Practical Issues in Underwater Networks

Presented by F. Bustamante based on

- J. Partan et al., “A survey of practical issues in underwater networks”, Proc. ACM WUWNet, 2006
- I. Vasilescu et al., “Data collection, storage, and retrieval with an underwater sensor network”, Proc. of ACM SenSys, 2005.

Introduction

- Group of sensors and vehicles deployed underwater and networked via acoustic, optical links, etc. performing collaborative tasks
  - Autonomous Underwater Vehicles (AUVs)
  - Underwater sensors (UW-ASN)
- Applications
  - Environment monitoring
  - Undersea explorations – detect underwater oilfields
  - Disaster prevention – monitoring currents, winds (Tsunamis)
  - Assisted navigation –locate dangerous rocks in shallow waters
  - Distributed tactical surveillance – intrusion detection (Navy)

Physical layer

- Radio waves are attenuated in salt water
  - Long-wave ratio for short-range 6-10m with 1-8kbps
- Light is strongly scattered and absorbed underwater
  - Maybe useful for very short range 1-2m at ~57kbps
- For long-range and typical clarity – acoustic comm.
  - Strong attenuation – limited bandwidth
  - Phase and amplitude fluctuation – forward error correction
  - Standard transducers cannot simultaneously receive and transmit – typically half-duplex communication
  - Easy to transmit than to receive at high rate – star topologies with AUV receiving small commands at low rate from buoy and transmitting large sensor data

Media Access Control (MAC)

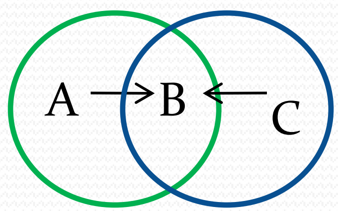
- MAC data communication protocol sub-layer`
- Part of the data link layer in the OSI model (layer 2), bet/
  - Physical layer, providing means for transmitting bits, and
  - Network layer, responsible for end-to-end packet delivery
- Data link layer normally implemented in software as a network card driver
- It interfaces with the physical layer, and
  - Logical link control sub-layer – same for != physical layers
  - Responsible for de/multiplexing protocols transmitted
  - Providing flow and error control
- Provides addressing and channel access control to allows several nodes connected to same medium to share it

Media Access Control (MAC)

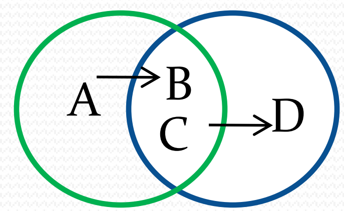
- May avoid or detect packet collisions …
- People trying to communicate, all in one room (channel)
  - Take turns speaking (Time Division - TDMA)
  - Speak at different pitches (Frequency Division - FDMA), or
  - Speak in different directions (spatial division)
  - Speak different languages (Code Division - CDMA)
- Instead of being nice and sharing, just compete
  - CSMA/CD – Carrier Sense Multiple Access with Collision Detection – Used in Ethernet
  - CSMA/CA – CSMA with Collision Avoidance – 801.11; listen and transmit if channel is idle (hard to listen when talking)
    - Request To Send (RTS) packet sent by sender to, and Clear To Send (CTS), by receiver, to make others shut up duration data xfer

MAC in UWAN

- MAC is an unresolved problem in UWAN
- FDMA is not ideal given limited bandwidth and frequency
- CSMA-based vulnerable to hidden (nodes close to target receiver but far from each other) & exposed terminal (nodes are far from target receivers but close to each other) problems



Hidden



Exposed

  - CSMA/CD is also hard given a half-duplex channel
- MACA/MACAW (RTS/CTS/DATA) a problem with long propagation delays (multi-way handshakes)

MAC in UWAN

- TDMA-CDMA clusters – shortening TDMA (intracluster) slot lengths, but increased overhead (cluster assignments)
- CDMA is promising, but require tight control of transmit/receive power - hard to get with half-duplex, low propagation comm.
- Some future directions
  - TDMA to share control and data for AUV swarms
  - Slotted Aloha to deal with long propagation delays (rather than listen before you send – CSMA)

Mobility and sparsity

- Sensor nodes are expensive - $3k just for the acoustic modem
- So are ship-based surveys - $5-25k/day
- Large interest area – Oceans cover ~70% of Earth’s surface w/ avg. depth of 4km
- Hard to gathered all the sensor data, recovery is expensive
- → Widespread use of AUV

Mobility and sparsity

- AUVs
  - Not cheap either ($50-250k/vehicle) – sparse networks
  - Require periodic navigation information
    - Navigation & comm. signals often share freq. bands, limit node density
    - With many nodes, reduce rate of positioning probes – navigation errors
- Sparsity and mobility
  - DTNs
    - Data muling - trying to maximize likelihood of paths to destination
      - Ongoing work on using nodes with controllable movements
    - Hard to control movements with currents
  - Large propagation delays, better transmit packet trains
    - Packet trains can capture channel & some AUVs are nearby only briefly
    - → MAC protocols that prioritize access to maintain long-term fair access to channel

Energy efficiency

- As with terrestrial networks, energy is limited in UWANs – MAC protocols optimized for it, e.g. UWAN-MAC
  - Node sends SYNC to announce its transmission period cycle; assuming constant propagation delays, a receiving node can wake up on time for next transmission
  - If cycle period >> transmission duration, little chance of collision
- Communication energy costs
  - Transmitting can be 100x more expensive than receiving
  - Acoustic modem
    - 0.2W while listening and 0.2-2W for equalizing and decoding packets
    - 50W for transmitting

Energy efficiency

- For many AUV, propulsion power >> network-comm. power
  - High-speed (1-3m/s) and short-duration (5-20hs)
- But network comm. energy is critical for long-duration glider missions
  - Low-speed (0.2-0.4m/s) and long-duration (months to years)

REMUS: 1.0-2.9 m/s, 5-20 hours Hotel load: ~30W   Propulsion: 15-110W

Webb Research glider (electric): 0.2-0.4 m/s, ~1 month; Hotel + Propulsion: ~2W

- Other issues with transmit power
  - Impact on marine mammals, maintain covert communication …
- Not always the critical metric to optimize for – Reliability and QoS?

An evaluation of data muling

- Combining mobile and static nodes
  - Static – aquaflecks
    - 170mm road for beaconing AUVs (LED) and pickup
  - Mobile – Amour
    - Can pick up aquafleck
    - Magnetic compass that enables navigation using 4 thrusters
  - Data mule – Starbug
    - Designed for visual navigation – 2 stereo vision heads
      - Locate aquaflecks and data mule for them
    - Fully actuated – 6 thrusters
    - Speed for maximum range – 0.7m/s

Networking and data retrieval

- Combined optical and acoustic
  - Optical – 2.5 Mbps
    - Used for short-range, line-of-sight, but high bandwidth data xfer and comm. bet/ sensor node and data mule
    - Affected by light absorption of water, scattering, beam divergence, ambient light (1m range in the Charles river)
    - Use a concentrator to improve effectiveness, but small angle also complicates positioning
  - Acoustic – 480 bps
    - Up to 15m at a 41 bps
    - To signal events and transmit small amount of data
- Positioning first based on GPS and later optical or through an acoustic-based positioning system
- Data transfer based on a master (AUV)-slave protocol
- Clocks synch based on mobile node clock

Summary

- Although there's no single operating regime for UWANs
  - Most will be sparse and mobile
  - Rely on acoustic channels for communication
  - Maybe combined optic and acoustic channels?
- In general, UWANs are quite different from terrestrial radio-based networks – careful with reuse
- Hardware and software reliability are very important
- Things like currents, surf, dirt, etc. make for key differences between pool and real deployments