[\begin{align*}
    &\text{④ Tx/Rx conflict at } N_R \\
    &\text{Cannot receive when transmitting}
\end{align*}\]
Modeling Framework

- Probability of a successful transmission

\[ P_s = \int_0^R 3d_{NSNR}^2 \frac{P_{ne} P_{Tx} P_{NH} P_{NC} P_{Rx} P_{RxRx} P_{RxRx} d_{NSNR}}{R^3} \]

- 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: $1 \times 10^{-5}$
  - 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
Model validation with different packet generation rates

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 $\lambda$

The optimal $\lambda$ 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 & Questions?