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UNDERWATER ACOUSTICAL NETWORK FOR ENVIRONMENTAL MONITORING

Tor Arne Reinen [1]

[1] SINTEF ICT Dept. of Acoustics

Abstract

An underwater acoustic network has been designed, implemented and tested at sea. The design targets underwater environmental monitoring, with low average traffic,but strict requirements on energy efficiency. A simple random access multihop system has been chosen, and has been found to work well under the design criteria. .
The work has been carried out in cooperation Kongsberg Maritime and several Norwegian and international partners.

Contact author: Reinen, T. A., SINTEF ICT Acoustics, P. O. Box 4760 Sluppen
N-7465 Trondheim, , NORWAY, email: tor.a.reinen@sintef.no

Introduction

Wireless underwater networking is an emerging technology with a wide range of applications in environmental monitoring, resource management, offshore safety and security etc. Wireless functionality is particularly important in systems with mobile units (e.g. AUVs), and for rapid ad hoc network deployment, e.g. in emergency situations. Acoustics is the preferred wireless communication modality in the sea, as radio waves attenuate rapidly, especially in salt water. Acoustic communication is mainly suited for local networks (few kilometres). For long distance communication (many kilometres), connection to cable or a radio/satellite link is recommended.

Underwater acoustic communication, both point to point and networking, is an active research topic internationally. Much work has been published, especially during the last 5-10 years. Summary articles are e.g. (Akyildiz, Pompili, & Melodia, 2007), (Partan, Kurose, & Levine, 2007). The work presented here focuses on environmental monitoring, with low average traffic but strict requirements on energy efficiency (battery life). This leads to quite a simple network protocol. Details are given in (Rustad, 2009) and (Faugstadmo, Pettersen, Hovem, Lie, & Reinen, 2010).

The work has been carried out in cooperation with Kongsberg Maritime and other partners in the Norwegian Research Council project NNN-UTS, and in the EU FP7 project UAN (http://www.ua-net.eu/), supplemented by the SINTEF internal project Ocean Space Surveillance .

Wireless propagation in the sea

Sound propagation in the ocean differs from radio propagation in air in several manners that are important for wireless networking:

- Low propagation speed: 1500 m/s vs. 300000000 m/s
- Low bandwidth, i.e. low data rate
- Absorption
- Limited energy, expensive recharging
- Challenging propagation channel with variability both on short and long time scales.

The low propagation speed leads to low medium exploitation in many cases. To illustrate this, assume that a 1000 bits message is to be transmitted at 1000 bits/sec over 3 km distance, with acknowledgement required from the receiver. At propagation speed 1500 m/s this gives a maximum medium exploitation[1], as seen from the transmitter, of 20%, whereas a corresponding radio link would have ≈ 100%.

The challenging propagation channel is illustrated in *Figure 1* which shows shadow zones into which very little energy propagates, and *Figure 2* which shows examples of measured impulse responses and corresponding Doppler spread. These are created by complex and time variable refraction and reflections of sound waves.

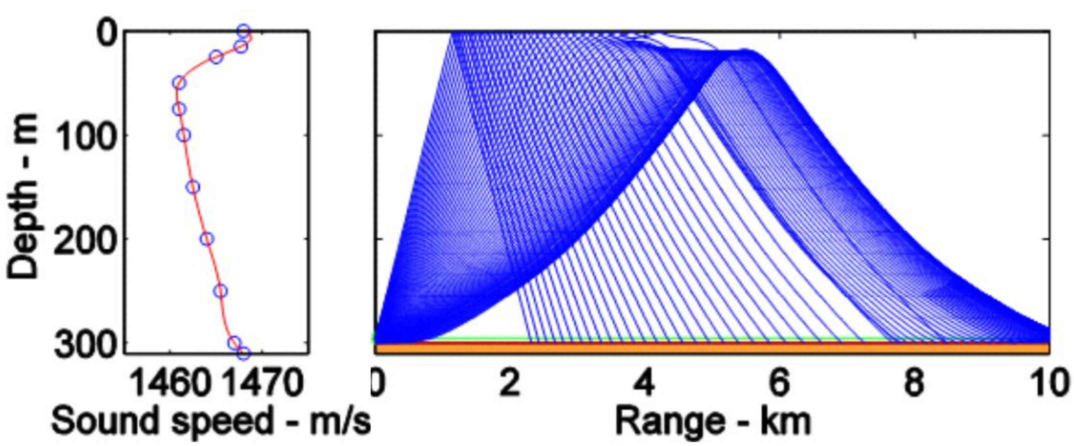

Figure 1 Sound propagation modelled using ray tracing. From (Hovem, Shefeng, Xueshan, & Hefeng, 2008)

[1] (Message duration)/(Message duration + 2-ways Transmission delay)

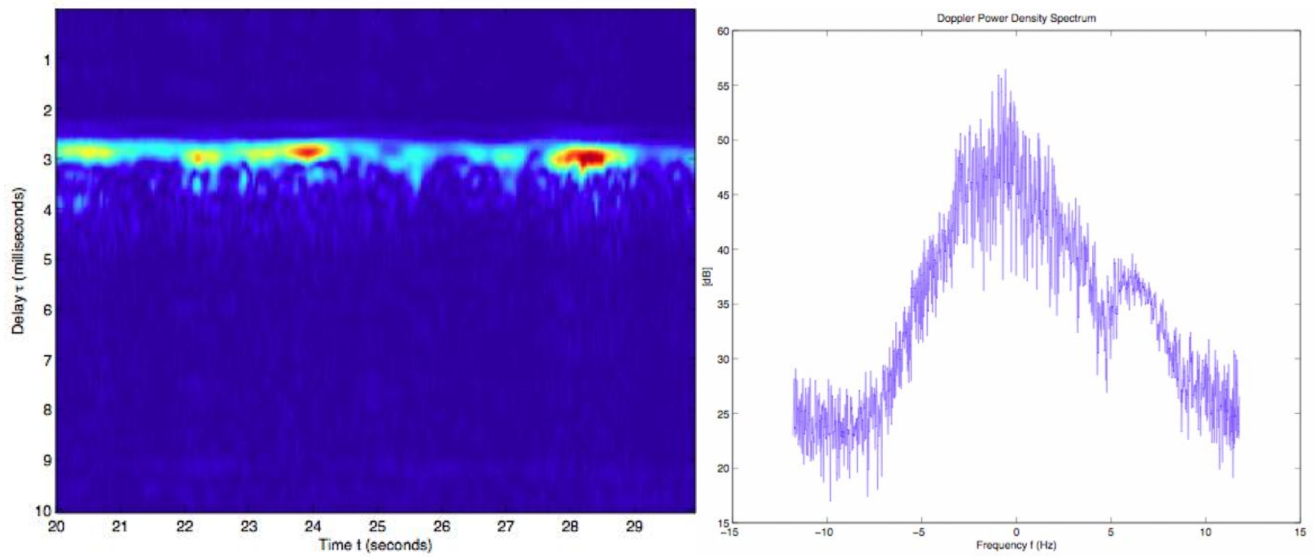

Figure 2 Impulse response measurement vs. time for a 2 km link (left) and corresponding Doppler power density (right). From (Grythe, Håkegård, Myrvoll, & Reinen, 2008).

Network protocol design for environmental monitoring

The following requirements and limitations are typical for a network that gathers environmental data, and have been determinative for our design:

- Self configuration
  - establish network
  - add or remove nodes
- Master node
  - sink for sensor data
  - source for commands
- Routing & transmission control
  - short hops and long hops with up to seconds round trip time
  - multi-hop routing
- Traffic
  - low volume sensor data
  - occasional high volume bulk transfers (can be coordinated by master)
- Energy efficiency
  - use high transmit power only when necessary
  - select most energy efficient multi-hop sequence
- Other
  - Simplicity
  - Robustness
  - Size

Based on these criteria, the following approach was chosen (Rustad, 2009):

- Medium access (MAC): Random Access, specifically Carrier Sense Multiple Access w. Collision Avoidance (CSMA/CA)
- Centralized routing based on initial mapping by “Flood” network discovery.

Medium Access (MAC)

The MAC protocol is based on CSMA/CA (IEEE 802.11 -WLAN). Each node can transmit when the water is silent, with exponentially growing backoff time if no acknowledgement is received for a transmitted message. Before long messages Request To Send/Clear To Send is exchanged. This reserves silent time and avoids collisions, and thereby saves power. Transmit power optimization is employed to save energy and avoid disturbing nodes farther off.

Network discovery and routing

Network discovery used the “Flood” method, initiated by the master broadcasting a FLOOD message. Every node repeats FLOOD several times with random delay, with data on received FLOODs appended. Finally every node reports FLOOD to master, who calculates transmission losses and distances without the need for synchronized clocks. Multihop routing is then calculated and distributed to the slaves. The result is a routing with

- Minimized transmit power for energy saving and minimum network disturbance.
- Possibility to distribute synchronized clock.
- “best next hop to master” in each node

New node discovery is initiated by the newcomer starting Flood.

Network simulations have been carried out to optimize parameters of MAC and routing, aiming to:

- Optimize efficiency/throughput in normal situations
- Ensure that the system is well behaved under traffic overload

Simulation parameters were:

- Omnidirectional nodes
- Multipath neglected
- Variable bitrate, up to 4000 bits/sec
- Variable transmit power

A network geometry used in the simulations is shown in Figure 3.

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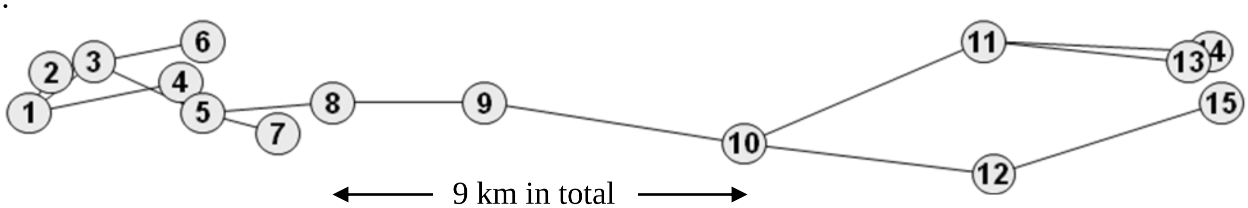

Figure 3 Network geometry used in simulations

Simulation results can be found in (Rustad, 2009). An example is shown in Figure 4, showing the throughput in as the traffic increases into capacity overload. The figure shows a well behaved system, with no capacity reduction in overload situations.

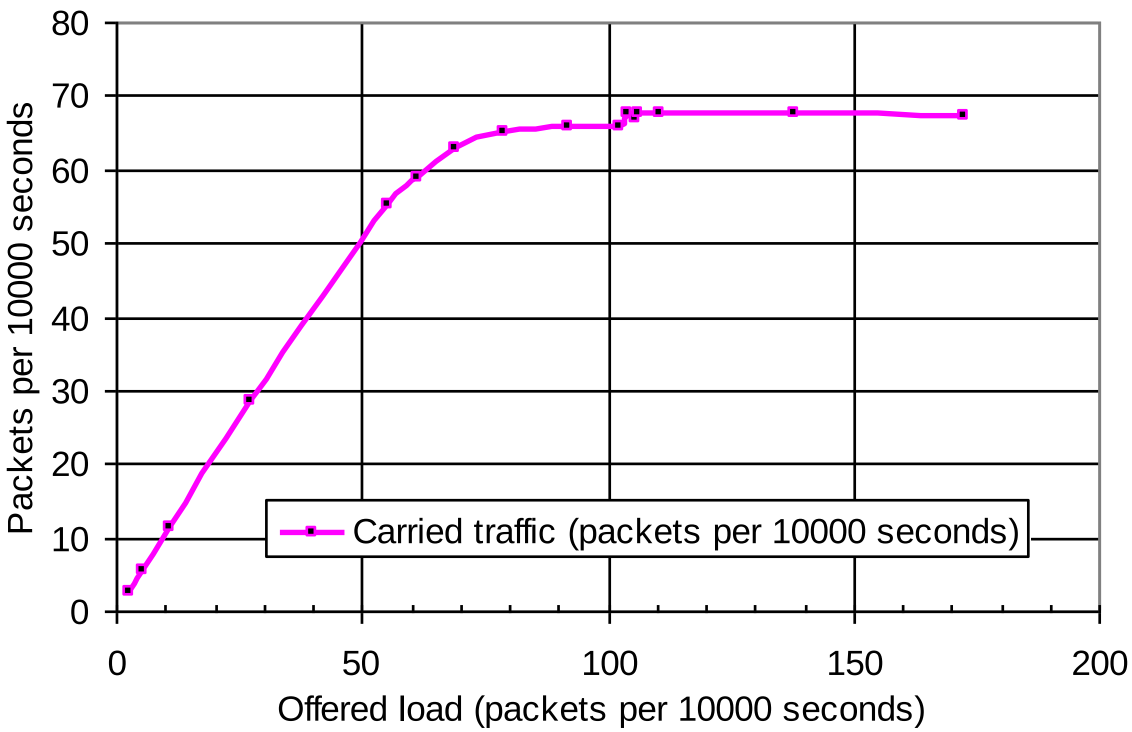

Figure 4 Throughput vs requested traffic

Implementation and testing at sea

The network has been implemented by Kongsberg Maritime, and was tested at sea in December 2009 (Faugstadmo, et al., 2010), using 5 sea floor nodes and a master under a surface vessel. This is illustrated in Figure 5. The system functionality was verified, including network discovery and routing, point to point and multihop communication, and MAC with retransmission of lost packets. The latter happens in random access networks if multiple packets collide, i.e. appear simultaneously at receiver node.

The system is being developed further in the UAN project (http://www.ua-net.eu/), including support for mobile nodes, and integration into a surveillance system. System tests were carried out in September 2010 at Pianosa, Italy.

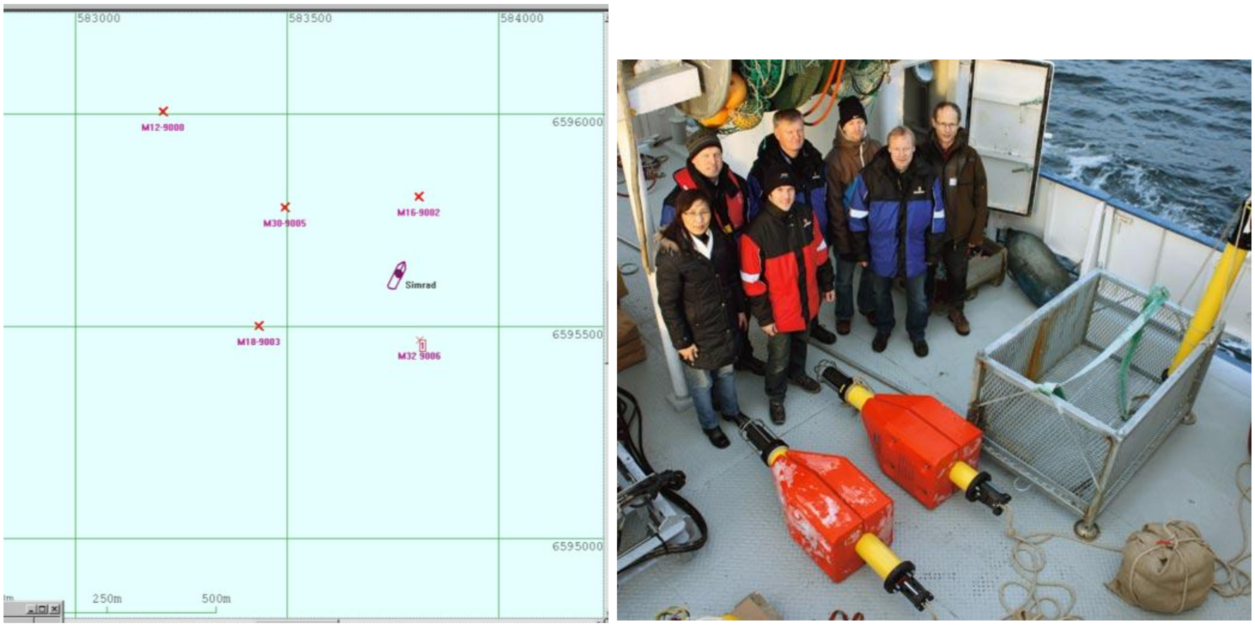

Figure 5 Network geometry during test (left) and two of the nodes used (right). The boat symbol in the left image designates the master node below a surface vessel

Summary and conclusions

Wireless networking is challenging under water, with large propagation delays, low bandwidths, together with delay spread and Doppler spread. Furthermore, these parameters vary considerably with time, on both short and long scales.
For applications with low average traffic, a simple random access multihop network works well under these conditions. In cases of higher average traffic more complex protocols are recommended.

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