Doppler Tolerant Link (DTL)

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Abstract: In order for a distributed system of stationary submerged bottom nodes to redirect an untethered vehicle to a rendezvous with an uncooperative vessel, an underwater acoustic communications link is designed and tested to operate in the shallow water (SW) environment without knowledge of the range rate, but with knowledge of the range rate limits. A probe signal that fully occupies the acoustic band is employed to permit adaptation to the acoustic environment. This environment is anticipated to vary spatially and temporally. The variation is expected to be rapid enough to justify use of packet communications techniques coupled with probes. Sixteen bit cyclic redundancy checking (CRC-16), a (7,4) Hamming Code generator, and interlace are combined with the probe and use of linear period modulation (LPM) signal chips to achieve the doppler tolerant link.

LINK DESIGN

A static bottom node transmits a message to a node travelling at a known speed in the water volume. Since the moving node is transiting at a speed that is approximately known, but the angle between the interceptor’s head and the transmitting node is unknown, the range rate is uncertain. The message is anticipated to be 51 bits long. The acoustic environment may change as the distance between the transmitter and receiver will change during reception of the message. Furthermore, the bottom and surface features will change during reception. It is desirable to shorten the packet as much as possible to reduce these environment alterations. A bit error rate of $10^{-4}$ is set as an arbitrary goal for operation in depths from 150 feet to 600 feet.

Channel fades, multipath, propulsion noise, and doppler spread surface reverberation are some of the contributors expected to characterize the acoustic environment. A wide range of depths, bottom types, sea states, and velocity profiles must be accommodated. The link design must, therefore, contain adaptive features. Since the sensor node that transmits the message is isolated on the bottom with a limited power source, power consumption is to be minimized. This, together with a desire for low probability of detection with regard to the opposed forces, results in a desire to transmit the minimum amplitude signal, consistent with the error rate goal. Figure 1 outlines the design features aimed at error correction and the interface function that is a well-known solution to the fading channel problem. The inner block of Figure 1 is expanded in Figure 2.

![Figure 1. Doppler Tolerant Link Block Diagram.](image)

SIMULATION

Estimation of link performance was made with a simulation of the link, the environment, and the relative motion that produced a frequency scaling (inaccurately referred to as doppler). Figure 2 illustrates the simulation and the modulation and demodulation scheme. Time constraints precluded the modeling of the surface reverberation frequency spreading. The message is divided into its one train and its zero train. These are convolved with their
respective signal chips and the results are added, preserving their temporal relationships. Since the chips are LPM and orthogonal (one is the time reversed version of the other) they will be optimally doppler tolerant, and they will not elicit a response from one another’s matched detectors. The probe, which can be seen to be the simultaneous sum of both chips in Figure 2, provides the mechanism for determining the channel impulse response. This is the adaptive component of the system. The noise in the receiver, mostly attributed to the flow and propulsion, makes deconvolution impractical. However, following the initial detectors (for the ones and the zeroes) with the frequency domain designed filter matched to the channel impulse response plus noise provides benefit. When the received energy per bit to noise ratio (Eb/No) is 10 dB, the simulations determined the benefit to be a drop in error probability from approximately .5 to .005. The error correcting procedure and interleaver are expected to provide further benefit, which has yet to be evaluated.

A field experiment is planned for spring 1998 at Dabob Bay. This experiment will transmit from a static node near the bottom to a high-speed vehicle in the water column to determine bit error probabilities and determine the channel impulse response given the environment and the motion. Results of the field experiment are to be compared with performance estimates yielded by the simulations.

FIGURE 2. Simulation and Modulation/Demodulation Block Diagram.

CONCLUSIONS

A formula relating source level (SL) to received Eb/No yields a worst case relation for the environment investigated. This relation is that SL is 123 dB higher than the Eb/No if a bit rate of 500 Hz is used and the worst transmission loss is 80 dB within 2,000 yards. The dotted line in Figure 3 shows the theoretical performance of a binary orthogonal communications system in additive white gaussian noise (AWGN). The reverberant multipath channel, modelled in the simulation, has an error probability of about 0.5 across all Eb/No levels if the convolutional multipath exploitation (shown in Figure 2) is not employed. With a reverberant channel, the louder the transmission, the louder the reverberation, so system performance is not improved much by turning the volume up. Figure 3 shows that an Eb/No of 13 dB is required to meet the $10^{-4}$ requirement when the convolutional multipath exploitation is included. Therefore, a source of 136 dB/$\mu$Pa is predicted to accomplish this task at a range of less than 2,000 yards, given the environment modeled. The authors expect to expand these conclusions to include the effects of the error correction coding and interleaver by June 1998.

FIGURE 3. Log Error Probability vs. Received Eb/No.