Development of Underwater Acoustic Communication Model: Opportunities and Challenges

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Abstract- **Acoustic propagation in the underwater channel influenced by three factors: signal attenuation, multipath propagation, and low speed of sound propagation. Understanding of underwater acoustic channel is the basis in the design of a reliable communication system, and until now there is no standard fading model for underwater acoustic channel. Experimental method supported with measurement data is a commonly method used as a first step in modeling of channel properties for underwater sensor network applications.**

In this study, we will begin a discussion about research development of underwater acoustic communications. In the next section will be presented about experimental planning for underwater propagation characteristics. The characterization results are used to evaluate the performance of communication system through software simulation. At the end of this paper, a PC-based soft acoustic modem test bed will be presented.

Keywords: *underwater acoustic communications, channel characterization, soft acoustic modem.*

I. INTRODUCTION

In the last three decades the field of maritime research, oceanography, oil exploration in offshore areas and the defense system has developed very rapidly. The continuity of recent year research has improved the performance and reliability of the systems than previous. This has been presented by Stojanovic and Preisig [1], which give direction for the field of underwater acoustic communication research.

Alkydiz, et al. [2], have presented a state of the art for underwater sensor networks, and provides an overview of the challenges in the underwater acoustic channel for the ocean environment monitoring system. The paper also give a guide line for researchers in the developing an underwater sensor network system.

A reference model for underwater acoustic sensor network can be seen as in Figure 1. A group of sensor nodes mounted on the seabed by using anchors for observations of environmental conditions such as temperature, pollution data, or the other environment data.

Communication between nodes, or from the node into the cluster head is done by utilizing the acoustic signal as a carrier. Data from sensor node are collected by using underwater sinks (uw-sinks), which is equipped with the ability to perform the data received from sensor nodes observations, then be sent to a surface station. The next step is sending the information to the offshore sink for data processing. Delivery of data to offshore of sink through horizontal transceiver with surface sink, or vertical transciever with satellite technology.

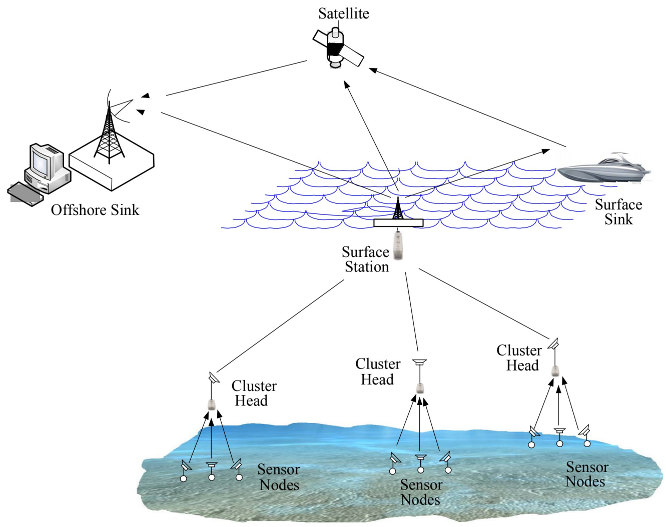


Figure 1. Under Water Acoustic Sensor Network System

This paper presented information collection of research developments underwater acoustic communication system. The author presents 16 papers related to the development of the characterization and modeling of underwater acoustic channel, 16 papers on transmission of information over an underwater acoustic channel, and 15 papers on the development of an underwater acoustic modem test bed. Survey method begins with an investigation of scientific papers related to the research to be conducted, and study problems in implementation.

Furthermore, the authors present three stages of research to realize a model of an underwater acoustic communication system with consideration of its feasibility. Based on the various marine conditions in Indonesia, we hope this research will give a contribution to an underwater communication system model.

To further this paper is presented as follows. Chapter II will present opportunities and challenges of the physical layer of communication systems research underwater acoustics. Chapter III will present a research plan to be conducted by the author. Chapter IV presents the conclusions and future challenge in the research on underwater acoustic communication system.

II. RESEARCH DEVELOPMENT ON UNDERWATER ACOUSTIC COMMUNICATIONS

Time delay spread between the first signal and the last signal arrived at the receiver on the order of milliseconds. The

change of the relative position between the transmitter and the receiver as a result of interference waves, sea or air flow can cause distortion or frequency of the Doppler effect.
Stojanovic [2] presents a survey of the development of the overall research and development related to the ideas that will be a key to the development of underwater communication network. Generally, there are two research topics. The first is underwater communications including channel equalizations & modeling, and multi-carrier & spatial modulation. The second relates to underwater networking that includes the data link layer and networking topology, clustering and AUV networking.

Characteristic of acoustic signal propagation in the underwater channels and problems in realization an underwater communication system by using acoustic signals as career waves was presented in [3] [4] [5] [6] and [7]. Channel characterization begins with a measurement of acoustic signal propagation parameters in the various configurations. The measurement results were statistically analyzed to investigate the characteristics of propagation. The technique was adopted from the modeling of radio communication systems. The basic parameters such as propagation delay, attenuation, path loss and multipath fading are evaluated.

In some research, characteristics of acoustic channels have been analyzed, with the range from very shallow to the deep conditions. For the more specifically, characterization of underwater acoustic channel for extreme conditions of very shallow and heavy noise environments (estuaries and harbors) are presented [8] [9] [10] [11] and [12]. A ray-tracing based approach is used as acoustic signal propagation model. The model validation was supported by using experimental data. Characterization of acoustic channel and its effect on single-carrier digital communications systems, and multi-carrier has been evaluated.

Further studies related to the characterization of acoustic propagation in more detail is presented in [13] and [14]. Here, have exploited the influence of surface water movement at the micro scale of the acoustic signals that pass through it. In [15] [16] and [17] have presented the characterization of the propagation channel non stasionary acoustic channel, and matching pursuit decomposition on modeling the incoming signal receiver. Development of characterization studies on underwater acoustic channel can be presented as in Table 1.

In the paper [18] and [20] have presented an investigation on the influence of the propagation channel of digital communication systems through simulation software. Measurement data that has been obtained through measurements of acoustic propagation is used as a test parameter of the modulation system that has been modeled.

The development of multi-carrier systems for the transmission of acoustic communication are also modeled in [21] [22] [23] [24]. Detection process at the receiver with OFDM ZP models have been developed, thus increasing the transmission bit rate and the ability to avoid the influence of multipath channel, especially in extreme conditions in shallow water. The validation process for the model has been supported by utilizing the measurement result data. The next development is focused on the capability of the receiver with channel estimation and equalization [25] [26] [27] and [28]. In this case the OFDM technique at the receiver is equipped with channel equalization based on ZF and MMSE techniques. The learning process is done by utilizing the pilot tone which inserted between sub-carriers.

Improved reception quality is developed using MIMO-OFDM techniques, as in [29] [30] and [31]. System performance is improved by the strengthening of the incoming signal at the receiver. Development of the transmission and modulation studies for underwater acoustic communication system can be seen as in Table 1.

Development of underwater acoustic communication research was supported by test bed of PC and DSP board based modem as in [32] [33] [34] [35] [36] [37] [38] and [39]. In this case, the development of soft acoustic modem algorithms can be done flexible and allow for reconfiguration of the system. Modem was designed starting from the basic digital modulation systems such as FSK, BPSK, and QPSK up to DS-SS Spread spectrum and multi-carrier OFDM technique. One obstacle is the difficulty of test bed implementation for the real system, because it involves a PC to drive a modem. In several studies conducted Zengli Zhou et all [35] and [37]. The modem was embedded to the DSP board memory, but still in a laboratory scale implementation.

The development of acoustic modem test bed has been done on a commercial scale such as Hermes, and T-mote base as in [40] [41] and [42]. The reliability of the system has been tested on the field scale testing in the sea for a various distance of transmitter and receiver [41] and [42]. The low cost test bed has been developed by Benson [40], but the coverage is relatively close and low data rate. This model is intended for environmental monitoring with small coverage.

TABLE 1. UNDERWATER COMMUNICATION RESEARCH PROGRESS

Main Topic	Sub Topic and Author		
Underwater Acoustic Channel Propagation & Modeling	Geometry Based Model (2009-2012) Alenka Zajic, Stuber	Physical & Micro Scale Surface Effect in Propagation (2008-2011) Peter Willet, Papandrau, James Preisig	Measurement Based Model (2006-2012) Stojanovic, Baosheng Li
Modulation & Transmission Technology	Multi Carrier ZP OFDM (2008 - 2012) Syarif, Peter Willet, Kai Tu, Fertonani	ZF & MMSE Equalization OFDM (2008-2012) Jun Tao, Rosa Zeng, Josso, Stojanovic, Baosheng Li	MIMO OFDM & Iterative Receiver Structure (2010-2012) Jan Eric, Linton, Stojanovic
Acoustic Modem Test Bed	PC-based & DSP board (2008 – 2012) Borowski, Feng Tong, Shengli Zou, Stojanovic	Commercial based Acoustic Modem (2006-2010) Benson, Beaujean	Low Cost Short Range Acoustic Modem (2009-2012) Pursey, Tores, Michael Frater

The development of acoustic modem with a lower cost than the commercial modem has been developed in [44], [45] and [46]. One flexible software dedicated radio has developed for network layer in the Tiny-OS and Linux platforms. This modem intended for uses in deliver end-to-end network for develop a physical layer and application layer [44] and [45]. The both of modems were designed for short range communication and the shallow water environment. The developing modem in FPGA was done by Nusrat, et all [46]. The modem is designed for a wideband and high rate transmission rate. Evaluation was done in the laboratory scale and limited environment conditions. The development underwater acoustic communication can be seen in Table 1.

III. UNDERWATER ACOUSTIC MODEL DEVELOPMENT

A. *Underwater Acoustic Channel Characterization*

Multipath channel has different attenuation factor, and time varying delay. This gives the effect on the amplitude and time of arrival of the signal at the receiver. If the complex signal from the transmitter represented as a form $s(t) = R[e^{j2\pi fct}]$, the bandpass signal at the receiver can be represented as:

$$x(t) = \sum \alpha_n(t) s(t - \tau_n(t)) \tag{1}$$

where $\alpha_n(t)$ and $\tau_n(t)$ is attenuation factor and propagation delay of the n^{-th} path respectivelly.

Equivalent low-pass channel can be described as a time varying impulse response as follows:

$$c(\tau;t) = \sum_n \alpha_n(t) e^{-2\pi f_c \tau_n t(t)} \tag{2}$$

When $c(\tau;t)$ is modeled as a complex Gaussin with zero mean, the envelope of $|c(\tau;t)|$ will have a Rayleigh distribution. This condition occurs in the propagation channel that does not has line-of-sight (LOS) path. At the other condition, when $c(\tau;t)$ is modeled as a complex Gaussin with no zero mean, the propagation channel will has a Ricean distribution.

A propagation process parameter measurements have been conducted in a towing tank with the dimensions of 20 x 6 x 200 meters, and the resuls as in [19]. This paper has presented the basic propagation parameter measurements on a laboratory scale. With the statistics approaching, it has been obtained that the channel noise has a Gaussian distribution and a spectrum almost white. Multipath fading parameter indicates the shape is similar to a log normal distribution.

For further research, the measurement process will be carried out on the real conditions around the coast of Surabaya, the more complex measurement parameters. Measurement scheme is simplified as in Figure 2.

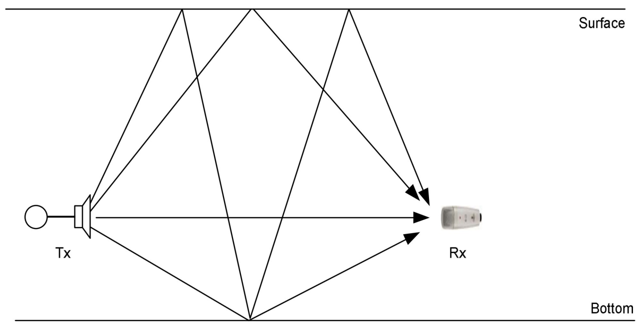


Figure 2. Underwater channel characterization

In this research will be carried out underwater acoustic channel characterization through measurement methods. Through an understanding of the properties of the propagation delay spread, signal attenuation, and the statistical properties of the other, is expected to be used as a reference in the modeling of communication systems that will be used.

B. *Underwater Acoustic Communications Simulation*

Multipath channel is represented in the *channel impulse response*, $H(t)$ as in equation (2). The channel characteristics have influenced the form of OFDM signal, so the arrival signal at the receiver became.

$$y(t) = \sum_{k=0}^{N-1} H_k X_k \exp(j2\pi k\Delta ft) + z(t) \tag{3}$$

where H_k and X_k are channel impulse response and symbol of k^{-th} sub-carrier.

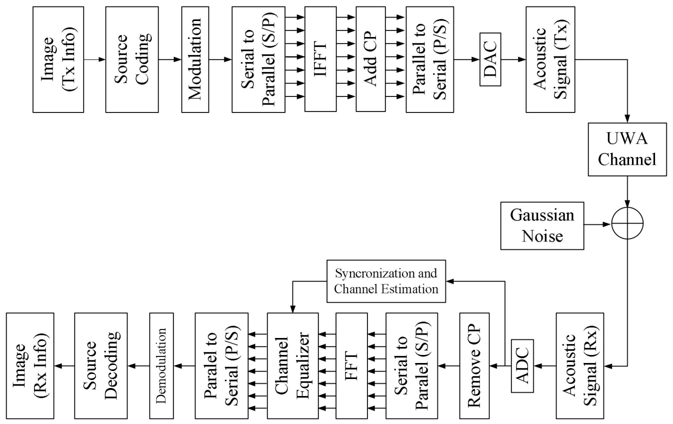
It is assumed that the channel is stationary and there is no relative motion between the transmitter and receiver. Environment noise $z(t)$ is Gaussian distributed and has a white spectral. The low-pass equivalent or baseband baseband signals can be represented as.

$$y(n) = \sum_{k=0}^{N-1} H_k X_k \exp(j2\pi kn) + z(n) \tag{4}$$

This research will be carried out through simulation by using a pilot tone for learning process and channel characteristic is detected block-by-block. The system is tested with a characteristic of an underwater acoustic channel, which has been obtained in the previous study.

The block diagram of OFDM simulation system can be seen as in Figure 3. The system developed at the level of the base band or low-pass filter ekuivalent. With a base band system, purposed to evaluate the performance of the system while the system as a whole represent functional. In this initial study, transmission system begins with the process of encoding an image into binary data with discrete cosine transform (DCT). The improved performance comes with Hamming error correction, and the use of pilot symbols for channel estimation process. The receiver is equipped with equalization technique of zero forcing (ZF) and minimum mean square error (MMSE). The evaluation process is carried on channel modeling results, which have been done in previous studies about channel characterization [19].

Future studies on the OFDM system, will be equipped with wavelet coding techniques and Reed Solomon error correction and BCH. The testing process utilizing channel modeling results of the characterization studies canals in coastal environments of Surabaya.



Gambar 3. Block diagram of image transmission using OFDM in the underwater acoustic channel

C. *Soft Acoustic Modem Test Bed*

With reference to the discussion that has been presented in Chapter 2, here is to construct a soft acoustic modem test bed. The development of modem is intended for testing algorithms and simulator has been done before. Acoustic modem test bed to be developed can be seen in Figure 4. Transmitter section consists of a PC that serves as a transmitter. The process started with processing of image information into binary sequences of data and performed coding for error correction purpose. Modulation used is FSK, BPSK, QPSK or higher techniques such as OFDM. Carrier frequency used is 7 ~ 15 kHz. The digital do analog (DAC) process is carried out by the external DAC for the better audio output signal.

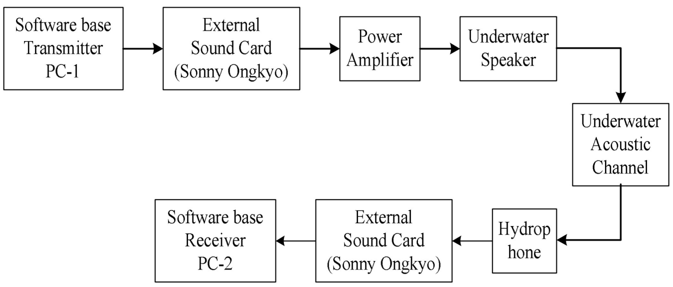


Figure 4. The design of underwater communication test bed

The reception process begins with the sound detection by using the voice activity detection (VAD) technique to determine the starting time of the recording process. Synchronization with the autocorrelation method for determining the starting point of the transmission signal, and the demodulation process can be performed by using coherent detection.

IV. CONCLUSSION AND FUTURE CHALLENGE

This paper has presented a review of research on the development of underwater acoustic communication systems and the challenges for researchers. In another section we also presented a research note that we are doing and the design of our future research.

Based on the summary of the research developments in Chapter 2, it's indicated that the trend of underwater acoustic channel modeling always starts with experimental process to obtain measurement data in the field. The next step is a statistical approach to obtain channel characterization approach by adopting a system of communication in the air. As of the writing of this paper there is no standard model of an underwater acoustic channel that has been agreed. This is a challenge for researchers to contribute to the modeling development of underwater acoustic channel.

Based on the summary in Chapter 2, it was showed that the simulation is widely used to study the development of transmission techniques algorithm. The other authors also presented a report on the research undertaken and try to contribute the development of a model study image transmission over underwater acoustic channel.

For the implementation of the communication system and advanced testing of the algorithms are developed, testing was conducted through the use of soft acoustic modem test bed as in Chapter 2. In this paper the author also tries to present the research design for the study soft acoustic modem test bed based PC, to be more flexible in the design and reconfiguration of the system.

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