RF propagation (Lecture 20)

Underwater Acoustic Channel (UAC)

- Possibly the worst, understanding undersea communication medium
- Hulknail speed may exceed sound
- Fast & slow fading / Frequency selective flat
- High frequency absorption not low frequency because conductive layer
- Low then absorbe
- Low speed propagation (200 m/s) results in significant Doppler shifts

Ray propagation model.

![Diagram of ray propagation model with sea surface and sea floor]

The ray model of the acoustic propagation.

- Due to pressure and temperature, the speed of acoustic waves vary with the depth. For low pressures, the acoustic waves do not propagate in the straight-line but are subject to refraction.
A reasonable approximation of the speed of sound in water is

\[ C(T, S, d) = 1492.2 + 4.6T - 0.055T^2 + 0.00029T^2 \]
\[ + (1.34 - 0.01T)(S - 35) - 0.016d \]

where:

- \( C \) = sound speed in m/s
- \( T \) = temperature in \(^\circ\)C
- \( S \) = salinity in ppt
- \( d \) = depth in meters (deeper than 30 m, the dependence on depth is neglected)

Deep water sound profile:

- Speed of sound
- 1550 m/s
- 4000 m
- 5000 m
- 6000 m
- 7000 m
- 8000 m
- 9000 m
- 10000 m

In shallow water the speed profile is very irregular. The signal intensity will vary with surface and bottom, leading to larger signal variability.
Signal losses and ambient noise

Primary mechanisms of signal loss:

1) Spreading loss

2) Absorption loss in both the water and the bottom

3) Scattering loss at the sea surface & the sea floor

Spreading losses

Spreading loss - Function of the separation between the transmitter and the receiver.

- \sim \frac{10 \text{dB}}{\text{dec}a}
- \sim \frac{10 \text{dB}}{\text{dec}a}

\log(d)

- Close to the transmitter loss \sim -20 \text{dB} / \text{dec}a (Spherical propagation)
- Far away from the transmitter loss \sim -10 \text{dB} / \text{dec}a (Cylindrical propagation)

- The energy of the wave is channelled by top and bottom of the sea.

Ambient losses

- Absorb energy becomes into heat
- By wind, wave, and wave dependence
Scattering losses.

* Acoustic signal is reflected from both the surface and bottom.
* If the surface is rough, some of the energy is reflected back to the TX, but most of it is scattered to the receiver.
* Scattered energy decreases rapidly and it is effectively lost.
* The energy scattered towards the RX causes signal variations (fade) on the small scale.
* In deep ocean present S.O.FAR limits the interaction of the acoustic wave with the surface and the bottom of the ocean.
* In shallow water, S.O.FAR does not exist and the effect of boundary surface is less pronounced.

Large scale propagation loss for acoustic channel may be approximated using following equation.
Average signal power at distance $r$ from a point source

$$\text{SL (dB)} = 169 + 10 \log_2 (P) - 20 \log_2 (r) - 10 \log_2 (d/2) \quad (*)$$

$P$ - radiated power in W
$r$ - distance between TX & RX in m
$d$ - depth of the ocean in m
$\alpha_5$ - attenuation factor in dB/m.

In (*) it is assumed that $r > d$ and that the source is omnidirectional.

Example. Consider an acoustic source operating at the frequency of 15 kHz in 50 m deep water. The radiated power of the source is 20 kW. Evaluate the average signal level at distances 1 km, 2 km, and 10 km. Assuming that $\alpha_5$ at 15 kHz is given as 1.5 dB/km.

$$\text{SL (dB)} = 169 + 10 \log_2(20) - 15 \cdot \text{d [km]} - 20 \log_2(25) - 10 \log_2 (\text{d [km]} \cdot 1000 - 25)$$

<table>
<thead>
<tr>
<th>d [km]</th>
<th>SL [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>122.66</td>
</tr>
<tr>
<td>2</td>
<td>118.04</td>
</tr>
<tr>
<td>10</td>
<td>99.06</td>
</tr>
</tbody>
</table>

Note: From the RF engineering standpoint, the units given in the table do not make sense.

For acoustic signal level measurements, the reference unit is set differently.
$\text{SL} [\text{dB}] = 10 \log \left( \frac{p^2}{p_0^2} \right)$

where $p$ = pressure of the acoustic signal
$p_0$ = reference pressure

For underwater communication $p_0 = 10^{-6} \text{ Pa}$

$p_0$ - corresponds to minimum detectable acoustic signal

As a reference: The hearing threshold in the air is given as $P_{0a} = 20.4 \mu\text{Pa}$

Ambient noise:

- Waves, rain, wind
- Marine life
- Passing ships

Ambient noise determines the minimum level of the detected signal.

There are many sources of ambient noise in the ocean:

- Waves, rain, wind
- Marine life
- Passing ships

With large numbers of possible sources, the ambient noise can vary significantly. Vehicular traffic 93-12018 has been reported.

Example 2: Consider the source area in Example 1. If the ambient noise is constant, calculate the SNR ratio at different distances from the transmitter.
<table>
<thead>
<tr>
<th>Time (s)</th>
<th>C/T (m/s)</th>
<th>C/T (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>127.66</td>
<td>420.9</td>
</tr>
<tr>
<td>2</td>
<td>118.09</td>
<td>388.6</td>
</tr>
<tr>
<td>3</td>
<td>98.06</td>
<td>323.3</td>
</tr>
</tbody>
</table>

C/T varies for the source in Example 1 (Assuming 90 dB at noise floor)

The underwater propagation

One of dominant influences on the propagation of acoustic wave.

- Micro-puls - water-to-water & slow-moving variations in the ocean
- Macro-puls - rapidly varying standing patterns at the ocean

Spatially & temporally varying sound speed at the ocean is given by:

\[ C(t, z) = c_0 \left( 1 + U_o(t, z) + \eta(t, z) \right) \]

where

- \( c_0 \) - Nominal speed of sound
- \( U_o(t, z) \) - Slow variations caused by pressure and temperature changes
- \( \eta(t, z) \) - Rapid fluctuations caused by internal waves and turbulence, waves, ...
Suppose we have a source transmitting signal at an IF. If \( H(\omega t) = 0 \), I see surface is flat and the bottom of the sea has only large-scale features.

The received signal would be:

\[
y(t) = \sum_{k=1}^{\infty} h_k(t) * x(t) = h(t) * x(t)
\]

\( x(t) \) - transmitted signal

\( h_k(t) \) - impulse response for \( k \)th hke

\( h(t) \) - overall impulse response of the channel.

In the vicinity of the transmitter, the hke is narrow and there is usually a single dominant ray. Within the hke is unsaturated channel.

At larger distances, there may be many rays within the hke.

- Fully saturated channel

- The probability of the fully saturated channel increases with frequency.

At 50 kHz, saturation occurs at distance of 1 km.

\( 1 \text{ km} \) - 50 km

Impulse response for non-saturated channel (PDP)

Amplitude behavior of individual multipath components are not

\[ P(t) \]
Power delay profile of allinable channel.

Amplitude variations of individual multipaths are

propagated as fading of the multipaths.

Additional multipath causes fading. Depending on the PDP of the environment, the fade fading can be quite severe.

(from a PDP measurement from Brady's paper)

Delay spread for UWA channel may range from 5ms to 20ms. Thus gives us a 0.5 coherence BW at only 33 Hz and 2.5 Hz respectively. Therefore - Acoustic channels need to be considered. However, typical speeds that are experienced in water are much smaller than what we experience in terrestrial environment. Good news for evolution.
UWA communication systems can be classified in several different ways. One possible classification is on the basis of diversity.

1) No diversity systems
2) Explicit diversity systems
3) At least implicit diversity systems

1) Early analog systems — used careful placement of hydrophones and the receiver diversity to eliminate multipath. Through distant anchor at control.

Early digital systems — the effects of multipath eliminated through very low delay rates.

2) Use of spurious frequency angle a time diversity to combat multipath.

propagation. Systems are digital comm frequency in 50 kg range and can have data rates of up to 100 Ks/sec.

3) Most advanced spread spectrum techniques have an attempt to

white multipath through of the channel to their advantage. Use

noise rejection. They can include distant at 20-40 Ks/Sec over

shorter distances.