Trajectory Scheduling for Timely Data Report in Underwater Wireless Sensor Networks

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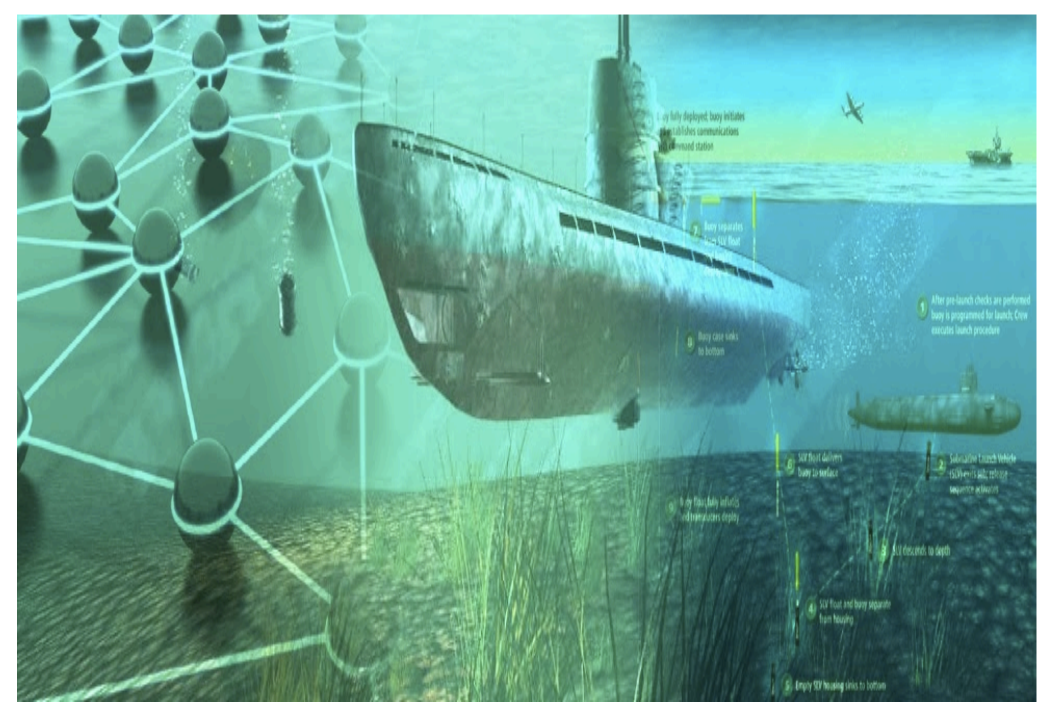
Agenda

- Motivation
- Model and problem formulation
- The idea of the proposed algorithms
- Performance evaluations

Motivation

- Ocean monitoring:
  - Research projects.
  - Pollution and disaster monitoring
    - 2004 Indian ocean earthquake
    - 2011 Japan nuclear disaster
  - Military and homeland security



Motivation

- **Traditional method (ocean-bottom)**
  - Acoustic communication are typically expensive (US$10k or more).
  - Can only get the data after the monitoring mission.
  - The amount of data can be recorded is limited.
- **New method (Autonomous underwater vehicles (AUV))**
  - Optical communication (cheap)
  - Collect data periodically.
  - The amount of data can collected is huge.

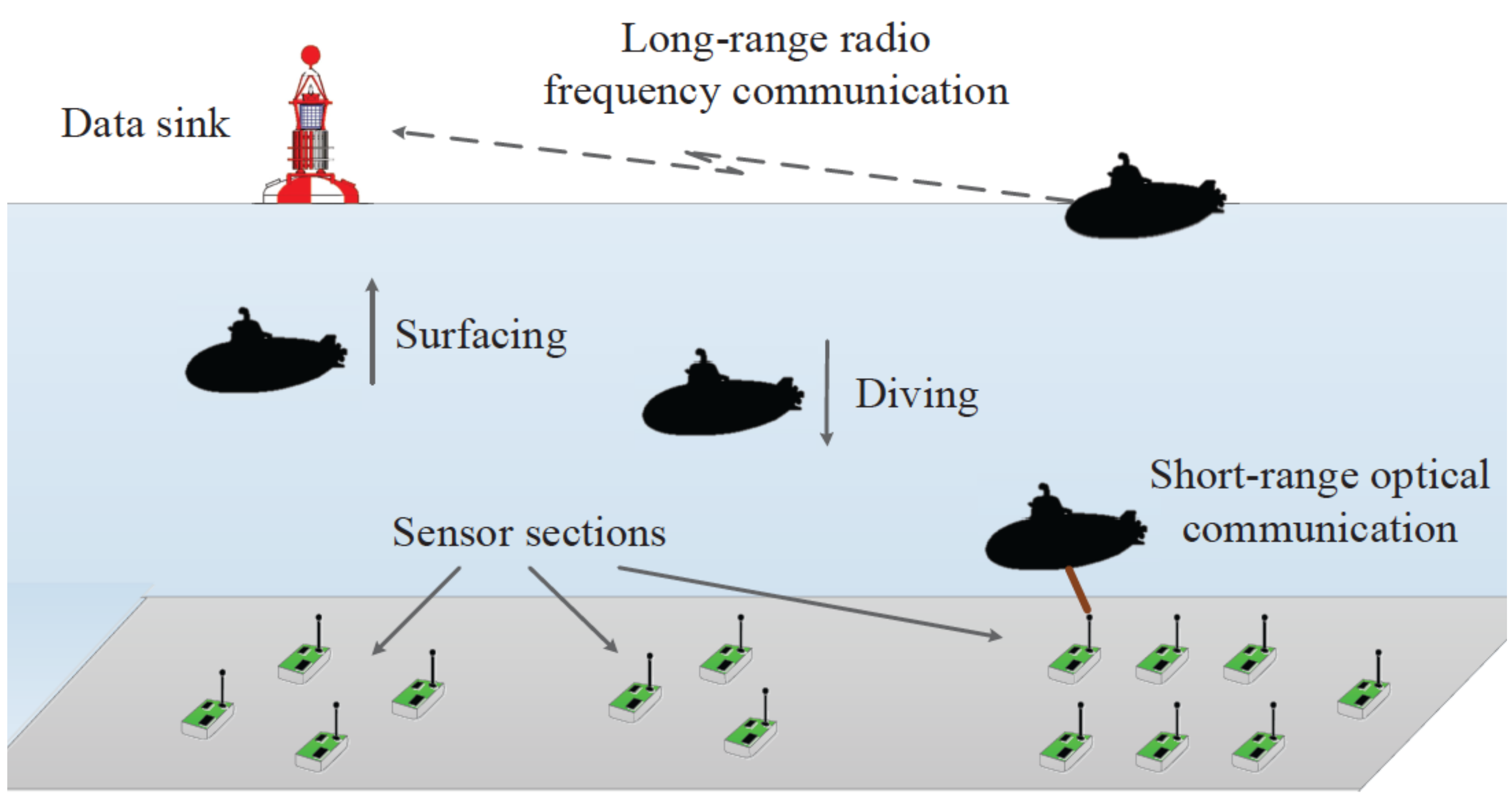
Related works

- Maximizing the value of sensed information in underwater wireless sensor networks via an autonomous underwater vehicle (INFOCOM 2014)

- Data Collection and Event Detection in the Deep Sea with Delay Minimization (SECON 2015)

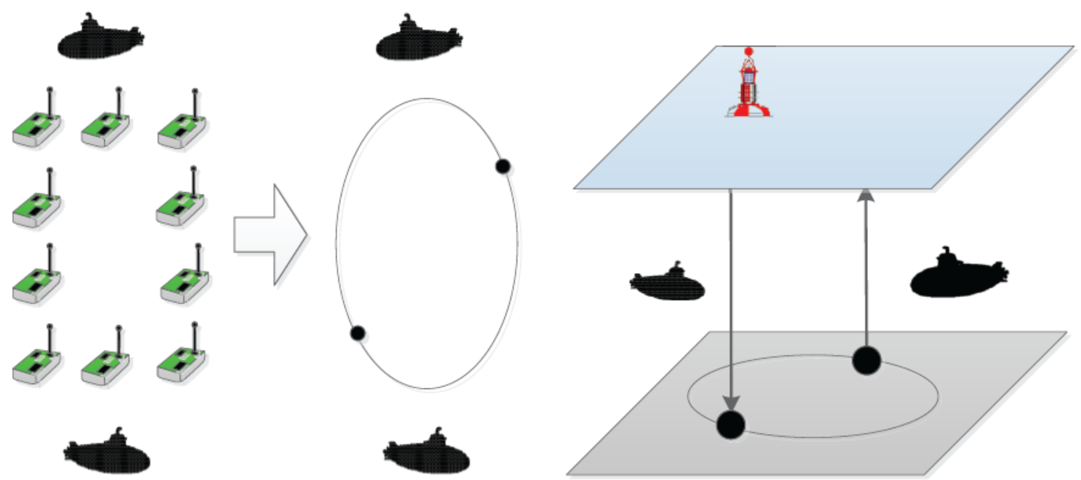
Network model and Problem

- Multiple homogeneous AUVs data collection.
  - Data are uniformly distributed with a fixed generation rate.
  - Problem: Collect all the data before their deadline.



Network model (cont'd)

- 2D Sensor Circle Abstraction
  - Each AUV periodically collects data.



(a) The circle abstraction (b) The surfacing points

C : the cycle circumference
L : the searching space depth
k : the number of AUVs

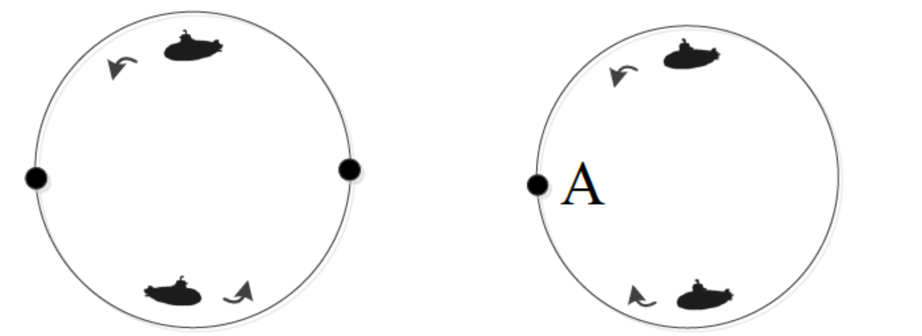
- If we have a larger AUV resurfacing frequency, the AUV can bring a node' s data to the water surface more quickly.
- However, a node's data needs to wait the next AUV for a longer time, since resurfacings take additional time.

Problem formulation

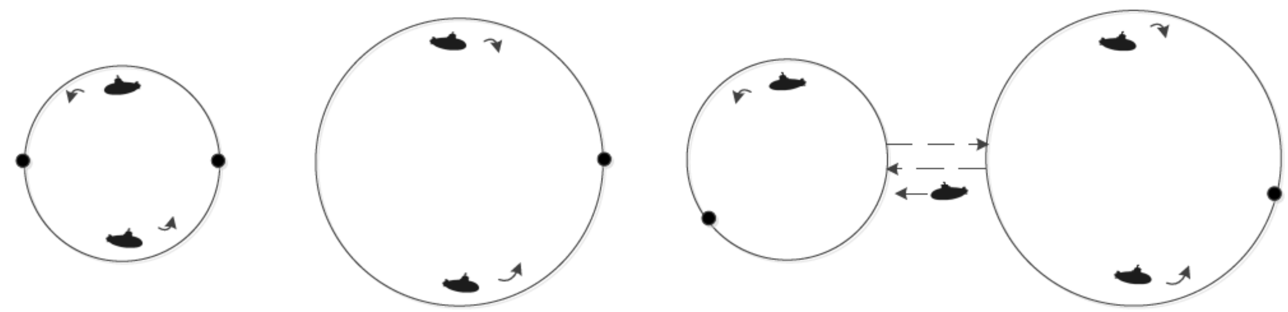
- Background:
  - Surfacing and diving is costly.
- Trajectory Scheduling problem:
  - cyclic tours with lengths $\{c_1, c_2, \ldots c_m\}$.
  - The number of homogeneous AUVs $\{k_1, k_2, \ldots k_m\}$,
  - How to minimize the whole amount of surfacing of AUVs, under the constraint that all the data generated by the sensors can be transmitted to the sink within the deadline, T.

Challenges

- Trajectory scheduling
  - One AUV
  - One cycle
    - Same direction
    - Different directions
  - Several cycles
    - Detour or not?
    - How?



(a) Same direction (b) Different directions



(c) Without detouring (d) With detouring

Within one cycle

- Same direction:
  - k AUVs evenly distributed in a cycle.

    If we have multiple AUVs (k AUVs), then we can evenly distribute these AUVs on the cycle.

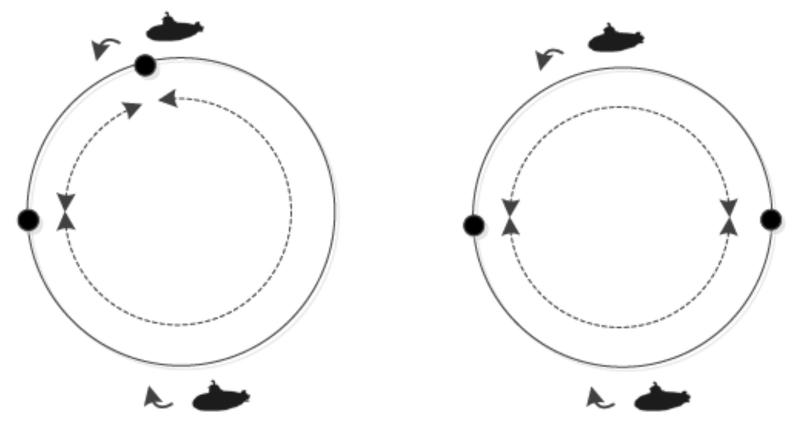
  - The reporting delay is bounded by:

$$\frac{1}{v}(\frac{2md+c}{k}+\frac{c}{m}+d)$$

C : the cycle circumference
L : the searching space depth
k : the number of AUVs
m: the number of surfacing in a cycle

Within one cycle

- Different directions:
  - Encountered AUVs can exchange data.
    - Save one surfacing

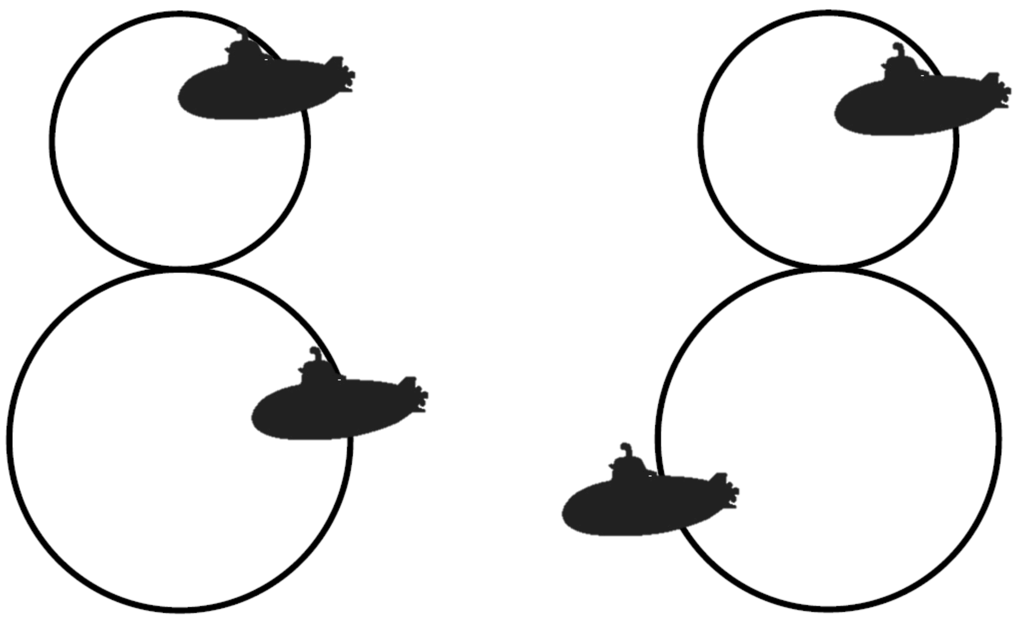


(b) Schedule 2 (c) Schedule 3

- Theorem: For a tour with an even number, k , of AUVs, the optimal schedule for minimizing the amount of surfacing is to assign k/2 AUVs in one direction to surface every time of T – (c/k+d)/v.

Within several cycles

- Why do we use of multiple small cycles instead only one large cycle to collect data?

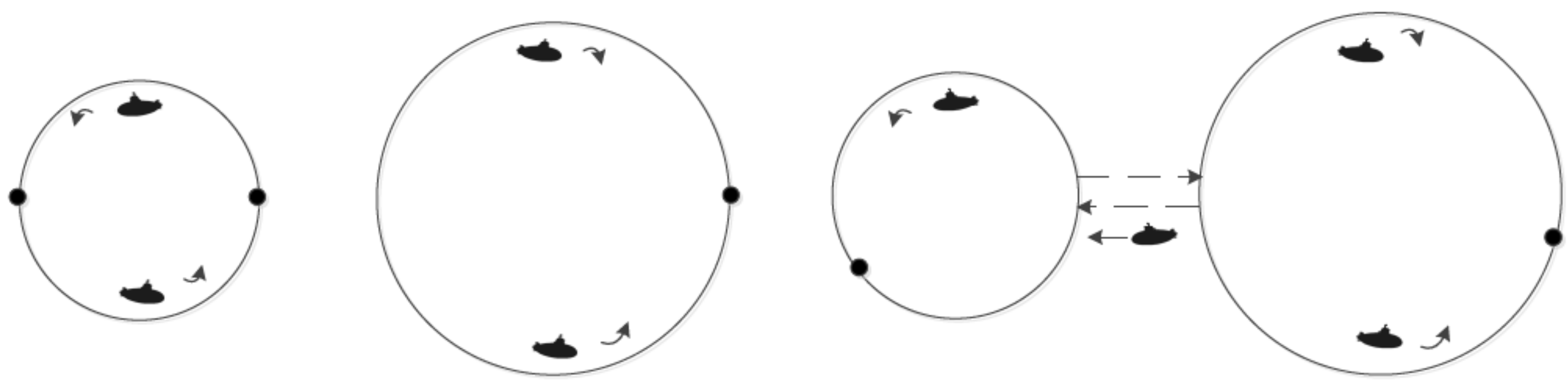


Scheduling 1 Scheduling 2

Theorem. Scheduling 2 is always no worse than Scheduling 1, due to more balanced cycling tasks among AUVs

Within several cycles

- The real situation:
  - To collaboratively schedule AUVs in two cycles will have some cost.



(c) Without detouring (d) With detouring

Scheduling 1 Scheduling 2

There exists a trade-off of benefit and the detour distance.

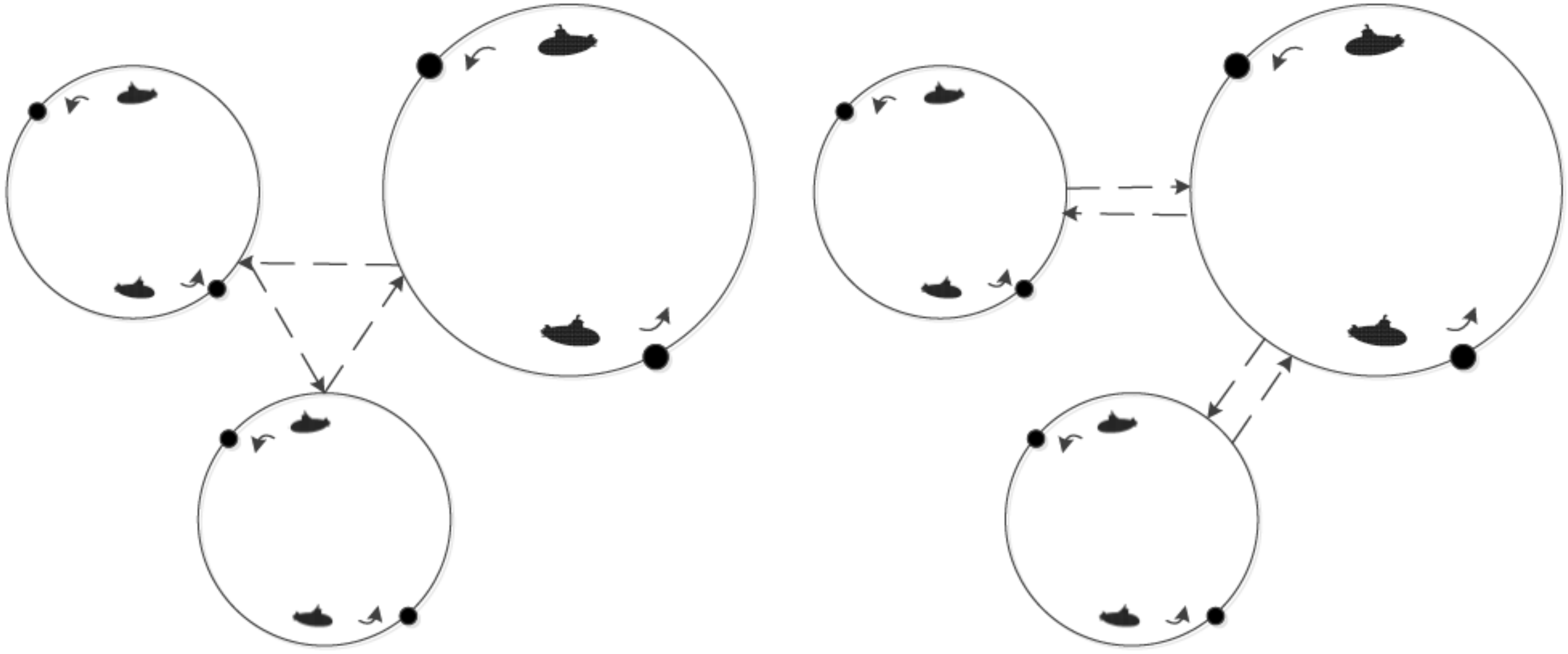
Within several cycles

- Algorithm
  - 1. Calculate the cost of schedule AUVs in two AUVs individually.
  - 2. Merge the two cycles into a big cycle, with some detour distance, using the previous method
  - Compare the 1 and 2.

Theorem. There exists an $1 + 2l/d$ approximation ratio between the schedule in this algorithm and the optimal solution in the merged cycle.

Within several cycles

- Three cycles merge

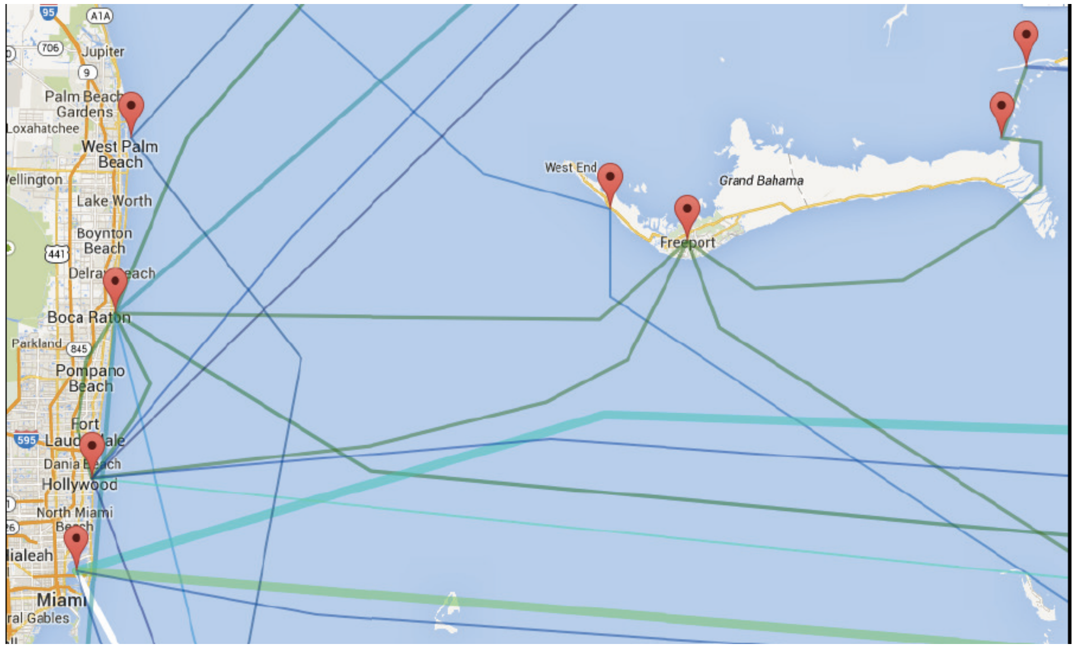


(a) Back and forth merging (b) Circle merging

Experiment setting

- Experiments setting
  - AUV speeds
    - 20 knots, 16 knots, 12 knots (diving, moving, surfacing)
  - 20 AUVs
  - The depth of the sea is 3682 m
  - Sensors are uniformly distributed

- The oil pipeline at Florida, USA

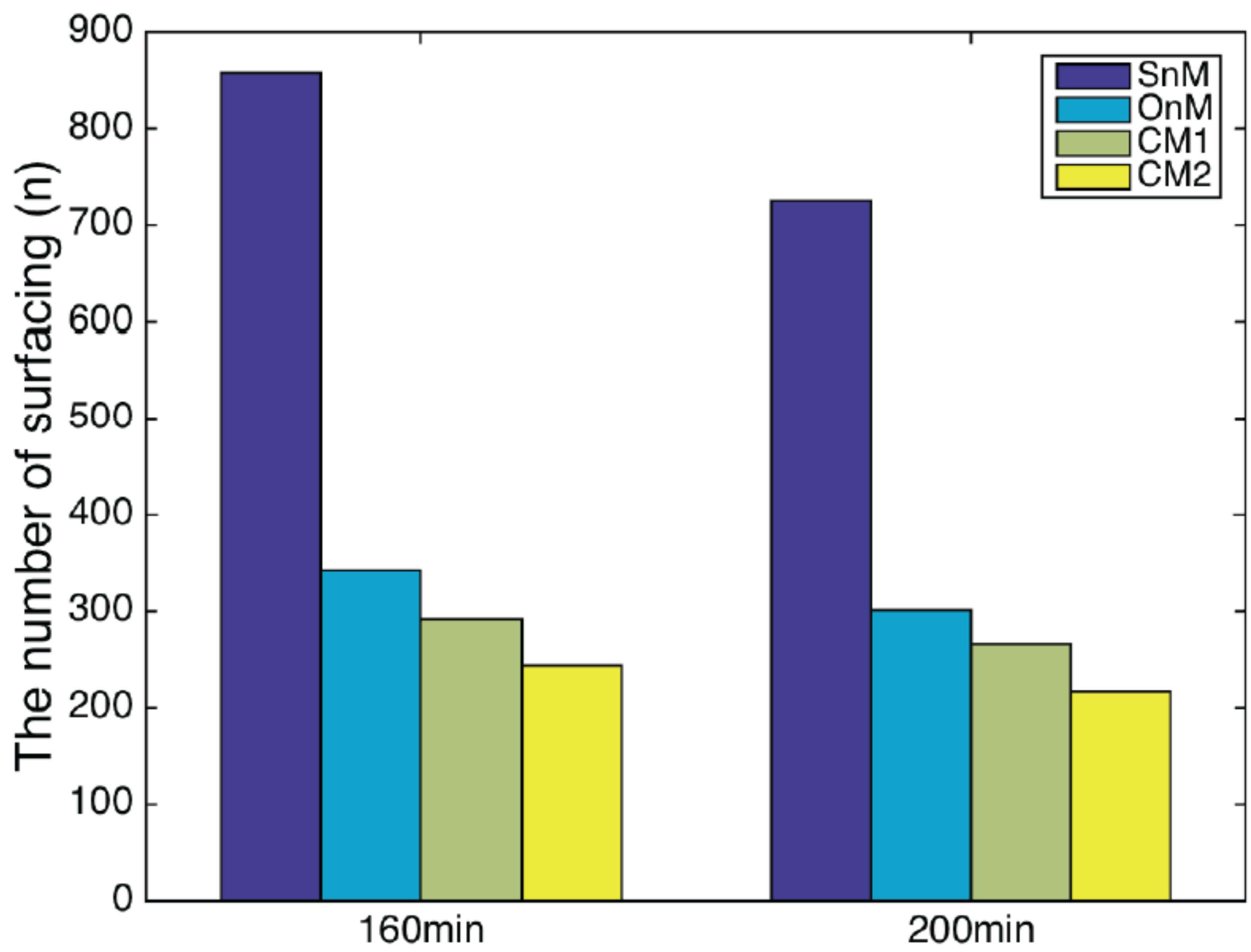


- BDNSi, Mid Atlantic Crossing (MAC) , GlobeNet, COLUMBUS II, III, WASACE, Americas II, cable of the Americas and BAHAMAS-2.

Algorithm comparison

- Algorithms:
  - SnM: same movement direction without merging.
  - OnM: different movement directions without merging
  - CM1: only two cycle merging
  - CM2 consider the 3-cycle merging

Experiment result



Conclusions

- We investigate the homogeneous autonomous underwater vehicles (AUVs) trajectory schedule problem in under water sensor networks (UWSNs), considering the time constraint.
- The different scheduling methods.
  - Different moving direction within one cycle.
  - The cycle merging.

Thank you!

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