MU-Sync: A Time Synchronization Protocol for Underwater Mobile Networks

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Outline

- Overview of the Problem
- MU-Sync Design
- Simulation Results
- Conclusions & Future Works

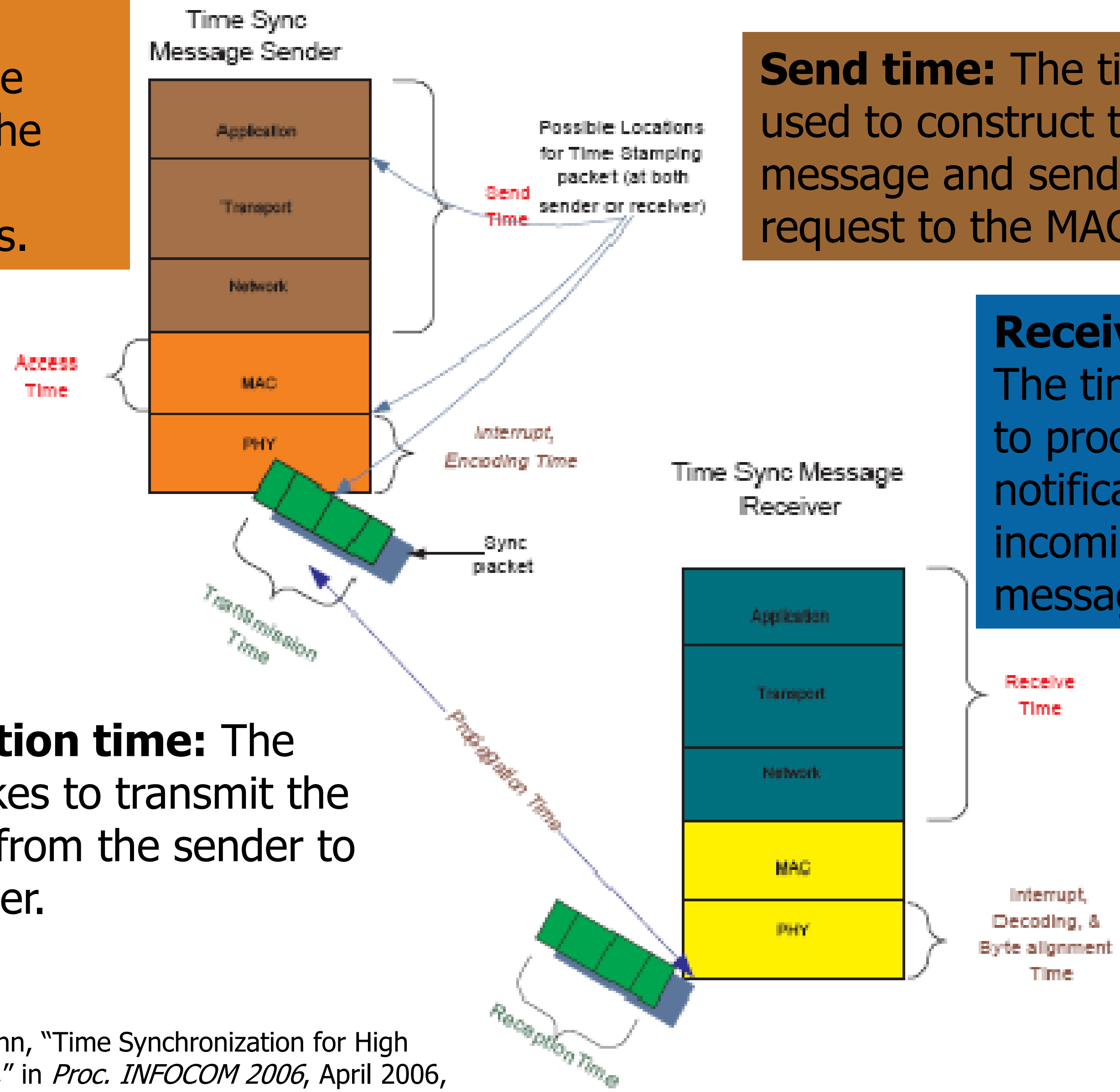
Overview of Underwater Mobile Networks

- Energy limitations (Battery operated)
- Low data rates
- Long propagation delays (1.5 sec / km)
- Time-varying propagation delay

Causes of Errors: Uncertainty of Message Delivery time

Access time: The delay incurred while waiting to access the channel until the transmission begins.

Send time: The time used to construct the message and send the request to the MAC layer.



Receive time: The time it takes to process the notification of an incoming message.

Propagation time: The time it takes to transmit the message from the sender to the receiver.

* Figure taken from [3]

[3] A. A. Syed and J. Heidemann, "Time Synchronization for High Latency Acoustic Networks," in *Proc. INFOCOM 2006*, April 2006,

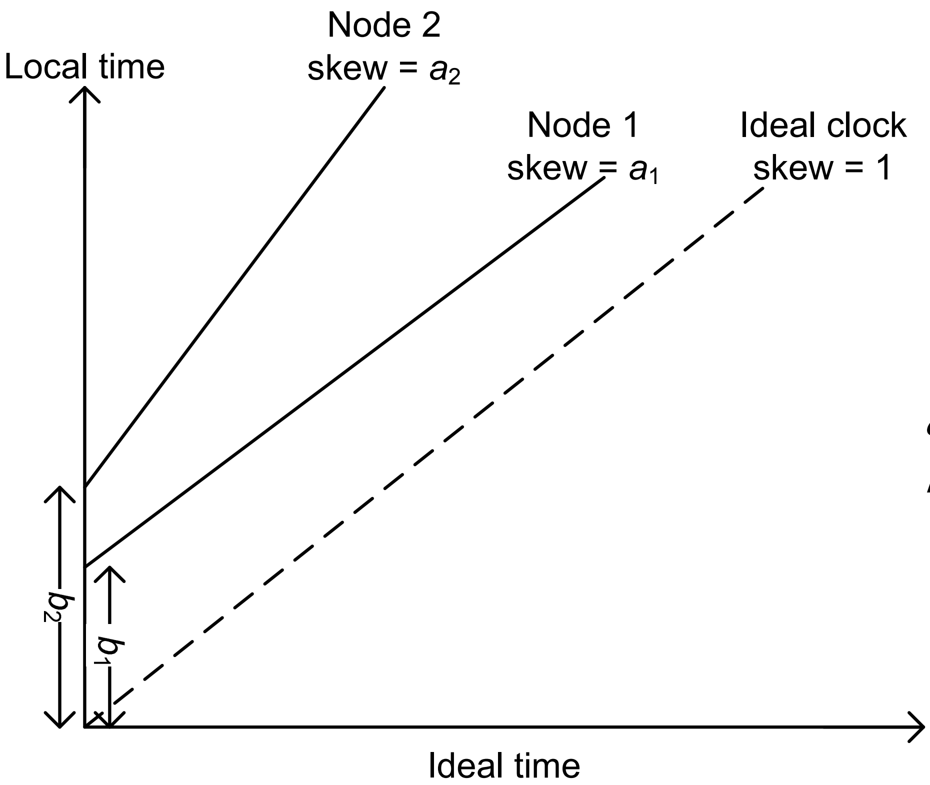
Causes of Errors: Other causes of errors

- **Change of Environment:**
  temperature, pressure, battery voltage

- **The interaction of other component**

  Ex. The sensor may miss interrupt while busy transmitting or receiving a packet

Clock drift between nodes



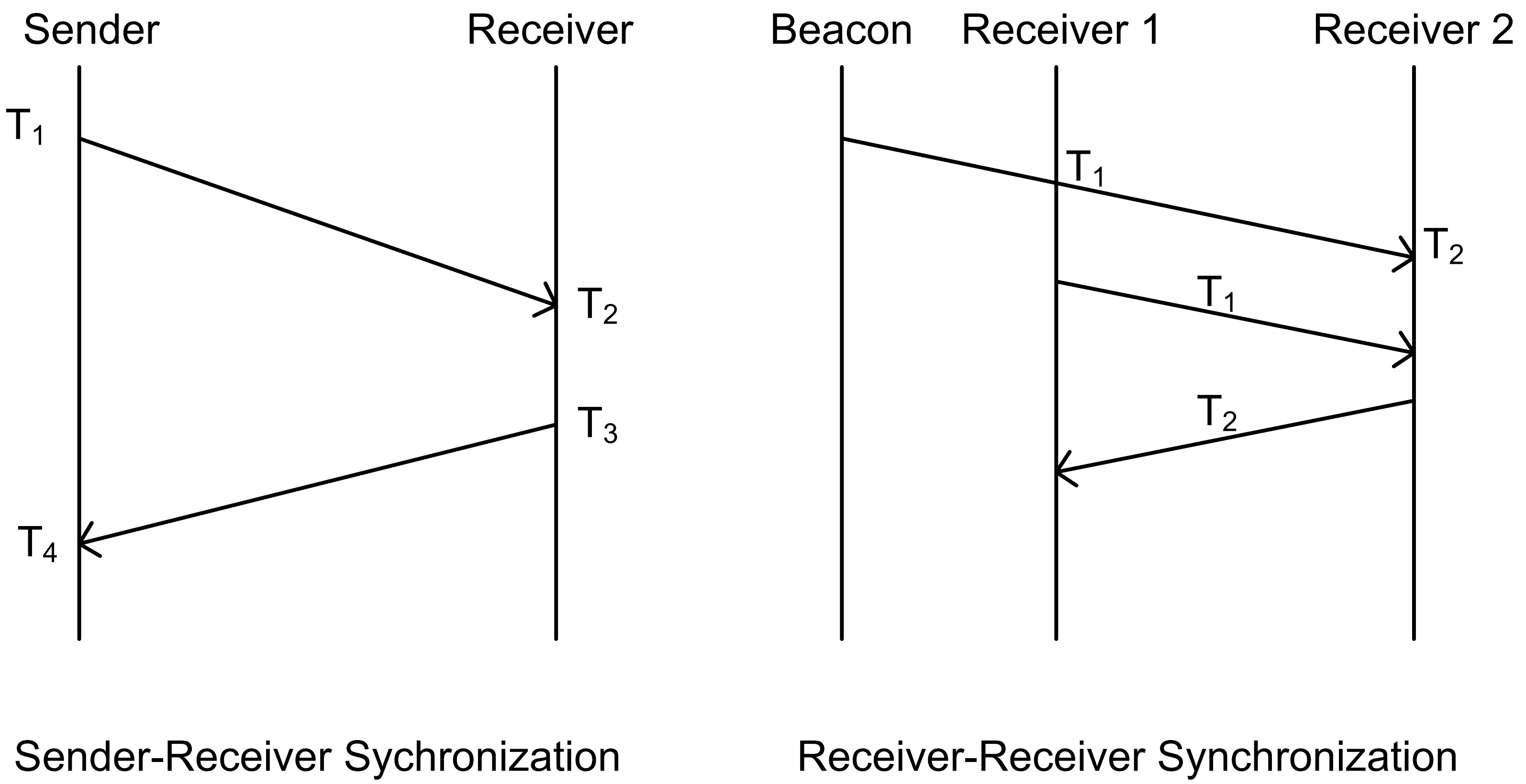
$$T_i(t) = a_i t + b_i$$

$T_i(t)$ = Local time of Node i at time t

a_i = Node i's skew

b_i = Node i's offset

Clock synchronization approaches: Sender-Receiver VS Receiver-Receiver



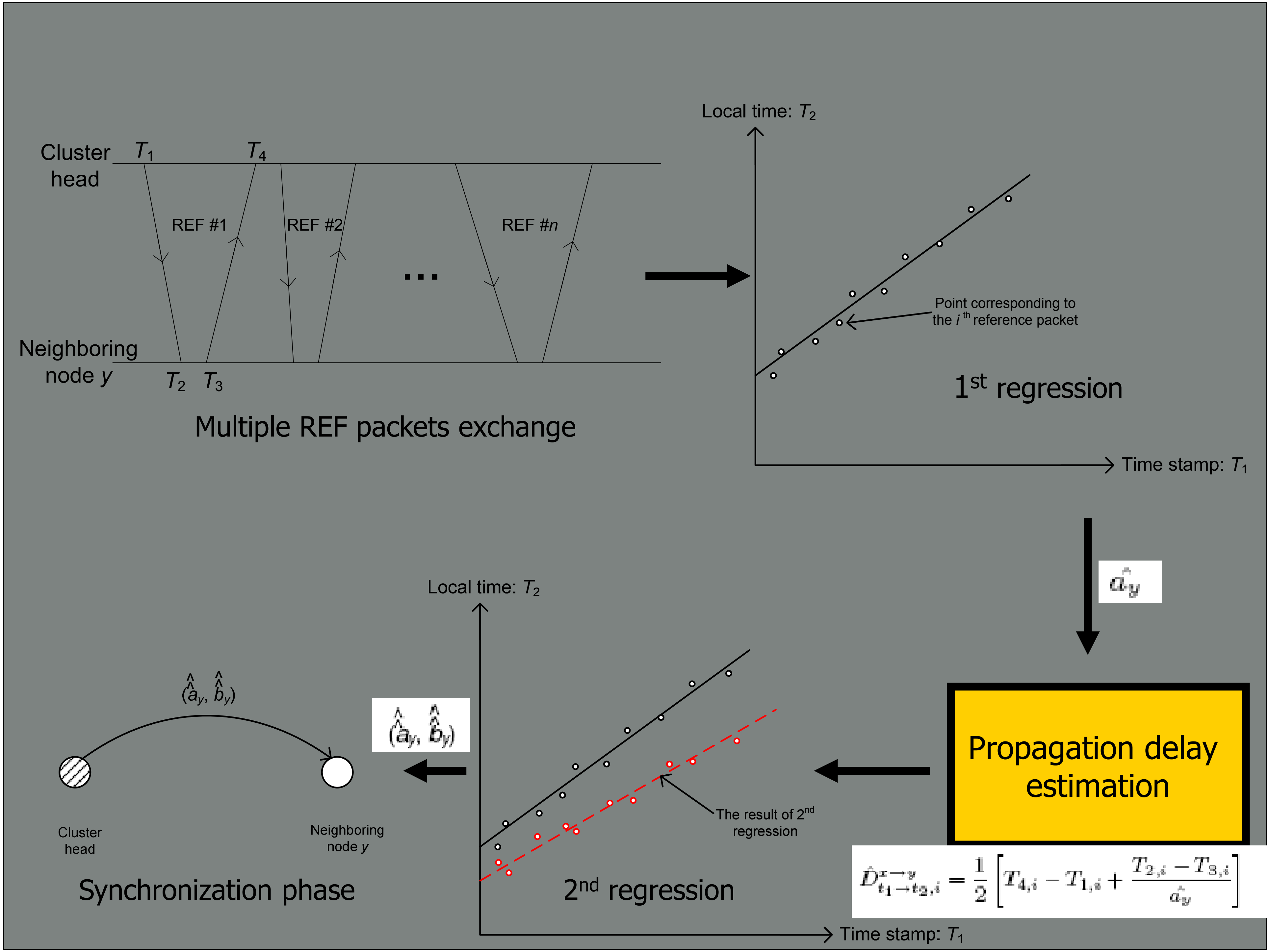
Overview of MU-Sync

- Cluster-based algorithm –
  Cluster head calculates both skew and offset for all its neighboring nodes
- Estimate both skew and offset –
  less frequent re-synchronization
- MAC time stamping –
  reduce the non-deterministic errors
- Two-way message exchange technique –
  able to extract the propagation delay
- Linear regression twice –
  offset the time-varying propagation delay

2 phases of operation

- skew and offset acquisition phase
  - output: The estimated skew and offset of neighboring nodes $(\hat{a}_y, \hat{b}_y)$

- synchronization phase
  - output: All nodes in cluster are synchronized.



Cluster head
T_1
T_4
REF #1
REF #2
REF #n
...
Neighboring node y
T_2 T_3
Multiple REF packets exchange
Local time: T_2
Point corresponding to the i th reference packet
1st regression
Time stamp: T_1
$\hat{a}_y$
Propagation delay estimation
$$\hat{D}^{x\to y}_{t_1\to t_2,i} = \frac{1}{2}\left[T_{4,i} - T_{1,i} + \frac{T_{2,i} - T_{3,i}}{\hat{a}_y}\right]$$
Local time: T_2
The result of 2nd regression
2nd regression
Time stamp: T_1
$(\hat{a}_y, \hat{b}_y)$
$(\hat{a}_y, \hat{b}_y)$
Cluster head
Neighboring node y
Synchronization phase

Simulation Setup

- 1000 m x 1000 m
- No skew variation
- Nondeterministic errors are Gaussian distribution of 15 μs.
- V_{max} = 2 m/s
- Clock skew = 40 ppm
- Clock offset = 10 ppm
- No. of beacons = 25
- $t_3 - t_2$ = 0 s.
- Time interval between two REFs = 5 s.

Benchmarking algorithm

- **TSHL (Time Synchronization for High Latency) [3]**

  - Estimate and compensate both skew and offset

  - MAC-layer time stamping

  - Bi-directional message exchange

  - Neighboring node calculates its own skew and offset

  - Assume no mobility
  (account only the long propagation delay)

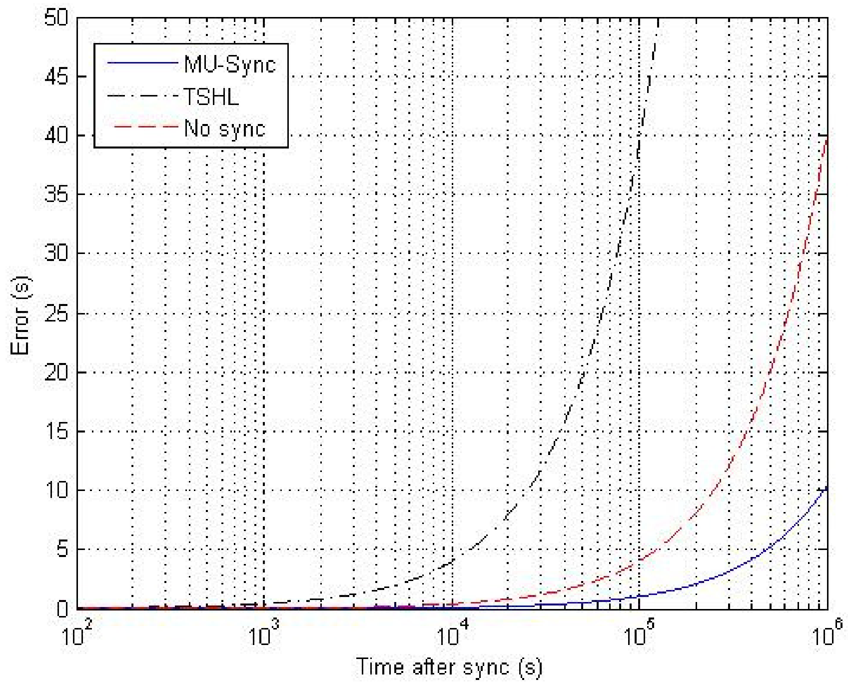
[3] A. A. Syed and J. Heidemann, "Time Synchronization for High Latency Acoustic Networks," in *Proc. INFOCOM 2006*, April 2006.

Parameters to be investigated

- The error after synchronization
- The node's initial skew
- The duration of t_3-t_2
- The frequency at which the sensors change direction
- The speed of the sensors

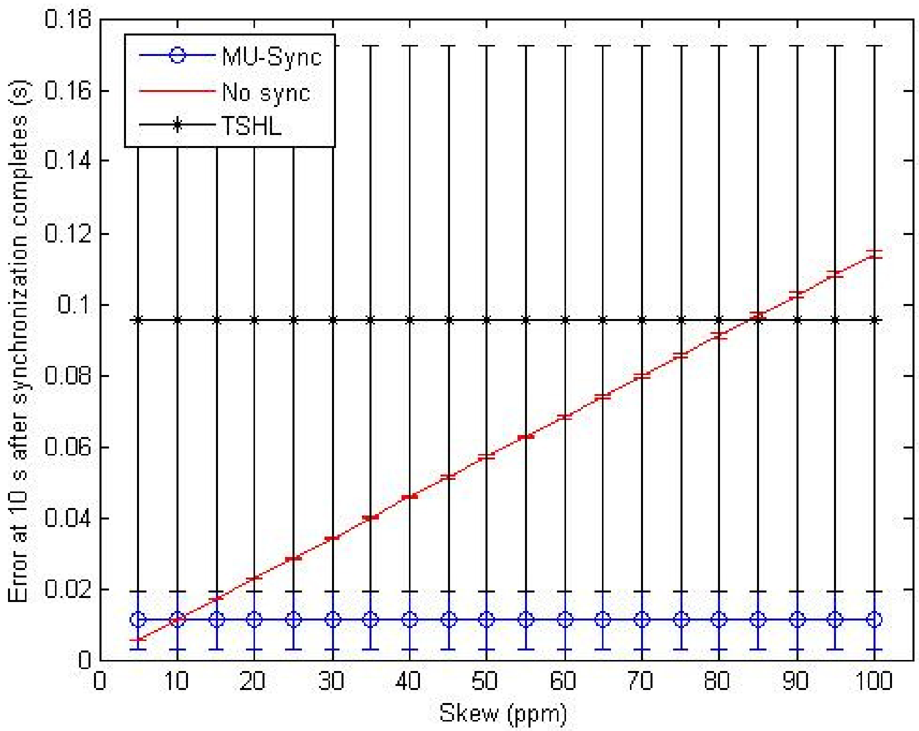
All the simulation results shown here are the average of 1000 runs.

The error in time estimation VS the time elapsed since synchronization



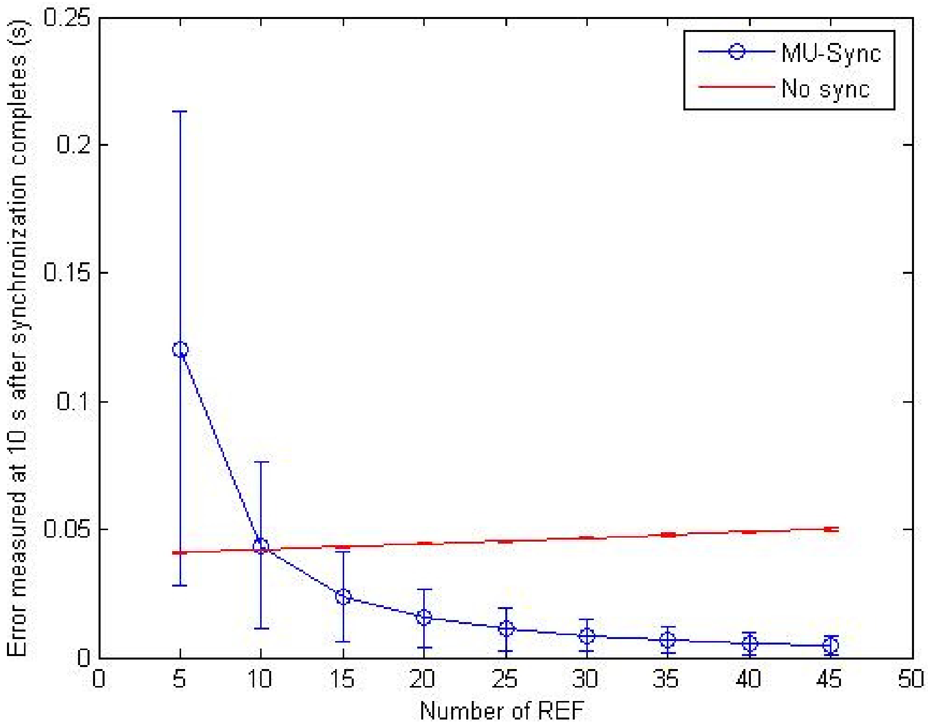
- MU-Sync outperforms all other schemes.
- Poor performance of TSHL is due to the poor skew estimation.

Effect of clock skew



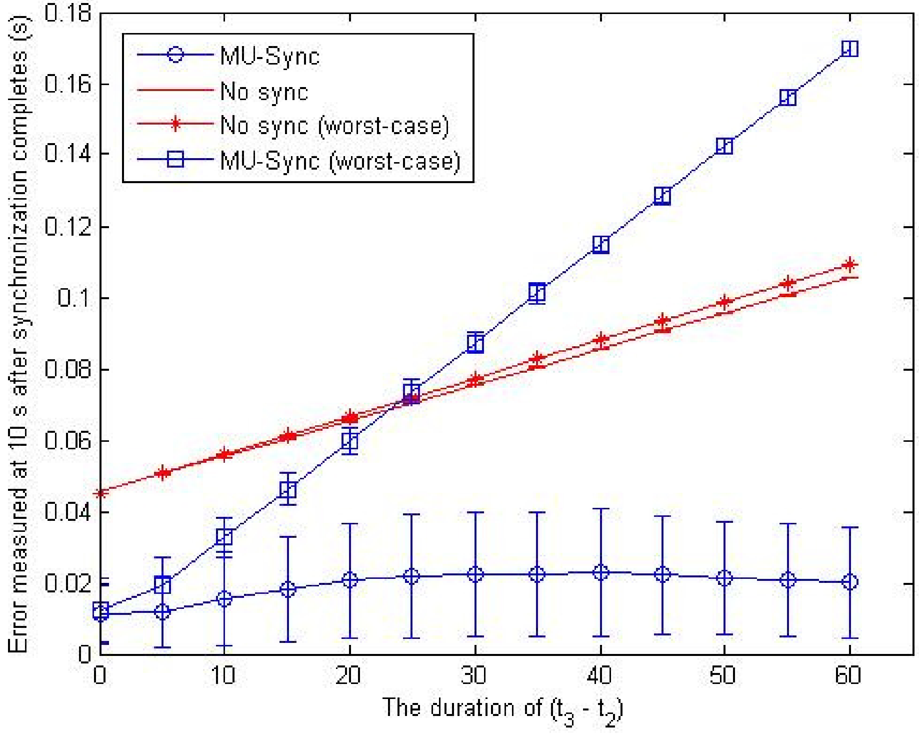
- MU-Sync's performance is independent of clock skew.
- Constant error for MU-Sync and TSHL is due to the skew compensation.
- Large std in TSHL is caused by the time-varying propagation delay.

Effect of the number of REF beacons on synchronization error



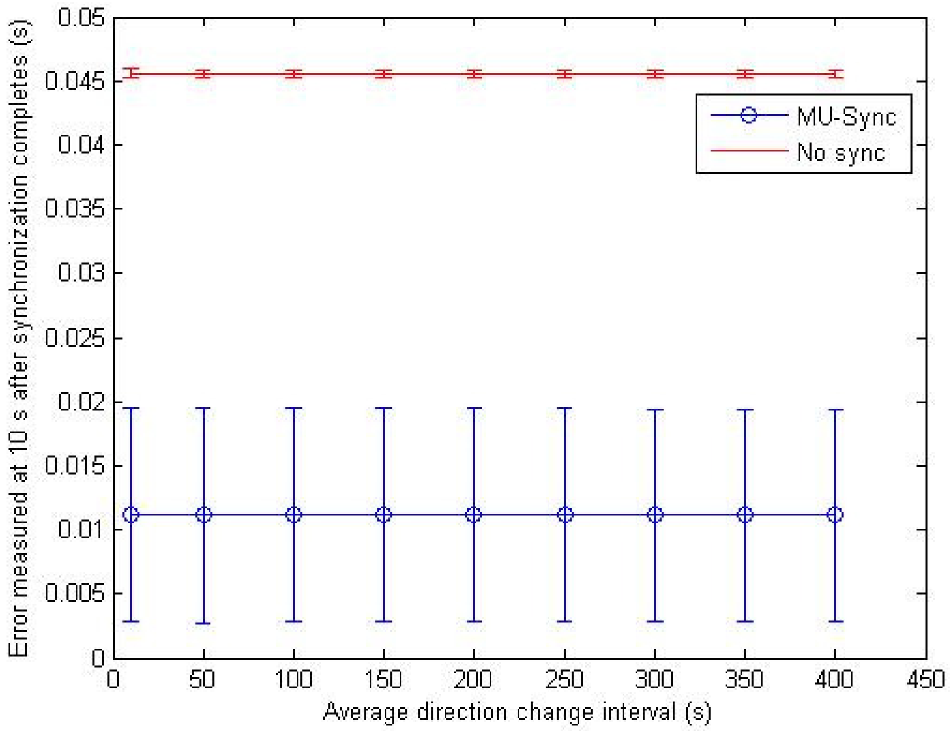
- Higher no. of beacons →lower error in estimation
- Finer synchronization can be achieved by adjusting the no. of REF beacons
- However, the larger no. of beacons, the longer it takes to synchronize.

Effect of (t_3-t_2) on synchronization error



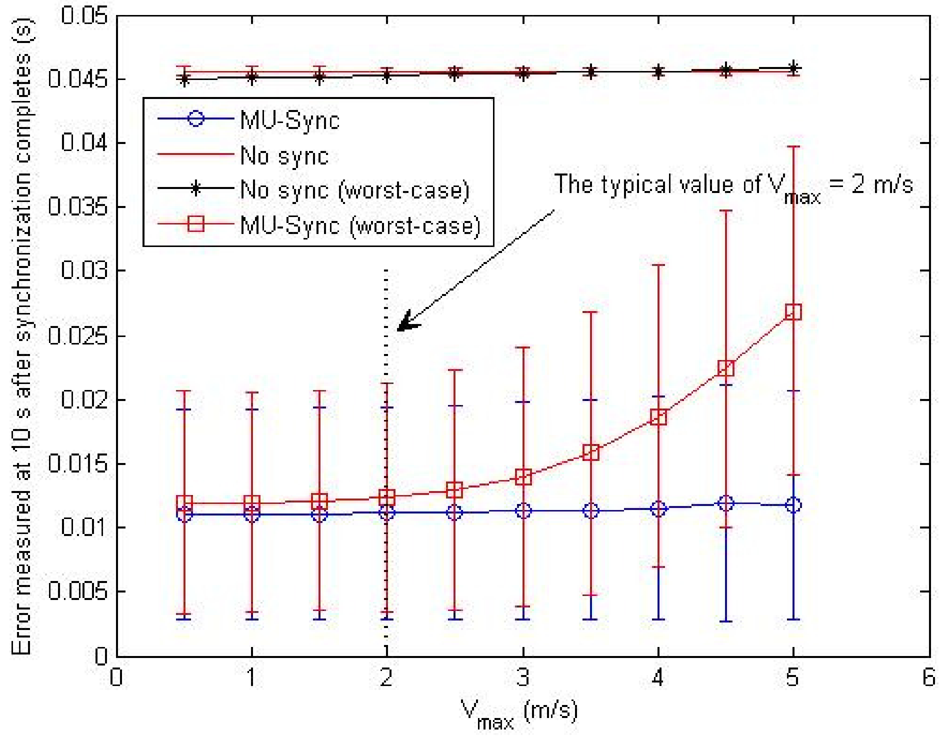
- t_3-t_2 does not directly affect the error, but the relative distance between nodes.
- Confirm by looking at the MU-Sync (worst-case)
- However, the effect is less significant when nodes move in random.

The effect of the average direction change interval



- No significant effect

Effect of sensor's speed on synchronization error



- Error increases with the increasing of sensor's speed (MU-Sync, worst-case).
- Large V_{max} → using half of the RTT may not be accurate enough to estimate the propagation delay.

Conclusions

- We propose MU-Sync, a cluster-based synchronization algorithm for mobile underwater acoustic networks.
- The design takes account of both long and time-varying propagation delay.
- Its accuracy is highly dependent on the accuracy of the propagation delay estimation.
- Future Work: Inter-node propagation delay estimation algorithm