# Preliminary OFDM based acoustic communication for underwater sensor networks synchronization

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***Abstract*— This work presents a first approach to wireless underwater sensor networks UWSN time synchronization, using OFDM (Orthogonal Frequency Division Multiplexing) acoustic communication and time reference served by a synchronization protocol. This synchronization and type of modulation allows getting a low drift clock on each sensor, on a high efficiency underwater communication network.**

***Keywords*— UWSN, Time synchronization, OFDM, acoustic communication.**

## I. Introduction

Underwater sensor networks (UWSN) have emerged as a major trend on oceanographic research, due to its facilities to cover huge areas and work on collaborative tasks with a low economic and energetic cost.

As occurs in terrestrial surface networks, a cabled communication is non-viable in economical and functional terms. This makes wireless communication as the most effective system, but the problem remains on the underwater electromagnetic waves, which on marine environment have high attenuation.

To overcome high attenuation on RF, the best underwater communication system is using sound waves. An acoustic transmitter/receiver is capable to send/receive information through thousands of meters with low Bit Error Rate (BER), due to low attenuation that affects sound waves.

Most effective acoustic modulations for underwater communication are frequency ones. These modulations are more robust to marine issues that cause communication worsening [1].

So in this paper is presented a communication system with frequency modulation compliance, and also is presented a synchronization system in order to be able to develop an UWSN without losing one of the main properties of all wireless sensor networks, synchronization between nodes.

This synchronization is necessary for being able to realize collaborative tasks between sensors inside the same network, and to time stamp detected events in order to provide them in a global network [2].

The innovation resides on the design of an acoustic communication modem, with synchronization capabilities. Because actual underwater communication systems, such as LinkQuest, RModem, or other brands, are designed to realize data communication, without taking into account indeterminate data delays, due to information process or forward data sending because of data losses [3] [4] [5].

So with actual acoustic modems is not possible to implement a synchronization protocol, based on framing exchange, because this indeterminate and unknown delay added to every data sending.

This common base time can be reached with timing message exchange as mentioned in introduction.

To achieve high accuracy on synchronization, a new protocol based on IEEE std. 1588 is used. IEEE std. 1588 works with time accuracy below few nanoseconds in a point to point Ethernet communication [6]. This synchronization accuracy is possible due to a precise hardware timestamp on the Media Access controller (MAC) [7].

Precision Time Protocol (PTP) IEEE 1588 is designed to work in networks with low propagation times, which is not portable to underwater networks, where a communication can take more than one second between a sender and a receiver.

To face long propagation problems, and the lack of acoustic modems with hardware timestamp capabilities, is needed a new protocol able to achieve high accuracy, with similar functionality than PTP has. The reason of using PTP as base protocol for this new development is the ability that it has to compensate propagation delays with more accuracy than other protocols has, such as NTP, MOBI-Sync, D-Sync, etc.

So a new hardware for acoustic communication will be needed, for achieving hardware timestamp on underwater wireless synchronization.

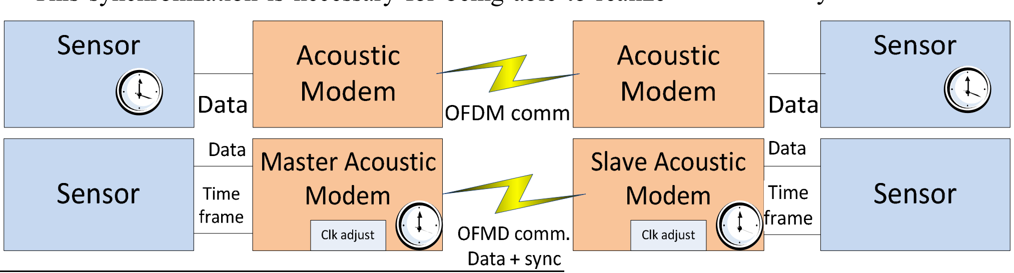


Fig. 1. Actual commercial modems functionaliy. (up). Acoustic modem with synchronization capabilities (down).

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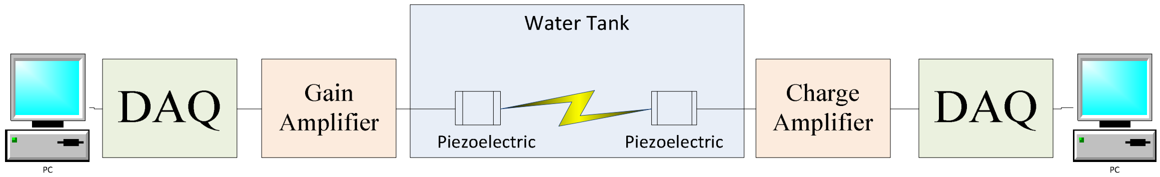


Fig. 2. OFDM communication work bench diagram.

The optimum modulation for communicate synchronization information, in addition to sensor data, between nodes in a reduced Bandwidth is Ortogonal Frequency Division Multiplexing (OFDM), due to it's a frequency modulation, so it will face water problems in communications, and the orthogonally between carrier frequencies allows the receiver to decode information, even though having the carriers without a guard band between them.

## II. IMPLEMENTATION

In order to achieve mentioned goals, is necessary to implement a new hardware, although in this paper only is studied synchronization issues with OFDM modulation, and this approach is designed to give synchronization to fixed nodes at the same distance between them.

These limitations of immobility between sensors are caused by the lack of hardware timestamp, which will be provided in future work.

To implement this system will be used a PC with DAQ. This is necessary for being able to generate and receive analog signals containing synchronization frames OFDM moduled.

As seen on implementation diagram, figure 2, we will have to PC's with one DAQ per each one. On this first approach one of these computers will work as transmitter and the other one as receiver.

The results with this distribution are going to show how it is possible to send synchronization frames with short transmissions in an OFDM modulation, without using a big percentage of the available Bandwidth.

We have transmitter computer with a generated OFDM symbol, containing synchronization beacon. This information is up mixed from base band to 120 kHz, which is the optimum frequency for transmit and receive signals through Brüel & Kjær piezoelectric. This signal is sent to DAQ output buffer, and once is the signal ready; it is triggered by 1 Hz signal, Pulse Per Second (PPS). With this trigger it is possible to time stamp the precise frame output from the system in order to be able to implement complete PTP algorithm in future work.

DAQ system, is a NI PCI-6115 which is a multifunction A/D converte and is connected directly to transmit to piezoelectric.

Piezoelectrics are Brüel & Kjær and have its optimum transmission frequency bandwidth between 120 kHz and 180 kHz.

On the other side, we have the receiver with same hardware distribution, but different software. The receiver is capable of decoding OFDM symbols and detects the propagation delay. This way if both piezoelectrics are immobile, and processing time can be approximated, is possible to implement a communication delay histogram. This histogram will be useful in order to calculate time synchronization correction between transmitter and receiver in this first approach.

Once developed hardware platform for this purpose [8], this histogram will be replaced for PTP framing exchange that is capable of compensate this communication delay without making approximations with a histogram.

So for this first approach for underwater sensor networks synchronization is necessary to evaluate ODFM modulation communication and synchronization accuracy obtained with a maximum probability algorithm.

## III. OFDM EVALUATION

First has been developed an application running on Matlab® able to send OFDM data to laptop's sound card, or to loopback this data and process this OFDM symbols to recover sent information.

Number of symbols, depends on information to be sent and number of subcarriers [9]. Each symbol is a point in constellation chart that is processed by Q-PSK modulation. So if we loopback all data that is processed by OFDM transmitter we will recover sent constellation perfectly, due to there are no external interferences or noise affecting our signal. Figure 3.

Once is performed this first simulation is tested the communication protocol between two different laptops with a speaker and a microphone. Here we have some interference on air medium and some phase distortion because of the speaker and microphone characteristics. As seen on figure 4 the recovered constellation now has some distortion although it's possible to recover completely sent signal.

In order to evaluate synchronization accuracy and communication parameters, a water tank is used. All simulations and tests are performed with the same Matlab® platform.

Inside the tank are placed a receiver and transmitter hydrophones connected to a charge amplifier. This amplifier is connected to data acquisition hardware that will be controlled by a computer, with OFDM and a new timing protocol, based on a frame reduction of PTP (Precision Time Protocol) IEEE std. 1588, as shown on figure 2.

With this implementation, is possible to assess the behavior of this new protocol on acoustic communications, and test OFDM with Q-PSK (Quadrature Phase Shift Keying) modulation implemented on Matlab®.

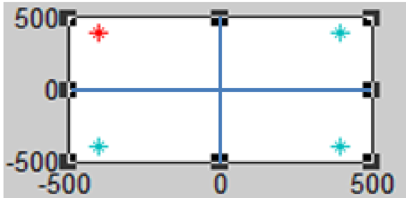


Fig. 3. TX/RX OFDM constellation in loopback mode

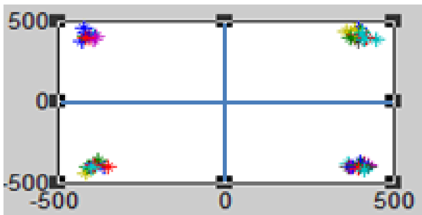


Fig. 4. RX OFDM constellation on air test

With 4 subcarriers, a cyclic prefix added at each symbol and a preamble to synchronize reception and transmission.

This first simulations show the transference of "Hello World" message.

If the receiver had capability to adjust its clock, synchronization messages would have effect on to this clock and synchronize two laptops.

To test this final stage, synchronization messages are sent and every precise second a pulse is triggered PPS (Pulse Per Second). This way it's possible to observe the difference between PPS rising edges of the transmitter and the receiver and determine delay between two systems.

## IV. OFDM RESULTS

First tests realized inside the water tank, demonstrate the proper communication of synchronization messages.

In figure 5 is represented the constellation of "Hello world" OFDM symbols. The echo effect produced by shallow water affects phase detection and distorts received constellation.

Anyway, it is possible to recover the transmitted signal completely. This allows synchronization message exchange.

This synchronization results can be seen in section V, where is demonstrated how can be synchronized a system with a precision below 100ms, with a low cost underwater communication systems without occupying too much communication bandwidth.

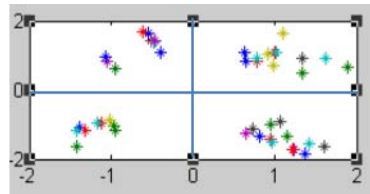


Fig. 5. RX OFDM constellation on water test with some distortion.

## V. SYNCHRONIZATION RESULTS

Synchronization results are taken from the work bench distribution shown on figure 2. Here are analyzed various nodes of the communication system, in order to detect transmitted and received information, the delay of every process and finally the compensation needed for each synchronization frame.

For this test, is sent a synchronization beacon containing 32 bits with 8 subcarriers OFDM modulated. Since we send a message containing timing information, we have to compensate delays due to propagation time and receiver processing time.

This way if the transmitter is sending a base time, the receiver will be able to get synchronized to this time, if it is able to correct propagation and processing delays.

For doing this, a beacon train is sent, and then the receiver processes a histogram and can adjust its time to transmitter node base time. We must assume that both nodes are immobile because of histogram calculus is only valid with the same propagation and processing times.

In figure 6 can be seen data transmission, which is a 8 subcarrier modulation. Then this signal is up mixed to 120 kHz where the piezoelectric has its optimum communication frequency.

After sending this information through piezoelectric it is received by other piezoelectric on the other side of the water tank. In figure 7 is shown received data. This data is processed in order to extract modulated information, and after a correlation between two preambles determines propagation time. Figure 8. It is possible counting cross correlation samples offset, and knowing the sampling rate it can be converted to seconds.

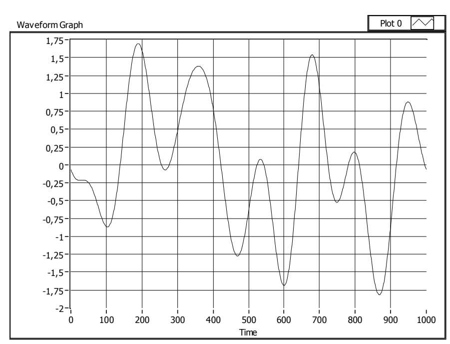


Fig. 6. TX synchronization beacon, containing time information

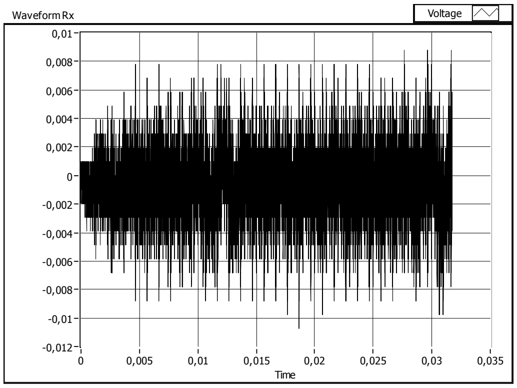


Fig. 7. 120 kHz received data with OFDM data

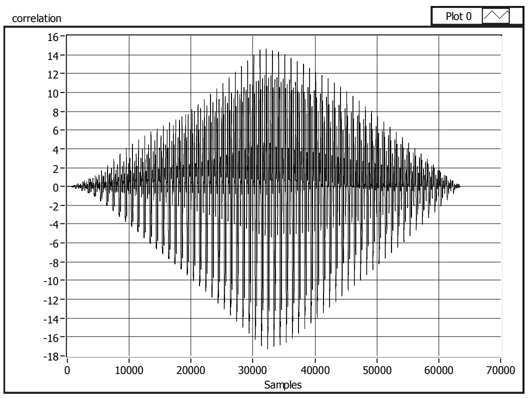


Fig. 8. Correlation between received signal with preamble, and expected preamble.

After processing data are recovered 8 subcarriers with diferent information Q-PSK moduled. In figure 10 can be seen recovered subcarriers. This subcarriers provide transmitter time stamp to receiver.

Now for adjust the time, we have propagation delay from the correlation algorithm, so it's needed processing time too. For aproximate this time in a Windows O.S. distribution, assuming round-robin slots to process data, is calculated acquisition and process time, triggering a counter when the reception starts and stoping it when the processing is finished.

This methodology for time delay detection is shown in figure 9.

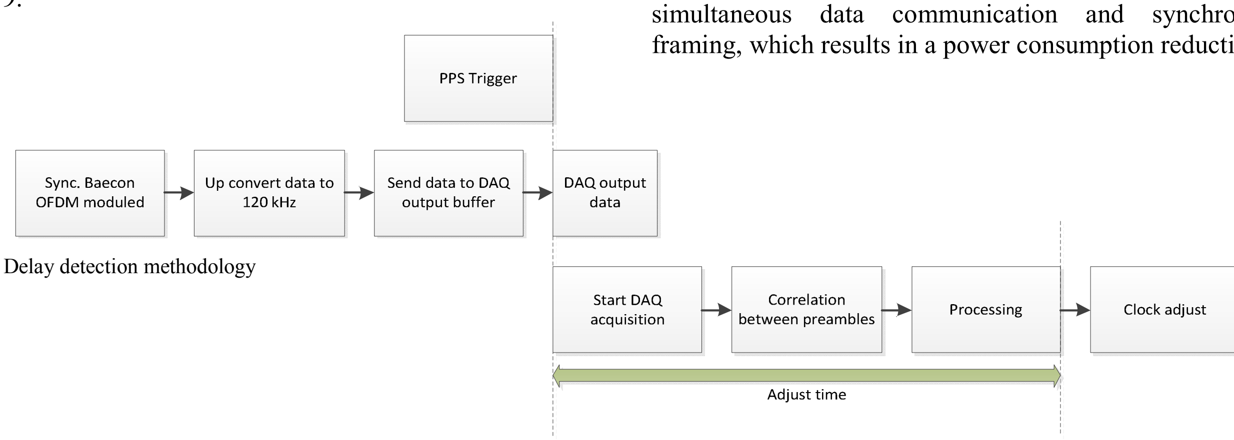


Fig. 9. Delay detection methodology

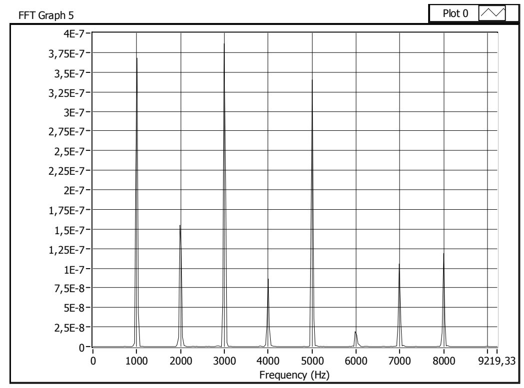


Fig. 10. Recovered subcarriers

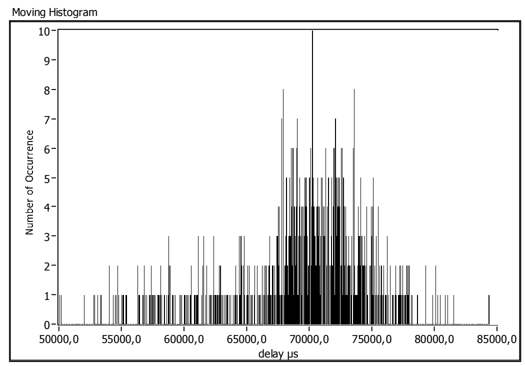


Fig. 11. Delay histogram

The histogram which represents most repetitive values for delay due to processing and propagation time is shown in figure 11, where have been taken in account 900 samples, equivalent to 15 minutes of synchronization algorithm running. If we add most repetitive delay value to the processed time stamp sent by the transmitter, we would have a maximum accuracy error of 25 ms approximately. Because is the maximum separation from the most repetitive value in the histogram and the less repetitive one detected in this case.

## VI. FUTURE WORK

A new technique for data communication and sensor synchronization has been developed and tested. This system based on OFDM acoustic communication modulation, allows simultaneous data communication and synchronization framing, which results in a power consumption reduction.

Real implementation is based on a microprocessor structure with DSP (Digital Signal Processing) characteristics such a dsPIC (digital Signal Peripheral Interface Controller).


## ACKNOWLEDGMENT

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