

# Simulation of Underwater Networks with KAM08 Acoustic Channel Measurements

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The performance of underwater acoustic networks (UWANs) suffers from multipath and fast channel fluctuation, which severely limit the capacity of acoustic channels. Due to both logistic and technical difficulties of deploying UWANs for realistic scenarios, research involving UWANs has always been limited to either theoretical analysis or simulation study. For simulation, however, there are few commonly accepted acoustic channel models of high fidelity, which makes simulation study less realistic.

During the months of June and July in 2008, the Kauai Acoustic communications MURI 2008 experiment (termed KAM08) was conducted in 100-meter deep water near the Kauai Island, Hawaii [1]. In KAM08, extensive acoustic communications were conducted by multiple sources and three vertical line array (VLA) receivers while the ocean environment was being monitored. A 35-hour experiment was conducted from JD180 (June 28) 05:00 to JD181 (June 29) 16:00, 2008, when binary phase shift keying (BPSK) signals were transmitted from the 8-element Marine Physical Laboratory's source array (MPL-SRA) and the University of Delaware's tripod source (UDEL-TRIPOD), respectively. The receiver of interest consists of 4 elements of the MPL-VLA1, deployed 4 km from the MPL-SRA and 2.5 km from the UDEL-TROPOD. These experiments provided us with first-hand, realistic measurements of acoustic channels.

In this paper, we describe the KAM08 experiment, explain how the KAM08 measurements of acoustic communications are converted into acoustic channel models interoperable with the QualNet simulator [2], design networking scenarios of UWANs, and evaluate adaptive modulation schemes to optimize the energy efficiency of the simulated UWANs using the acoustic channel models.

To use the KAM08 experimental data for acoustic network simulations, the time reversal receiver presented in [3] is used in the physical layer where the communications signals are demodulated by time reversal combining followed by a single channel decision feedback equalizer (DFE). The output signal-to-noise ratio (SNR) measured at the soft output of the DFE feeds to the network simulator. As shown in Fig. 1(a), where the source was placed 67.5 m below the sea surface and the receiver used 4 elements of the MPL-VLA1 in the lower water column, the output SNR of the receiver experienced significant change (6-7 dB) during the 35-hour period because of the

fluctuation in the acoustic channel.

Since UWANs are operated by batteries, it is paramount to conserve energy so as to maximize life time. One major energy drain of underwater devices is data transmission. Although lowering the transmission power may extend devices' life time, it also increases the rate of data corruption since SNR might not be high enough to ensure successful transmission. Thus, we are motivated to design a scheme that consumes less energy while yielding lower data corruption rate. To archive this goal, we define *energy efficiency* as:

$$\frac{\text{total number of data bits received successfully}}{\text{total energy used for transmission}} \quad (1)$$

which measures how many data bits can be transmitted successfully using one unit of energy.

We maximize energy efficiency by choosing proper modulation schemes according to the fluctuating channel conditions. The performance of higher data rate modulation is extrapolated based on that of BPSK transmissions. It is evident that high data rate modulation can encapsulate more bits into one single symbol (*e.g.*, two bits per symbol for 4-phase shift keying (QPSK), etc.), and consequently, transmitters will require less time to transmit a single data frame, given the same symbol rate. This leads to less energy consumption if assuming the transmission power is constant and the overall energy consumption is proportional to transmission duration. Higher rate modulation may lead to higher probability of a frame being corrupted since they require higher SNR for successful reception. In other words, the decision about whether to use high data rate modulation depends upon the channel condition. With good channel condition, we should choose schemes with higher data rates so as to minimize transmission duration. Otherwise, lower data rate modulation schemes become superior as they lower the probability of frame corruption. Therefore, to maximize the energy efficiency, we propose an adaptive scheme which allows the transmitter to detect channel condition, choose an appropriate modulation scheme, and then transmit the data frame using the optimized modulation.

Fig. 1(b) compares the energy efficiency achieved by static and dynamic modulation schemes during the 35 hour period. It shows that dynamic modulation always selects the modulation with high energy efficiency. We can see from Fig. 1 that when the output SNR is good (roughly above 10

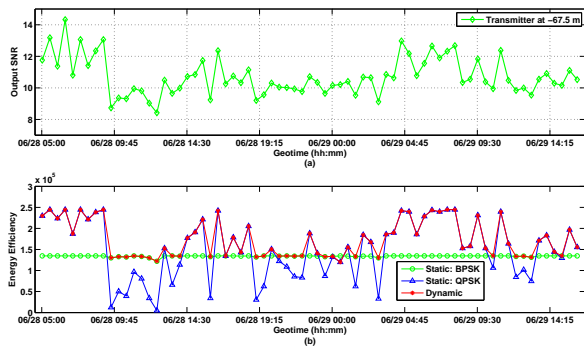


Fig. 1. Receiver performance and Energy Efficiency of Transmitter at -67.5m

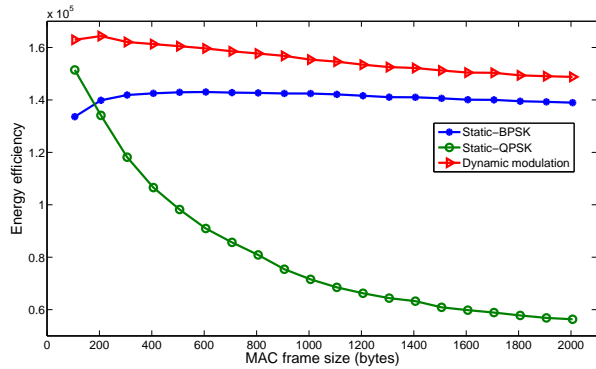


Fig. 2. Energy efficiency against different MAC frame size of transmitter at -67.5m

dB), QPSK is selected since it can reduce the transmission duration; otherwise, BPSK is used to avoid frame corruption since it provides better bit-error-rate (BER). Fig. 2 shows the performance improvement using dynamic modulation schemes with different frame sizes. Large frames are more likely to be corrupted since they contain more data bits, and we can see that energy efficiency decreases with the increase of MAC frame size. The dynamic modulation outperforms static BPSK by around 20% when MAC frame is small, and even for large MAC frame, performance improvement of 7% can still be achieved.

## REFERENCES

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