Exploring Architectural Challenges in Scalable Underwater Wireless Sensor Networks

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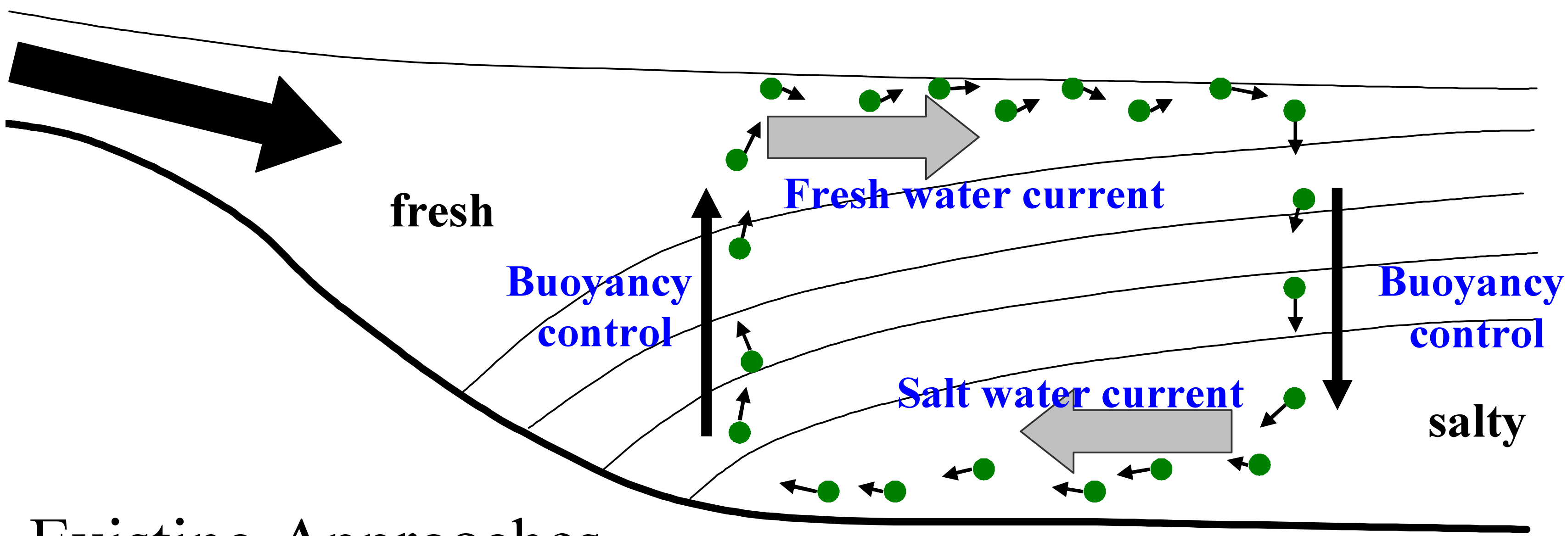
Outline

- Motivation of underwater wireless sensor networks (UWSNs): Aquatic applications
- Design challenges in UWSNs
  - Communications
  - Networking algorithms/protocols
- Architectural issues in UWSNs
  - Workload characterization
  - Energy-efficient design and resource management
  - Lifetime estimation
- Summary

Underwater wireless sensor networks: application-driven

- Environmental monitoring and data collection
  - Temperature, salinity, ocean currents, etc.
    - Influences on climate and living conditions of plants and animals
  - Marine microorganism
  - Pollution
- Disaster early warning and prevention
  - Seismic monitoring
  - Tsunami
- Off-shore exploration and underwater construction
- Coastline protection and tactical surveillance
- Target detection
  - Mine
  - Shipwreck

Application example: estuary monitoring

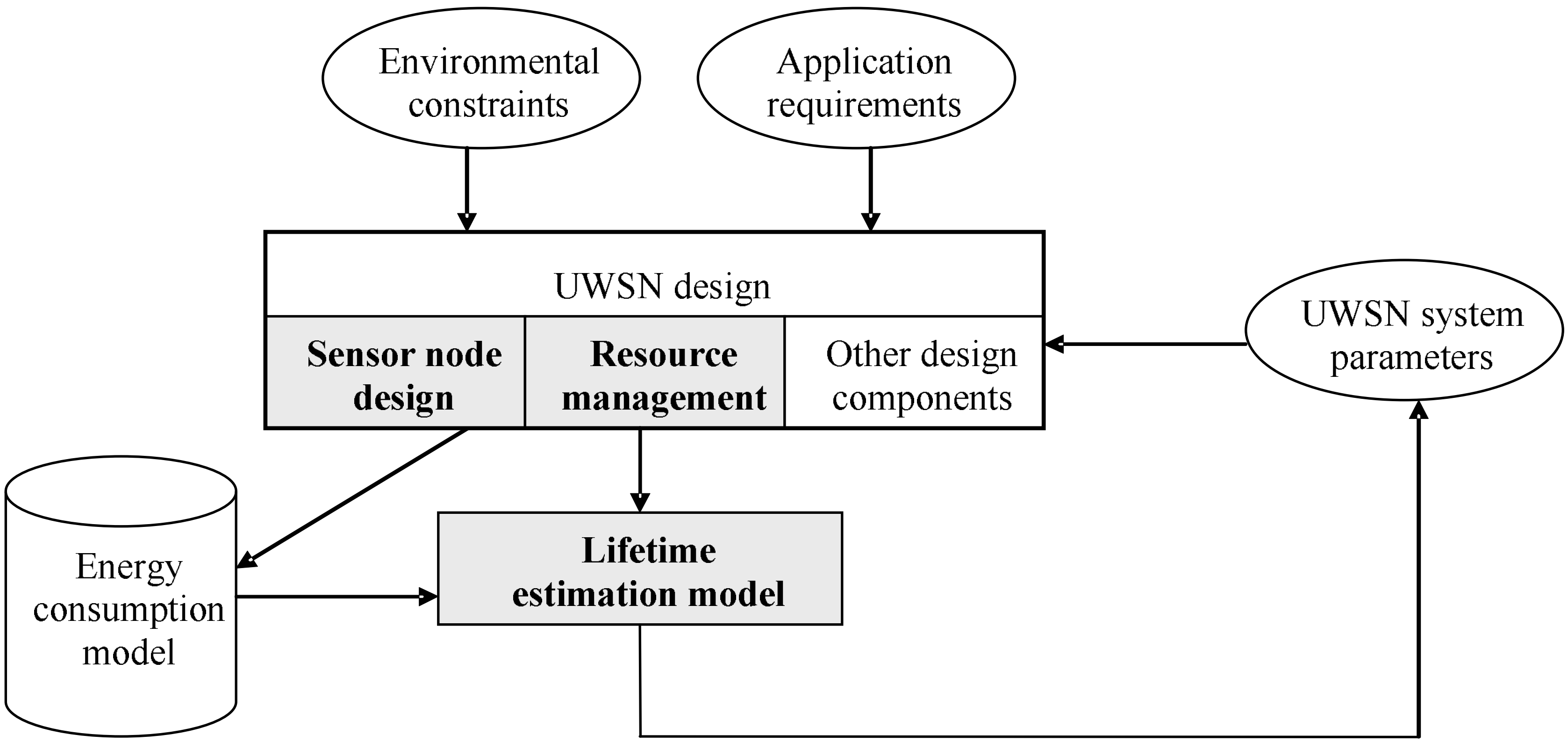


- Existing Approaches
  - Ship tethered with chains of sensors moves from one end to the other
  - Cons: no 4D data, either f(x, y, z, fixed t), or f(fixed (x, y, z), t); and high cost
- Using UWSN
  - Easily get 4D data, f(x, y, z, t), mobile sensors
  - Reduce cost significantly
  - Increase coverage
  - Have high reusability

Challenges in different aspects of UWSNs

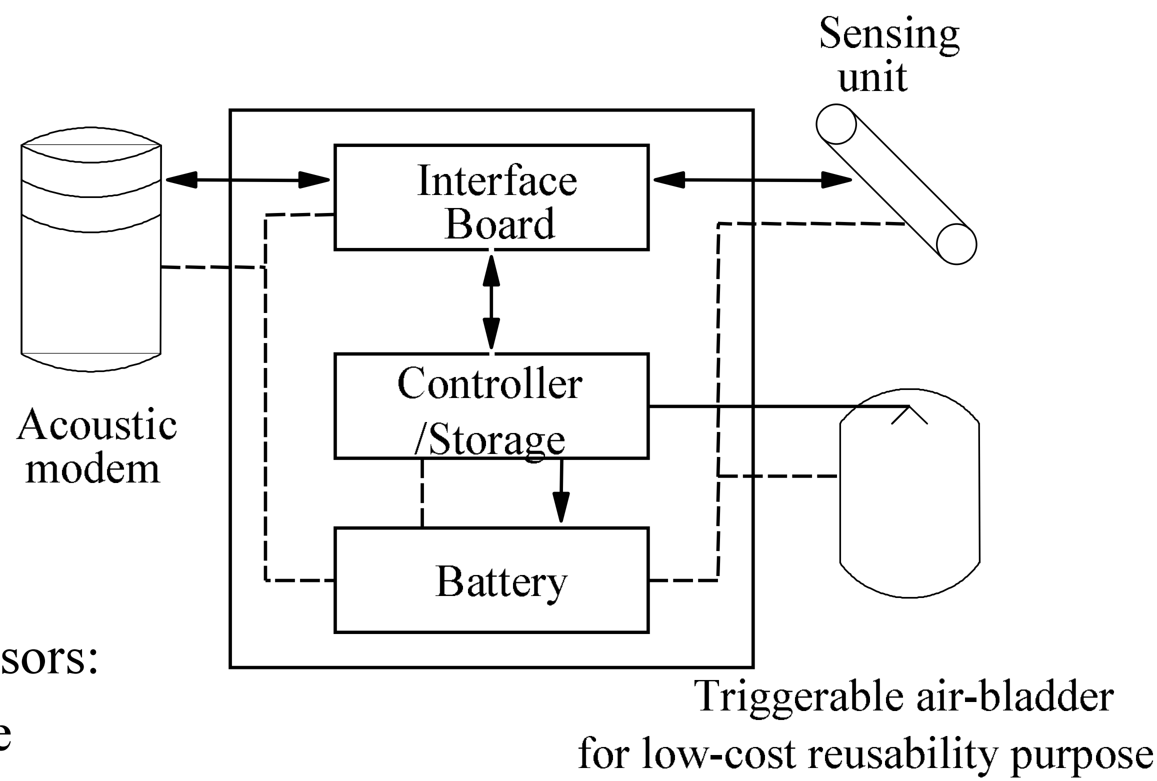
- Communications
  - Radio does not work well in water
    - 120cm at 433 MHZ reported at USC
    - Low frequency → large antennae and high transmission power
  - Acoustic channels adopted
    - Limited bandwidth: Bandwidth × Range product = 40 kbps·km
    - Long delay: 1.48×10^3 m/s vs. 3×10^8 m/s
    - High bit error rates
    - Multi-path and fading problems
- Networking
  - Medium access control: high channel utilization
  - 3-D networking, geographical-based routing: robust to dynamic topology
  - Data transfer: reliable and high throughput
  - Localization & time synchronization : GPS-free
  - Robustness: resilient to network disconnection

System design of UWSNs



Typical structure of a sensor node

- Sensor probes
  - Interface circuitry
- Controller (processors)
- Trans-receiver
  - Acoustic modem
- Storage
- Battery
- Triggerable air-bladder



Different from land-based sensors:

- Larger and more expensive
- More power hungry
- Prone to failures

Goals of underwater sensor nodes

- Easy to customize for different applications: workload characterization
  - Satisfying performance
    - Computing capacity
  - Storage
  - Bandwidth
- Long operation time: low power
  - Energy becomes more critical
    - Acoustic communications, memory, air-bladder, etc., more power-hungry
    - Energy harvesting difficult: solar and wind energy are not available
- Reliable operations
- Low cost: allows deployment of large amounts of nodes
  - Decomposable or retrievable

Energy-efficient design at the node level

- Design choices: ASIC, ASIP, FPGA, microcontroller
- Power-efficient design of individual components
  - Acoustic communication modules
  - Flexible packet relaying circuit
    - Only wake up the microcontroller when needed
- Proper task assignments and scheduling
  - Sampling, processing, storing, transmitting, receiving, and forwarding
- Exploiting opportunities in the underwater environment
  - Long and frequent sleep mode due to the long delay of acoustic channels

Power management at the network level

- Power-aware routing algorithms
  - Short-range vs. long-range communications
  - Reliability vs. energy trade-offs
- Power-aware localization algorithms
  - Accuracy vs. energy trade-offs
- Configuration strategy
  - Choosing working parameters adaptively in the field
- In-network computations
  - Utilizing short-range one-hop communications
  - Balance the power consumption of nodes located in different areas

Lifetime estimation model

- Impact of network design parameters on power consumption
  - Average one-hop signal transmission distance
  - Data transmission period
  - Acoustic channel frequency
  - Network topology (3-D, distances, clustering, etc.)
  - Sensor lifetime
- Simulation of UWSNs
  - Hierarchical energy model
  - Output: statistic information, e.g., data communication throughput, retransmission rate, data drop rate, average power consumption, and sensor network lifetime.

Conclusions

- Opportunities: interesting and promising area
  - Requires interdisciplinary collaborations

- Challenges: a lot of new challenges, especially in resource management and energy-efficient system design – a cross-layer effort!