Underwater Electromagnetic Communications Using Conduction – Simulation and Experiment

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ABSTRACT
In our previous research in underwater electromagnetic communications, we showed that magnitude variation with frequency, and time-invariance of the channel, motivated the design of an orthogonal frequency division multiplexing (OFDM) system with unequal bit loading, which is the subject of our current research in simulation and experiment. We have also analytically estimated symbol error rate (SER) sensitivity to range variations based on the experimental results from the previous experiment and devised a simple range estimation technique based on the phase model of the measured channel. In addition, we have included channel coding, namely low-density parity check (LDPC) codes, in our simulations. This channel coding solution performs well in low SNR conditions and is expected to be useful in extending the physical range of operation.

Categories and Subject Descriptors
B.8.2 [**Hardware**]: Performance and Reliability – *performance analysis and design aid.*

General Terms
Algorithms, Measurement, Performance, Design, Reliability, Experimentation, Theory, Verification.

Keywords
Underwater RF, bit loading

1. INTRODUCTION
In our previous experiment we obtained phase vs. frequency curves at 35cm and 50cm distance, based on the model fitting to the original measurements in a tank [1]. We created a simple model of range dependence of the phase by interpolating between those two curves and by extrapolating to distances shorter than 35cm and longer than 50cm. One way to improve upon the channel estimation and range estimation is to explore the magnitude and phase models that are based on the measurements. We fit the parameters of the model and then use the result to infer the entire frequency response. Since there are many fewer model parameters than carriers, we would expect improved performance in channel estimation and range estimation.

We simulated the unequal bit loading strategy, using transmit power P_t=100mW, bandwidth W=6.25 MHz, and K=1024 subcarriers. Based on our measurements in the ocean, we estimated a reasonably flat power spectral density (PSD) of the noise at -165+/-1dBm/Hz. For the sake of building a conservative estimate of the channel capacity that we could rely on in more general conditions, we set the noise PSD value somewhat higher than the measurements in the ocean showed, hence we used N_0 = -155dBm/Hz. For bit load optimization we adopted an algorithm from digital subscriber line (DSL) communication theory due to relatable similarities in the spectral properties of the channel. The algorithm uses target SER in optimization, which we set to 10^{-3} for uncoded case. This relatively low target SER value drives comparatively high bit rate, with the premise that coding will bring the SER down. The range we first assumed was r=0.1m, which corresponds directly to our original experiment at 5m deep ocean. According to this bit loading technique there could be 8bits on some of the used subcarriers, although practically it seems reasonable not to have more than 6bits. By reducing the number of bits on some of the subcarriers we lose in data rate, but benefit in SER. In addition, the simulation was for 100mW, while our transmitter is geared for 1W output power. That should give us even more leverage in terms of SNR and hence SER. Total simulated number of bits equals b_t=4965bits, resulting in bit rate $R=b_tW/K$=30.3Mbps. Geared toward the newly designed experiment, the bit loading analysis is a natural extension of our semi-analytical results related to the channel capacity [2].

2. EXPERIMENT
2.1 Motivation
The simulation results, based on the previous experiment, indicated that the SER is highly sensitive to range variations. With the range deviation of just 1cm from the nominal (expected) value of 0.1m, SER rises from 10^{-3} to 10^{-2} . The observed and modeled range dependence of the channel magnitude was nearfield-like, or inverse cubic. Preliminary results in our experiment with the new equipment are showing significantly better, or less lossy, channel magnitude vs. frequency and range. Therefore, we are feeling optimistic that the new equipment has created significantly less severe conditions and a part of our expectations is highly improved SER sensitivity.

2.2 Description

The new experimental setup serves for experimental analysis of data throughput, including unequal bit loading transmission, and utilizing phase information to estimate range. The dimensions of the experimental 40-litter water tank are 85x45x20 cm. By controlling the amount of salt in the tank, we vary salinity of the water in steps of 20ppm to measure the effect of conductivity on the channel and the system performance. The copper electrodes are 3cm long and 7mm in its widest diameter. They are attached to solid wires, which are held by two sliding bars across the tank that control distance adjustment between the transmitter and the receiver. The hardware consists of Altera's DE2-115 development board with Cyclone IV type FPGA and an expansion card for D/A and A/D conversion.

Altera Quartus II Web Edition FPGA design software is used for system design and its SignalTap II Logic Analyzer tool is used for data collection. Data have already been collected at transmitter-receiver distances between 10cm and 40cm. The measured channel magnitude looks like a low-pass filter, with attenuation varying between -3dB at 100kHz and -8dB at 6.35MHz.

We have implemented OFDM systems of 1024 QPSK modulated subcarriers and 1024 QAM-16 modulated subcarriers, measuring channel magnitude and phase and evaluating BER at distances between 10cm and 40cm. One of the benefits of the measured channel frequency response is properly selecting the number of bits per subcarrier in the unequal bit loading solution. We will experiment with bit-loading in the channels by analyzing throughput and measuring the bit error rate (BER), as well as measuring the effect of range estimation error on the system performance.

3. PRESENTATION

The poster shows the experimental equipment, including the hardware and the software tool from Altera that is used to drive the experiment, acquire data and display received signals. Measurement results, such as channel magnitude and phase at several distances between the transmitter and the receiver, as well as different water conductivities, will also be shown. In addition, we will illustrate the range estimation based on the phase model of the channel and finally the communication system performance, such as BER for 2- and 4-bit quadrature amplitude modulation (QAM) and variable number of bits per symbol (bit loading).

4. ACKNOWLEDGMENTS

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5. REFERENCES

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