UCLA

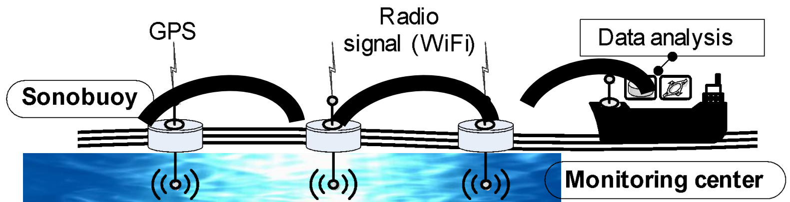
M-FAMA: A Multi-session MAC Protocol for Reliable Underwater Acoustic Streams

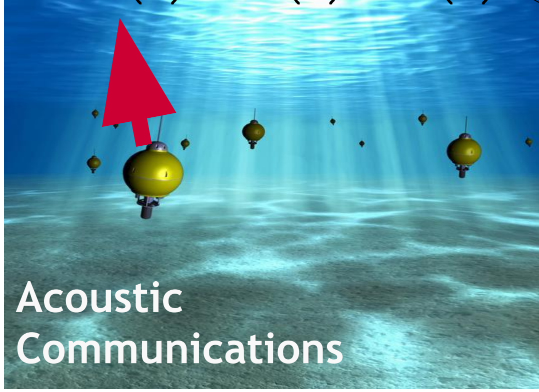
Seongwon Han (UCLA)
Youngtae Noh (Cisco Systems Inc.)
Uichin Lee (KAIST)
Mario Gerla (UCLA)

Network Research Lab
Communication Innovation

SEA-Swarm (Sensor Equipped Aquatic Swarm)

- Monitoring center deploys mobile u/w sensors (and sonobuoys)
- Mobile sensors collect/report data and images to center
- The center performs data analysis
- Applications: untethered aquatic explorations: oil/chemical spill monitoring, anti-submarine missions, surveillance etc.





Example: UCSD Drogues

Acoustic modem
Pressure (depth) sensor
Depth control device
+ Other sensors

Pictures from: http://jaffeweb.ucsd.edu/node/81

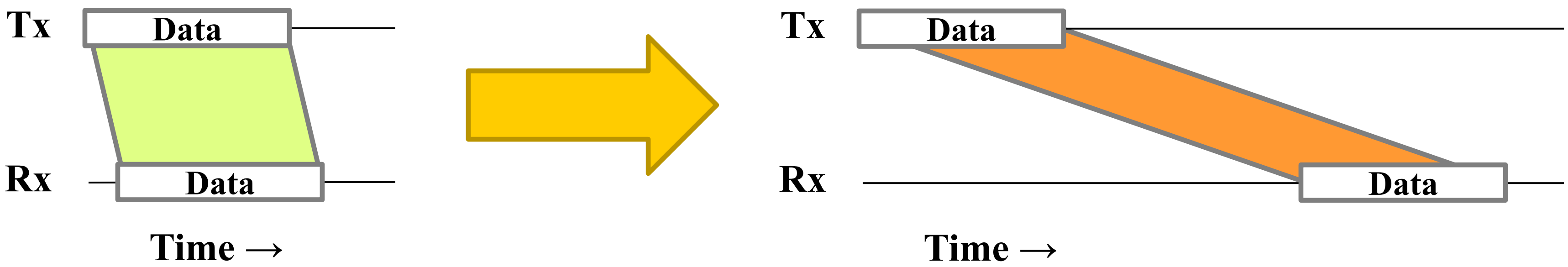
SEA-Swarm Acoustic Channel Limitations

- Long propagation delays
  - Speed of light = 3.0*10 m/s
  - Speed of sound in water = 1,484 m/s
- Low throughput
  - 8-50kbps typical
- High bit error rates
  - Ambient noise
  - Signal scattering/fading
  - Propagation speed affected by differences in temperature, pressure, and salinity
- Node mobility due to currents (about 1 m/s)

Acoustic Channel Limits (cont)

Propagation delay is the biggest problem!

- Significance?
  - Longer propagation → channel occupied longer

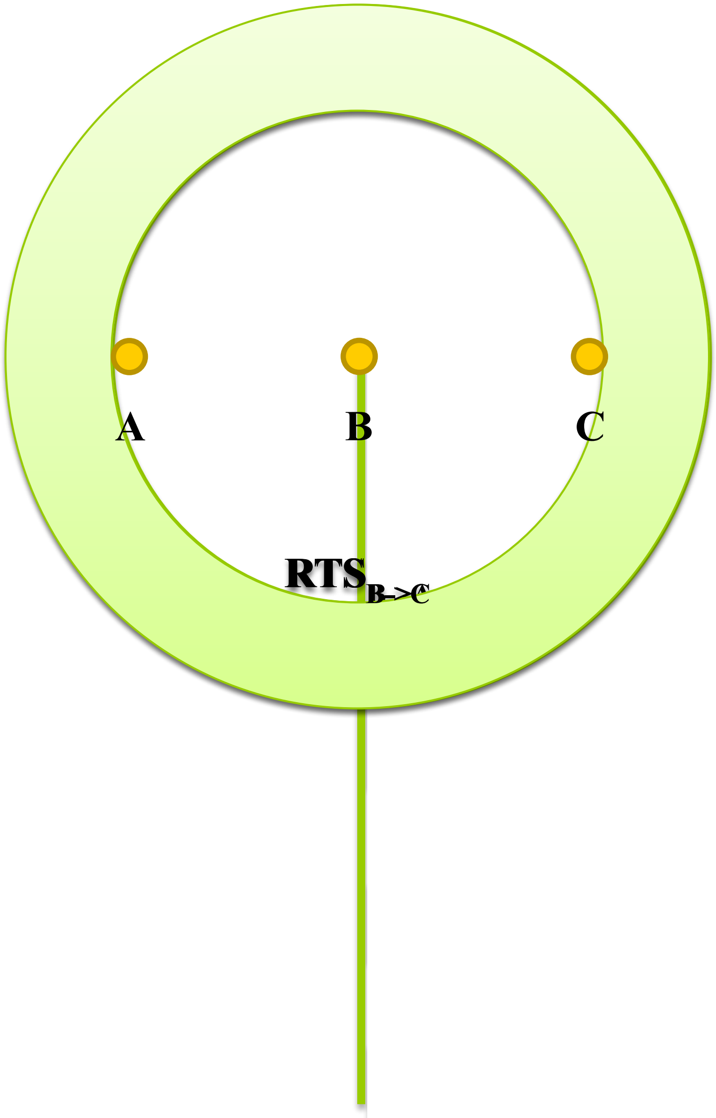


  - Most UW MAC protocols transmit one message at a time (no pipelining)
  - **Our Solution -> Channel Reuse!**
  - **Main assumption : Time Synchronization**

Sync for High Latency (TSHL) on Underwater Acoustic Networking plaTform (UANT) [Syed et al., INFOCOM'08]

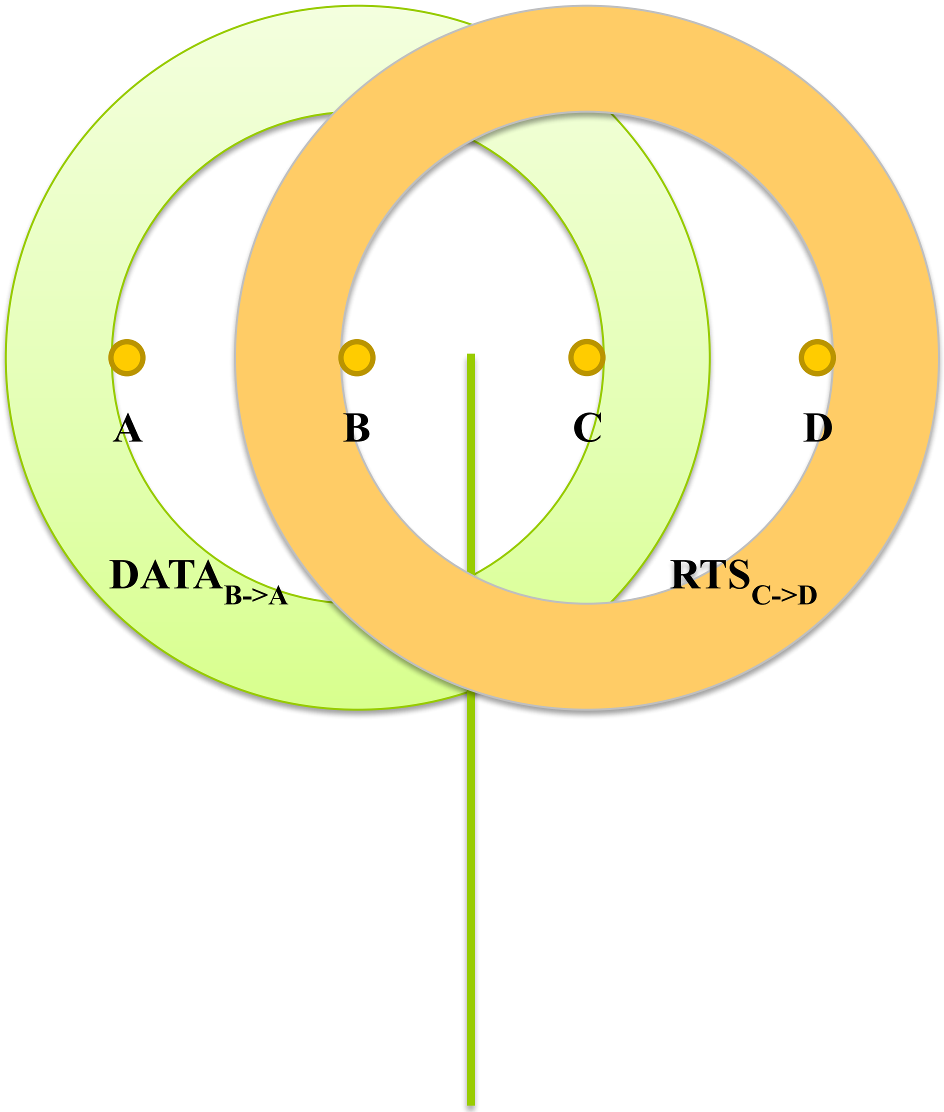
Temporal Reuse

- Allows **one sender** to send communications to multiple nodes (overlapping during propagation time)



Spatial Reuse

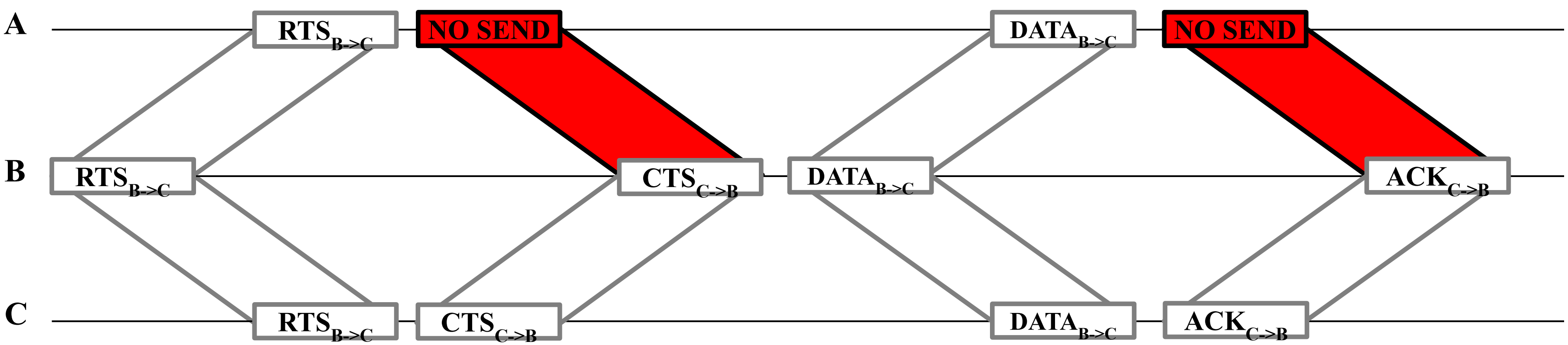
- Allows **different senders** to transmit to different receivers over the same channel space



Delay Map Creation

To harness temporal and spatial reuse

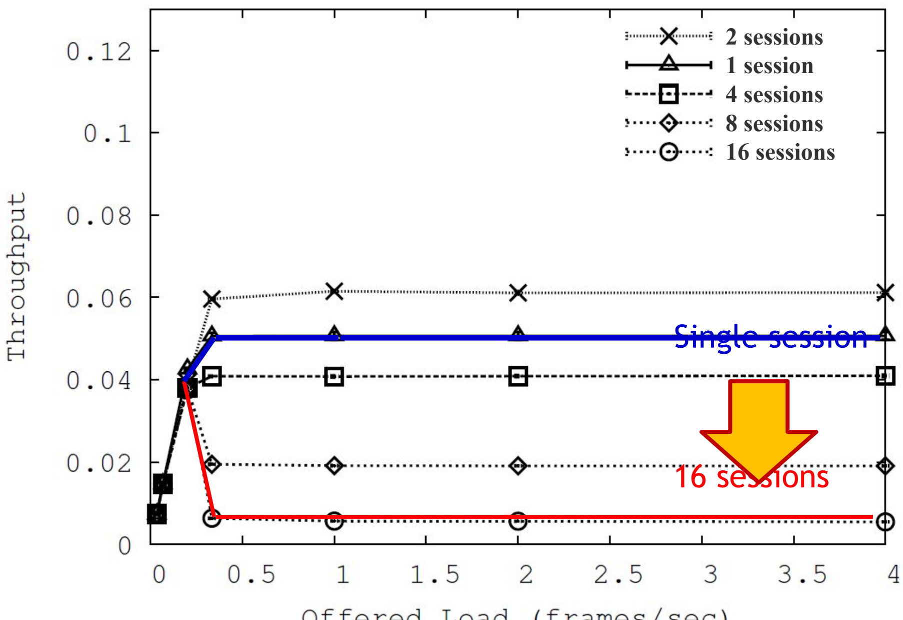
- Using passively overheard packet information
  - Timestamp with time Sync Time
  - Data length
  - Expected propagation delays
- With this basic idea, we can use overheard messages to predict future transmissions to avoid a collision (the delay map)



M-FAMA Design Issues

Naïve approach

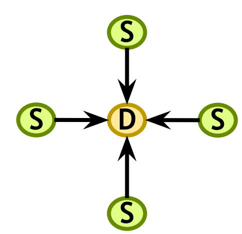
- Our initial approach involved opening a new session any time a network-layer message arrived and no collision would occur
- This approach was fine with one single session at a time; it leads to spatial capture (poor fairness) in multi session scenarios



4 senders 1 sink (high contention)

Problem: irrational Increase of active sessions will not increase the throughput

We cannot avoid collisions between RTSs exchange!



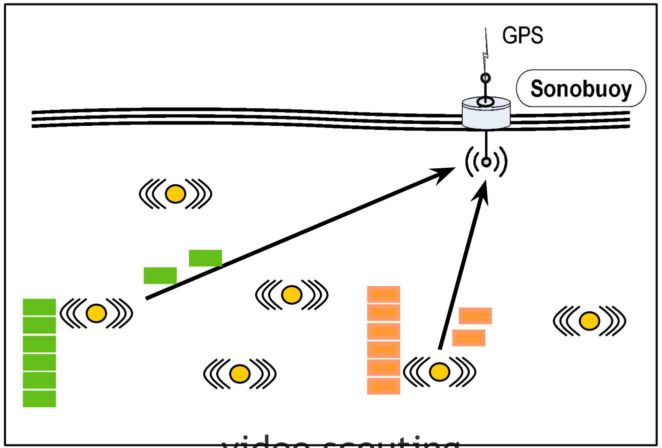
M-FAMA Contributions

Fairness and Congestion protection

- We address **fairness** using Bandwidth Balancing
- **Cong control** - two protocols (with Bandwidth Balancing):
  - **M-FAMA Conservative**
  - **M-FAMA Aggressive**

Objective

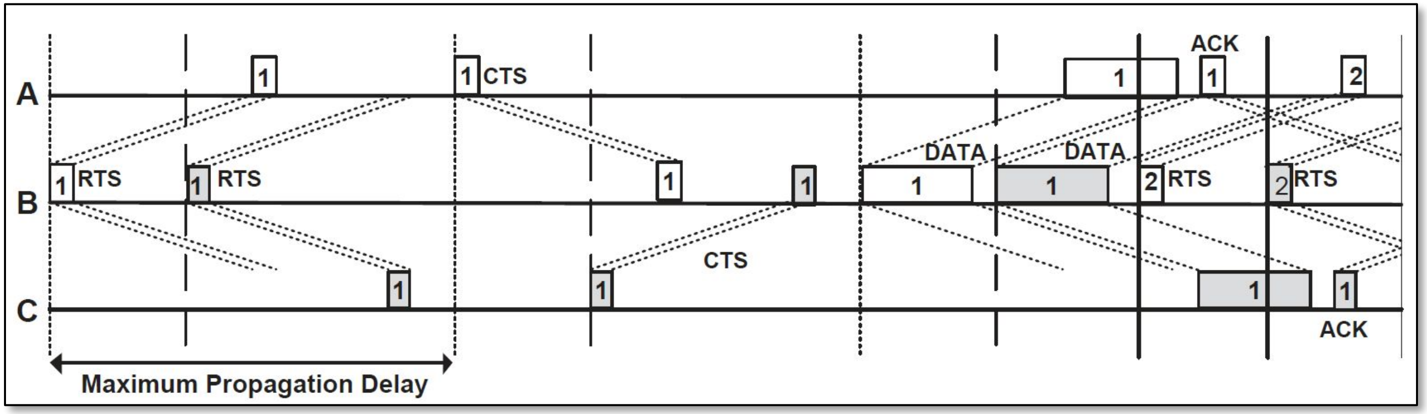
- **Provide high throughput & fairness**
- **Support node mobility**
- **M-FAMA is useful for video scouting**



video scouting

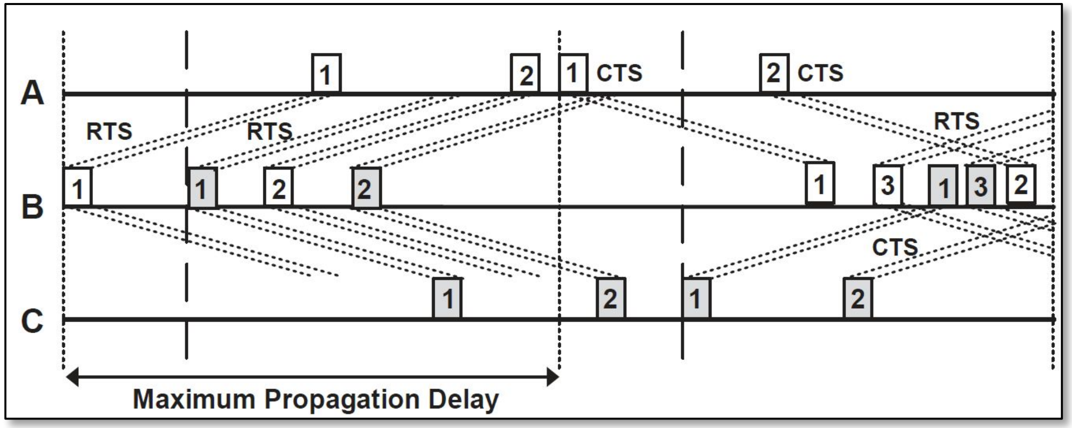
M-FAMA Conservative

- Before sending an RTS to open a new session, validate against delay map to ensure no collisions
- If a collision is anticipated, reattempt the session after a backoff period
- If there is already a session open to the intended destination, withhold the new RTS until the current DATA packet is transmitted.
  - BUT it can freely open new sessions with different destinations, taking advantage of spatial reuse
- M-FAMA Conservative limits pipelining to prevent unfairness



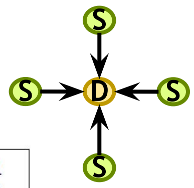
M-FAMA Aggressive

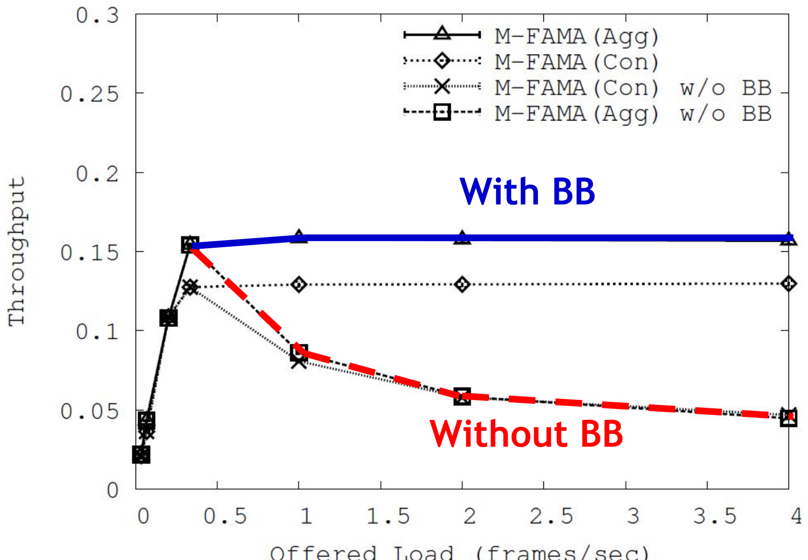
- Designed to provide higher throughput in cases of low channel contention
- Before sending an RTS to open a new session, validate against delay map to ensure no collisions
- Unlike M-FAMA Conservative, a new session can be opened any time regardless of previous sessions to same destination
  - Allow a sender to open as many sessions per destination as the propagation delay permits



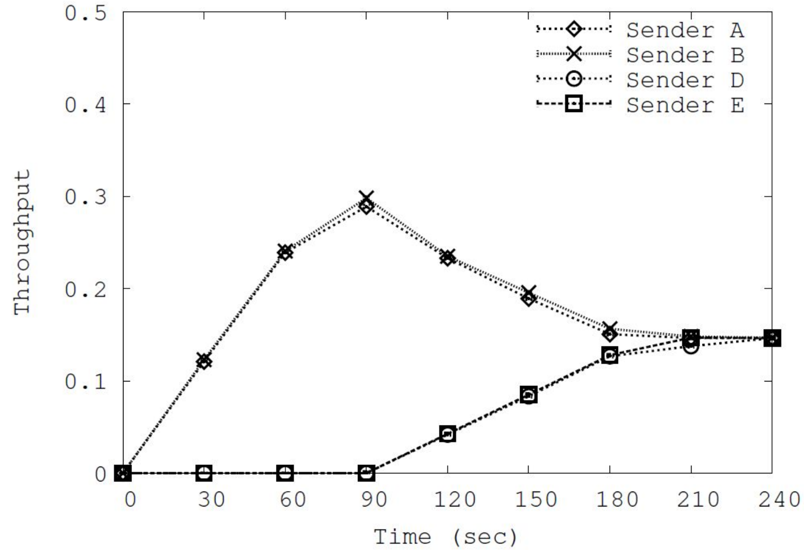
Bandwidth Balancing

- M-FAMA is a greedy protocol that attempts to maximize throughput at the expense of fairness
- To fix this -> Bandwidth Balancing algorithm
  - Each source measures over a proper history window, the residual (unused) bandwidth of the channel
  - Instead of adjusting the data submission rate, in M-FAMA, BB decides when to allow extra sessions based on observed residual bandwidth
  - Guarantees max-min fairness across multiple contending sources



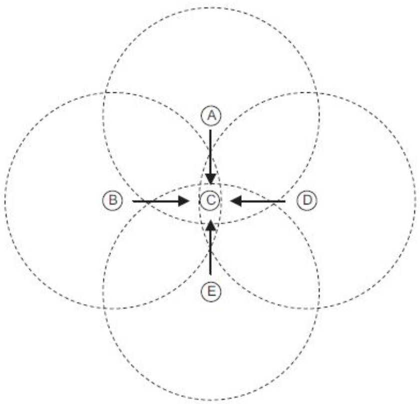


4senders-1sink: Bandwidth Balancing

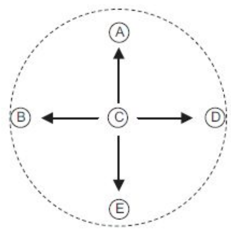


4senders-1sink: throughput convergence

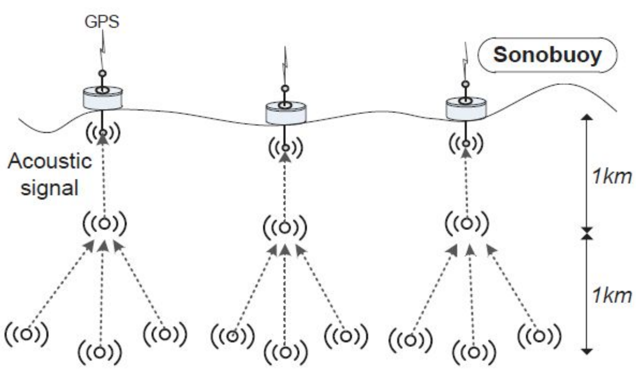
Simulation Setup



(a) 4-Senders 1-Sink



(b) 1-Sender 4-Sinks



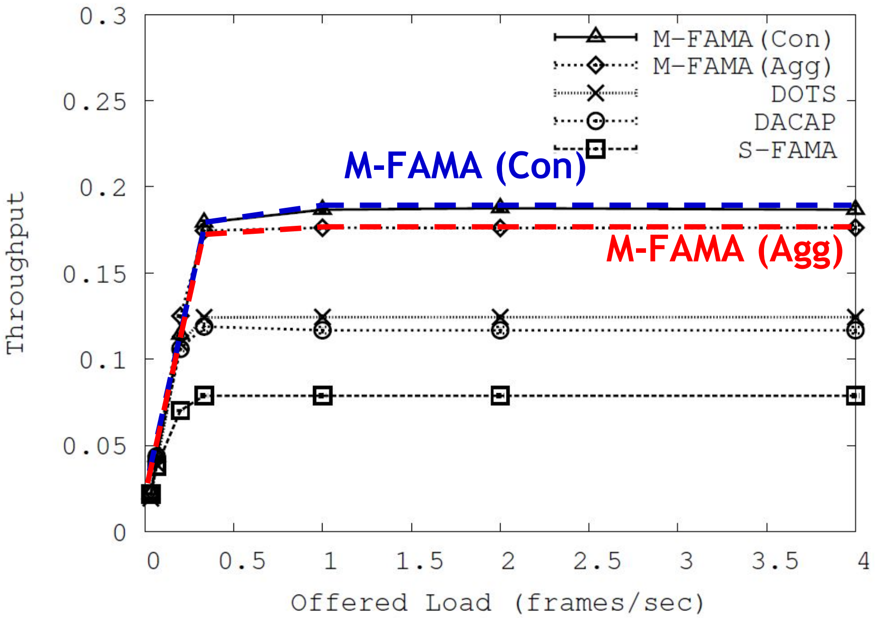
(c) Sea Swarm (tree)

- QualNet enhanced with an acoustic channel model
  - Urick's u/w path loss model: $A(d, f) = d^k a(f)^d$ where distance d, freq f, absorption $a(f)$
  - Rayleigh fading to model small scale fading
- Data rate is set to 16kbps
- The packet size is 128bytes
- The load is varied between generating a single frame every 30 sec down to a single frame every 0.25sec
- Mobility model: 3D version of Meandering Current Mobility (MCM) [INFOCOM'08]

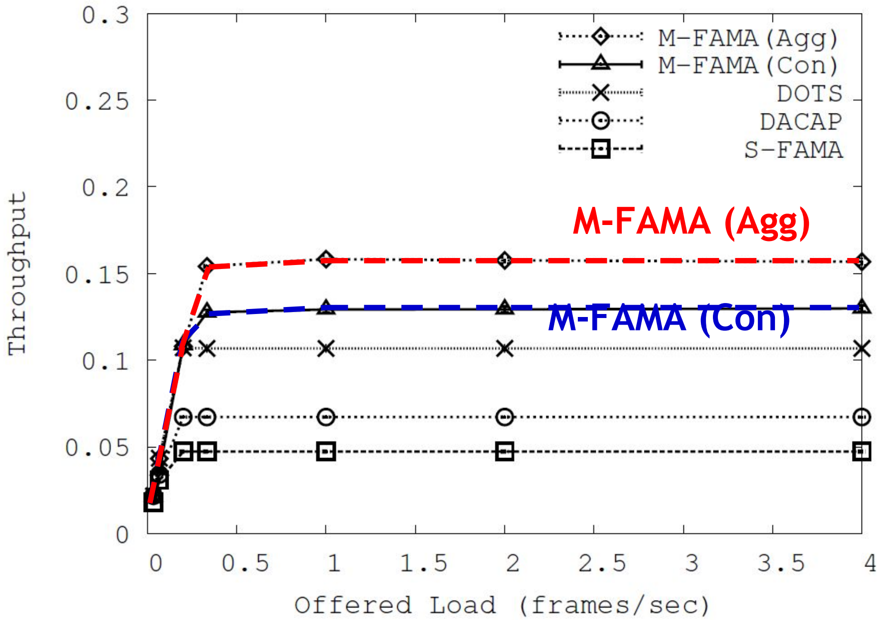
Topology

- 4-senders 1-Sink : aggressive traffic
- 1-sender 4-sinks
- Sea Swarm (tree)
- Random

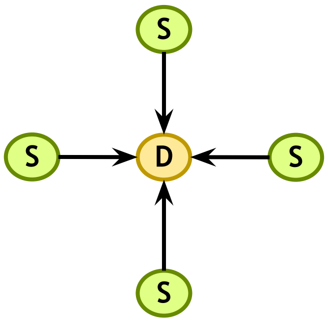
Results: 4-Senders 1-Sink Topology



4-Senders 1-Sink: tx range of 750m



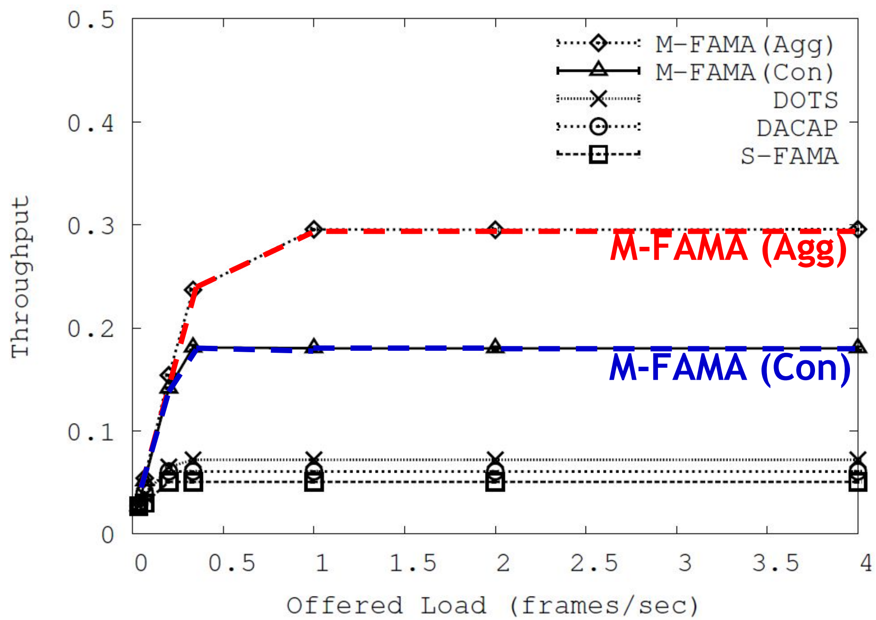
4-Senders 1-Sink: tx range of 1500m



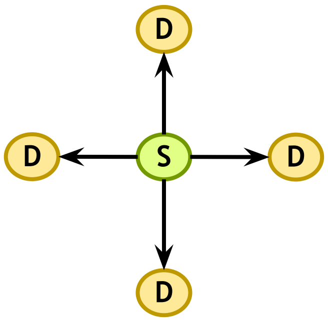
$$\text{Offered Load} = \frac{\#\text{ of generated } \textit{data} \text{ frames} \times \text{Data size}}{\text{Simulation Duration} \times \text{Data rate}}$$

$$\text{Throughput} = \frac{\#\text{ of rx } \textit{data} \text{ frames} \times \text{Data size}}{\text{Simulation Duration} \times \text{Data rate}}$$

Results: 1-Sender 4-Sinks Topology



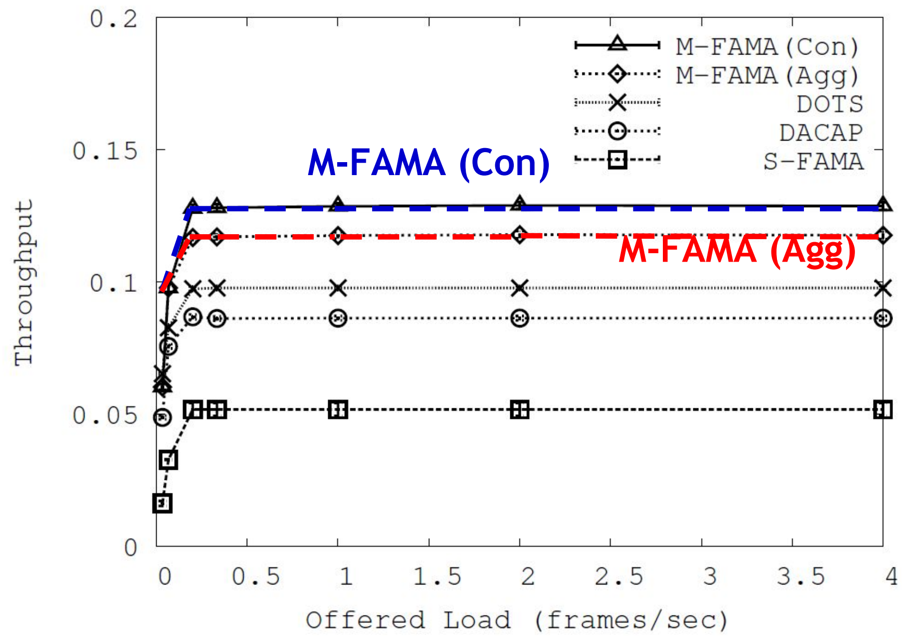
1-Sender 4-Sinks: tx range of 1500m



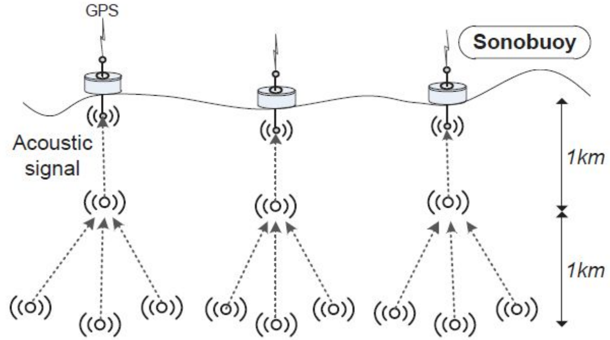
$$\text{Offered Load} = \frac{\#\text{ of generated } data \text{ frames} \times \text{Data size}}{\text{Simulation Duration} \times \text{Data rate}}$$

$$\text{Throughput} = \frac{\#\text{ of rx } data \text{ frames} \times \text{Data size}}{\text{Simulation Duration} \times \text{Data rate}}$$

Results: Sea Swarm (tree) Topology



Sea swarm (tree)

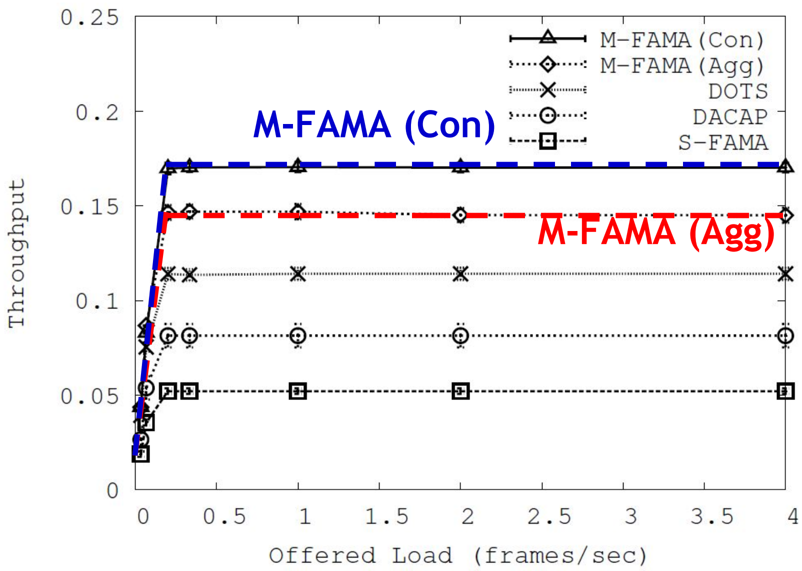


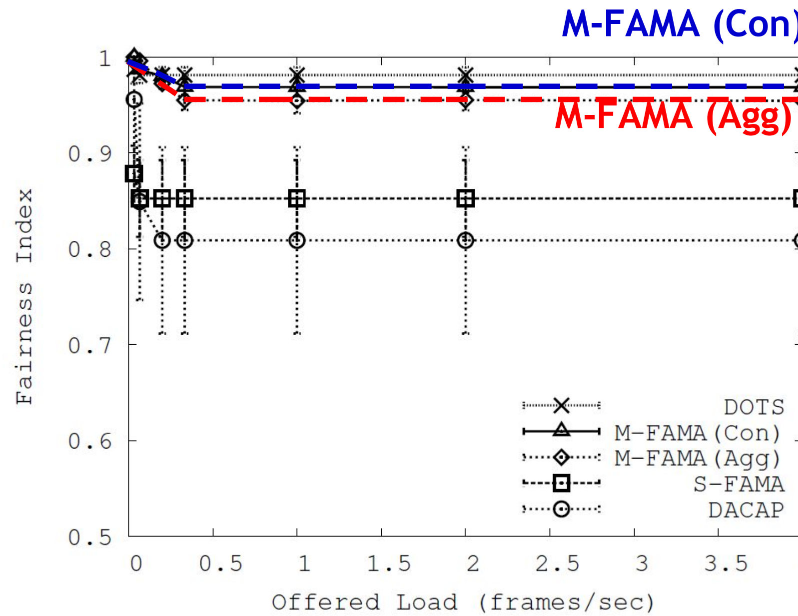
Sea Swarm (tree)

$$\text{Offered Load} = \frac{\#\text{ of generated } data \text{ frames} \times \text{Data size}}{\text{Simulation Duration} \times \text{Data rate}}$$

$$\text{Throughput} = \frac{\#\text{ of rx } data \text{ frames} \times \text{Data size}}{\text{Simulation Duration} \times \text{Data rate}}$$

Results: random topology w/ MCM

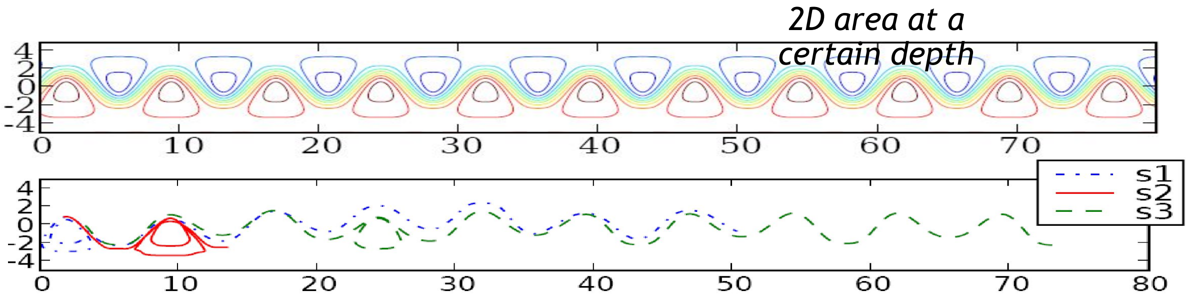




10 nodes (5 pairs) are randomly deployed in a 3D cube with dimensions (866m*866m*866m)

Jain's Fairness Index

- **Mobility : MCM (0.3m/s)**



Example trajectories of three nodes: s1, s2, s3

Meandering Current Mobility (MCM) [INFOCOM'08]

Conclusion

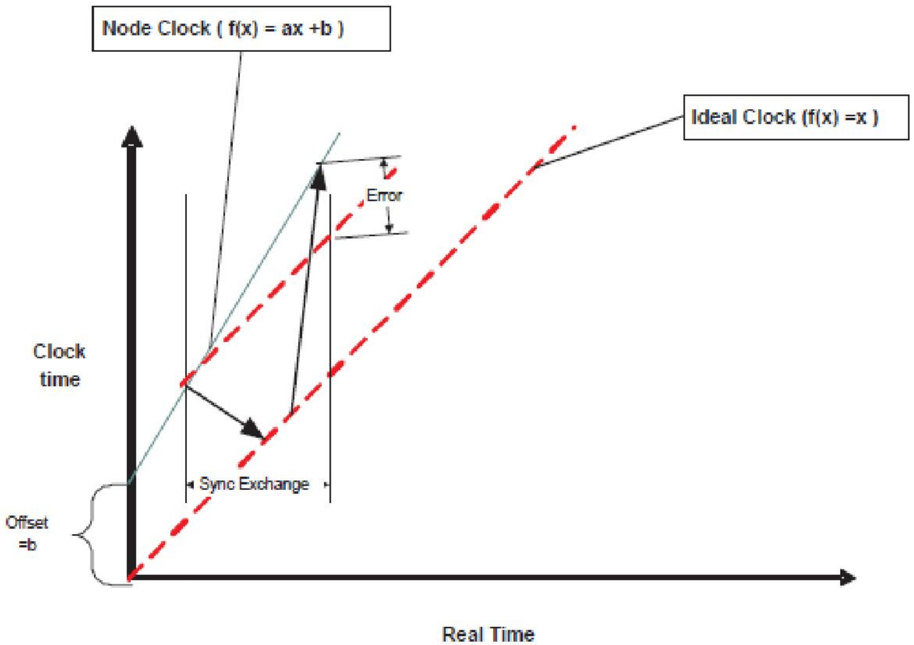
Long propagation delay permits multiple packets “pipelining”

M-FAMA:

- Supports packet pipelining on the same link with significant throughput improvement
- Achieves temporal/spatial reuse on multiple links concurrently
- It supports node’s mobility yet avoiding collisions by careful accounting of neighbors’ transmission schedules
- M-FAMA’s greedy behavior is controlled by a Bandwidth Balancing algorithm that guarantees max-min fairness

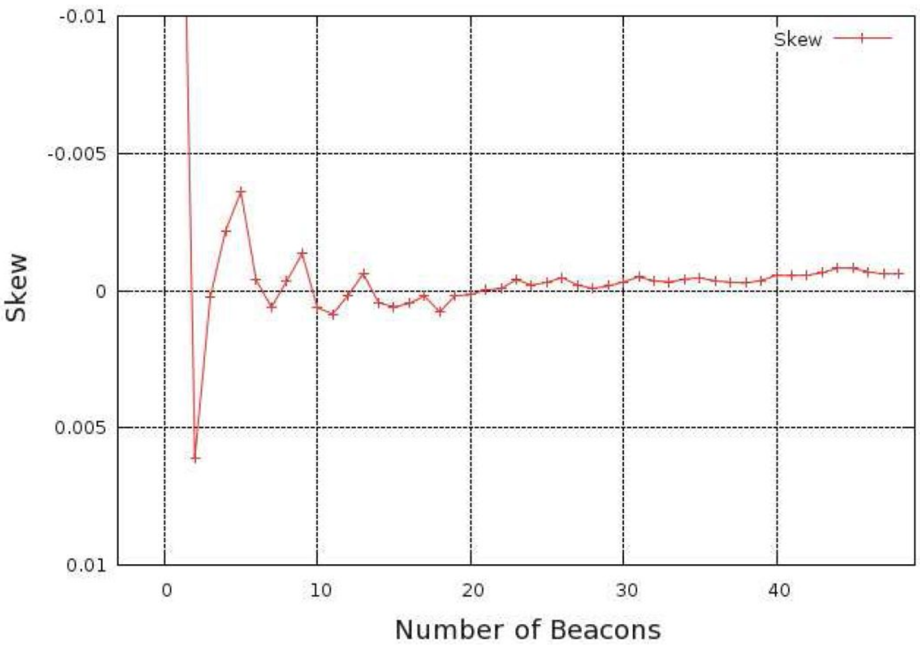
Q&A

Time Synchronization



- Implement Time Sync for High Latency (TSHL) (Syed et al., INFOCOM'08) on Underwater Acoustic Networking plaTform (UANT)
- Clock offset:
  - Requires 2 msg exchanges
- Clock rate:
  - Requires about 10 msg exchanges
  - Computes a linear regression
- Dedicated h/w will decrease # of msgs
- Overhead of periodic resynchronization can be reduced by reference clock

Time Synchronization



- Implement Time Sync for High Latency (TSHL) (Syed et al., INFOCOM'08) on Underwater Acoustic Networking plaTform (UANT)
- Clock offset:
  - Requires 2 msg exchanges
- Clock rate:
  - Requires about 10 msg exchanges
  - Computes a linear regression
- Dedicated h/w will decrease # of msgs
- Overhead of periodic resynchronization can be reduced by reference clock