Wide Area Ocean Networks: Architecture & System Design

Sumit Roy
Dept. of Electrical Eng., U. Washington
roy@ee.washington.edu

Payman Arabshahi, Dan Rouseff, Warren Fox
Applied Physics Lab, U. Washington
payman,rouseff,warren@apl.washington.edu
Outline

• System Concepts: Ocean Observatories
• SeaGlider
  ▪ Role/Functionality (Cost Effective Wide-Area Monitoring)
  ▪ Propulsion/Dynamics Sub-System
  ▪ Communication Sub-System
• Future: Acoustic Networking
• A Design trade-off (Power Budget vs. Coverage)
Ocean Observatories Initiative

Basic Infrastructure:
Network providing high bandwidth communications and electrical power

Three primary components:
Global-scale moored buoy systems
Regional-scale seafloor fiber optic cable system
Coastal observatories

Cyberinfrastructure will allow users to remotely control their instruments, perform in-situ experiments, construct virtual observatories, and access data in near real-time.

The OOI will provide the ability to investigate processes at the scales at which they occur
Regional Ocean Observatories

Undersea cabled backbone → power and bandwidth for regional seafloor network

NEPTUNE: Enable real-time interactions between land-based scientists and an ocean observatory (sub-surface cabled backbone, moored vertical profilers, array of UUVs, surface buoys …)
Other Pieces of Infrastructure

Schematic of moored vertical profilers for measurements

Extending the power and communications capabilities throughout the water column
Seaglider: Background

• Collaborative effort between UW and APL
  – An ocean instrumentation tool
    • To measure temperature, conductivity (salt content), dissolved O₂, optical backscatter, pressure in the water

• Long endurance (6 months)
  – 1/2 knot on 1/2 watt

• Deep diving (1000 meters)

• GPS and Iridium satellite navigation and control via web interface (APL/Oceanography)

• > 20 Seagliders built and deployed worldwide
How does it work?

- GPS and Iridium antenna at tail
- Nose down orientation at surface provides robust communications
- Change buoyancy to dive or ascend
- Wings for forward propulsion
- Move batteries fore and aft to change pitch
- No propeller, or other external moving parts. Can be carried by two people.
Seaglider Components

- 3m nose to tail
- 55kg dry weight
- No moving parts (outside)
Cost Budget Analysis

- **Seaglider water sampling**
  - Unit build cost: $105K (Commercial estimate $80K)
  - Exercise cost: $105K – 374 profiles over 27 days
  - $560 per profile

- **Iridium costs 15 Jun – 10 Jul (187 dives):**
  - Total cost: $658.80
  - $3.70 per dive
  - $0.27 per kilobyte

- **...P-3C water sampling**
  - Assume 25 BTs per flight at cost of $57,000
  - $2,280 per profile on one day
Power Budget Analysis

- **Simplified SeaGlider Trajectory**: Periodic Sawtooth

\[ T_c = \frac{2D}{U \sin \theta_g} \]

- \( \theta_g \): glide angle
- \( D \): target depth
- \( U \): velocity of dive

Dive Cycle Duration
Principles of SeaGlider Operation: Basic HydroDynamics

\[ K_{D_1} \alpha^2 - K_L \tan \theta_g \alpha + K_{D_0} = 0 \]

Solve for \( \alpha \) (Attack Angle)

\( K_{D_1}, K_{D_0} \): drag coefficients \quad K_L: \) lift coefficient
Basic Hydrodynamics II

Net Buoyancy

\[ B = \rho \Delta V \]
\[ \Delta V: \text{volume change} \]

\[ U = \sqrt{\frac{B \cos \theta_g}{K_L \alpha}} \]
Power Budget Analysis

- SeaGlider Sampling: 2-D uniform grid

![Diagram](image)

\[
\text{# grid points} = \frac{D}{U \tau \sin \theta_g} \times \frac{D}{U \tau \cos \theta_g} = \left(\frac{D}{U \tau \sin \theta_g}\right)^2
\]

Hence, \# bits/cycle = \(r\) \left(\frac{D}{U \tau \sin \theta_g}\right)^2 \quad r: \# \text{ bits/sample}
Power Budget Analysis II

Per Cycle Energy expenditure

Pumping at bottom of dive for surfacing

Work done to cause volume change $\Delta V$ against hydrostatic pressure $\rho gD$ (at depth $D$) with conversion efficiency $\eta(D)$

$$\rho gD\Delta V / \eta(D)$$

Energy for Data Uplink

Energy for Iridium uplink

$$E_{up} \quad r \left( \frac{D}{U \tau \sin \theta_g} \right)^2$$

$E_{up}$: Joules/bit
Power Budget Analysis III

- Given initial battery budget $E_B$:

  \[ N_c = \frac{E_B}{\rho g D \Delta V / \eta(D) + E_{up} r (D/ U \tau \sin \theta_g)^2} \]

  \text{Total Mission duration } T_M = N_c T_c

\[ T_M = \frac{E_B}{\rho g D \Delta V} \left( \frac{U \sin \theta_g}{\eta} + \frac{E_{up} r D}{\tau^2 U \sin \theta_g} \right) \]
Power Budget Analysis IV

- Denominator:
  
  1st term $\alpha U \sin \theta_g$
  
  2nd term $\alpha (U \sin \theta_g)^{-1}$

- Energy efficient propulsion $\rightarrow$ lower $\theta_g$

  Lower Communication energy $\rightarrow$ higher $\theta_g$

- 1st order necessary condition (set derivative = 0)

  $\frac{C_1}{\eta} = \frac{C_2 D}{x_*^2}$

  $x = U \sin \theta_g$

  $C_1 = \rho g \Delta V$

  $C_2 = \frac{E_{up} r}{\tau^2}$
Optimum Dive Angle I

\[ \sqrt{\frac{B}{K_L \alpha}} \sqrt{\cos \theta_g \sin \theta_g} = \sqrt{\frac{C_2}{C_1}} \sqrt{D \eta} \]

\[ \Rightarrow y^3 - y + A = 0 \]

\[ y = \cos \theta_g \]

\[ A = \frac{K_L \alpha \eta}{(\rho \Delta V)^2 g} \frac{E_{up} r}{\tau^2} D \]
# Optimum Dive Angle - Computations

## Parameters

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<tr>
<th>Parameter</th>
<th>Value Details</th>
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<tbody>
<tr>
<td>$K_L$</td>
<td>0.00224</td>
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<tr>
<td>$r$</td>
<td>8 bits/sample</td>
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<tr>
<td>$\tau$</td>
<td>10 sec</td>
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<tr>
<td>$\alpha$</td>
<td>0.3 rad</td>
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<tr>
<td>$g$</td>
<td>9.8 m/s²</td>
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<td>$E_{up}$</td>
<td>35 J/KByte</td>
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<td>$\rho$</td>
<td>1027 Kg/m³</td>
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<td>$\eta$</td>
<td>0.5</td>
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<tr>
<td>$\Delta V$</td>
<td>840 cm³</td>
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## Depth (Km) vs. Optimum $\theta_g$

<table>
<thead>
<tr>
<th>Depth (Km)</th>
<th>Optimum $\theta_g$</th>
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<tbody>
<tr>
<td>100</td>
<td>3.24</td>
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<tr>
<td>300</td>
<td>5.67</td>
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<td>500</td>
<td>7.34</td>
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<tr>
<td>1000</td>
<td>10.42</td>
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Looking to the Future

• SeaGliders to be equipped with WHOI Micromodem

• Adaptive Link Layer
Acoustic Network

- Deliver simulation (ns-2) propagation models for acoustical channel
- Decide on MAC layer
- Network performance analysis for 1-hop (star) and multi-hop topologies