Underwater Sensor Networking at ISI (work in progress)

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22 July 2005

This work is partially supported by the NSF under grants IIS-0226336 and IIS-0226348, and an Intel Corp. (Hardware grant).

What Is A Sensor Net?

- lots of computers interacting within the world  
  - physically distributed, different perspectives
- lots of computers interacting within the world  
  - near what’s sensed
  - some can fail
- lots of computers interacting within the world  
  - intelligent: can collaborate and decide
- lots of computers interacting within the world  
  - sensing, responding, acting

Wide-Area Underwater Sensing Today

Neptune Project  
3000km fibre optics  
NOAA Deep-ocean Assessment  
and Reporting of Tsunamis

Characteristics of Today's Systems

- comm: long-range (km)  
- density: sparse  
  - often assume point-to-point  
  - or assume wired connections  
  - expensive  
- computing: often not  
- acting: UAVs? primarily ROVs  
  - underwater autonomous vehicles  
  - remote operated vehicles (human operated)

Benthos ATM-885  
6-10km  
point-to-point, single access  
includes data logging  
~$8k

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Desired Characteristics

- comm: long-range (<500m)  
- density: sparse  
  - often assume point-to-point  
  - or assume wired connections  
  - expensive  
- computing: often not  
- acting: UAVs? primarily ROVs  
  - flocks of UAVs  
  - get the advantages of surface sensornets, underwater
Outline

- background
- applications
- challenges
  - communications
  - protocols
  - applications

Potential Applications

- underwater seismic monitoring
- underwater construction
- marine microorganism monitoring
- collaborative robotics

Seismic Monitoring of Oil Fields

- must monitor oil reservoirs
- current approaches
  - some surface fields monitor frequently
  - high cost (ship, crew, array)
  - more frequent is not cost effective
- frequent monitoring can enable 4-D Seismic: views of reservoir
  - watch dynamic evolution of reservoir
  - support early operational intervention
  - adjust injection rates
  - correct blow-downs (water into oil pockets)

Underwater Construction

- increasing underwater construction
  - today: large off-shore oil platforms
  - tomorrow: all-underwater oil processing
- need monitoring and support during construction
- also during maintenance
  - short-term underwater sensor networks

Marine Microorganisms and Cooperative Robotics

- biologists want to track; underwater features
  - physical/chemical concentrations, thermoclines, etc.
- current approaches:
  - busy-suspended sensors
  - robotic data collection
- possible approach:
  - cloud of free-floating or controlled robots
  - requires underwater communications
- concept explored with Gennady Sabatini and David Caron, CENSC

Commonalities Across Applications

- physical proximity to what’s being sensed
  - simplify the sensing problem
- multiple underwater sensors
  - need to look from multiple directions at same time
- interactive communication
  - strongest in robotic flocks
  - important in other cases
  ⇒ motivates research choices
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    - communications (hardware)
    - protocols
    - applications

Underwater Acoustic Telemetry: Assumptions

- Point-to-point short range links
  - focus on short range (50-300m) vs. traditional underwater acoustics (>1km)
- Multi-hop network architecture
  - vs. traditional single-hop
- Multiple access control and omni-directional transducers
  - vs. traditional point-to-point
- Design for low energy consumption

Why Short Range?

- supporting dense sensor networks
  - exploit spatial reuse
  - can leverage multi-hop communication for long ranges
- minimize impact of some underwater interference
  - wind/surface reflections
  - signal attenuation
  - multi-path reflections
  - temperature variations
  - environmental noise (ships, fish)

Low Power Telemetry

- Energy consumers
  - Highest: transmitter
  - Moderate: receiver/demodulator
  - Lowest: wake-up detector
- Power conservation
  - Sleep mode: power down when inactive
  - Resume operations on “wake-up”
  - Wake-up detector
    - Indicates presence of transmission “preamble”
    - Very simple, near-zero-power circuit

Wake-up Circuit

- Implementation
  - dual-gate FET cascode amp with tuned load
  - diode rectifier at amplifier output is detector
  - AM detector (similar to crystal radio)
- Current status:
  - designed and preliminary simulations
  - testing prototype
  - expect about 500uW power requirements

Transmit/Receive

- design targets
  - 50-500m
  - 5kb/s
  - about 30mW tx power
  - simple FSK signaling
  - expect software-level control
  - (like Mica-1/RFM radio)
- current status
  - design completed
  - testing prototypes
  - not optimized for size at all
  - starting with in-the-air testing

Prototype transmitter
**Outline**

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**Why Are Protocols Different?**

- latency!
  - speed of light: $3 \times 10^8$ m/s (and constant)
  - speed of sound: $1.5 \times 10^3$ m/s & variable due to temperature
  - 5-orders-of-magnitude slower
- propagation delay:
  - 50m: 33ns
  - 150m: 100ns
  - 500m: 300ns
- need to revisit time synchronization, localization, MAC...
  - focus today: time synchronization

**Prior Work in Time Sync**

- NTP [Mills, ’89]
  - assumes continuous connection (Internet)
  - tolerates high latency
- RBS [Elson et al., ’00]
  - leverage sensor net broadcast domain
  - shifts to receiver-side synchronization
  - assumes simultaneous, rapid reception
- TPSN [Ganeriwal, ’03]
  - exploit MAC-layer timestamping
  - sender-receiver exchange to eliminate send/receive/MAC jitter
  - assumes rapid message propagation

**Correcting Clock Differences**

- offset: different clock times
- correct by two-way exchange
  - like NTP and TPSN
- skew: different clock rates
- correct by repeated one-way observations
  - like NTP and RIB
  - reference A sync’er B

**Challenge of High Latency**

- current protocols factor out propagation delay
- but not skew during propagation
- for RF, this never matters
- for acoustics, it can be critical

**Time Synchronization for High-Latency Networks**

- new protocol: TSHL (Time Synchronization for High Latency)
  1. exchange several messages to estimate clock skew
     - like NTP and RIB
  2. then use 2-way message exchange to calculate skew-corrected offset
     - like TPSN, except considering skew
     - limit message exchanges
     - like RIB, TPSN, FTSIP
Offset Accuracy vs. Distance

Considering skew is important underwater acoustics beyond 100m

And modeling skew is essential when synchronization is not frequent.

Protocol Design Observations

- assumptions about latency underlie existing sensor net protocols
  - sometimes with disastrous results
- need to revisit each
  - time synchronization
  - localization
    - easier than RF (high latency is good for localization?)
    - media-access control
    - TDMA? scheduled protocols like S-MAC? low-power listening like B-MAC?
  - others?

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Application Design

- how to cope with very low bandwidth, high delay, and lots of data?
- can exploit Delay Tolerant Networking concepts
  - cache data at nodes (exploit local storage)
  - coordinate data retrieval
- designing for mostly-asleep networks
  - seismic network should be off for a month, then "boot" and run for 5-10 minutes
  - like Intel "fib app" [Ramanathan et al, EmNets, 2005]
- work in progress

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Underwater Testing

- long-term, plan to test in the field
  - start in Marina del Rey
  - move to offshore facilities
  - (or maybe collaborate with CENS folks and test at JR?)
- but underwater testing still painful
In-the-air Acoustics as Test 0
[Syed, Wills, Heidemann]

- Concept: simulate underwater acoustics with in-air acoustics
- Will get some noise
  - probably very different than underwater
  - but much better than nothing
- Propagation 5x slower than underwater
  - helpful? allows emulation of long distances
- Tests are ongoing
  - combine acoustics and RF
  - Challenge: short range of Cricket

Sample hardware for in-air stand-in testbed: Cricket node
- developed at MIT
- ultrasound-based transmit and receive
- same software platform as other nodes

Conclusions

- lots of interesting directions
- a long way to go...
- http://www.isi.edu/silense
- papers