2018 NSF Workshop on Underwater Wireless Communications and Networking

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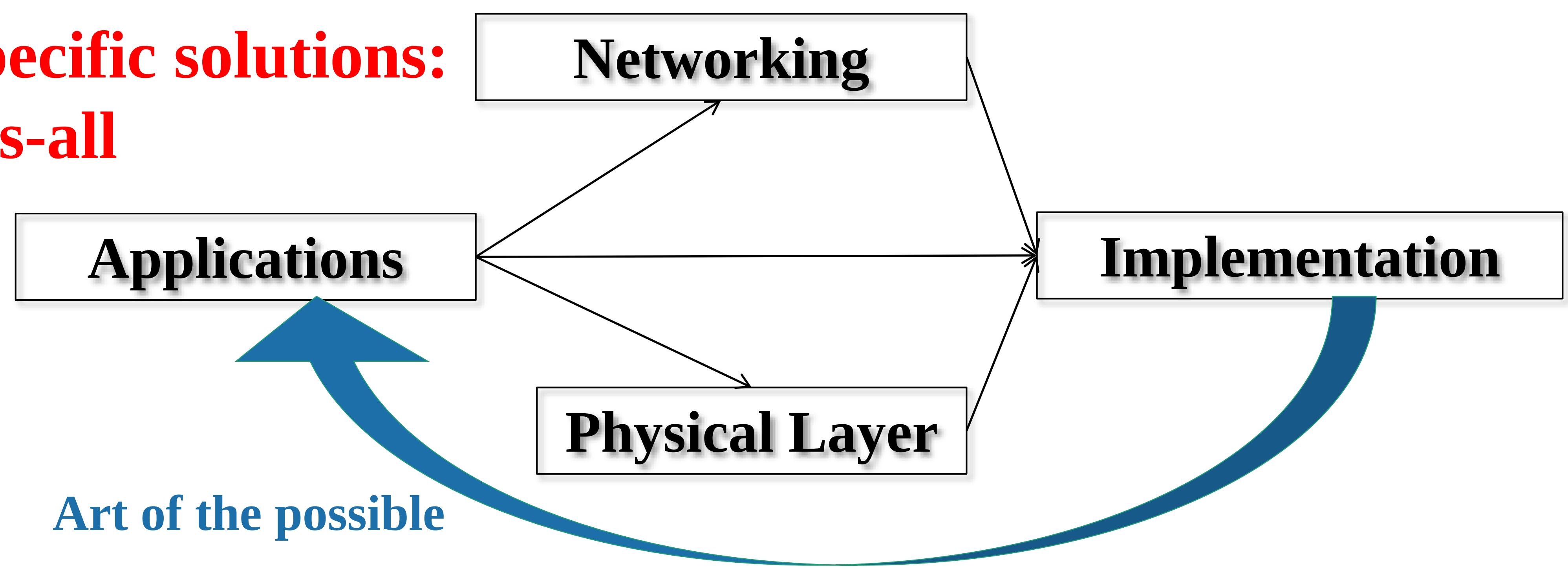
Washington DC, March 19-20, 2018

Sponsored by the NSF
Division of Computer and Network Systems

Application-Driven Road Map

- Strong need to broaden research participation
  - Multi-disciplinary collaboration with industrial partnership
  - Open-source software/simulators and affordable & miniaturized hardware
  - Common test grounds
  - Community infrastructure to lower thresholds for data collection and algorithm validation

Application-specific solutions:
No one-size-fits-all



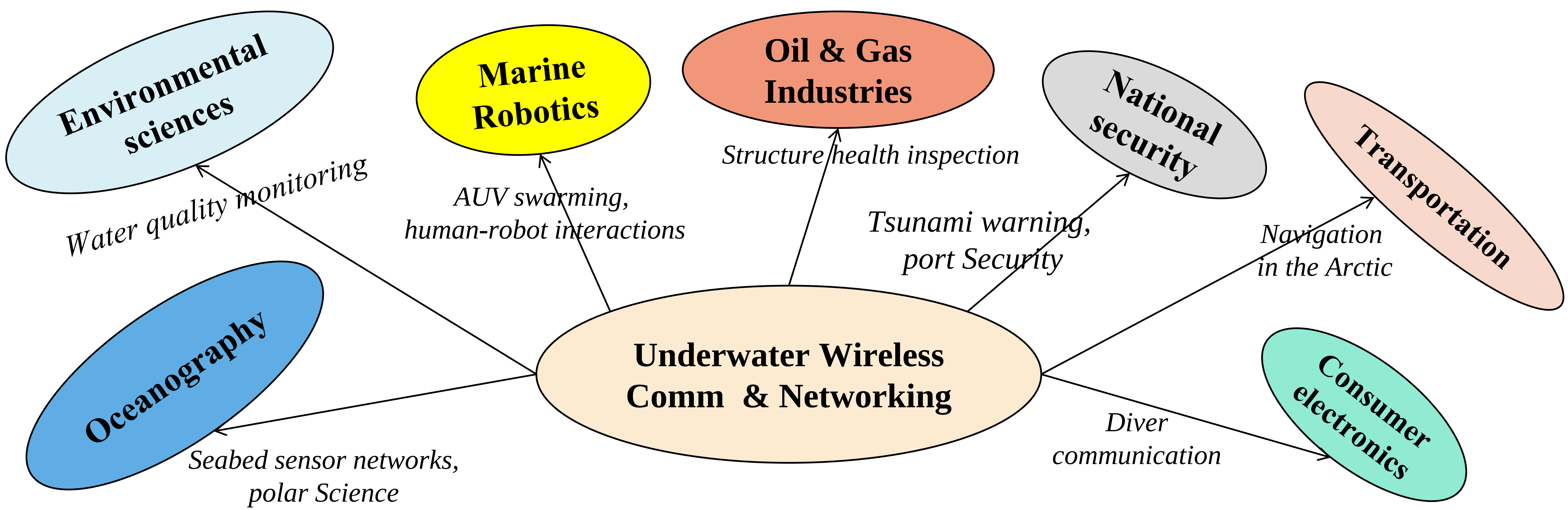
Applications: Where are the Gaps?

- Lack of friendly user-interfaces
  - No consistency or guarantee of communication performance
  - No user-oriented simulation tools
- Lack of application-driven investigations that provide good use examples.
  - No reviews and comparison among acoustic modems
- No efficient power solution for extended underwater deployment and for compact systems
- High cost and large size of underwater modems
- High threshold to conduct verification at-sea

Applications: Promising Directions

- Open-source software/hardware, affordable miniaturized hardware for
  - Easy integration with moving platforms
  - Large deployments

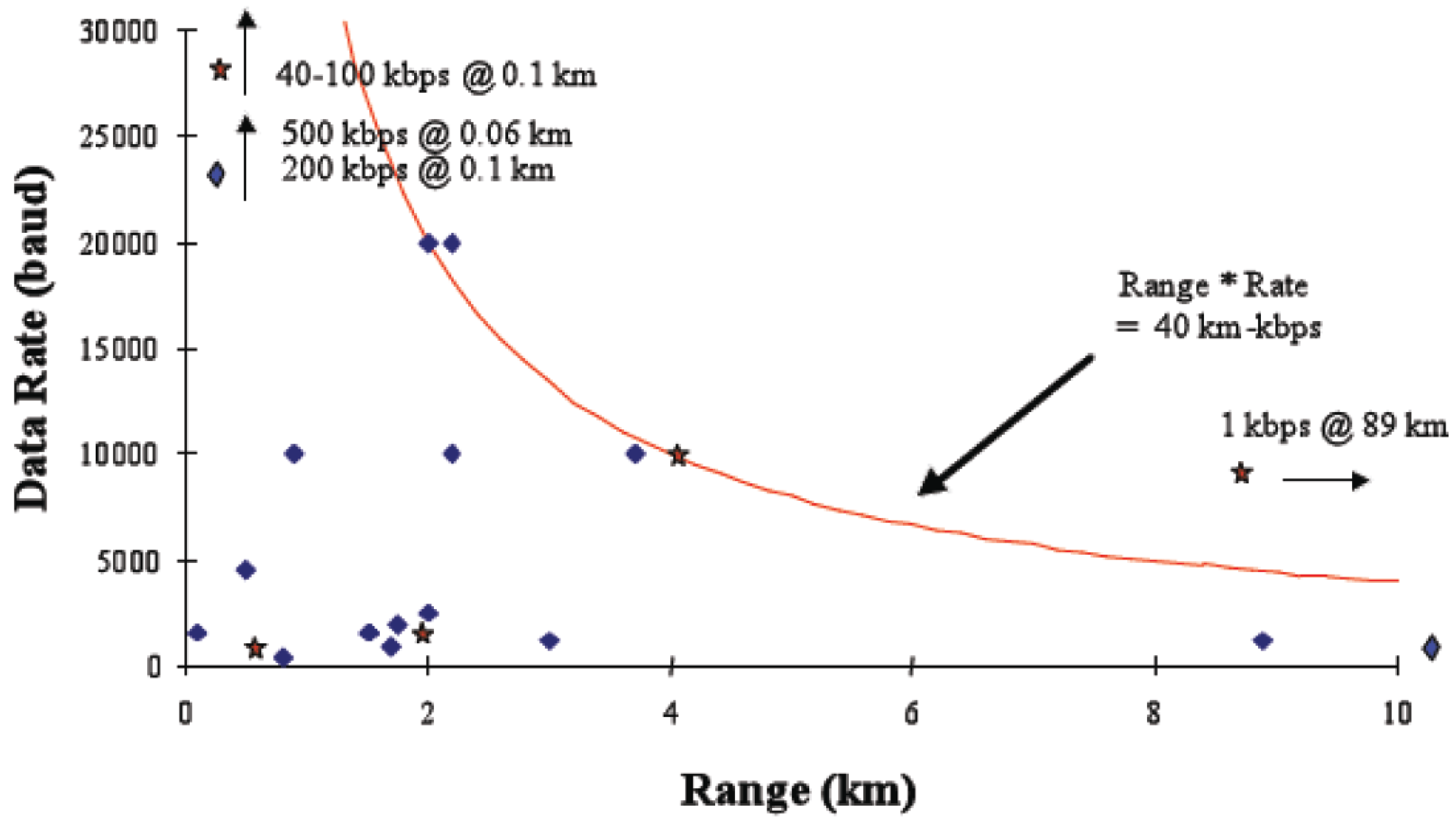
Thinking underwater wireless communications as a service



Applications: Promising Directions (II)

- AUV swarming and autonomy research with realistic underwater communication constraints
- Deployments in the Arctic, under-ice environment
  - Sensing, communications, and networking applications
- Deployments in lakes and rivers
  - Attract more users for pollution monitoring, water quality survey, etc.
- New power technology for extreme environments or extended deployments
- Incorporating big data, cloud computing, and IoT ideas into underwater environments
- Biofouling and equipment maintenance in a relative permanent installation: Endurance and reliability

PHY: Where we stand on range/bit-rate



Published experimental performance of underwater acoustic telemetry systems is summarized in this plot of rate (kbps) vs. range (km). The channels vary from deep and vertical to shallow and horizontal. In general, the high rate or high range results are for deep channels while the cluster of low range, low rate are for shallow channels. Modems developed by the research community are represented with diamonds while stars denote commercially available systems. The range-times-rate bound represents an estimate of the existing performance envelope. While there are exceptions, most reviewed systems are bounded by this performance limit.

Source: Stojanovic and Beaujean. "Acoustic communication." In Springer Handbook of Ocean Engineering, pp. 359-386. 2016.

PHY: Common test grounds

- Urgent need to establish a public repository of channel responses & measurements for research, algorithm validation and performance prediction
  - Typical channel types (3-10 of them)
  - Ambient noise
  - Directivity, spatial dependence, frequency dependence
  - Statistical model based on channel responses
- NSF funding for 1) collection of channel measurements and 2) dissemination of data
  - ONR may be able to provide some datasets, and testing facilities
- Publication, citation, and peer-reviewed process for datasets (Suggest to IEEE OES TC for an initiative)

PHY: List of important topics

- Physical layer feedback: adaptive modulation, large scale vs small scale
- Capacity analysis
- Interference management
- Multimodal communication (acoustic, optical, EM or new methods)
- Directional transmissions
- Asymmetric links (uplink vs downlink)
- Underwater localization & "GPS"
- Cooperative distributed communication (spatial diversity)
- Full-duplex modems
- Low computational complexity performance prediction to position mobile nodes

Networks: Architecture

- Software-defined, information (or content) centric, mobility-aware architectures at the network layer
  - Address large delay and low bandwidth, support robustness/reliability
  - Application-optimized hierarchical, hybrid architecture
  - Centralized, cellular-like networks
  - Scalability over large coverage
  - Optimization for different deployment environments
- Reprogrammable, self-organizing, self-healing, self-optimized at the MAC/PHY layers
- Underwater IoT: Use of surface floats/platforms
  - Take advantage of or address mobility
  - Multi-tier networks
- Other issues: Standardization, security, and authentication

Routing over Spatial Variability

- Routing for moving nodes is a unique challenge
- Efficient routing algorithms considering control overhead, number of nodes, multimedia traffic/priority
- Support for multi-modal and multi-medium networks
- Resource allocation and reuse with bandwidth and power constraints
- Exposure-limited or covert communications, topology discovery and management
- Distance-based/application-specific use of different modals/interfaces i.e. optical, acoustic, magnetic induction

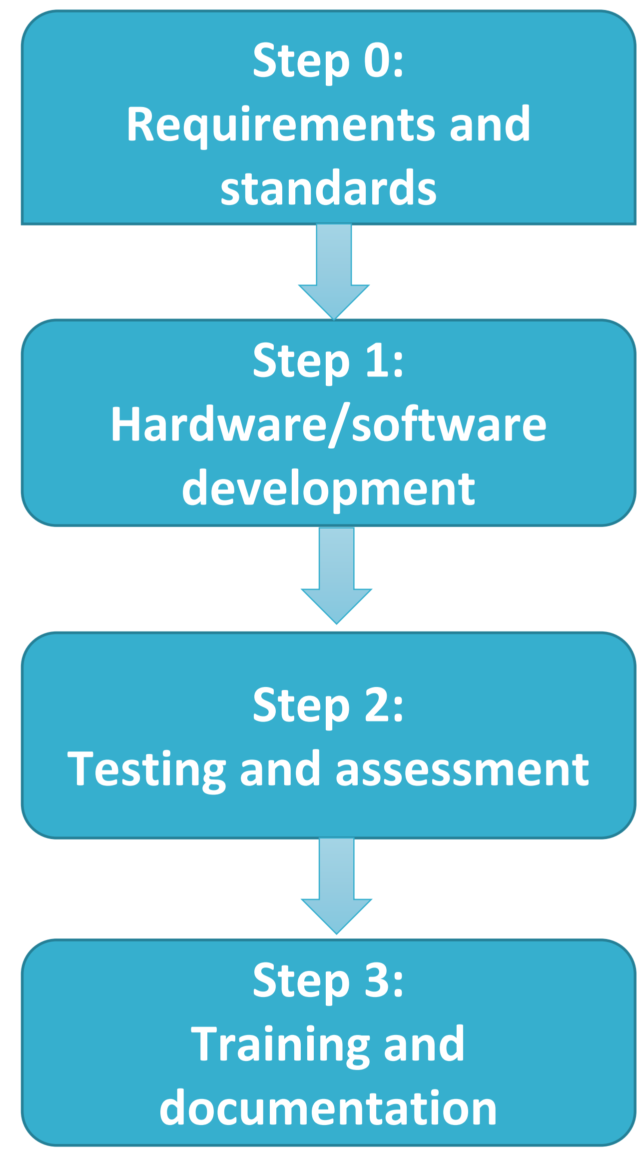
Gap between Networking Simulations and Experimental results

- Accessible network testbeds for the community
    - Low operation costs and easy deployment
- Network simulators
    - Need to address the channel model/simulations
    - Time-varying channels, realistic channel replay or simulations
    - Environmental parameters from measurements or ocean models
- Benchmarks and validation

Implementation: Challenges

Take state of the art/science, and translate it to devices and capabilities for specific mission or need

Implementation procedures



- There is no single one-size-fits-all solution
- Lack of standards for implementation framework: Software, hardware, testing, assessment, etc.
- Constraints on implementation: Numbers of transducers or hydrophones, space & power budget, etc.
- Barriers: Difficulties in platform integration
- How to test?

Implementation: Open Research

- Opportunities at the extremes of size, weight, power, cost, performance, etc.
- Develop an architecture or framework where different technologies can be plugged into
    - APIs for different modems to ease integration across systems
- Industry standards for different components: Software, hardware, testing, and assessment
    - Efforts both from the research community and the industries
- Standardized testing frameworks that include ocean model, mobility model, autonomy
- More: Hardware in the loop testbeds, benchmark implementations, hardware/software development kits, mapping algorithms into processor structures (FPGA, GPU, DSP, etc).

Grand Challenge

Implement an Underwater Wireless Communication Network On-the-Fly

- Solve a problem or accomplish a specific mission in underwater acoustic communications and networking
  - Imagine that a devastating earthquake attacked a densely populated port city near the Arctic region
- Goal: Build network in real-time, over multiple scales, with different platforms and gateways; Deliver data to users, provide command and control
- Metrics: bit rate, amount of data (information delivered), latency, reliability, etc.

Action item

- Acomm/robot student competition