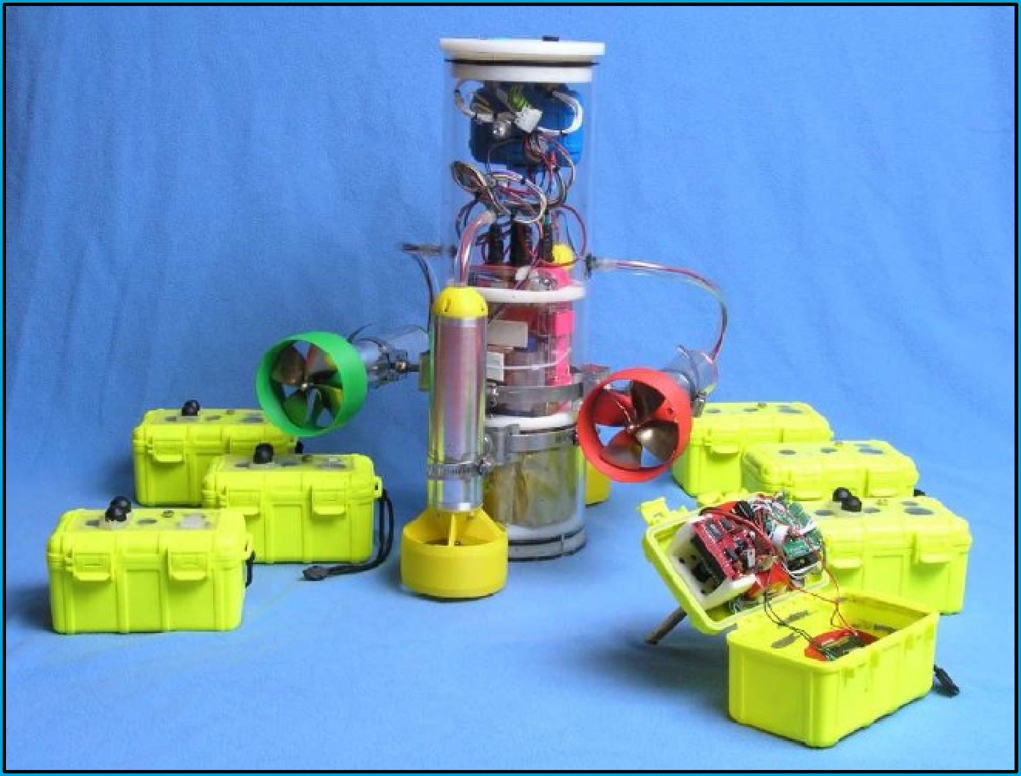
Data Collection, Storage, and Retrieval
with an
Underwater Sensor Network



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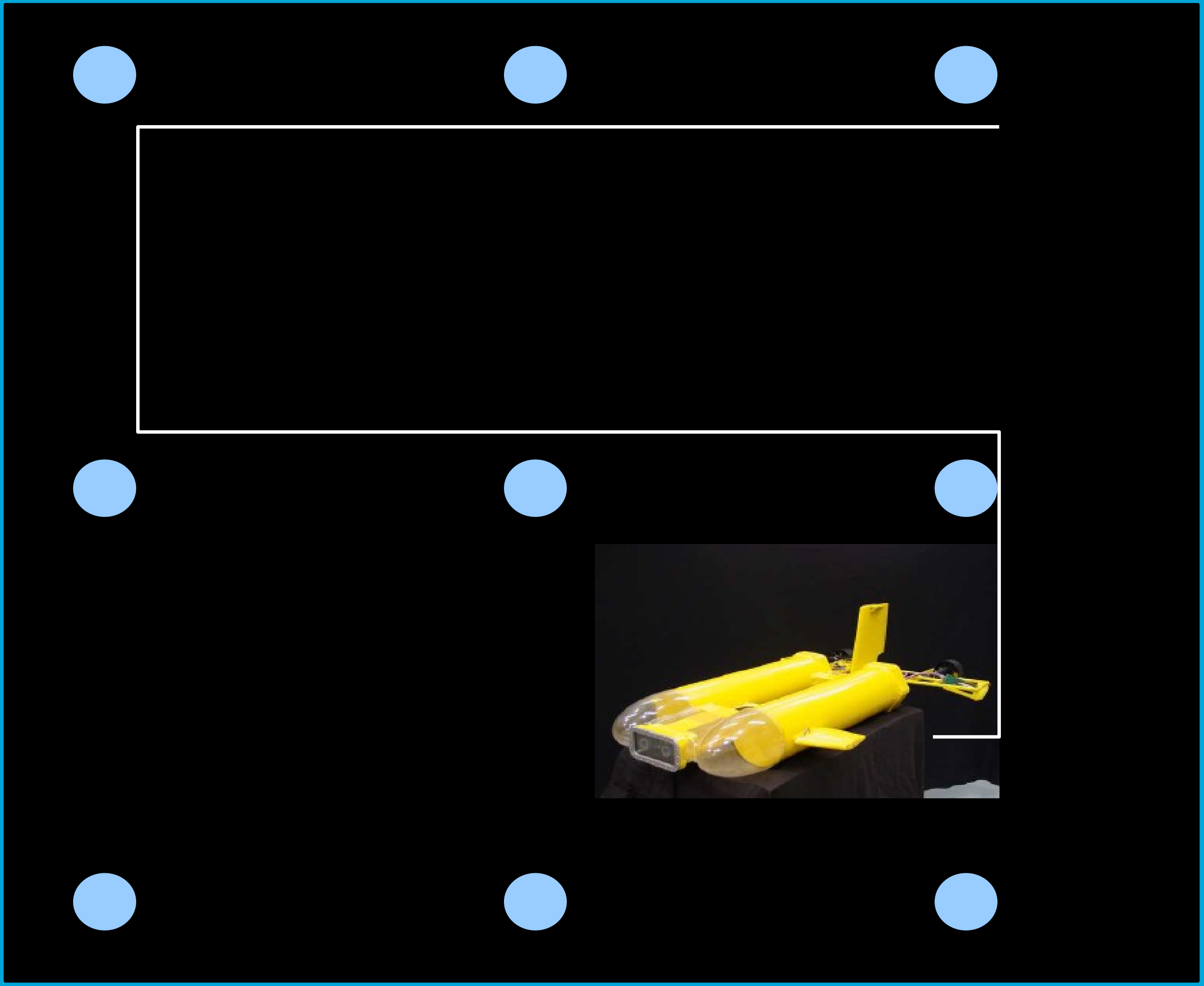
Introduction

- Oceans cover 70% of surface
- Monitoring is difficult and expensive

- Common problems
- Different problems (Communication)

Scenario

- Asymmetry



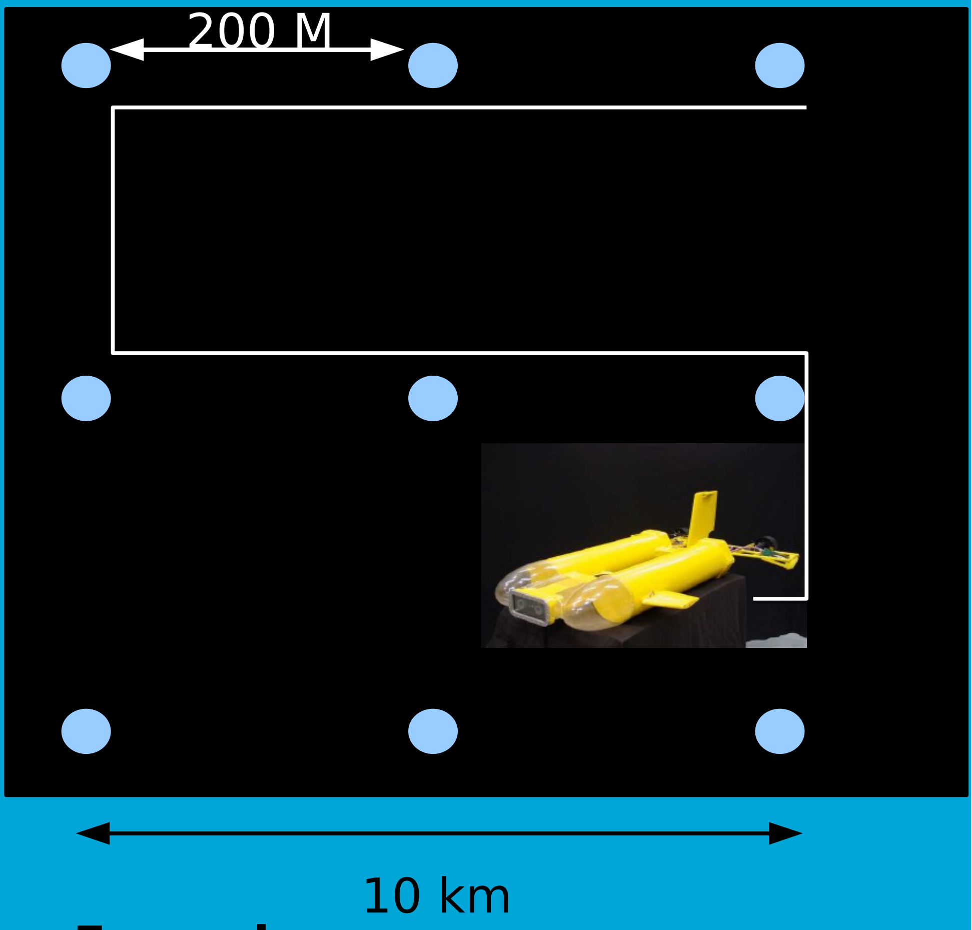
Why data muling?

Data Muling

- Short range optical comm.
- 28 hours (0.5 m/s)
- 256 sec (320 kbit/s)
- 174 J

Acoustic & routing

- 48 hours (480 bps)
- 377 kJ (4.5mJ/bit)



Example

- 200 M grid (50 x 50)
- 10 MB data

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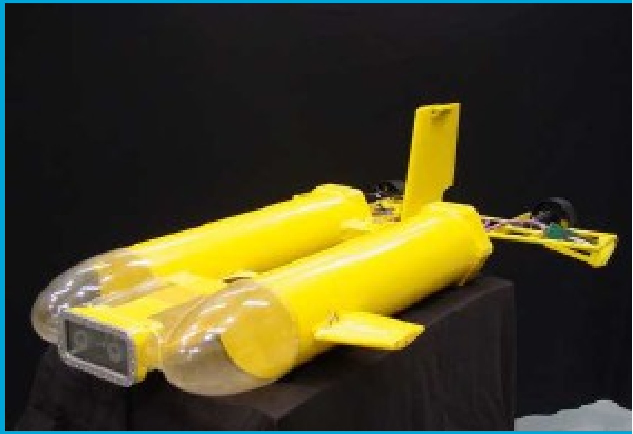
Hardware - Aquaflecks

- Mica2 like node
- In a yellow watertight box
- Optical comm.
- Acoustic comm.
- Pressure / temp / 255 x 143 Cam
- 170 mm Rod with LED for Beaconing and Transportation


Hardware - AUVs

Amour Autonomous Underwater Vehicle

- Magnetic Compass
- Cone shaped cavity for docking
- 4 light sensors to determine direction
- 200 N latching mechanism



Starbug AUV

- Two stereo vision heads for odometry and obstacle avoidance
- Visual Servoing

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Networking

- Radio signals
  - Highly attenuated by salt water
- Optical
  - Much less attenuated
  - High speed
  - Directional and Short Range
- Acoustic
  - Been used extensively (SONAR)
  - Reflections
  - Slow / Costly

Data Transport

Event Signaling
3D Localization

Networking - Optical

Range is affected by

- Light absorption
  - Green Light
- Divergence
  - 30° cone
- Ambient Light
  - Green filter
- Scattering

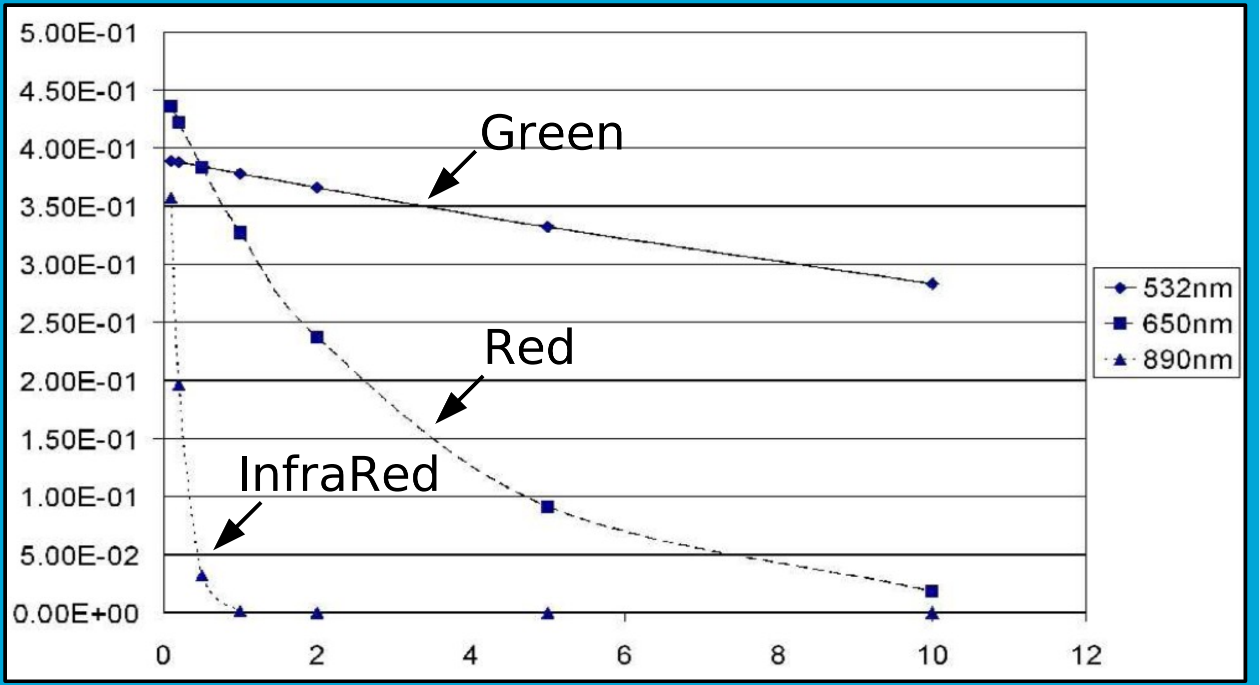

Photo Diode Output = $S \times e^{-k(d1 - d0)} \times P$

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Network – Optical - Protocol

State	Time Interval
Data bits 00	4.0us
Data bits 01	4.5us
Data bits 10	5.0us
Data bits 11	5.5us
End of byte	6.0us
End of packet	10.0us

- VFIR (Very Fast Infrared)
  - Pulse Position Modulation
  - Pulse width 250 ns
  - On average:
    - (4 + 4.5 + 5 + 5.5 + 6) / 8 = 3.125 us
    - 320 kbit/s
    - 1094nJ/bit (RF: 760 nJ/bit)
- TDMA

Network – Optical - Experiments

Distance	Received Packets	Missed Packets	Packet Success Rate
2.1m	199	0	100.0%
4.3m	199	0	100.0%
5.3m	199	2	99.0%
6.4m	199	0	100.0%
7.0m	199	8	96.0%

Setup:

- 7 Watt LED
- 30 – 40 cm under water
- 199 Packets at 1 Hz
- Max 8 m in clear water / 1 m in highly turbid water
- Extra focusing increases the range

Networking – Acoustic

- Mature field
- Commercial Modems are Expensive
- Cheap Commercial Land Transducers can be used
- 25 m

Networking – Acoustic – Experiments

Tow Tank:

- 30 – 40 cm
- 1Hz square wave
- No glitches till 10 m

River:

- 30 – 40 cm
- 50Hz square wave
- No glitches till 5.8 m

Communication (PPM):

- 41 bit/s due to reflections
- Expected to be higher in open water

Networking – Acoustic – Experiments

- Ranging / Localization
- "Robust Distributed Network Localization with Noisy Range Measurements"

Distance	Elapsed Time	Estimated Distance	Error Percentage
1m	1.4ms	1.04m	+3.7%
2m	2.78ms	2.06m	+3.0%
4m	5.55ms	4.11m	+2.8%
6m	8.21ms	6.08m	+1.4%
8m	11.1ms	8.23m	+2.8%

Mobility

Challenges:

- Locate first node (Spiral Search)
- Locate next node in sequence
- Hovering
  - Visual Servoing (Starbug)
  - Active Beaconing (Amour)
- Data Transfer
  - Mobile node queries static node
  - Data is send in 239 byte packages

Data Collection

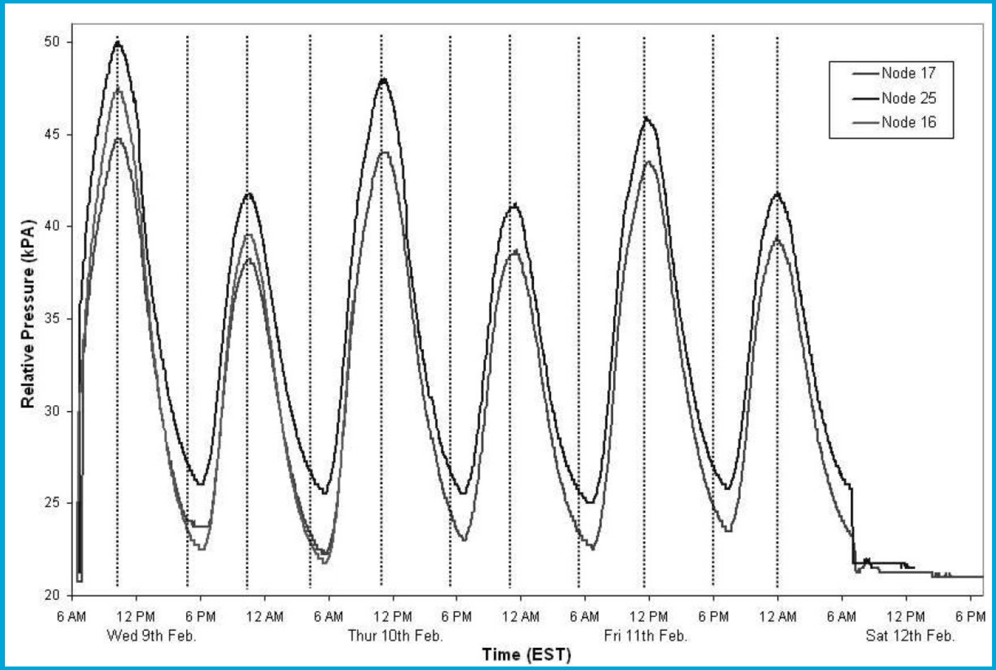
- 512 kB of data memory (flash)
- 101 kJ battery
- Download costs:
  - 512kB * 8 bit * 1094nJ = 4.59J
  - 512 kByte/ 320kbit = 13.1 s

Synchronization

- Synchronize to the Mobile node only
- No global clock sync.

Data Collection - Experiments

- Three nodes logging temperature and pressure
- Every 150 sec for 7 days -> 110 kB of data



Experimental Results

- 8 x 8 Grid topology
- Starbug and Amour traverse the network
- Starbug was routinely able to visit all nodes in the network

Everything works!?

Conclusions

- Sensor networks are feasible underwater
- Mobility provides effective and power-efficient means for networking the system
- Data muling is effective

Questions?

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