AN UNDERWATER ACOUSTIC CHANNEL SIMULATOR

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The need for acoustic channel simulators

There is a growing interest in underwater acoustic communications. As a result of this a large number of new modulation schemes have been developed, which require testing. Testing at sea is expensive, and it is also difficult to have control over all the environmental factors affecting sound propagation. A channel simulator gives the ability to test modulations in laboratory, and to compare modulations under identical conditions.

In terrestrial communications a number of standard channels are defined, which makes comparison of modulation schemes convenient. This is not the case in underwater communications, which up to now have been based on measured channels. Another use of channel simulators is in the definition of standard channels.

The acoustic channel

There are many effects that need to be taken into account in order to obtain realistic simulations of the propagation effects that are important for communications, see Fig. 1. The underwater channel is characterized by time-varying multipath propagation. For stationary systems, time variance at a time scale which affects the performance of communication systems mainly comes from scattering of sound by the moving sea surface, including the bubble layer. The effects of bubbles are to cause attenuation, to refract sound towards the surface resulting in a seemingly rougher surface, and to scatter sound causing reverberation. Source or receiver movements add Doppler shifts, and due to multipath propagation also Doppler spread.

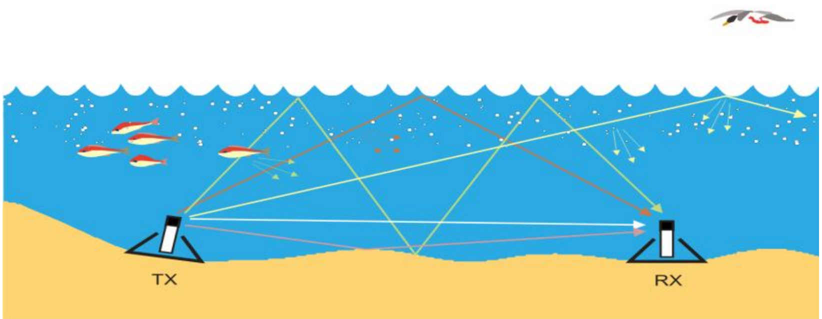

Figure 1 Mechanisms that affect sound propagation in the acoustic channel.

Channel soundings

Measurements of the time-varying channel impulse response (CIR) of the channel are required for driving and validating channel simulators. Measurements are also used to build an archive of acoustic channels. To measure the CIR, probe signals with good resolution in delay and Doppler are used, such as Pseudo-Random Noise (PRN) sequences. The probe signal consists of a concatenation of identical PRN sequences (of length T) transmitted for typically 30 sec. There are two conflicting requirements in the signal design: for tracking rapidly fluctuating channels T should be small, while for avoiding aliasing in delay T should be larger than the total delay spread of the channel. If the product of delay and Doppler spread of the channel is larger than 1, these requirements cannot be simultaneously satisfied, and aliasing in either delay and/or Doppler will occur. Aliased channel measurements will cause the channel simulator to predict wrong communication performance.

Channel measurements at three different sites in Norwegian waters (several fjord and continental-shelf environments) have revealed an amazing diversity in channel types. The channels include benign single path stationary channels, well-behaved stationary channels as well as cyclo-stationary and non-stationary channels. A few examples are given in Fig. 2. The channels may exhibit uncorrelated or correlated taps; correlation may be among neighboring taps only, or among widely separated taps.

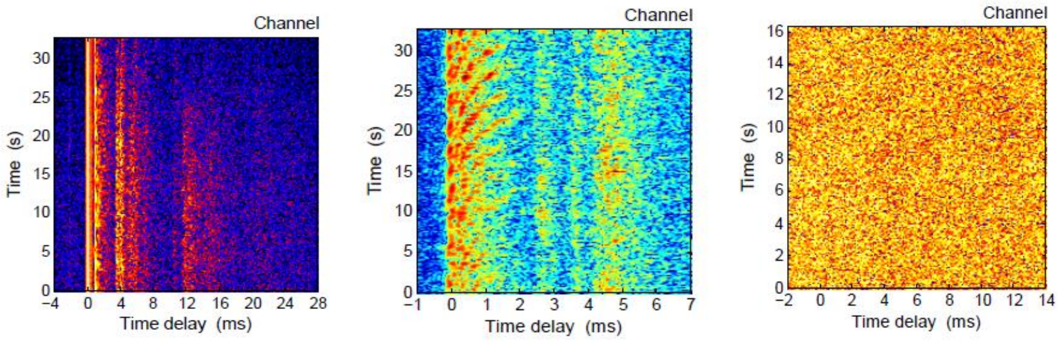

Figure 2 Examples of acoustic channels; non-stationary (left), cyclo-stationary (middle) and highly overspread (right)

Measured Doppler spectra are in most cases well described by stretched-exponentials [1], in contrast to theory which predicts Gaussian Doppler spectra for a rough sea.

A characteristic which is often found in the measured CIRs is a long reverberation tail. The tail has a wide Doppler spectrum. Such tails are not accounted for by standard forward ray-trace modeling, indicating that 3D effects (and possibly bubbles) need to be included in the modeling.

Channel simulation - methods and validation

Channel simulation could be based on measured or modeled channels. For measured channels, simulation can either reproduce the time-varying impulse response or the scattering function of the channel. The scattering function is a statistical description, allowing any number of realizations of the channel to be generated.

Simulation based on modeling from environmental information is the most flexible, but also the most demanding method. Direct simulation is based on generating a realistic evolving sea surface and propagating eigenrays at many time instants to obtain the time-varying impulse response. The method is general, but too computer intensive for many applications. A simpler, faster method is based on computing the power delay profile (mean impulse response) using e.g. a ray-tracer and the Doppler power spectrum from theory, eventually using an empirical spectrum such as the stretched-exponential spectra discussed above.

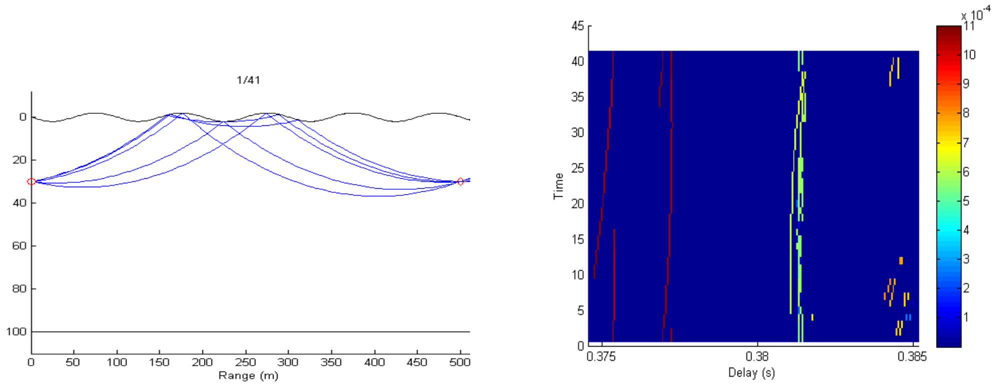

Figure 3 Time-varying channel impulse response (CIR) obtained through direct modeling using the stepped frozen sea approach. Left panel shows eigenrays at one time instant, right panel shows resulting time varying CIR.

The validation procedure consists in comparing measured and modeled channel characteristics (CIR, scattering function) and communication performance (bit error rate, signal-to-interference ratio).

Results of the validation are that the method based on replaying measured CIRs works well as long as the measurement is of good quality, i.e. has a high signal-to-noise ratio and low aliasing. The method based on generating stochastic realizations of the CIR from measured scattering function works well for stationary channels, but breaks down (as expected) for non-stationary channels. The method based on modeling is still its infancy. However, our sea trials have provided high quality environmental data that are well suited for further development and validation of the channel simulator.

References

1. P. A. van Walree, T. Jenserud and R. Otnes, “Stretched-exponential Doppler spectra in underwater acoustic communication channels”, JASA Express Lett. 128, EL329-EL334 (2010).