Impact of MAC on Localization in Large-scale Seabed Sensor Networks

Jong-Pil Kim[1] Hwee-Pink Tan[2] Ho-Shin Cho[1]

[1]School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu, (Korea)

[2]Networking Protocols Department, Institute for Infocomm Research (Singapore)

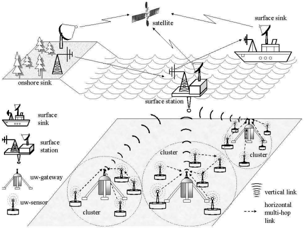
KNU

A*STAR Institute for Infocomm Research

Outline

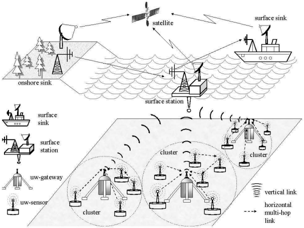
Motivation

- Large-scale Underwater Seabed Sensor Networks for offshore engineering, e.g., deepwater mooring systems
  - Measurement of foundation strength and mooring tensions and dissemination via *acoustic communications*
  - *Long-duration* deployments preferred due to high costs



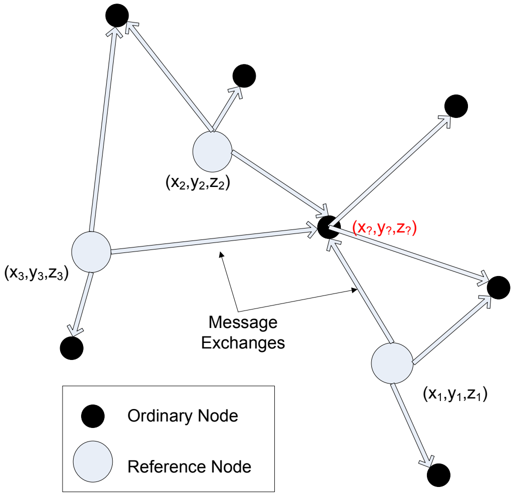
Motivation

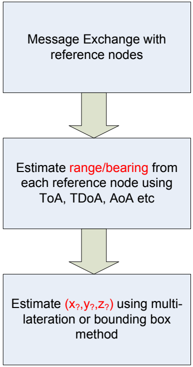
- Large-scale Underwater Seabed Sensor Networks for offshore engineering, e.g., deepwater mooring systems
  - Measurement of foundation strength and mooring tensions and dissemination via *acoustic communications*
  - *Long-duration* deployments preferred due to high costs



- Location of sensors needed for meaningful interpretation of sensed data
  - Use of GPS infeasible for seabed (2D) nodes
  - At least 3 pre-positioned nodes as *reference* nodes
  - Exchange of messages underwater needed to localize *ordinary* (non-reference) nodes

Fundamentals - Range-Based Localization





Single vs Multi-Stage

Range-based localization can be classified according to the characteristics of ordinary nodes:

Single vs Multi-Stage

Range-based localization can be classified according to the characteristics of ordinary nodes:

Single-stage

- Each ordinary node only exchange messages *directly* with the reference nodes;
- Once localized, it does not contribute towards localizing other ordinary nodes.

Single vs Multi-Stage

Range-based localization can be classified according to the characteristics of ordinary nodes:

Single-stage

- Each ordinary node only exchange messages *directly* with the reference nodes;
- Once localized, it does not contribute towards localizing other ordinary nodes.

Multi-stage

- Each ordinary node exchange messages with *all* nodes;
- Once localized, it becomes a reference node and helps to localize other ordinary nodes.

Requirements and Challenges for Underwater Localization

Requirements:

- Accurate
- Fast
- Low communications costs
- Wide coverage

Requirements and Challenges for Underwater Localization

Requirements:

- Accurate
- Fast
- Low communications costs
- Wide coverage

Challenges:

- Nodes drift due to underwater currents
- Harsh Underwater Acoustic Channel
- Sparse deployment due to high costs
- Battery-powered nodes

Requirements and Challenges for Underwater Localization

Requirements:

- Accurate
- Fast
- Low communications costs
- Wide coverage

Challenges:

- Nodes drift due to underwater currents
- Harsh Underwater Acoustic Channel
- Sparse deployment due to high costs
- Battery-powered nodes
- $\rightarrow$ **short-range, multi-stage schemes preferred over long-range, single-stage schemes!**

Multi-stage Underwater Positioning

Challenges of multi-stage schemes

- Error propagation
- Node mobility
    - *integrate 3D Euclidean distance estimation with recursive location estimation*
    - *mobility prediction*

Multi-stage Underwater Positioning

Challenges of multi-stage schemes

- Error propagation
- Node mobility
  - *integrate 3D Euclidean distance estimation with recursive location estimation*
  - *mobility prediction*
- Coordination of high volume of message exchanges $\rightarrow$ **Not addressed!**

Multi-stage Underwater Positioning

Challenges of multi-stage schemes

- Error propagation
- Node mobility
  - *integrate 3D Euclidean distance estimation with recursive location estimation*
  - *mobility prediction*
- Coordination of high volume of message exchanges → **Not addressed!**

Our contributions

- Identify suitable MAC schemes for multi-stage underwater localization
- Evaluate localization performance in terms of coverage, speed and communications costs

Recursive Position Estimation

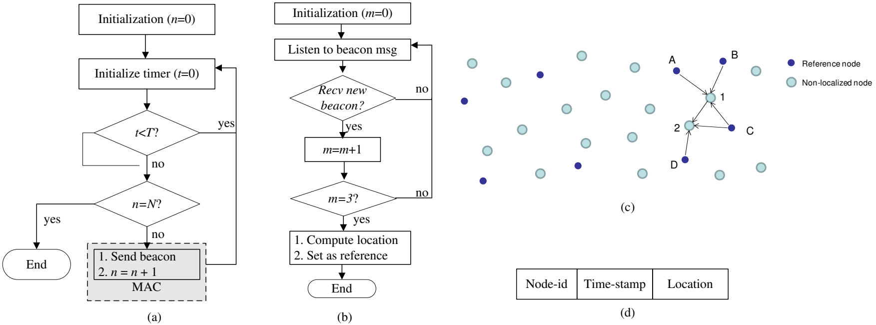


Figure: Localization procedure for (a) reference and (b) ordinary node, (c) illustration and (d) beacon structure

Medium Access Control

Most proposed underwater MAC schemes not suitable for localization

- Ordered CSMA: Difficult to determine transmission order for large scale networks
- FAMA and MACA-MN: reference node does not know number of CTS packets needed

Medium Access Control

Most proposed underwater MAC schemes not suitable for localization

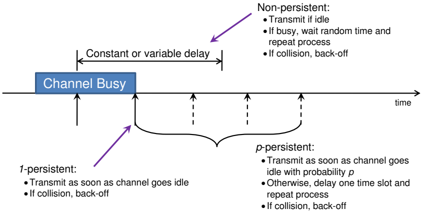
- Ordered CSMA: Difficult to determine transmission order for large scale networks
- FAMA and MACA-MN: reference node does not know number of CTS packets needed

We consider two representative schemes

- CSMA series (no node coordination)
- T-Lohi (light coordination)

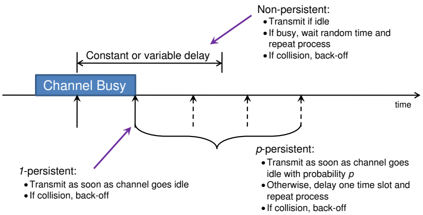
CSMA vs T-Lohi

Channel Access with CSMA

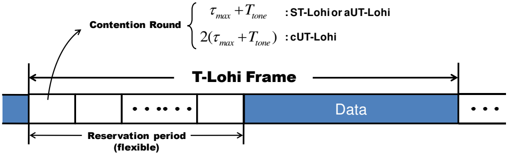


CSMA vs T-Lohi

Channel Access with CSMA



Frame structure of T-Lohi



Scenario and Performance Metrics

Scenario:

Table: Simulation parameters

Parameter	Value
Deployment area	5 km $\times$ 5 km
Number of nodes (K)	100
Beacon packet size	32 Bytes
Tone detection time (T_{tone})	4 ms
Data rate	10 kbps
Transmission range	1 km
Maximum back-off time	1 s
Localization period (T)	1 s
Transmission limit (N)	20
Transmission probability (p)	[0.01, 0.04, 0.07, 0.1, 0.2]
Bit Error Rate	$10^{-5} \sim 10^{-2}$

Scenario and Performance Metrics

Scenario:

Table: Simulation parameters

Parameter	Value
Deployment area	5 km $\times$ 5 km
Number of nodes (K)	100
Beacon packet size	32 Bytes
Tone detection time (T_{tone})	4 ms
Data rate	10 kbps
Transmission range	1 km
Maximum back-off time	1 s
Localization period (T)	1 s
Transmission limit (N)	20
Transmission probability (p)	[0.01, 0.04, 0.07, 0.1, 0.2]
Bit Error Rate	$10^{-5} \sim 10^{-2}$

Metrics:

- Coverage
- Speed
- Collision Rate
- Communication Costs

Results - Characterization of *p*-persistent CSMA

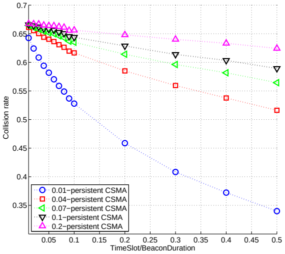


Figure: Collision Rate

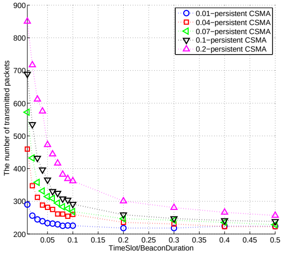


Figure: Cost

Results - Characterization of *p*-persistent CSMA

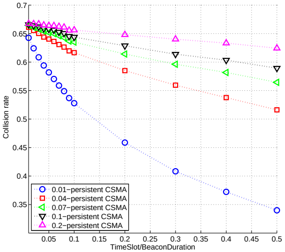


Figure: Collision Rate

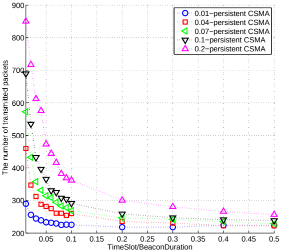


Figure: Cost

- Collision (and costs) $\downarrow$ as $t_{slot} \uparrow$; Perfect carrier sensing for $t_{slot} \geq 2\tau_{max}$!
- Collision $\uparrow$ as $p \uparrow$

Results - Characterization of *p*-persistent CSMA

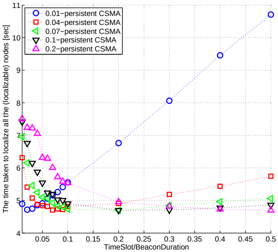


Figure: Speed

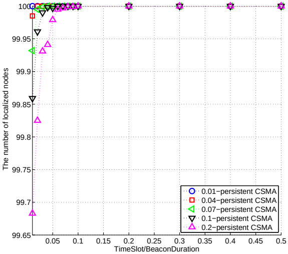


Figure: Coverage

Results - Characterization of *p*-persistent CSMA

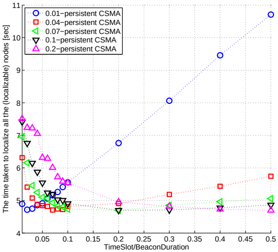


Figure: Speed

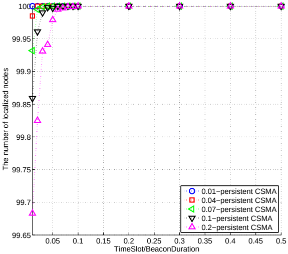


Figure: Coverage

- Turning point, $t^*(p)$, for $p \leq 0.1$
  - Improvement in speed due to reduced collisions > degradation due to time wastage for $t_{slot} \leq t^*(p)$
- Coverage $\uparrow$ as t_{slot} $\uparrow$; Full coverage with $\frac{t_{slot}}{t_{beacon}} \geq 0.1$!

Results - CSMA vs T-Lohi

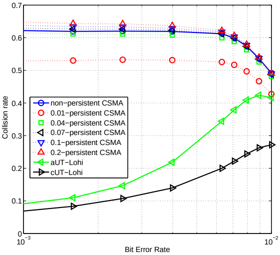


Figure: Collision Rate

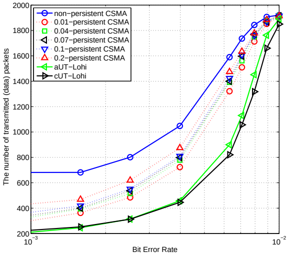


Figure: Cost

Results - CSMA vs T-Lohi

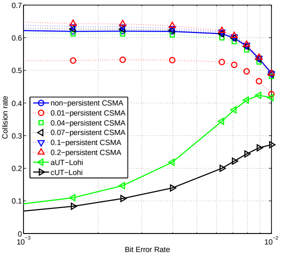


Figure: Collision Rate

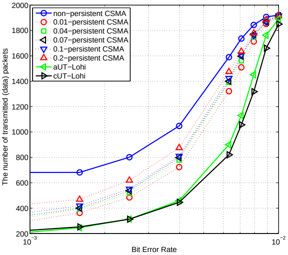


Figure: Cost

- T-Lohi incurs lower collisions (costs) than CSMA due to channel reservation
- Collision ↓ as BER ↑ for CSMA due to higher packet transmission errors (higher costs)
- Collision ↑ as BER ↑ for T-Lohi due to reservation failure

Results - CSMA vs T-Lohi

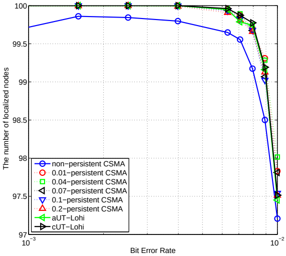


Figure: Coverage

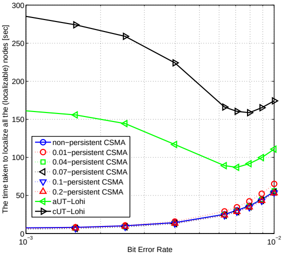


Figure: Speed

Results - CSMA vs T-Lohi

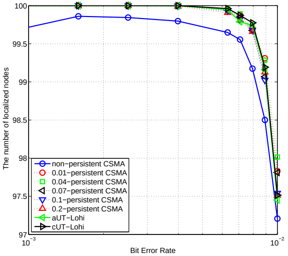


Figure: Coverage

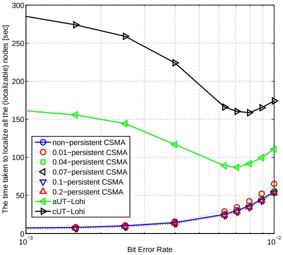


Figure: Speed

- Coverage ↓ as channel degrades
- Speed ↓ as channel degrades for CSMA due to higher packet errors
- Speed ↑ as channel degrades for T-Lohi due to shorter frame length

Conclusions and Future Work

- Investigated impact of MAC in multi-stage localization in large-scale seabed (underwater) sensor network
  - MAC should require little or no node coordination to achieve good localization performance efficiently
  - We consider CSMA (no node coordination) and T-Lohi (light coordination)

Conclusions and Future Work

- Investigated impact of MAC in multi-stage localization in large-scale seabed (underwater) sensor network
  - MAC should require little or no node coordination to achieve good localization performance efficiently
  - We consider CSMA (no node coordination) and T-Lohi (light coordination)
- ***p*-persistent CSMA achieves better localization performance at the expense of higher communications costs**

Conclusions and Future Work

- Investigated impact of MAC in multi-stage localization in large-scale seabed (underwater) sensor network
  - MAC should require little or no node coordination to achieve good localization performance efficiently
  - We consider CSMA (no node coordination) and T-Lohi (light coordination)
- ***p*-persistent CSMA achieves better localization performance at the expense of higher communications costs**
- Future work
  - Evaluation of localization performance for a broader class of underwater MAC protocols
  - Accounting for beacon aging effect due to node mobility
  - Evaluation using more realistic underwater acoustic channel model