

THE ROBLINKS UNDERWATER ACOUSTIC COMMUNICATION EXPERIMENTS

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Within the EU-MAST III project ROBLINKS 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 resulting data set consists of recordings of the newly developed waveforms, of more conventional communication signals for comparison, and of signals to probe the acoustic channel. Environmental data have also been collected to analyze and understand the propagation conditions during the transmissions. The most interesting and illustrative part of the data set will be made available for further analysis after the end of the ROBLINKS project.

1. INTRODUCTION

The aim of the MAST III project ROBLINKS is to develop waveforms and algorithms to establish robust long range shallow water acoustic communication links (range-depth ratio in excess of 100:1) with reasonable data rates (> 1 kbit/s). ROBLINKS focuses on new underwater acoustic communication techniques, based on continuous parallel identification of the channel response, with the aim to provide self-adaptive algorithms insensitive to the channel conditions. The word robust in the project title refers to this objective. 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 adverse effects. This approach has the disadvantage that only half of the signal energy is devoted to the communication part of the signal. The blind approach avoids this disadvantage; no reference signal is transmitted and hence all energy is used for the communication signal. To correct for the adverse effects of the acoustic channel conditions the response of the channel can be estimated by monitoring the (second or higher order) statistics of the received signal. The two approaches are evaluated on basis of data collected during a sea trial that has been held under realistic shallow water conditions, in the North Sea from April 30 to May 7 1999.

The ROBLINKS project is a collaborate effort of the following partners: Thomson Marconi Sonar (TMS-SAS, project co-ordination and communication using a reference signal), Ruhr University Bochum (RUB, blind identification), the Physics and Electronics Laboratory of TNO (TNO, trial organisation and comparative evaluation), IFREMER (data banking) and MARIS (data-management consultancy). Further information about the project can be found in [1] and on the project homepage <http://www.tno.nl/instit/fel/roblinks/>.

This paper focuses on the sea experiment to collect a set of acoustic and environmental data to evaluate the communication signals. The most interesting part of this set will be made available via the data holding centre of IFREMER for other parties after the end of the project, to evaluate their own processing algorithms. The content of this data-set will also be described in some detail.

2. DESCRIPTION OF THE TRIAL

2.1. Goals of the trial

The overall objective of the trial was to collect a data set to

- Assess the propagation conditions,
- Evaluate and improve the techniques using a reference signal and the blind identification methods,
- Make a comparative evaluation of the two approaches, with respect to each other and with respect to standard signalling schemes like Phase Shift Keying and Amplitude Shift Keying.

An additional objective of the trial was to collect a small data set for SWAN, the MAST III sister project of ROBLINKS. A SWAN trial was scheduled at the same location after the ROBLINKS trial. During each of the trials a small percentage of the time was devoted to experiments defined by the other project, thus limiting the risk that one of the projects would be left with no useful data at all.

2.2. Experimental set-up

The trial has been performed in the North Sea, approximately 10 km off the Dutch coast near the village Noordwijk. The water depth at that location is approximately 18 m. The (sand) bottom is relatively flat, except for sand rims with a height of up to one meter. Two platforms were involved in the trial.

HNLMS Tydeman, an oceanographic research vessel of the Royal Netherlands Navy, acted as the transmitting platform. The acoustic source used to emit the signals had a broad frequency band from 1-15 kHz, and a source level between 185 dB (re 1 μ Pa @ 1m) at 1 kHz and 195 dB from 8 to 10 kHz. The source was deployed at a depth of nine meters. The signals were generated before the trial and stored as wave files. These files were played during the trial using the soundcard of a PC. This procedure had the advantage of simplicity and small risk. A disadvantage was that the soundcard caused a slight upward shift in frequency that had to be accounted for in the processing afterwards.

The Meetpost Noordwijk, a fixed research and monitoring platform owned by the Dutch Directorate-General for Public Works and Water Management, was the receiving station. A vertical array of 20 hydrophones, 60 cm apart and thus covering almost the complete water column, was fixed vertically between a beam connected to the platform and a weight on the bottom of the sea. The received signals were band filtered between 100 Hz and 15 kHz, digitized (with a sample frequency of 48 kHz) and stored with a SONY SIR 1000 recorder. During transmissions the signals could be monitored audibly and by using spectral analysers.

Fig. 1 shows the set-up of the acoustic experiments. It also shows some of the many problems encountered in a shallow water environment: multipath propagation, and scattering of the sound against bottom and surface.

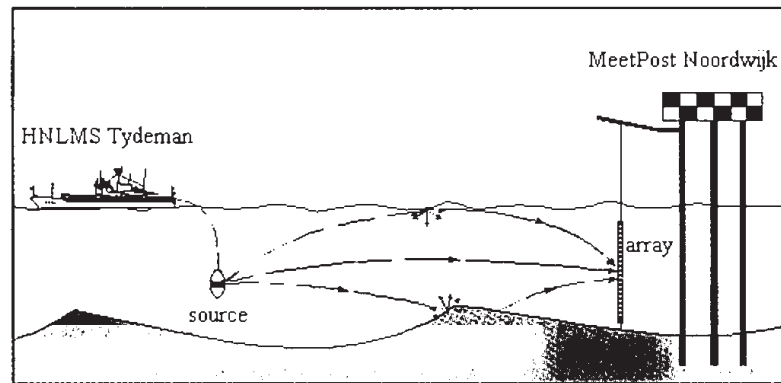


Fig. 1. Set-up of the experiment

2.3. Measurements

Eight days of measurements were planned. On six of these days transmission would take place in a fixed-point to fixed-point configuration (HNLMS Tydeman anchored), and the last two days in a moving-point (HNLMS Tydeman sailing) to fixed-point configuration. Two different tracks were defined: the primary track in western direction, and the secondary track along the coast. A peculiarity of this region is that fresh water from the Rhine and Maas estuary sometimes causes stratification of the water column near the coast. This effect can (and in fact did) cause sharp jumps in the temperature and salinity profiles, particularly along the secondary track, which is closest to the coast and to the estuary. Fig. 2 shows the trial area. The two tracks are indicated in red. The blue dots indicate the envisaged moorings of the Tydeman (1 km, 2 km, 5 km, 10 km and 20 km on the primary track and 2 km on the secondary track). The two blue lines indicate SWAN-tracks.

As a part of the collaboration with the SWAN project the Tydeman made bathymetry scans along all these tracks.

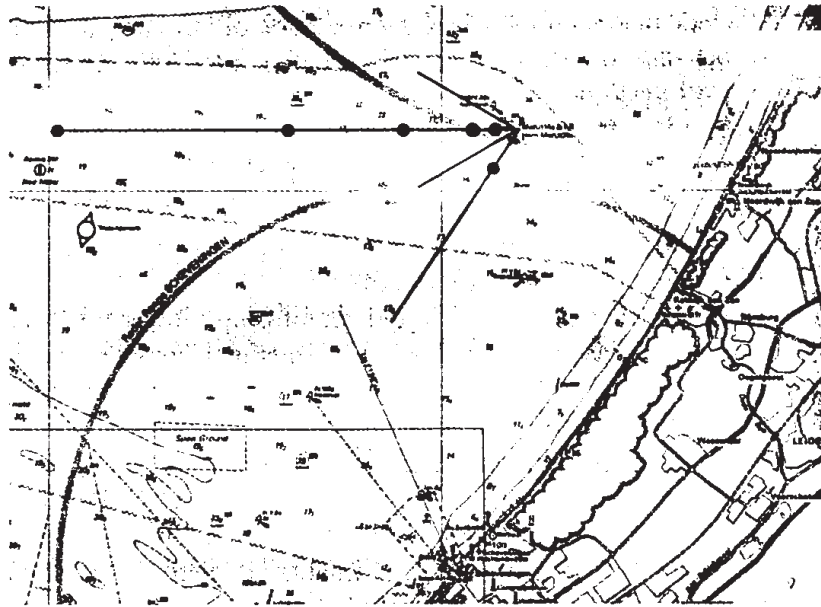


Fig. 2. Tracks and moorings.

All acoustic experiments to test the new waveforms were structured as shown Fig. 3.

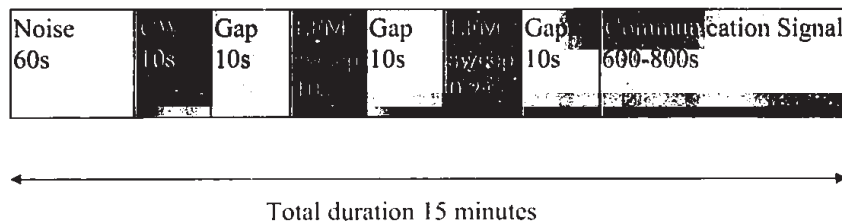


Fig. 3. Typical acoustic communication experiment.

To probe the channel conditions, each communication signal (taken long enough to perform statistics on) was preceded by

- A noise measurement (60 s), to determine the noise level at time of transmission.
- A CW (10 s) at the centre frequency of the communication signal, to determine the Doppler spread.
- A linear FM sweep (10 s) over the frequency band 1-14 kHz, to determine multipath propagation. The LFM was taken long enough to filter into subbands, so that frequency dependent propagation could be investigated.
- A short linear FM sweep (0.2 s) over the same frequency band as the communication signal, to determine the multipath structure.

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

2.4. Overview of significant events

April 30, start of the trial. Tydeman anchored at 1 km on the primary track. The experiments started exactly on schedule. The weather was relatively calm, and would only improve further in the course of the week that followed. Apart from problems with the CTD

probe (XBT's were casted instead) everything worked fine, and almost all scheduled experiments could be performed.

May 1, Tydeman anchored at 2 km on the primary track. Apart from some not very disturbing soft clicks in the acoustic array, everything worked fine. Even the CTD probe had been repaired. Again almost the complete schedule of experiments could be completed.

May 2, Tydeman anchored at 5 km on the primary track. The soft clicks that were present already the previous day turned into sharp, jamming clicks that threatened to ruin the experiments. Although from time to time it was still possible to make good quality recordings, particularly during slack water when the array was not stretched, the total time for experiments threatened to be unacceptably shortened. Since it had become very unlikely that it would be possible to obtain an adequate data set using the broken array, it was decided to request assistance from the SWAN colleagues of TNO-TPD. Considerable signalling time was lost during this day, and since it was to be expected that this would again be the case the next day, it was decided upon to skip the 20-km range, originally scheduled for May 4. Instead, the Tydeman remained anchored at 5 km from MPN for one more day.

May 3, Tydeman anchored at 5 km on the primary track. Thanks to the prompt assistance of the SWAN colleagues, the back-up hydrophones were mounted and worked properly in the evening.

May 4, Tydeman anchored at 10 km on the primary track. No problems were encountered during this day. A very successful day of measurements.

May 5, Tydeman anchored at 2 km on the secondary track. Again a very successful day of measurements. The equipment functioned well and the weather left nothing to be desired.

May 6, Tydeman sailed along the primary track. The first of two days of transmissions in a moving-point to fixed-point configuration. On this day, the Tydeman sailed along the primary track at a moderate speed. Although the source was not designed to be towed, the signal-to-noise ratio remained surprisingly high during most of the experiments, even at 10 km and beyond. During the day stratification of the water column near the coast became noticeable, both visually as in the CTD measurements.

May 7, the last day of the trial. Tydeman sailed along the secondary track. Also this day stratification occurred. In the evening, during the final experiments, the weather changed. It started to rain and the wind started to blow.

The size of the total acoustic data set is 700 GBytes. Part of the data is of poor quality (due to the malfunctioning of the array), but a very large portion is of high quality, with a signal to noise ratio in excess of 20 dB at shorter ranges.

3. THE ROBLINKS DATA SET

Out of the vast acoustic data set a selection has been made to enable analysis by other interested researchers after the end of the project (end of the year 2000). This selection comprises the most interesting and most intensely analysed signals. Among these are waveforms with a reference signal based on Oppermann and Gold sequences and signals for blind identification using several modulation techniques (MSK, offset QPSK, and DPSK). Most signals contain random sequences of bits, but also signals that contain actual information like pictures and text are included for demonstration. The above waveforms are all preceded by the signals to probe the channel as indicated Fig. 3. In addition to the above, communication experiments for the comparative evaluation using PSK and ASK modulated signals are included as well as experiments to investigate the short-term variability of the channel with a sequence of FM sweeps.

Of the selected acoustic experiments, three different transmission ranges are included, and the recordings of all hydrophones. The total size of the selected acoustic data is approximately 50 GByte. The data are stored in a platform independent format.

The data set also contains non-acoustic data. All CTD and XBT data and the bathymetry measurements made by HNLMS Tydeman are included.

Information about the data set, like formats used and how it can be obtained can be found on the ROBLINKS archiving web site: <http://www.ifremer.fr/sismer/program/roblinks/>.

4. CONCLUDING REMARKS

The first results of the analysis of the data by the project partners show promising results. An extensive analysis of the response of the acoustic channel using the CW and FM signals and the non-acoustic measurements is given in [2]. Results of the analyses of the communication signalling schemes with a reference signal at ranges of 2 and 5 km using signals from a single acoustic channel are presented in [3]. It is shown that transmission with very low bit error rate ($\text{BER} \sim 10^{-4}$) is possible for data rates up to 800 bits/s. Results with a blind receiver consisting of timing recovery and multichannel decision-directed equalization are presented in [4]. At 2 km range a BER of approximately 10^{-4} has been achieved for a data rate of 4000 bits/s. These results give confidence that the objective of ROBLINKS will be reached.

5. ACKNOWLEDGEMENTS

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REFERENCES

- [1] **D. Cano, M. van Gijzen, A. Waldhorst**, Long Range Shallow Water Robust Acoustic Communication Links ROBLINKS, In *Third European Marine Science and Technology Conference*, Lisbon, Volume III, pp. 1133-1136, 1998.
- [2] **P.A. van Walree, M.B. van Gijzen, D.G. Simons**, Analysis of a shallow-water acoustic communication channel, To appear in *The proceedings of the fifth European Conference on Underwater Acoustics, 2000*, Lyon, 2000
- [3] **J.M. Passerieux and D. Cano**, Robust shallow water acoustic communications based upon orthogonal sequences and real-time channel identification, To appear in *The proceedings of the UDT Europe Conference, 27-29 June 2000*, London (UK), 2000
- [4] **A. Waldhorst, R. Weber and J.F. Böhme**, A Blind Receiver For Digital Communications in Shallow Water, Submitted to *Oceans 2000*, Providence, Sep. 2000.