Software Defined Transceiver for Underwater Communication

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***Abstract*—New applications for autonomous underwater vehicles require underwater wireless communication with data rates up to several megabit per second and a transmission range up to several meter. Regular radio transceivers achieve a poor performance in seawater. Therefore, our project evaluates and implements new approaches for optical, acoustic and electric underwater communication. The goal is to implement a flexible software defined transceiver consisting of a FPGA with exchangeable communication modules.**

Keywords—Software Defined Transceiver; Wireless; Underwater; Acoustic; Optical

I. Introduction

Advances in exploration of the subsea originate new requirements for underwater communication. In our project BOSS (Bionic Observation and Survey System) a communication system for a small group of autonomous underwater vehicle (AUV) and underwater base stations is developed [1]. The system requirements include e.g. data uplink of collected data (over 1-5m), video streaming during the docking maneuver (less than 10m) and communication between the AUVs (up to 10-20m) for mission coordination. For these applications a duplex data link with rates between several kilobit per second and 10 megabit per second is required. Currently, these requirements are not fulfilled by available underwater technologies, which are optimized to high range and low data rate. Furthermore, standard wireless radio frequency communication solutions perform very poorly in underwater communication channels since high frequency electromagnetic waves experience high attenuation due to the electric conductivity of seawater. Therefore, technologies such as IEEE 802.11 and IEEE 802.15 achieve only transmission ranges of few centimeters.

II. Approach

In our project we develop a modular design for such an underwater wireless transceiver to fulfill the previously described requirements. Our design consists of a Xilinx Virtex6 FPGA for software defined signal processing and corresponding communication modules for different physical carriers respectively transmission media and different modulation schemes. Optical, acoustic and electric (at medium frequency, less than 10 MHz) communication are planned to be implemented and evaluated. A first evaluation is based on simulation models, followed by prototyping and initial testing. The experimental prototypes are implemented with Xilinx ML605 FPGA [2] development board and the corresponding frontends and peripherals. The FPGA development board is equipped with an FMC150 daughter card providing two channels of 14-bit ADC at 250 Msps and two channels of 16-bit DAC at 800 Msps [3]. Figure 1 shows the modular transceiver design. The FPGA is connected to the AUV-controller via Ethernet. Furthermore, the transceiver is powered via Power over Ethernet.

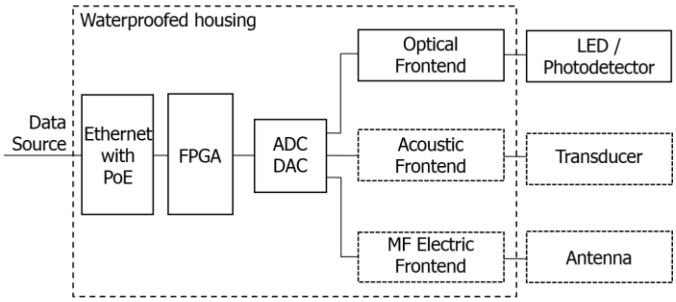

Fig. 1. Modular Design of the Underwater Wireless Transceiver

The FPGA performs encoding and decoding depending on the attached and exchangeable communication modules. Software defined solutions from Matlab and Simulink converted to VHDL perform software defined signal processing. First packet formatting and forward error correction with interleaving are accomplished. Then bits are modulated into signals for the attached communication module. A digital to analog converter creates analog signals for a transmission medium specific driver circuit with transmitter. Figure 2 illustrates the protocol architecture. The ADC and DAC implementation as well the implementation of the Ethernet interface is based on a reference design provided by Xilinx [4, 5]. The receiver amplifies the signal and an analog to digital converter samples the signal which the FPGA then demodulates, decodes and sends frames via Ethernet to the AUV controller. This modular approach enables a flexible and extendable transceiver, comparable to a software defined radio for RF transmission. With this software defined functionality, just the communication module and parts of the software have to be replaced for a change of the transmission medium. This allows faster and easier development, since large parts of the design are reusable for the different approaches. Furthermore, optimization is performed by software changes rather than replacing parts of the hardware. The following section describes details of the implementation of the optical communication.

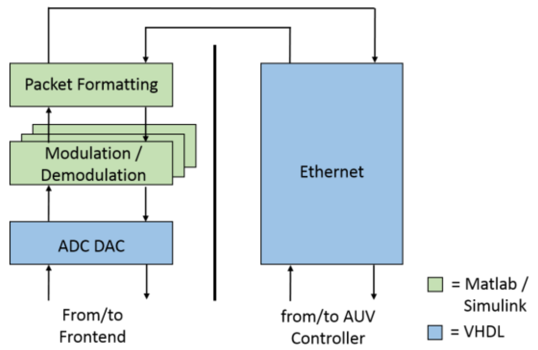

Fig. 2. Protocol Architecture of the Software Defined Transceiver

A. Optical Communication Module

Optical communication in seawater is a relatively new field of study which has become of increasing interest due to the improvement of LEDs in recent years. On these grounds, part of this project is evaluating and prototyping a communication module utilizing a LED array for high bandwidth (up to 10Mbps), low range communication (up to 10m). The underwater communication channel is highly volatile with an attenuation which is magnitudes higher than the attenuation in air. Therefore the range at which light can effectively carry information is very limited. LEDs can achieve ranges of more than 10m in good water conditions, depending on the transmitted power and beam width [6]. This high attenuation limits multipath propagation effects to reflective objects close to the transceiver. Reflection occurs also at the water surface. Due to the shallow depth of the Baltic Sea, which is the main testing location for this system, multipath propagation and resulting intersymbol interference have to be taken into consideration. The software defined approach allows different solutions to reduce these effects, possible approaches include an inverse filter at the receiver to reduce the channel effects as well as a Viterbi algorithm to determine the most likely transmitted signal. A Dual Header-Pulse Interval Modulation (DH-PIM) is currently considered the most promising modulation scheme [7].

B. Further Communication Modules

Most commercial underwater communication systems apply acoustic signals in the kilohertz range, which offer limited bandwidth but high range [8]. For the acoustic communication module the maximum required range of 20m allows a maximum bandwidth of 150 kHz. Using advanced modulation schemes such as OFDM achieves data rates up to several hundred kilobit per second. Additionally, measures to handle the low propagation speed of sound in the link establishment and management are evaluated. Doppler shifts are not negligible even for slow moving AUVs due to the slow propagation speed of sound in water, therefore, methods for compensation are assessed [9]. Furthermore, multipath propagation significantly affects the communication as the main employment area of the AUVs are shallow waters with many reflections close to the transceivers. This software defined system is designed with Matlab and Simulink, and converted to VHDL. A third communication module will be implemented in the future based on electric signals.

C. Performance Evaluation

The performance of underwater communication systems strongly varies with the physical conditions of the water in which the AUVs are deployed. Hence, a variety of tests in very different environments such as deep sea, shallow costal water with varying water compositions would be necessary. However, the software defined approach allows for a simulation of the communication channel applying different models. Therefore, it ensures an easier and cheaper way of verifying the designs in the laboratory before conducting exemplified test under real world conditions.

III. Summary

This paper describes the design and implementation of a software defined communication system for AUVs for optical and acoustic communication. The software defined transceiver design offers versatility and efficiency for underwater communication. Furthermore, it presents advantages of software defined implementations in the evaluation process.

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