ARRAY PROCESSING TO MITIGATE CHANNEL FLUCTUATIONS IN HIGH-SPEED SHALLOW-WATER COMMUNICATION

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Abstract: *Rapid time fluctuation of shallow-water high-frequency acoustic channels can be a major obstacle for reliable and persistent high-speed acoustic communication. Coherence times below 30 ms and channel lengths exceeding 8 ms may occur for a 250 kHz carrier. To allow for high-speed communication and real-time processing of such a channel, the coherence time must be increased in a cost efficient way. This paper presents a method for slowing down the rapid time fluctuation of the channel. The method utilizes several antennas and can in some situations successfully increase the channel coherence time by several hundred percent. The method, which builds upon traditional beam-forming, has been evaluated on real data from two different high-frequency shallow-water experiments suffering from short coherence times. The experiments were conducted in August and November 2016 at a location in the Oslofjord with a water depth of 18 meters over ranges of a few hundred meters. The transmitter was located on the seabed transmitting long bursts of repetitive* m*-sequences (2047 symbols long in August, respectively 1023 in November) using a 250 kHz carrier and a baudrate of 78 kBd. The receiver, a 64-element line-array, was located on a boat slowly drifting with the wind, mimicking a slanted seabed to surface communication channel. The results indicate that the aperture of the array is an important design parameter, and that the number of active elements is of secondary importance.*

Keywords: *High-speed communication, coherence time, channel fluctuation, beam-forming*

1. INTRODUCTION

Acoustic communication at low and medium frequency is evidently slow. Low transducer bandwidth effectively limits the achievable data rates. In the strive for higher data rates, higher frequency bands must be exploited. Higher frequency regimes will benefit from improved bandwidth, a lower ambient noise level and possibly a reduction in reverberation. However it comes with the cost of higher attenuation and an increase in Doppler-spread, and as a result a reduction in coherence time.

In this paper, we consider a specific type of high-frequency channel, namely the slanted shallow-water channel. For this scenario we have measured coherence times of the same order of magnitude as the delay spread of the channel. The channel may change on a time scale shorter than the required convergence time of equalizers, leaving little room for actual payload data. In order to effectively communicate in these channels, the fluctuations must be reduced, and the coherence time increased.

The problem with short coherence times arises in channels with large Doppler spread. Notable causes are surface gravity waves acting as moving reflectors, and relative transmitter-receiver motion. Due to the low speed of sound, and the high-frequency, even small scale motions yield a non-negligible Doppler. A method to reduce the time varying Doppler is to reduce the amount of scatterers. This can be achieved with narrow beams either on the transmitter or on the receiver side.

Already in [3] it was suggested that narrow beams could increase the coherence time. Moreover [1] and [2] examined the idea for narrow-band systems in an isotropic environment, and tested the concept on simulated data. The contribution with this paper is that we will analyze the method in a underwater non-isotropic context, for a channel severely limited by Doppler-spread. We will in this paper evaluate the method for a high frequency, 250 kHz, wide-band, 78 kBd, channel and present results from measured channels, sampled with a 64 elements half-wavelength line-array. In section 2, a short description of the data collection and experiment. This is followed by section 3, a presentation of some our results. Section 4 will give our conclusions.

2. EXPERIMENT

The data presented in this paper come from two experiments conducted in the Oslofjord during August and November 2016. The test site was Horten Inner-harbor, a natural harbor two kilometer wide, with a typical water depth of 18 meters. The system setup was designed to mimic a SIMO (Single-input and multiple-output) system where a slowly moving surface vessel is communicating with a submerged sensor.

The receiver was a 64-element half-wavelength spaced line-array. It was attached to the surface vessel pointing 45 degrees downward relative to the surface. Creating a slanted channel towards the single element transmitter attached to a steal frame on the seabed, Fig. 1. The angle of the transmitter relative the seabed was 30 degrees in August and 0 degrees in November. The horizontal start distance from the transmitter was 330 meters in August, respectively 380 meters in November. From the start location the vessel was then allowed to drift off (0.2-0.3 m/s) with the wind, with the receiving transducer array pointing towards the transmitter, while data from all elements were recorded.

The transmitter transmitted long bursts of repetitive m-sequences (2047 symbols long in August and 1023 symbols long in November). The sequences were centered on a 250 kHz carrier, and had a baud-rate of 78 kBd.

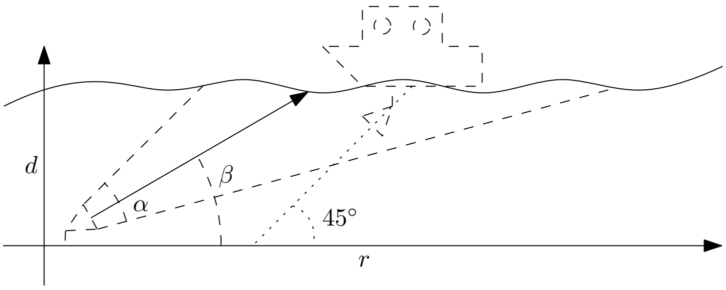
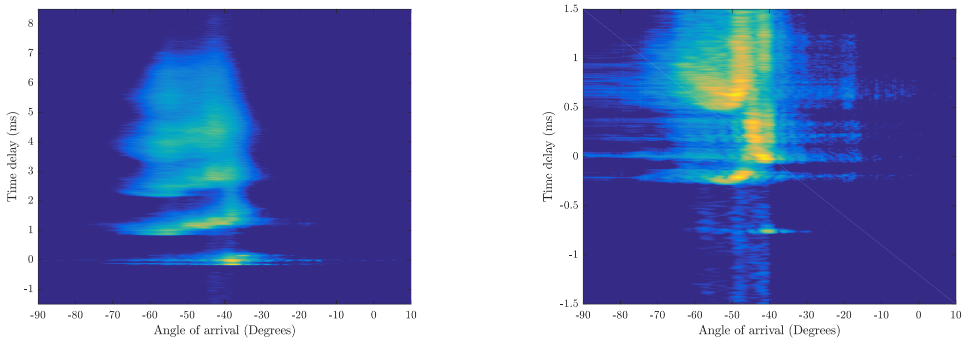


Fig. 1: Setup of the experiment, α is the opening angle and β the transducer orientation relative the seabed.



(a) *(b)*

Fig. 2: Beam-formed impulse response, (a) November sounding, (b) August sounding.

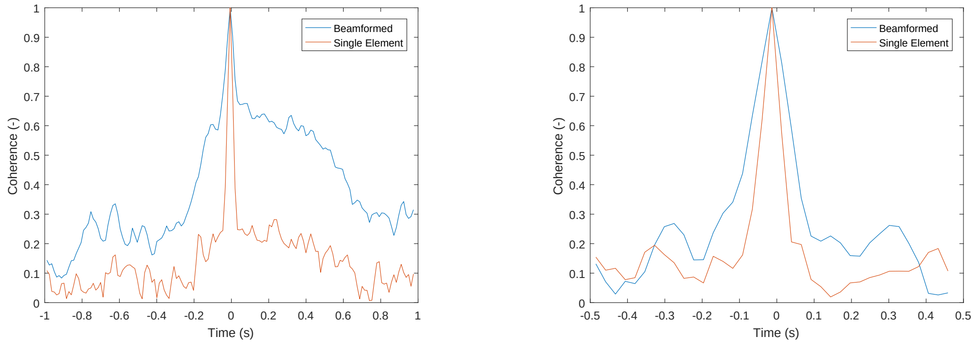
3. RESULT AND DISCUSSION

An estimate of the channel impulse response $h(t, \tau)$ as function of time and time delay is obtained with a channel sounder. It can be considered as the true channel impulse response convolved with the ambiguity function of the channel probe, in this case either a 2047 or 1023 symbols long m-sequence. For details regarding channel sounding see [4].

A snapshot of the two channels, beam-formed impulse response, can be seen in Fig. 2, representing the spread of the signal both in time and over angle. In Fig. 2a there is a narrow direct path followed by a wide cloud of subsequent arrivals, whereas the delay and angle spread in Fig. 2b is smaller.

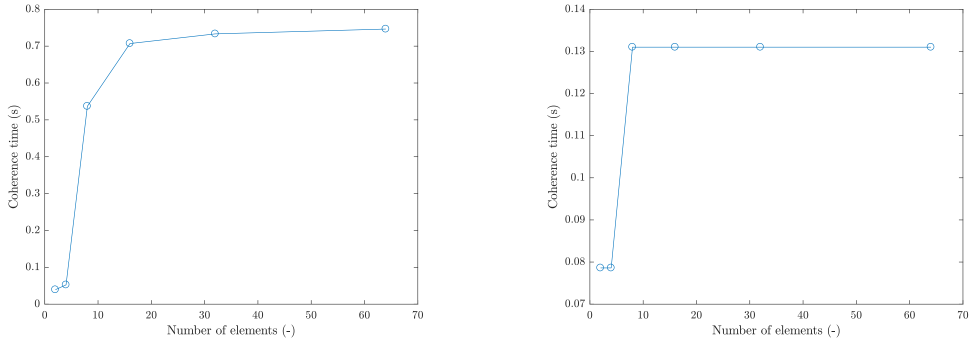
In order to reduce the channel fluctuations, both the interference from out of angle arrivals and out of time arrivals must be reduced. This leads to a two dimensional optimizing problem where both the channel behavior over time delay and angle must be considered. Traditional beam-forming can create narrow beams, spatially filtering out-of-angle arrivals. Selecting the strongest beam for further processing is not necessarily a good choice since it may contain a long tail of rapidly fluctuating reflections. Instead, a beam with a low-energy tail is a better choice. In Fig. 2a the direct path is the best choice, whereas in Fig. 2b one of the later arrivals arriving at $-55°$ is the channel with least interference.

To quantize the channel fluctuations we have used the normalized instantaneous zero-lag cross-correlation of the impulse response, compensated for constant Doppler, see [4] for details, as a measure of the channel coherence. The result for the two measurements can be seen in Fig. 3, comparing the beam, utilizing the full array, channel coherence to a single-element channel coherence. Considering the channel correlated when the coherence exceeds 0.5, one notes that



(a) *(b)*

Fig. 3: Temporal coherence for a narrow beam, using the full array, compared to temporal coherence for a single element, (a) November sounding, (b) August sounding.



(a) *(b)*

Fig. 4: Temporal coherence as function of elements, keeping the aperture size constant with lineary spaced elements, (a) November sounding, (b) August sounding.

beam-forming almost doubles the coherence time for the August measurement, and multiplied the coherence time for the November measurement.

Using a full array to double the coherence time of the channel, can be considered a bit wasteful. However examine Fig. 1 we can conclude that the scattered signal is fairly limited in angular spread. Keeping the aperture size we can start to thin out the array. As long as grating lobes do not interfere with the arrival and side-lobe level get too high, this can be done without a loss of coherence time, Fig. 4. Indicating that we in this case can reduce the number of active elements from 64 to 8 without significant loss in channel stability. This should have significant impact on both the cost and the processing time.

4. CONCLUSION

The method presented in this paper can reduce the channel fluctuations of a wide-band acoustic channel. Our measurements shows that the increase in channel coherence time is mostly due to the aperture size of the array rather than the number of participating channels, which helps reduce the cost of a practical system. Further work will examine the correlation between beams, refining the beam selection rule and examining other methods to thin the arrays.

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