ADVANCES IN THE ROBLINKS PROJECT ON LONG-RANGE SHALLOW-WATER ROBUST ACOUSTIC COMMUNICATION LINKS

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4. Abstract

Within the ROBLINKS project waveforms and algorithms have been developed to establish robust underwater acoustic communication links with high data rates in shallow water. To evaluate the signalling schemes, a wide range of experiments has been performed during a sea trial that has been held in May 1999, in the North Sea, off the Dutch coast. The analysis of the resulting data set shows that the original aims of ROBLINKS with regard to data rate and transmission range are achieved and in some respects even surpassed.

INTRODUCTION

The importance of underwater acoustic communication is steadily increasing. This communication is of importance for underwater activities ranging from data transfer between underwater and surface platforms, remote control applications such as underwater vehicles and robots, communication with divers, etc. With regard to underwater acoustic communication, the main difficulty associated with a large range/depth ratio is time spreading due to pronounced multipath propagation. This occurs in addition to high temporal (phase) and spatial variability.

The scientific innovation of the ROBLINKS project is that it focusses on continuous parallel identification of the channel response, to provide self-adaptive algorithms insensitive to channel fluctuations. Two competing strategies are investigated: identification with parallel monitoring and blind identification. Identification with parallel monitoring is established by transmitting a superposition of a known reference signal and a communication signal that is taken from an alphabet of signals orthogonal to the reference signal. By monitoring the reference signal one can estimate the response of the channel and correct for its detrimental effects. This approach has the disadvantage that only part of the energy is devoted to the communication signal. The blind approach does not utilize a reference signal. To correct for adverse channel conditions a self-trained, decision-directed equalization algorithm is used. The two approaches are evaluated on basis of data collected during a sea trial in a coastal part of the North Sea, which took place from April 30 to May 7, 1999. Further information on the project can be found in [1] and on the project homepage http://www.tno.nl/instit/fel/roblinks/.

OBJECTIVES

Present communication systems have good performances but they either have poor bandwidth efficiency (noncoherent methods), are limited by a time spread that is less than the symbol duration (differentially coherent), or require operator assistance to adjust the receiver parameters to the channel. The specific objectives of ROBLINKS are:

1. To develop new signal concepts and algorithms for optimal coherent signal processing in the time domain to achieve reliable long-range underwater acoustic communication in shallow waters at a large range/depth ratio (≥ 100). The aim is to achieve this at reasonable data rates (≥ 1 kbit/sec), and within the frequency band 1-15 kHz. The proposed algorithms should be self-adaptive with regard to environmental variations. The word "robust" in the project title is used in this particular sense.
2. To evaluate experimentally the performance of these waveforms and processing algorithms with data acquired during a shallow-water sea trial. Selected waveforms and processing algorithms are implemented in a real-time system and the real-time performance is evaluated with data recorded during the sea trial.

THE SEA TRIAL

Experimental set-up

A trial has been executed in the North Sea, approximately 10 km off the Dutch coast near the coastal resort Noordwijk. A data set was collected to evaluate the communication waveforms and processing algorithms and to assess the propagation conditions. The water depth at the location of the trial is approximately 18 m. The bottom is relatively flat with sand rims reaching heights of up to one meter. Two platforms were involved in the trial, HNLMS Tydeman and Meetpost Noordwijk.

HNLMS Tydeman, an oceanographic research vessel of the Royal Netherlands Navy, acted as the transmitter platform. The acoustic source used to emit the signals had a source level between 185 dB (re 1 μPa @ 1m) and 195 dB over the frequency band from 1-15 kHz. The source was deployed at a depth of 9 m.

Meetpost Noordwijk, a fixed research and monitoring platform owned by the Dutch Directorate-General for Public Works and Water Management, was the receiver station. A vertical array of 20 hydrophones, 60 cm apart and thus covering the greater part of the water column, was vertically fixed between a beam connected to the platform and a weight on the bottom of the sea.

Fig. 1 displays the set-up of the acoustic experiments. It also indicates the main problem encountered in shallow-water acoustic communications, namely multipath propagation. Sound scattering off the sea bottom and water surface is also indicated. This gives rise to reverberation. Further, reflections off moving surfaces, such as waves, contribute to the Doppler spread of the signals.

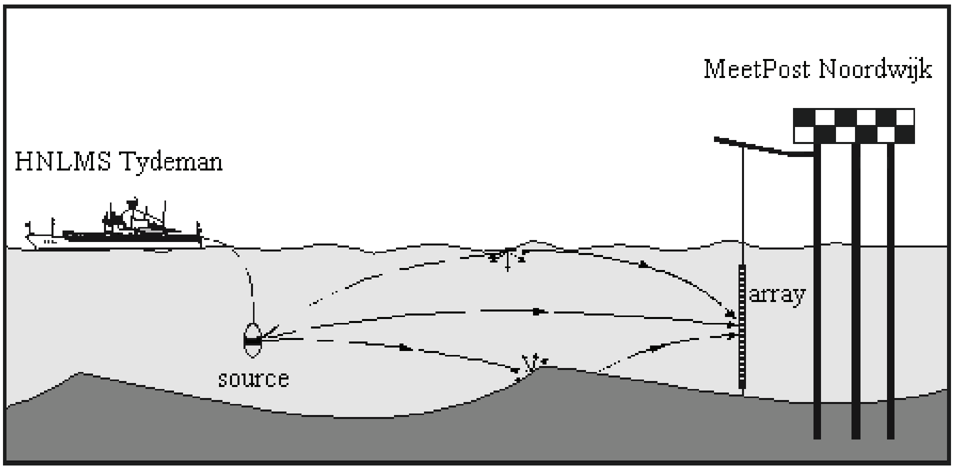

Fig. 1. Set-up of the experiment

Measurements

Communication signals were transmitted along two different tracks: a primary track from west to east, and a secondary track along the coast (more or less south → north). The first part of the experiments took place in a fixed point to fixed point configuration with moorings of HNLMS Tydeman at 1 km, 2 km, 5km and 10 km distance from Meetpost Noordwijk on the primary track and at 2 km distance on the secondary track. A moving point to fixed point configuration was used in the second part of the experiments in which the HNLMS Tydeman was sailing along the primary and the secondary track.

To assess the propagation conditions, each communication signal (with a typical length of about 13 minutes) was preceded by

- 60 seconds of noise recording to determine ambient noise levels;
- A CW (10 s) at the passband centre frequency, to determine the Doppler spread;
- Two linear FM sweeps (10 s over the frequency band 1-14 kHz and 0.2 s over the signal passband) to determine multipath propagation.

All project partners defined a set of communication signals. TMS created sequences containing a reference signal, RUB concentrated on blind equalization algorithms and TNO confined itself to more conventional modulations like BPSK to enable a comparative evaluation with the newly developed waveforms.

The acoustic experiments were complemented by a range of environmental measurements, such as CTD probes to determine sound velocity profiles and XBT casts to record temperature profiles, and echo soundings to determine the bathymetry of the tracks.

The trial has resulted in a vast, high-quality data set. The most illustrative and interesting part of the data set will be made available to the EU research community via the IFREMER/SISMER data banking centre. Information about this selected data set can be found in [2] and at the ROBLINKS archive http://www.ifremer.fr/sismer/program/roblinks/.

RESULTS OF THE DATA ANALYSIS

Analysis of the channel response

The 10-s FM and the CW signals have been analysed to estimate the time spread and Doppler spread, respectively. This is reported in detail in [3]. Typical values for the time spread are between 14 ms at shorter ranges (1 and 2 km) and 8 ms at the longer ranges (5 and 10 km). The structure of the different arrivals is rather stable at lower frequencies, whereas at higher frequencies (above 6 kHz) the temporal and spatial variability is significant. A typical value for the relative Doppler spread is $\Delta f / f = 2 \times 10^{-4}$.

Performance of high data-rate BPSK-signals

For the comparative evaluation of the newly developed waveforms with conventional modulations, a number of BPSK signals were broadcasted. These signals consist of standard Nyquist raised cosine pulses, supplemented with a pseudo random learning signal and two displaced carriers. The learning signal serves to estimate the channel response, and the displaced carriers are useful for timing recovery. Processing at the receiver includes linear least-squares equalization, adaptive beamforming and decision-directed equalization. After some fine-tuning quite good results can be obtained. For example, a signal of 4 kbit/s transmitted in a moving point to fixed point configuration is successfully demodulated to yield a zero bit error rate. The details are reported in [4].

Transmission using parallel monitoring

Results of the analysis of the communication signalling schemes with a reference signal at ranges of 2 and 5 km are presented in [5]. The transmitted signal is based upon Gold or Oppermann sets of sequences and consists of a superposition of one fixed reference sequence for the purpose of channel identification and up to 16 sequences with arbitrary indices and phases to carry the useful information. First analyses, using long signals (2 minutes) from a single hydrophone channel and robust and simple reception algorithms (without fine operator tuning and/or delay for channel identification), have already shown that transmission with very low bit error rate (BER ~ 10^{-4}) is possible for data rates up to 800 bit/s.

Transmission using blind identification

To investigate the feasibility of a completely self-recovering equalization and synchronization method, a system which uses offset-quadriphase-shift keying (OQPSK) signals was designed first. The number of message bits in each of these signals was approximately 10^5. By exploiting the special OQPSK modulation structure and by jointly processing the outputs of 3-7 hydrophones, a relatively simple symbol-spaced linear adaptive multichannel-equalizer could be applied with great success to the entire medium-range (2-5 km) experimental data. It could be demonstrated that bit error rates of approximately 10^{-4} were attainable without channel coding and with data rates ranging from 500-4000 bit/s. The results also show that virtually the entire number of bit errors per signal occur during the initial acquisition phase of the equalizer which lasts for a few thousand symbols at most. Additional details are presented in [6].

CONCLUDING REMARKS

ROBLINKS continues until the end of November 2000, and the receiver algorithms will continue to be improved until that day. Yet, the results more than half a year before the project end already eclipse the original objectives in several respects, viz.,

- The reported bitrate of 4 kbit/s surpasses the 1 kbit/s minimum objective;
- The transmission range of 5 km exceeds the 2-km distance that corresponds to a range/depth ratio of 100:1;
- Successful *mobile* underwater acoustic communication at high data rate has been demonstrated.

During the remaining project duration, further algorithm improvements will focus on the aspect of robustness. Furthermore, a real time implementation of the 'best' algorithms is being made.

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