# *DTN for Maritime and Underwater Sensor Networks*

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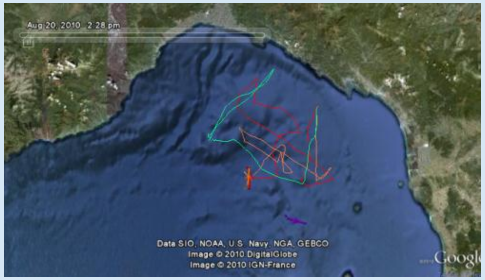
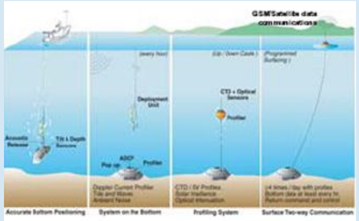
DTNRG session - IETF 83
*Paris, 25-30 March 2012*

# *Applications of underwater communications*

- Persistent monitoring sensor networks
  - Security applications
  - Environmental applications
  - Pollution (oil spill, radioactivity)
  - Ocean sampling networks

- Environmental monitoring
  - Climate change
- Undersea exploration
- Disaster prevention
- Assisted navigation
- Coordination in swarms of AUVs
- Distributed tactical surveillance and tracking
- Mine reconnaissance

# Comparison of Underwater Communications technologies

| | Benefits | Limitations |
| --- | --- | --- |
| **RF** | •Crosses air/water/seabed boundaries easily<br>•Prefers shallow water<br>•Unaffected by turbidity, salinity and pressure gradients<br>•Works in non-line-of –sight<br>•Immune to acoustic noise<br>•High bandwidths (up to 100Mb/s) at very close range | •Susceptible to EMI<br>•Limited range through water |
| **Acoustic** | •Proven technology<br>•Range up to 20 Km | •Strong reflections/attenuation when transmitting through boundary air/water<br>•Poor performance in shallow water<br>•Affected by environmental parameters (conductivity, temperature, density, bathymetry)<br>•Limited bandwidth (0 to 20 Kb/s)<br>•Impact on marine life |
| **Optical** | •Ultra-high bandwidth (gigabit per second)<br>•Low cost | •Does not cross air/water boundaries easily<br>•Susceptible to turbidity, particles and marine fouling<br>•Requires tight alignment of nodes<br>•Very short range (meters) |

*Source: IEEE Communications Magazine, December 2010*

# *Underwater acoustic communications*

- Acoustic communication is the foundational technology to interconnect nodes in the underwater domain
- Design of underwater communication protocols is affected by:
  - Propagation delay
    - sound propagation in water is 1500 m/s, five orders of magnitude higher than EM
  - Time varying multipath and fading
  - Noise (ambient, biological, man-made)
  - Doppler distortion
  - Available acoustic bandwidth
  - High power medium absorption at high frequencies (>50 kHz)
  - Energy constraints
    - Low duty-cycle operations



# Typical acoustic modems performances

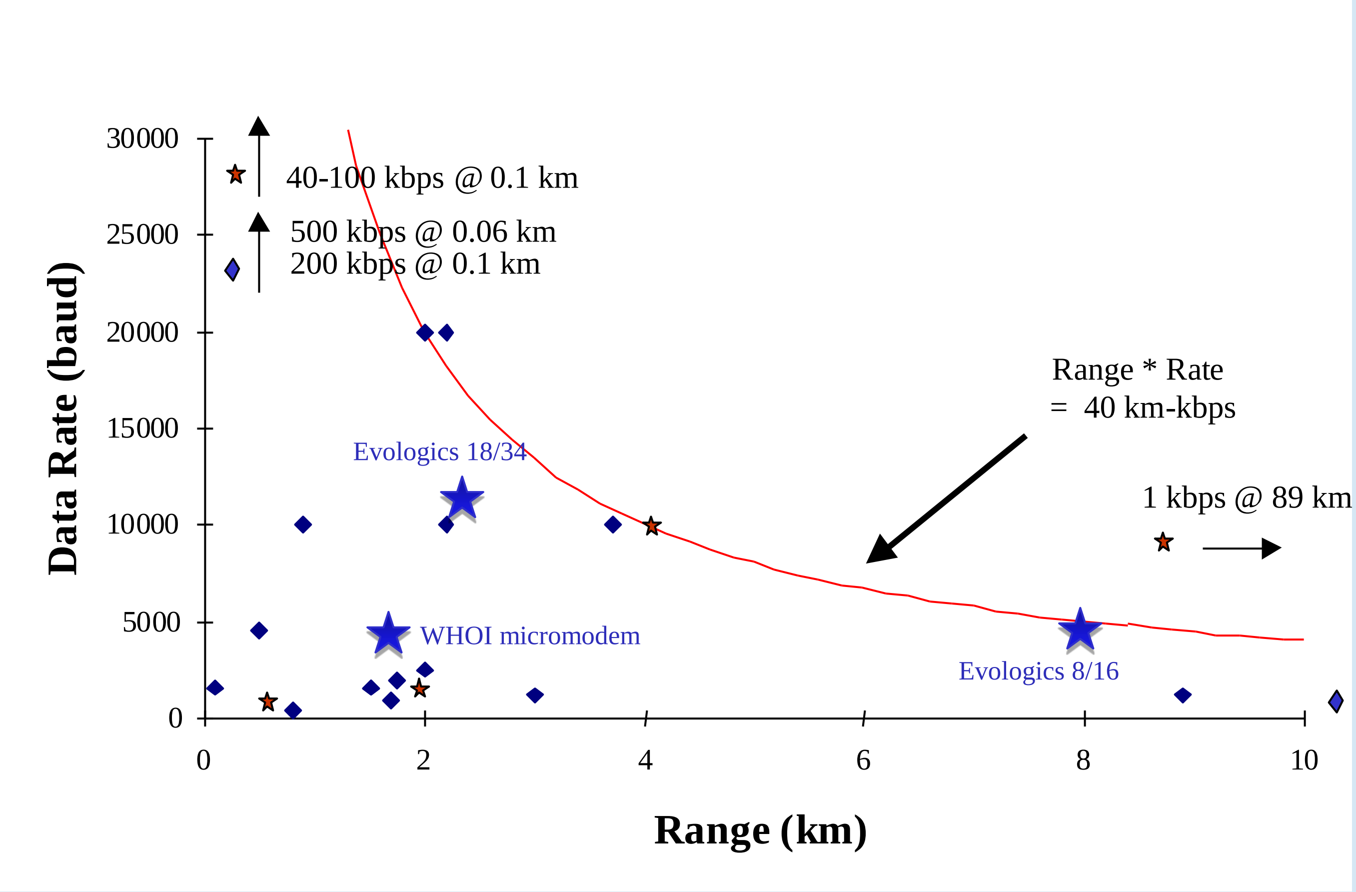
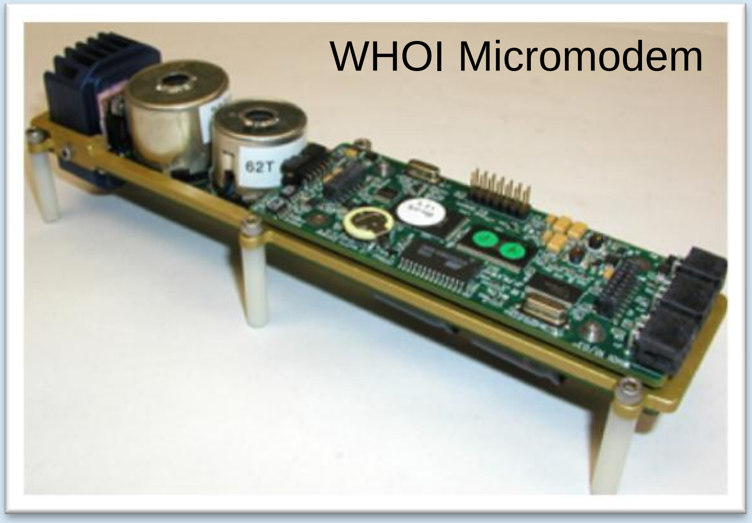



***Image from: "The state of the art in underwater acoustic telemetry"***
*Kilfoyle, D.B.; Baggeroer, A.B.;*
*MIT & Woods Hole Oceanogr. Instn. Joint Program in Oceanogr. Eng., Woods Hole Oceanogr. Instn., MA*
*IEEE Journal of Oceanic Engineering, Jan 2000*

# Examples of acoustic modem performances


- **WHOI Micromodem**
  - Operational range: up to 1500 m
  - nominal acoustic bitrate: up to **80 bps** (FSK), up to **5400 bps** (PSK)
  - operational frequency band: 15kHz - 25kHz - 28 kHz
- **Evologics 18/34**
  - operational range: up to 4500 m;
  - nominal acoustic bitrate: up to **13.8 kbps**
  - operational frequency band: 18kHz - 34kHz
- **Evologics 8/16**
  - operational range: up to 8000m;
  - nominal acoustic bitrate: up to **6,9 kbps**
  - operational frequency band: 8kHz - 16kHz

# Objectives of our work

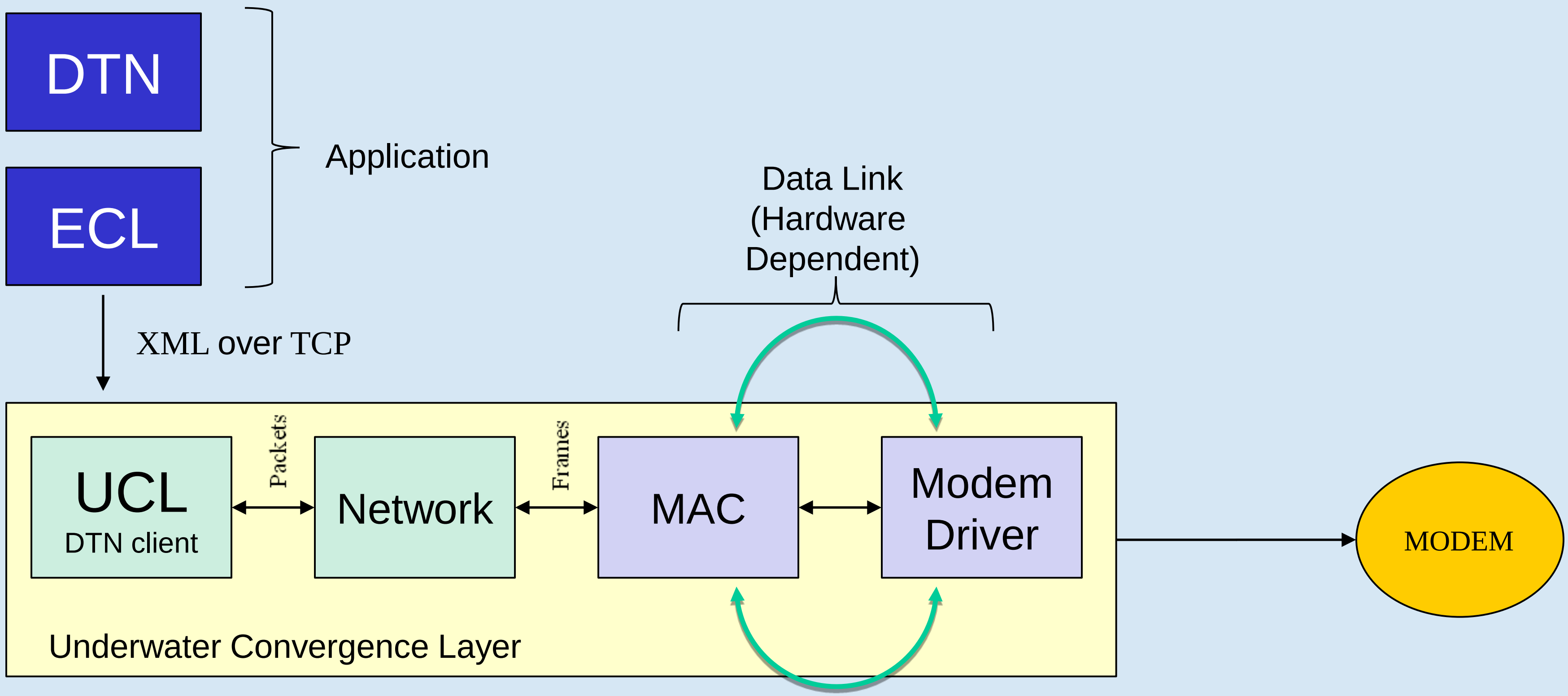
- Evaluate suitability of Delay/Disruption Tolerant Networking (DTN) to create networks composed of heterogeneous links (radio and acoustic)

- Develop of open-source software communications framework (Underwater Convergence Layer – UCL) to abstract the access to acoustic modems of several vendors

- ***Joint effort of NURC and the Faculty of Engineering of Universidade do Porto (Portugal)***

Initial bench tests

# Software Architecture

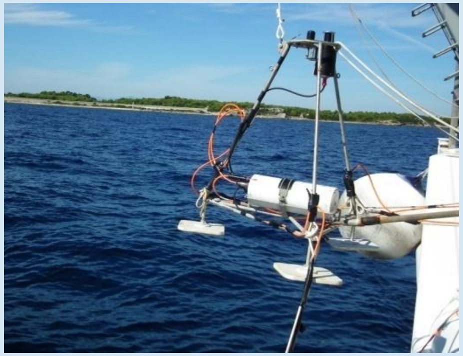


# Software modules

- **Platform Access and Abstraction (PAA) Module**
  - logging relevant messages and performance statistics to files and to the system console
  - configuring and performing bi-directional communication with serial port devices and TCP/IP sockets
  - support for threading and concurrency
- **Data Link (DL) Module**
  - delivering and receiving frames
  - maintaining a list of reachable nodes
  - advertising the local node
- **Modem Driver**
  - services requests to transmit data.
  - sends notifications to other modules
- **Network Module**
  - exposes an interface to send and receive data in the form of packets
  - implements transparent compression and decompression
  - performs fragmentation and reassembly
- **ECL Client**
  - interacts with the local DTN2 ECL
  - maintains a list of links that are presently open
  - parses, validates and generates DTN ECL compliant XML messages
  - uses the ECL XML Schema for communication with the local DTN daemon
  - informs DTN about acoustic links available within range

# *Field tests*

- **three fixed bottom-moored acoustic nodes**
  - positioned to form a triangle with side length in the order of 1 km (positioned at 15, 21, 30 m depth);
- **one fixed acoustic node mounted on a buoy**
  - positioned at 13 m depth, repositionable to vary the topology of fixed nodes
- **three hybrid (acoustic + RF) mobile nodes**
  - equipped with acoustic modem (at variable depth) and IEEE 802.11n wireless interface
  - one mounted on Research Vessel Leonardo, the other two mounted on rigid-hulled inflatable boats (RHIBs)



# *Initial results from field testing*

- The principal objectives of the field testing were
  - demonstrate advanced network functionalities
  - application of DTN concepts to the maritime domain
    - in a heterogeneous context comprising underwater nodes communicating acoustically and surface nodes communicating with radio frequency
- During the field testing we were able to verify that the UCL operated according to the specifications
- A performance issue was observed with denser deployments (6 acoustic nodes)
  - the contention of the shared underwater channel became evident through a very high number of collisions.
  - The cause of this issue was tracked down to an implementation flaw that allowed for node advertisements to bypass the MAC module

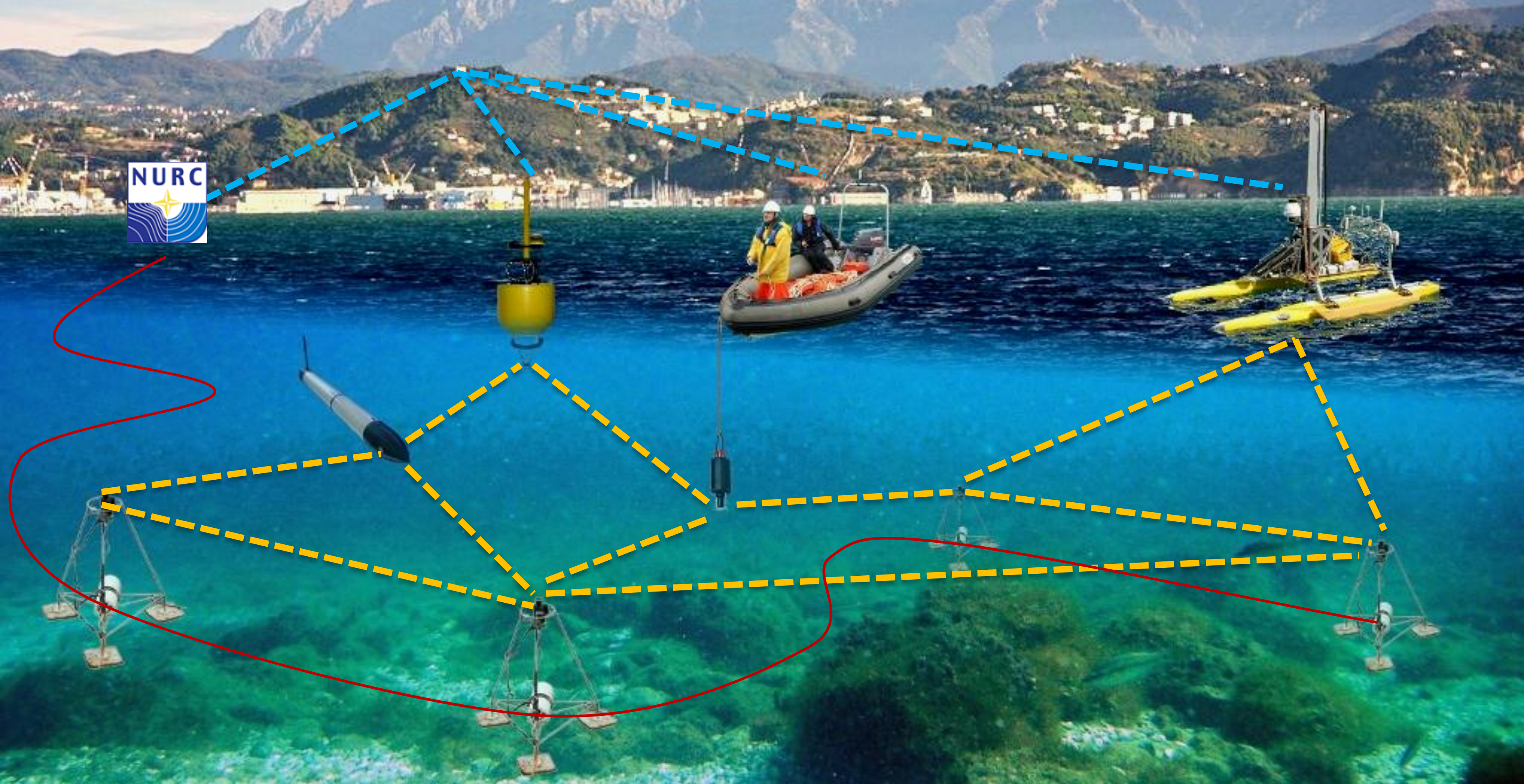
# *Current work*

- **Improve the existing API**
  - support additional acoustic modems
  - support for multiple MAC protocols
- **Experiment aggressive optimizations to the DTN bundle protocol**
  - Reduce header/protocol overhead
  - Test a DTN-lite implementation for the maritime environment
- **Support for dynamic routing**
  - New protocols specifically adapted to persistent surveillance scenarios, swarm networking etc.
- **Interoperable communication between heterogeneous underwater clusters**
  - Acoustic ↔ RF ↔ Acoustic
  - Platform-independent, DTN enabled middleware
  - DTN-enabled communication module for MOOS-IvP (Mission Oriented Operating Suite - Interval Programming)
    - MOOS-IvP is a software suite to provide autonomy on robotic platforms, in particular autonomous marine vehicles

# Semi-permanent testbed at NURC

# *LOON (Littoral Ocean Observatory Network)*
## *hybrid communications testbed*

- 4 Underwater fixed acoustic nodes, connected with underwater cables to NURC
- up to x AUV with Acomms (e-folaga)
- 2 RHIBs with Acomms, connected via RF wireless with NURC
- 1 gateway buoy with Acomms, connected via RF wireless with NURC
- 2 USV with Acomms, connected via RF wireless with NURC



# Conclusions

- **We have demonstrated that DTN and UCL can be used to transparently and reliably interconnect "traditional" IP-based and acoustic networks**

- **DTN is suited for use in maritime hybrid networks, for mission critical transactions where data must be delivered reliably across a set of highly heterogeneous links in order to reach the intended destination.**

- **If used with current acoustic modem technologies, DTN requires adaptation to cope with the limited available bandwidth**

# Thank you for your attention

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