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THERE IS NO “TYPICAL” UNDERWATER ACOUSTIC CHANNEL. IN DIFFERENT ENVIRONMENTS, DIFFERENT ENVIRONMENTAL FACTORS DOMINATE THE CHARACTERISTICS OF THE CHANNEL AND RESULT IN DIFFERENT CHALLENGES!
• Signal Attenuation Due to Absorption

• Speed of Sound and Channel Coherence Times

• Reflection and Refraction: Shadow Zones, Multipath and non-minimum phase channels

• Signal Attenuation due to Bubbles

• Channel Dynamics and Surface Scattering (platform motion also a source of channel dynamics)
Signal Attenuation Due To Absorption

- Available Bandwidth is Range Dependent.
Speed of sound and comms networks

- Speed of sound is approximately 1500 meters/second.
- Channel coherence times often << 1 second. Channel quality can vary in < 1 second.

- Timeliness of channel feedback
- Water velocities up to 1 meter/second. Travel time between 2 nodes can be asymmetric with differences on the order of 0.1%. Impacts synchronization algorithms using 2 way travel time differences.
Variability of the Speed of Sound

• The speed of sound varies spatially and temporally.

• Temporal variability tends to be slow (order minutes or tens of minutes) but impacts network connectivity. Usually only an issue in stratified environments.

• Spatial variability gives rise to refraction (bending) of sound. (Snell’s Law -> Sound “bends” away from areas of higher sound speed towards areas of lower sound speed.)

• Refraction and reflections from the sea surface and bottom gives rise to multipath propagation.
Sometimes there is no direct path (unscattered) propagation between two points. All paths are either surface or bottom reflected or there are no paths.

- Problem with communications between two bottom mounted instruments in upwardly refracting environment (cold weather shallow water, deep water).
- Problem with communications between two points close to the surface in a downwardly refracting environment (warm weather shallow water and deep water).
Shadow Zone Examples (Deep Water Profile)

Bottom Source/Receiver

Surface Source/Receiver
Typical Shallow Water Sound Speed Profile

- Surface
- Typical Sound Speed Profile
- Upper Mixed Layer
- Transition Layer
- Bottom Layer
- Xmit
- Rcvr
Non-minimum phase impulse response

- Shallow Water (100 meter depth) example
- Continuously downwardly refracting environment
- Largest arrival is not always the first arrival!

Sample Impulse Response
3.2 km range
Implications for Communications Networks

- Vertical sound speed profile impacts
  - the characteristics of the impulse response
  - the amount and importance of surface scattering
  - the amount of bottom interaction and loss
  - the location and level of shadow zones
- Temporal variability of the sound speed profile results in a slow amplitude fading of arrivals at nodes.
- Impact on Network topology and routing: For slow time variability, see Siderius et al. and more recent work by this group (accepted in JASA).
Bubbles

- Bubbles are created by breaking waves such as those around the surf zone or “white caps” in the open ocean.
- Bubbles are either injected into the water column by the breaking action itself or advected into the water column by wave induced vertical circulation or other mechanisms such as Langmuir Circulation.
- Bubbles scatter and absorb sound and can persist in the water column for minutes.
- Bubbles also generate sound in the first few milliseconds of their existence.
Bubbles and breakers in the surf zone
(144 meter range in the surf zone at Scripps Pier)
Bubbles and wave action around the surf zone
Implications for Communications Networks

- Bubbles can cause communications channels to suddenly disappear.
- Bubbles increase surface scattering losses. Up to wind speeds of about 6 m/s, additional losses are small. At 10 m/s wind speed with significant white capping, losses are order 10 dB per surface bounce (Dahl).
- Attenuation within a bubble cloud can be 20 dB/meter.
- Attenuation by bubbles is frequency dependent and peaks near 30 kHz.
Channel Dynamics

- Two primary sources on time scales of seconds or less.
- Platform motion
- Scattering off of the moving sea surface.
Impulse Response During Wavefronts II Experiment

Surface Wave Field

Impulse Response Estimation Error

Relative Delay (ms)

Time (sec)

Intensity (dB)
Acoustic Focusing by Surface Waves

Time-Varying Channel Impulse Response

Dynamics of the first surface scattered arrival

Relative Delay (mSec)

Time (seconds)

Depth (m)

Range (m)

Doppler (Hz)

Relative Delay (mSec)

(d) t = 20.377 sec
Time-Varying Channel Scattering Function

QuickTime™ and a decompressor are needed to see this picture.
Changes in channel “quality” and the periodic channel (15 meter depth, 250 meter range).

Time-Varying Channel Impulse Response

Contribution of each multipath arrival to overall estimation error
Impact of the Periodic Channel on Comms Performance

Signal Prediction Error
(indicator for channel estimation error)

One and four channel DFE Bit Error Rate

Sensitivity to surface waves may be directionally dependent
Implications for Communications Networks

- Channel sensing and quality prediction (both effect of surface scattering and attenuation by bubbles)
- Message Routing
- Coding and Interleaving
Summary

• Many physical processes create communications channel conditions that are significantly different than those of the wireless radio channel.

• The characteristics of the underwater acoustic channel can impact systems performance at many layers.

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