Acoustic Channel Simulator

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The channel simulator takes into account physical aspects of acoustic propagation as well as the effects of inevitable random channel variations. Channel variations are classified into small-scale and large-scale, based on the notion of the underlying random displacement being on the order of a few or many wavelengths, respectively. While small-scale variations occur over short displacements, and correspondingly short intervals of time (e.g., sub-second) during which the system geometry and environmental conditions do not change much, large-scale modeling takes into account variations caused by location uncertainty as well as varying environmental conditions.

The basic (time-invariant, deterministic) model of an acoustic channel is that of a multipath channel with additional low-pass filtering. Low-pass filtering accounts for energy absorption which is higher for higher acoustic frequencies. The signal also attenuates with distance, according to the energy spreading law (quadratic with distance for spherical geometry of spreading, linear for cylindrical). Fig. 1 illustrates this effect.

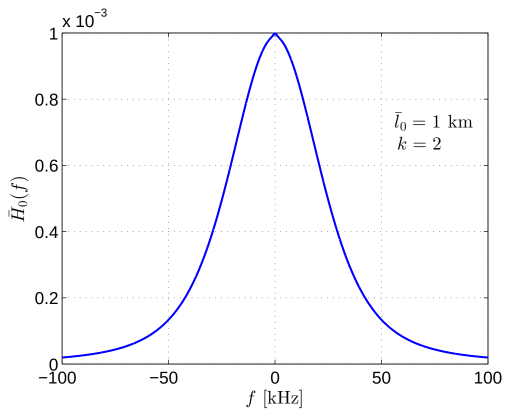

Fig. 1. Transfer function corresponding to a single reference path of length 1 km and spherical spreading (path loss exponent $k = 2$).

In a multipath channel, all the paths can be approximated as having the same reference transfer function, but a different gain and delay. A nominal channel geometry can be used to determine the nominal path gains and delays, $\bar{h}_p$ and $\bar{\tau}_p$, as shown in Fig. 2.

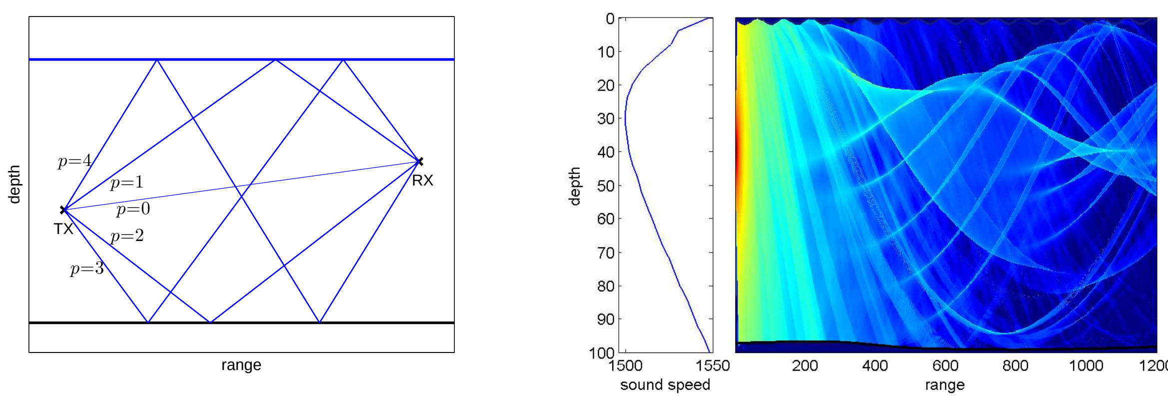

Fig. 2. In shallow water with constant sound speed, geometry of the channel can be used to calculate nominal path lengths and angles of arrival (left). In deep water, or in shallow water with depth-dependent sound speed, the Bellhop ray tracer can be used to determine the multipath profile (right).

Because of the location uncertainty, the actual path gains h_p and delays τ_p deviate from the nominal ones. This type of random deviation is classified as a large-scale phenomenon. Given a particular realization of the large-scale parameters at some time t_n, additional variation is caused by small-scale phenomena such as random surface scattering and local motion (transmitter/receiver drifting, surface waves, etc.). Fig. 3 illustrates the two types of random phenomena.

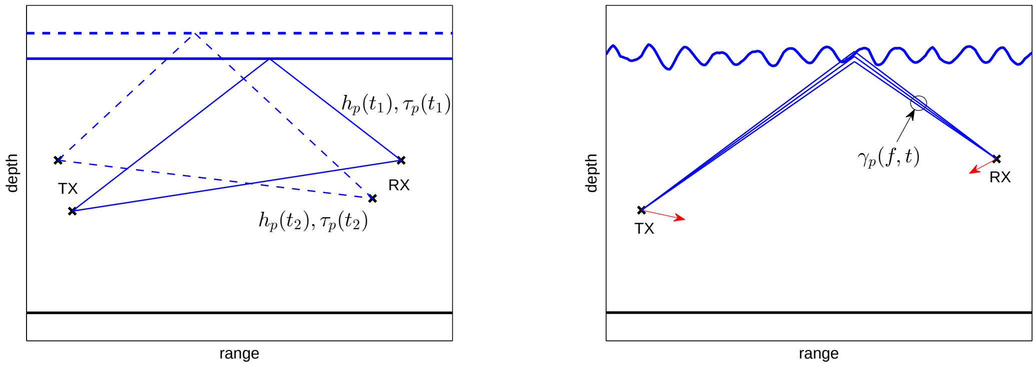

Fig. 3. Deviations from the nominal channel geometry cause the path gains and delays to deviate from the nominal ones (left). Surface scattering causes each path to split into a number of intra-paths, while unpredictable local motion causes random Doppler shifting (right).

The effect of time-varying multipath is modeled by the transfer function

$$H(f,t) = \sum_p h_p(t_n)\gamma_p(f,t)e^{-j2\pi f \tau_p(t)}, t \in T_n$$

where $\gamma_p(f,t), p = 0, 1, \ldots$ represent the scattering coefficients, and $\tau_p(t) = \tau_{p0} - a_p t$ represent the path delays which vary in time according to the (random) Doppler scaling factors a_p. Scattering coefficients are modeled as complex-valued Gaussian processes, whose statistical properties (correlation in time and frequency) are determined from the variance $\sigma^2_{\delta p}$ and the Doppler bandwidth $B_{\delta p}$ of the intra-path delays. Details about the channel model can be found in [1].

The **simulation algorithm** is given below.

Algorithm 1: Channel simulator

Initialization: set $\bar{h}_p, \bar{\tau}_p, \sigma^2_{\delta p}, B_{\delta p}$ — *Set the nominal channel geometry and environmental statistics*
for each realization of the large-scale process **do**
  set h_p, τ_p — *Use Bellhop or a simplified multipath calculator*
  for each realization of the small-scale process on $t \in T_n$ **do**
    for $p = 1, \ldots, P$ **do**
      $\gamma_p(f,t) = \frac{1}{h_p}\sum_i h_{p,i} e^{-j2\pi f \delta\tau_{p,i}(t)}$ — *Generate directly as indicated, or use a statistically equivalent model*
      $\tilde{\gamma}_p(f,t) = \gamma_p(f,t) e^{j2\pi a_p f t}$ — *Add motion-induced Doppler; allow for time-varying Doppler scaling factor*
    $H(f,t) = \bar{H}_0(f)\sum_p h_p \tilde{\gamma}_p(f,t) e^{-j2\pi f \tau_p}$ — output: channel transfer function
    $\tilde{G}(t) = \frac{1}{B}\int_{f_0}^{f_0+B} |H(f,t)|^2 df$ — output: instantaneous channel gain
  $G = E_{\tilde{\gamma}}\left\{\tilde{G}(t)\right\}$ — output: locally-averaged gain (ensemble average over small-scale realizations)

The **simulator package** is available for download at `http://millitsa.coe.neu.edu/?q=projects`. It consists of two main Matlab codes: `set_channel_params.m`, which a user edits to set the channel parameters, and `channel_simulator.m`, which performs the simulation. The simulator can be set up to use Bellhop or a simplified multipath calculator for generating large-scale channel realizations. Small-scale scattering coefficients can be generated directly from a set of intra-path delays, or based on a statistically equivalent model. For any further questions, please contact qarabaqi@ece.neu.edu.

[1] Qarabaqi, P.; Stojanovic, M., "Statistical Characterization and Computationally Efficient Modeling of a Class of Underwater Acoustic Communication Channels," Oceanic Engineering, IEEE Journal of, vol.38, no.4, pp.701,717, Oct. 2013