

# Design and Simulation of an Underwater Acoustic Local Area Network

**Ethem M. Sozer, Milica Stojanovic, and John G. Proakis**

Northeastern University, Communications and Digital Signal Processing Center

409 Dana Research Building, Boston, MA, 02115

esozer@cdsp.neu.edu/www.cdsp.neu.edu

## ABSTRACT

An underwater acoustic (UWA) local area network (LAN) is designed and tested using Opnet's Radio Modeler. The network consists of master and sensor nodes that will be deployed in sea with battery powered modems. We modeled the UWA channel using the Radio Transceiver Pipeline stages supplied with Opnet. Since the network nodes are stationary, we assumed that channel is slowly varying and stays constant during a packet interval. An important parameter of battery powered network nodes is the power consumption. The power control algorithm and the power consumption of nodes are also tested using Opnet. The network models and simulation results are presented.

## I. INTRODUCTION

In this work, we investigated the underwater local area network (LAN) that was first tested during SeaWeb'98 [1]. The network consists of a number of sensor nodes that collect data from the ocean bottom, and a master node. The master node is responsible for gathering the collected data, transferring it to a control center on shore, and for controlling sensor nodes. The network traffic consists of asynchronous data delivery from the sensor nodes to the master node and remote command and control of oceanographic sensors in the other direction.

Network nodes use acoustic modems to communicate [2]. The speed of acoustic signals is 1500 m/s, which is much less than the speed of radio waves. Thus, packets experience large propagation delays. Also, current modems used for underwater communications can only provide bit rates in the order of tens or hundreds. This can create situations in which before a node finishes transmission of a packet, the receiver node may begin the reception of the same packet. Since the modem that will be used in the network nodes is not capable of processing signals from different sources simultaneously, nodes can establish only one session at a time.

We propose a packet transfer protocol that provides reliable transmission of information through an underwater LAN. In Section II, we present the network

topology used in simulations. Section III gives the node structure. The process models are defined in Section IV. The pipeline stage models used to simulated underwater acoustic channel are provided in Section V. The last section presents the results of the simulations.

## II. NETWORK MODEL

The network consists of two types of nodes:

- **Sensor Nodes:** These nodes collect data using their sensors. The collected data is then passed to the master nodes through the network. There may be as many sensor nodes as needed depending on the area to be covered.
- **Master Nodes:** Master nodes are responsible for collecting data from sensor nodes. The collected data is then passed to a gateway node that connects the acoustic network to the user on shore. In this simulation, we don't include gateway connection. Master nodes can also issue commands to control sensor nodes.

The sensor nodes are connected to the master node in a hierarchical manner. The number of hops that is required for a sensor node to communicate with the master node determines the level of the node.

The available frequency band is divided into sub-bands and each sub-band is assigned to a *cluster* of nodes. A cluster of nodes is deployed in the same general geographical region. The neighboring clusters are assigned different frequency bands to assure low interference. Each cluster communicates with the master node through its first level node.

Figure 1 shows the network topology created using the network editor of Opnet. The network consists of a single master node and fifteen sensor nodes. Sensor nodes are divided into three clusters. Master node uses frequency group M. Sensor nodes are assigned frequency groups A, B, and C, as shown in the figure. The lines connecting the nodes represent the virtual communication paths created by the acoustic modems.

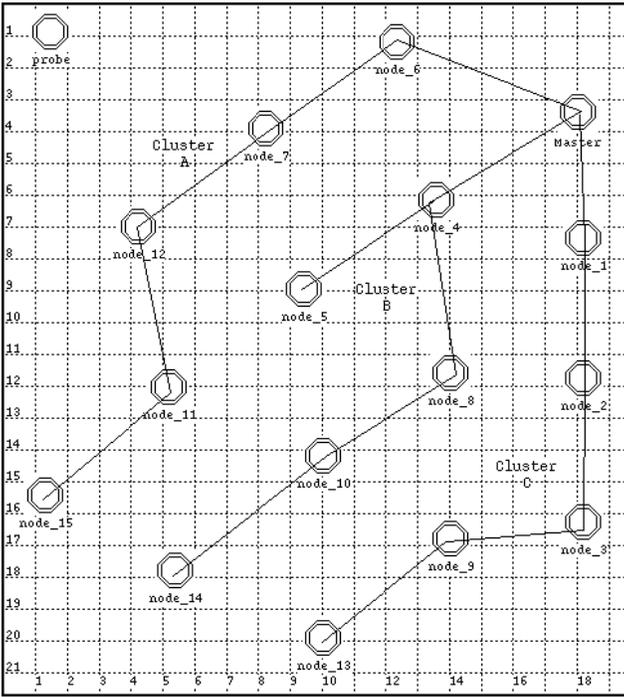


Figure 1: Network topology consists of one master and fifteen sensor nodes and a probe.

There is also a probe node in the network that is used for simulation purposes. The probe node initializes the random number generators and records statistics at the end of the simulation.

### III. NODE STRUCTURE

Each node in the network consists of an antenna, a receiver, a transmitter, tree processors, and an ideal generator to simulate data generation of the senders. Figure 2 shows the node model used in the simulations.

The ideal generators use exponential inter-arrival time distribution. The data generation rate,  $\lambda$ , of the sensors is set at run time by the user.  $\lambda$  represents the offered load for the system and used as the input parameter for the simulations.

Three processors are used to model the Layer 3, Layer 2, and Modem Control protocols. The details of these processors are given in the following sections.

### IV. PROCESS MODELS

In this section, we explain the protocols carried out by the processors presented in the previous section. The following logical node designations are used in this section:

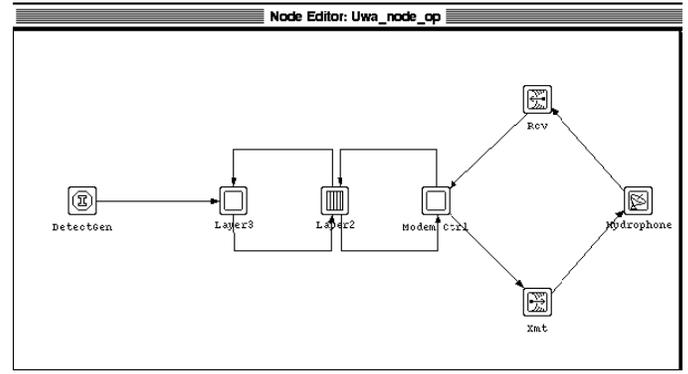


Figure 2: Node model used in network nodes.

- *Source node*: a node that transmits an acoustic packet
- *Destination Node*: the node that receives an acoustic packet from a source node
- *Sender Node*: the node at which an information sequence was first created
- *Recipient Node*: the node to which the information sequence generated by the sender will ultimately go

#### 1) Modem Control Process

Modem Control corresponds to the physical layer or the first layer of the system [3]. This layer is responsible for creating a virtual link through an acoustic channel. To achieve this function, commercially available Datasonics ATM-875 modems [2] are used. These modems have a low-power state to decrease energy consumption. A modem powers up when it hears the wakeup signal that is uniquely assigned to it.

This process controls the acoustic modem used in the system. Modem parameters are set according to the commands passed by Layer 2 at this layer. Figure 3 shows the finite state machine for Modem Control process.

After initialization, modem control process waits for packets. This state corresponds to the low-power state of the node. When an acoustic packet is received and passed to Modem Control by the receiver, it first checks the wakeup sequence. If the wakeup sequence matches the unique wakeup assigned to the corresponding node, the modem wakes up and accepts the packet. Then, Modem Control retrieves the Layer 2 packet and gets the received SNR. SNR is placed into an ICI and send to Layer 2 together with the Layer 2 packet.



the master node. Layer 3 also decides the next hop (destination node) of the current packet.

If a destination node receives a Layer 3 packet and decides that it is not the recipient node, it decides on the next hop, and passes the Layer 3 packet onto Layer 2.

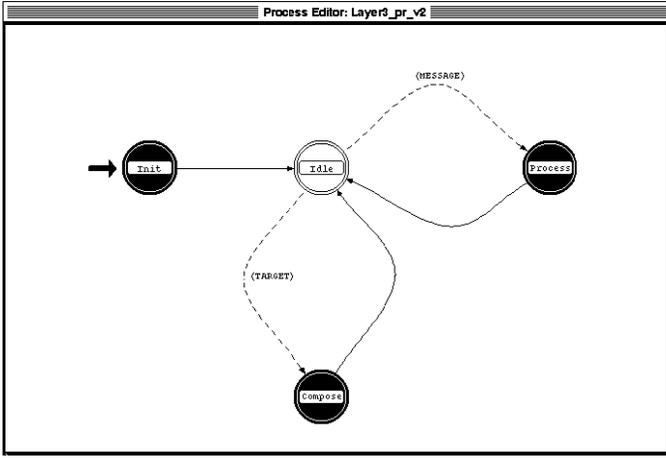


Figure 6: Layer 3 finite state machine.

For routing purposes, Layer 3 maintains a general tree that contains node's IDs formatted according to their levels. For example, if node A is the parent of nodes B and C, B and C appear as the leaves of node A. Each node keeps its parent ID together with Layer 3 tree.

The next hop (destination node) is determined by tracing the Layer 3 tree. If the recipient ID cannot be found in the tree, destination ID is set as the parent id. If recipient is in the tree, then destination ID is set to a one-layer-higher node that contains the recipient in its tree.

## V. MODIFIED RADIO PIPELINE STAGES

In this subsection, we discuss modifications done to the pipeline stages of Opnet to represent the underwater acoustic channel.

### 1) Power Model

The path loss in underwater channels is defined by the following formula:

$$g(f) = \left( \frac{0.11f^2}{1+f^2} \right) + \left( \frac{44f^2}{4100+f^2} \right) + 2.75 \times 10^{-4} f^2 + 0.003$$

$$loss = d^\gamma \exp(d \cdot g(f) / 10)$$

where  $d$  is the propagation distance,  $\gamma$  is the path loss exponent, which is set to two, and  $f$  is the center frequency of the transmission [4].

In addition to the path loss, we also defined a Rayleigh

random variable that represents fading. When received power of a packet is calculated, two Gaussian random variables with zero mean and unit variance are generated, and the Rayleigh fading coefficient is calculated. The resulting number is multiplied by the received power after loss. Since we make this calculation for the entire packet, this is equivalent to simulating a quasi-stationary channel [5].

### 2) Background Noise

Background noise of the system is fixed throughout the simulations. The noise level is calculated to achieve 20dB SNR at maximum range. This SNR level ensures  $10^{-3}$  bit error rate with Hadamard coded MFSK modulation on AWGN channel.

### 3) Propagation Delay Model

The propagation speed of acoustic signals is 1500 m/s under water. The standard propagation delay routine of Opnet is modified by replacing the speed of light,  $c$ , with this value.

## VI. RESULTS

In the simulations we use offered load, which is defined as the average time between detections for a single node, as the input parameter. We tested the performance of our system under several load conditions.

Figure 7 shows the total network energy consumption. As the offered load increases, the number of transmissions and the energy consumption of the system increase.

The energy consumption of node levels is obtained by probing sample nodes from each level. Figure 8 presents battery consumption of master node, node 4 (level 1), and node 7 (level 2). We see the same trend in all plots. The battery consumption decreases for higher level nodes. This is due to the fact that lower level nodes carry more traffic.

The average network throughput is calculated by counting the number of Layer 3 information sequences received by recipient nodes and dividing it to the total simulation time. Figure 9 shows the change in the average throughput of the system as a function of offered load. The throughput of the system increases until the offered load reaches 0.0015 packets per second. At this point, the system has barely enough time to complete a transaction before a new detection occurs. The throughput of the system is so small because of the low data rate, high propagation delay of the underwater

channel and the slow handshaking protocol.

Figure 10 gives the end-to-end packet delay of the system. As expected, the end-to-end delay experienced by the information sequences increases with increasing load. However, after 0.0015, end-to-end delay begins to decrease. This is because of the highly congested higher level nodes. Due to congestion, high level nodes cannot complete their transaction. However, the first level nodes continue to communicate with the master node, and the only completed transaction occurs between first level nodes and the master node.

The number of Inf\_Xmt transmissions before completing a successful transaction is presented in Figure 12. The Info\_Xmt packets can be lost due to channel conditions. The interference present at the channel increases with increased load, and then the number of successfully decoded packets decreases.

We observed that if the offered load stays below 0.0015, the packet transfer protocol provides reliable communication between network nodes. However, the throughput of the network is very low. A faster algorithm such as selective repeat can speed up the network traffic. Also, the network configuration is poor, however it is chosen to facilitate the experimental deployment.

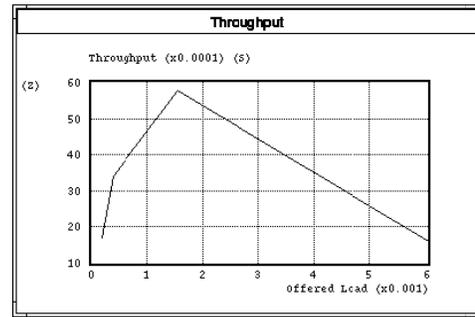


Figure 9: Throughput of the network.

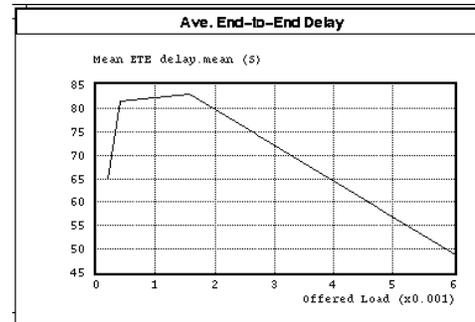


Figure 10: End-to-end delay in the network.

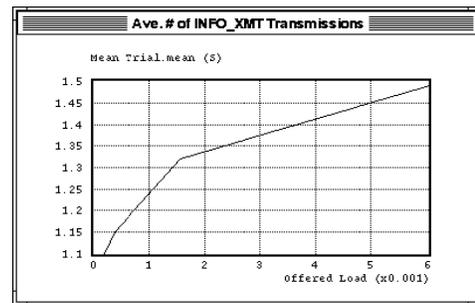


Figure 11: Number of Info\_Xmt transmissions before completing a successful transaction.

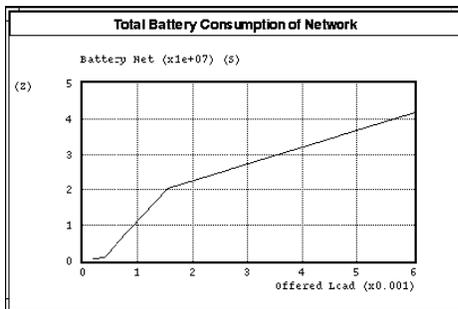


Figure 7: Total battery consumption of the network.

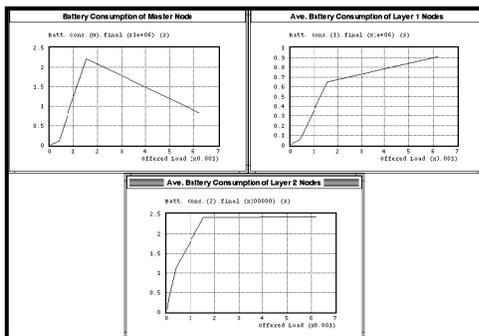


Figure 8: Battery consumption of node levels.

## VII. REFERENCES

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