Development of a Reconfigurable Underwater Acoustic Networking Testbed

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WINES — Wireless Networks and Embedded Systems Lab

Architecture of UW-Buffalo Testbed

- UW-Buffalo testbed
- University at Buffalo and Teledyne Benthos [1]
- Shared, reconfigurable platform
  - UDB-9000 universal deckbox with acoustic transducer
  - 11 Telesonar SM-75 modems
  - one sonar modem

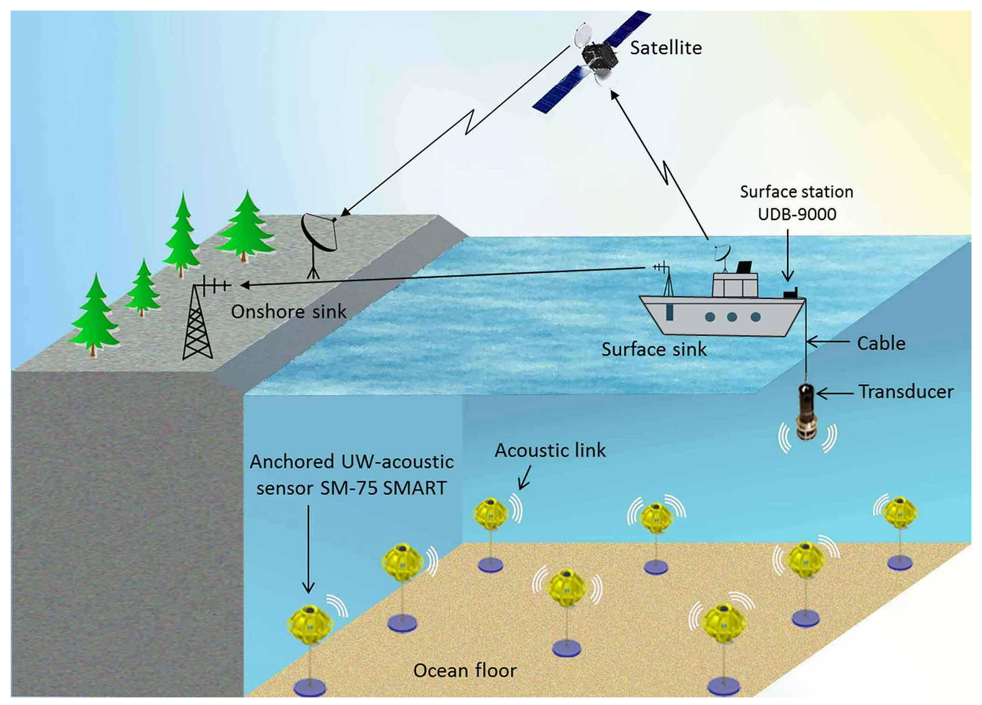

Fig. 1. Architecture of an underwater acoustic sensor network.

UW-Buffalo Testbed

- Reprogrammable from PHY to higher layers
  - Can transmit custom-designed waveforms
  - Record acoustic data, process offline
  - Emulate MIMO capabilities
  - Reprogram MAC and network layer in software
  - Defined interfaces among layers, allows retaining control of lower layer functionalities
  - IP compatible
- Shared: Available to the research community
- Laboratory experiments, deployed twice a year

SM-75 Modem and UDB-9000 Deckbox

Teledyne Benthos SM-75 telesonar modem

- PSK data rates 2,560− 15,360 bit/s
- MFSK data rates 140−2,400 bit/s
- RS-232 sensor interface
- ranging accuracy 0.3 m
- can transmit custom-defined waveforms
- data recorder with two SD card slots

Fig. 2. SM-75.

UDB-9000 Universal Deckbox

- monitoring of all acoustic activity
- over the-side transducer
- graphical user controller
- releasing, communicating and controlling the SM-75
- two RS-232 serial ports for data/command line interaction

Fig. 3. UDB-9000.

Node Architecture

- SM75 modem interfaced with Gumstix on Tobi expansion board

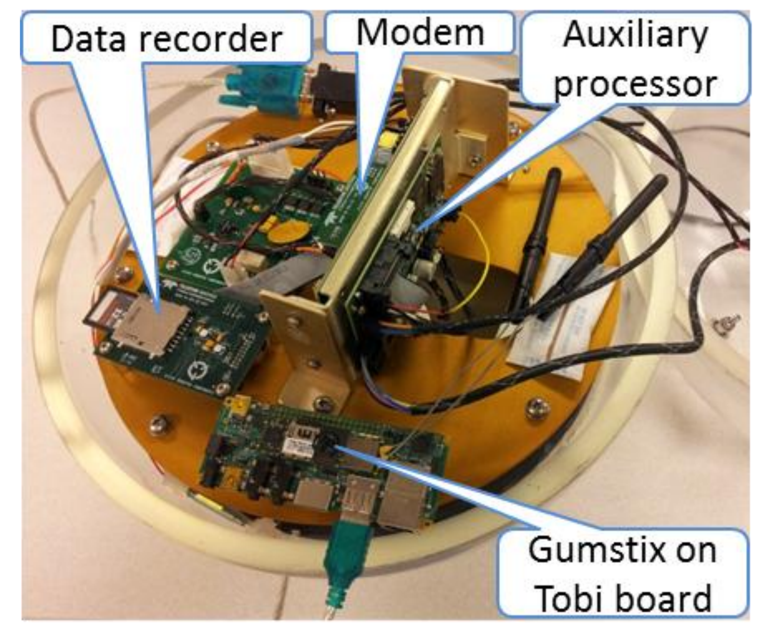

Fig. 4. Open view of SM-75 electronics with auxiliary processor, data recorder and Gumstix residing on Tobi expansion board.

- Gumstix hosts control logic in charge of implementing networking functionalities at all layers of the protocol stack by building on the physical/link layer application programming interface (API) exposed by the Benthos modem.
- On sonar modem Gumstix allows storing and processing data from multiple channels, to allow MIMO and cooperative signal processing functionalities.

Exposing PHY/LINK: A Networking API for SM75

- **PAST**: All networking functionalities, including channel access negotiation, selective repeat request (SRQ), and waveform selection, resided within the core DSP of the individual modem, and could not be reconfigured by the end-user.
- **CURRENTLY**: A networking API software interface has been developed by Teledyne Benthos to remove hardcoded bond between the embedded link and network layers in the modem [4].
- New serial binary control protocol called Modem Management Protocol (MMP).
- **MMP**: unambiguous binary interface for machine based command and control of the acoustic modem.

Develop. of Networking Protocols through the MMP

- Native SM-75 network layer is bypassed and its duties are passed to the Gumstix whose behavior can be defined by the end user
- The original data link and physical layers can remain unchanged
- Gumstix can be used to control the lower protocol layers on the modem through the use of MMP

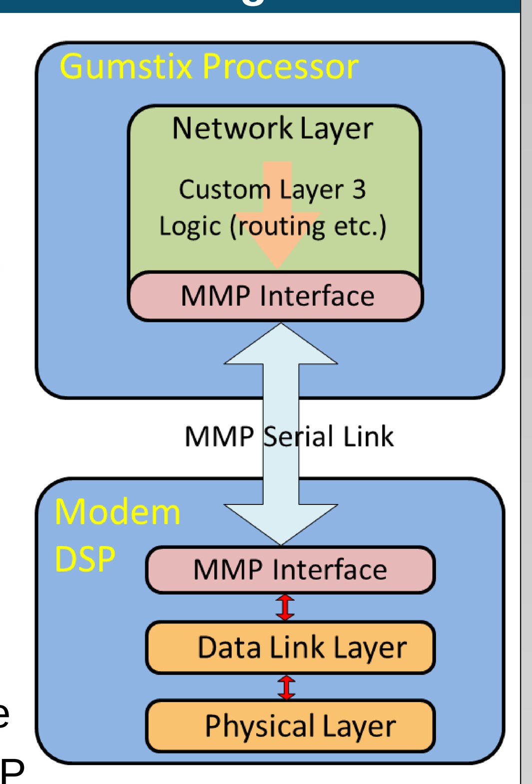

Fig. 5. Open PHY/Link networking interface.

Cross Layer Controller Architecture

- The logic in control of the networking functionalities is implemented in the C language and housed on the Gumstix [2].
- The Gumstix interfaces with the modem via the established API

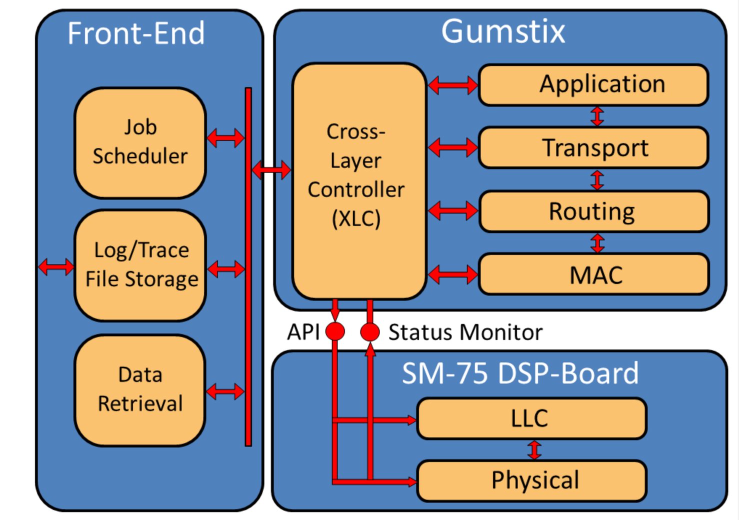

Fig. 6 Software architecture.

- State information from lower layers of the protocol stack available to higher layers and vice versa (cross-layer information sharing) [3].

Implementation of Baseline Networking Protocols

- **IPv6 Compatible Network Layer**
  - In the current version of the Benthos modems there is no standard network layer protocol. We are working on making the modems IP-compatible by designing a Linux driver for the SM-75.
- **Implementation of Medium Access Control Primitives**
  - The MMP interface includes primitives for link establishment and negotiation and for packet transmission and acknowledgement.
  - We are designing reconfigurable MAC protocols based on these primitives.
- **Implementation of Routing Protocols**
  - Based on the IP-compatible addressing.

UW-A Network Channel Emulator

- **The UW-A channel emulator**
  - resides in a PC,
  - interfaced with SM-75 modems through RS-232 serial port,
  - controls the modems to transmit and record custom defined acoustic waveforms.
- The transmitted signals are captured by an audio input device, fed to the channel emulator and signal processed to account for channel effects.

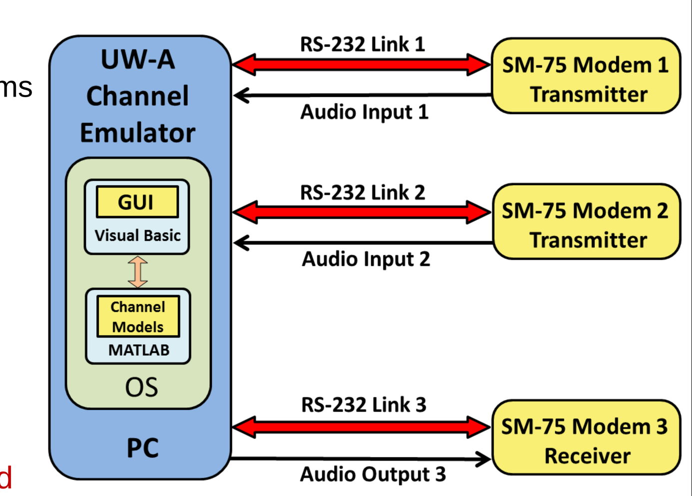

Fig. 7. Architecture of the channel emulator.

- The emulated signal is played to one or more receivers (as desired signal or interference).

Channel Emulator GUI

- The user may select:
  - SISO or MIMO transmission schemes,
  - location of the modems,
  - parameters affecting the UW-A channel.

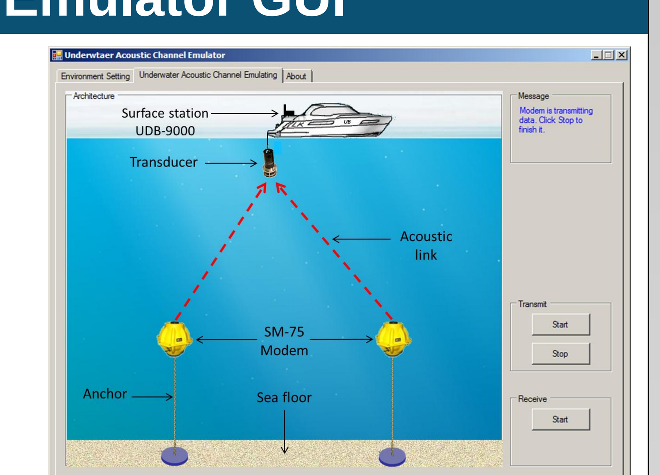

Fig. 8. Underwater acoustic channel emulator in action.

Channel Emulation Results for SISO

- SISO scenario under light and heavy multipath environments for different transmission distances
  - A 512 bit/s, BPSK raised-cosine pulse shaped waveform
  - Transmit power = 2.5 W
  - 1.25 MByte data
  - Minimum distance decoding

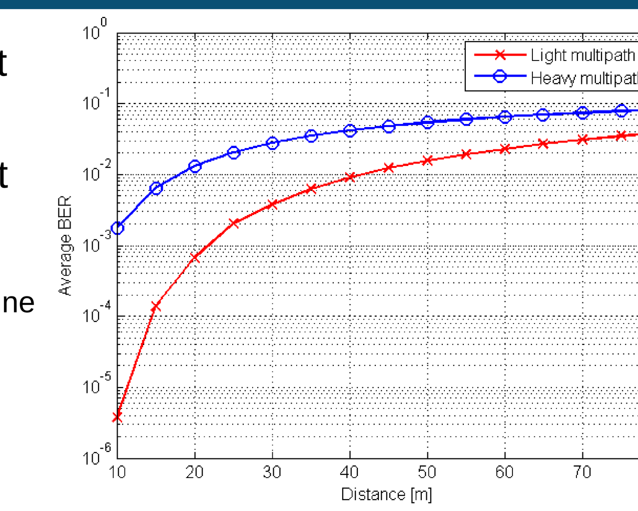

Fig. 9. SISO transmission with transmission distances.

Channel Emulation Results for MIMO

- MIMO scenario for different arrival delay times of the two signals.
  - Range: 30 m and 80 m
  - A 512 bit/s, BPSK raised-cosine pulse shaped waveform
  - Transmit power = 2.5 W
  - 1.25 MByte data
- As anticipated the avg. BER for 80 m range transmission is higher than the 30 m.
- As the arrival delay increase the avg. BER increases and eventually saturates at 0.2 ms.

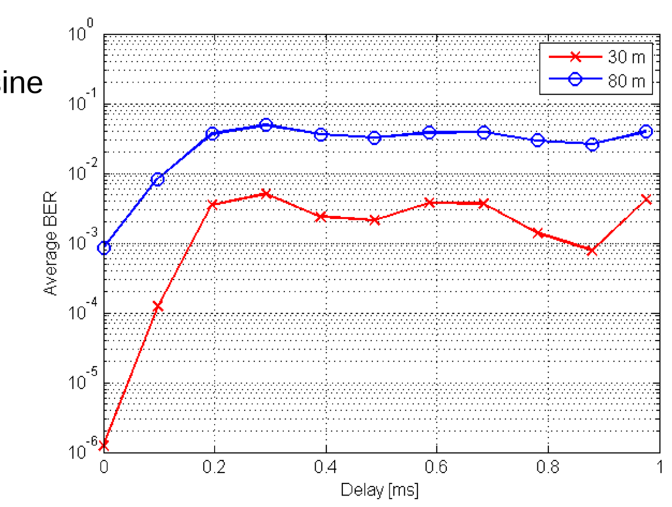

Fig. 10. MIMO transmission with different second signal arrival delay time.

Experimentations in the Diving Pool at UB

- Experiments conducted inside the diving pool of the Alumni Arena at University at Buffalo
  - Dimensions of the pool 22 m × 16 m × 4.9 m (length, width and depth)
  - Transducers are at a depth of 2 m from the surface
  - Range 20 m

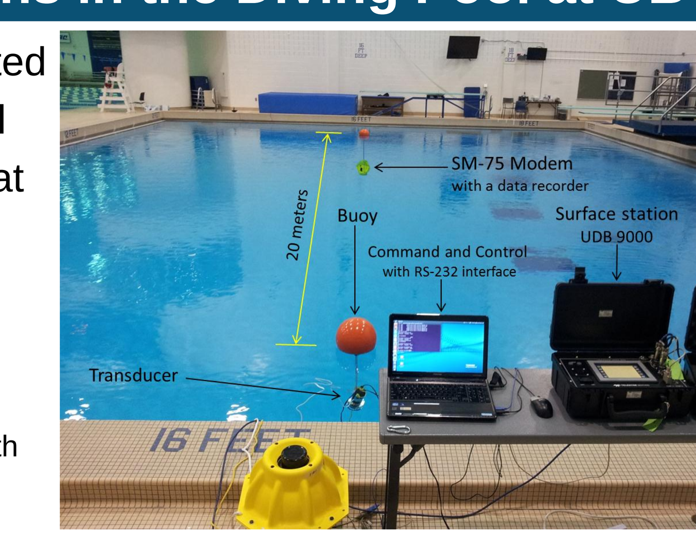

Fig. 11. Experimental setup in the diving pool of University at Buffalo.

Emulator and Experimental Results

- DS-CDMA acoustic waveform transmission
  - 1.25 kBytes of data transmitted with different transmit power levels from −21 dB (1.78W) to 0 dB (20W)
  - Conventional RAKE-matched-filter used to decode the transmitted bits
  - The BER performance for the real experimental results is slightly worse than the emulator results due to the severe multipath in the diving pool at UB.

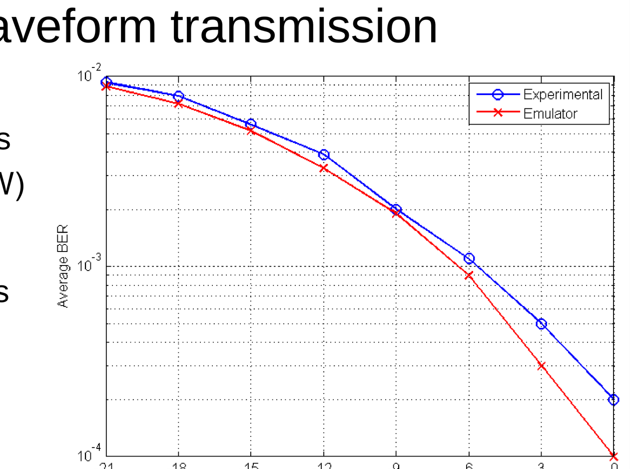

Fig. 12. Average BER performance for experimental and emulation results of DS-CDMA transmission with different transmit power levels.

References

[1] Teledyne-Benthos, Acoustic Modems. http://www.benthos.com.
[2] Gumstix Inc. [Online]. Available: http://www.gumstix.com.
[3] H. Kulhandjian, L. Kuo, T. Melodia, D. A. Pados, and D. Green. Towards Experimental Evaluation of Software-Defined Underwater Networked Systems. In *Proc. of IEEE UComms*, Sestri Levante, Italy, September 12-14, 2012.
[4] T. Melodia, H. Kulhandjian, L. Kuo, and E. Demirors. *Advances in Underwater Acoustic Networking*. In Mobile Ad Hoc Networking: Cutting Edge Directions, Eds. S. Basagni, M. Conti, S. Giordano and I. Stojmenovic, John Wiley and Sons, Inc., Hoboken, NJ, 2013.