Modeling the Underwater Acoustic Channel in ns2

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Challenges: Underwater Networks

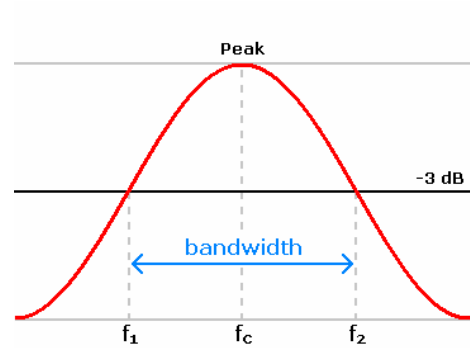
- Slow propagation speed
  - Long delays
  - Doppler effect
- Bandwidth-distance relationship
- High error rates
- Orientation-dependent fading
- Complex multipath effects
- Constant mobility
  - Current
  - Sea life

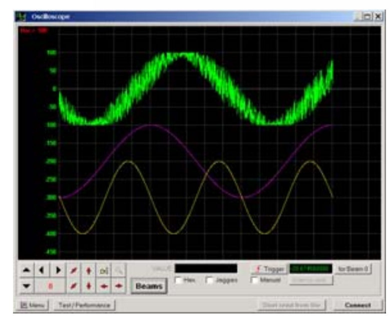
(COURTESY NOAA)

Need a consistent simulation tool

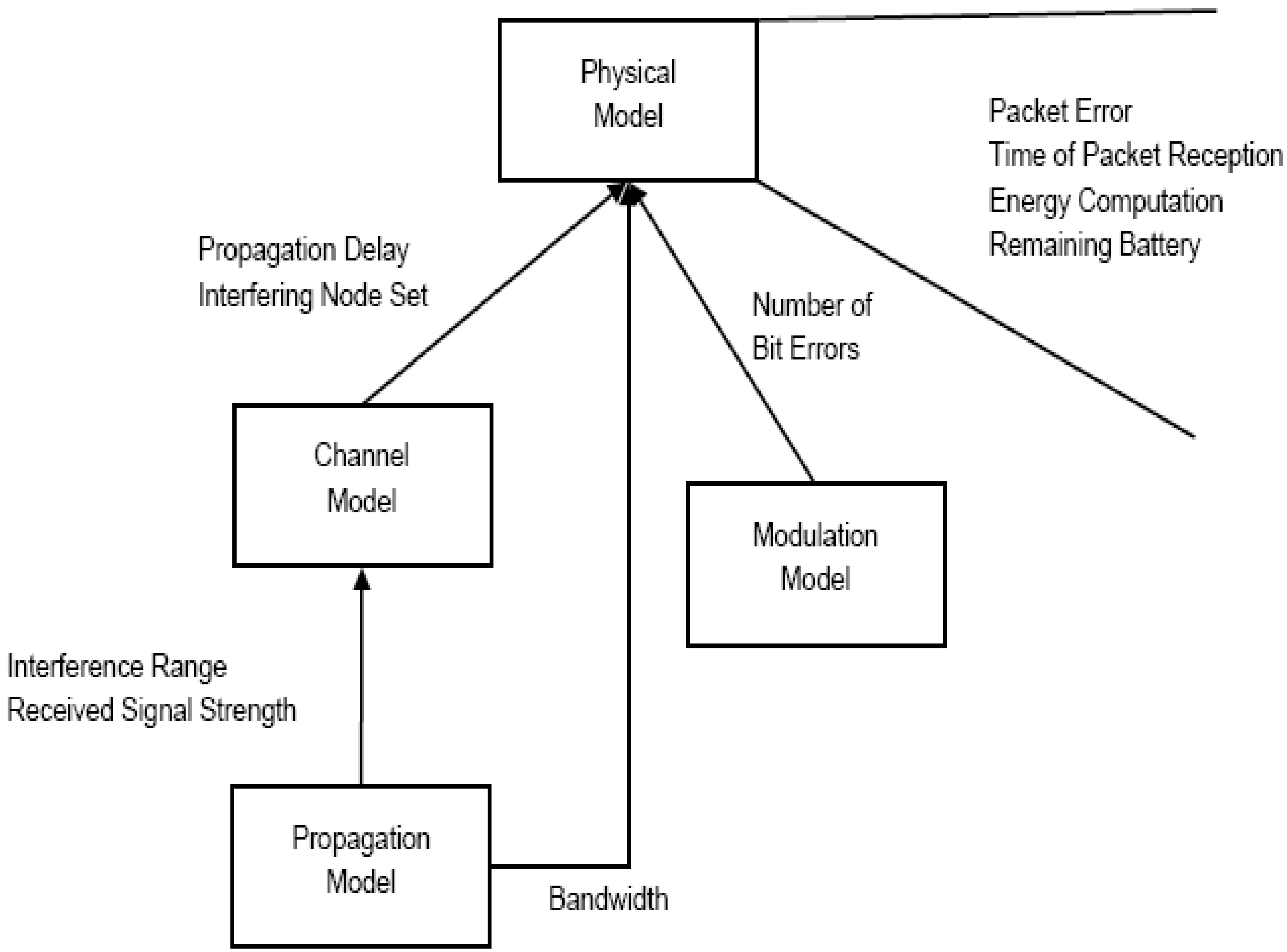
Three Important Underwater Channel Characteristics

- Bandwidth
  - Distance dependent
  - AN factor
    - Attenuation
    - Noise
- Transmission power
  - Signal-to-noise requirement
  - AN factor
- Delay
  - Location in water
  - Salinity and temperature of water





The ns2 Model



Underwater Attenuation-Noise

- Attenuation is both distance and frequency dependent

Absorption factor
(frequency dependent as O(f^2))

$$10 \log A(l, f) = \underbrace{k \cdot 10 \log l}_{\substack{\text{Spreading loss} \\ \text{(k=2 for spherical)}}} + \underbrace{l \cdot 10 \log a(f)}_{\text{Absorption loss}}$$

- Noise is frequency dependent
- Four common components
  - Turbulence
  - Shipping
  - Wind
  - Thermal

Turbulence, Shipping: Dominant for low frequencies

Wind, Thermal: Dominant for high frequencies

Absorption Factor

- Major factor limiting usable bandwidth
- Increases very rapidly with frequency

$$10\log a(f) = 0.11\frac{f^2}{1+f^2} + 44\frac{f^2}{4100+f} + 2.75\cdot 10^{-4} f^2 + 0.003$$

Thorp's approximation

Underwater Ambient Noise

$$10\log N_t(f) = 17 - 30\log f$$

$$10\log N_s(f) = 40 + 20(s - 0.5) + 26\log f - 60\log(f + 0.03)$$

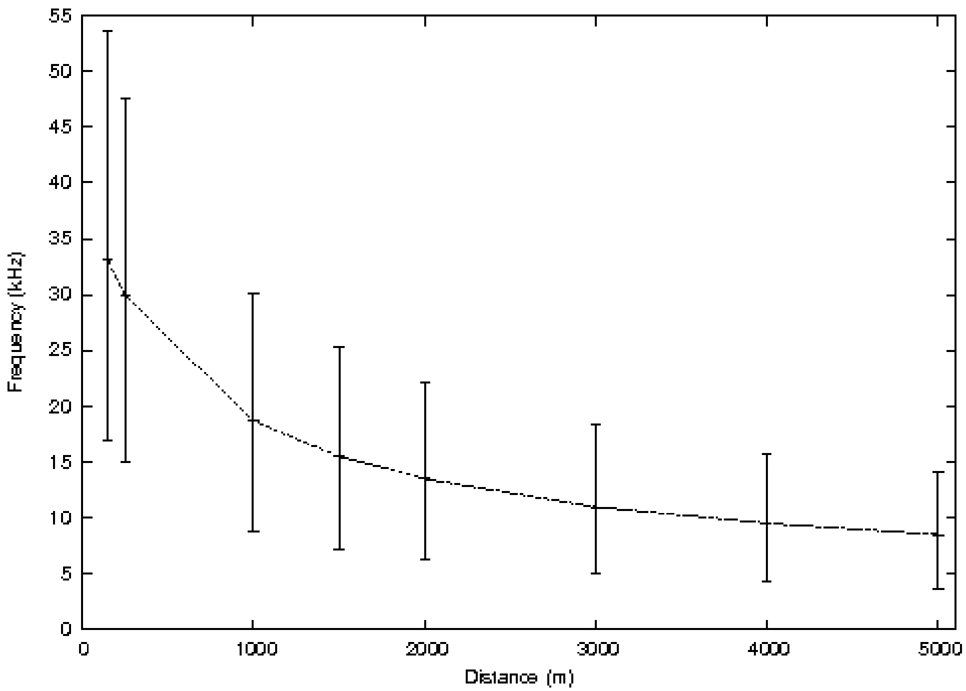
$$10\log N_w(f) = 50 + 7.5w^{1/2} + 20\log f - 40\log(f + 0.4)$$

$$10\log N_{th}(f) = -15 + 20\log f$$

f = frequency
s = shipping factor [0,1]
w = wind speed (m/s)

- Four components
  - Turbulence (t)
  - Shipping (s)
  - Wind (w)
  - Thermal (th)
- Short ranges (higher frequencies)
  - Wind and thermal dominant
- Long ranges (lower frequencies)
  - Turbulence and shipping become a factor

Bandwidth-Distance Relationship

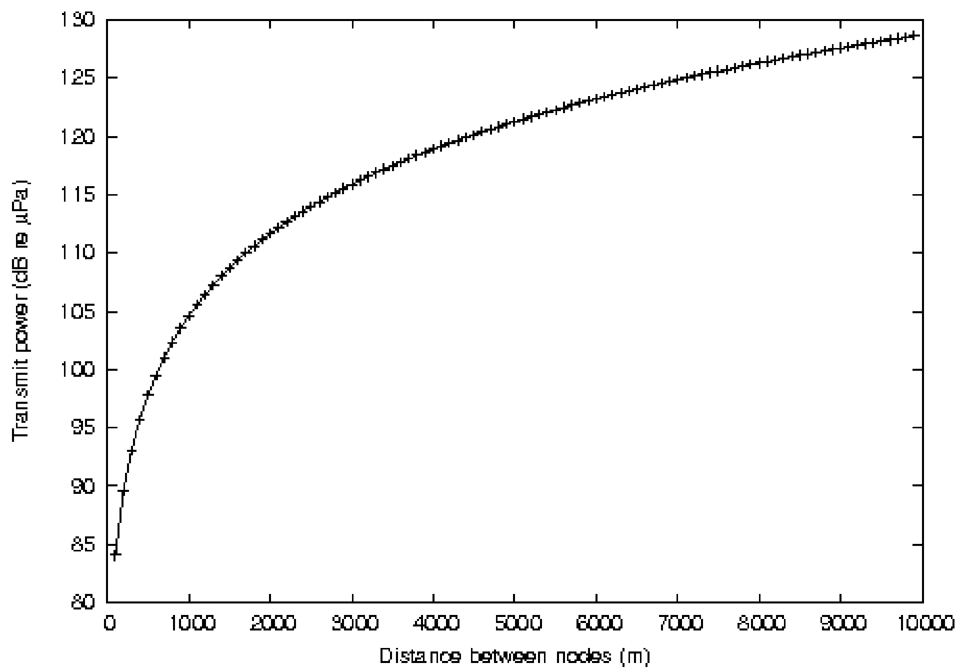


- Find frequency center
  - Frequency with minimal attenuation given the distance
- Find bandwidth
  - 3 dB definition for example
- Both the frequency center AND the bandwidth vary with distance between nodes

Transmit Power

- Signal-to-noise ratio (SNR)
  - Related to
    - Bandwidth (B(l))
    - Attenuation (A(l,f))
    - Noise (N(f))
- Calculate needed transmit power (W)
  - Distance between nodes
  - SNR threshold

$$SNR(l) = \frac{\frac{W}{B(l)} \int_{B(l)} A^{-1}(l, f)df}{\int_{B(l)} N(f)df}$$

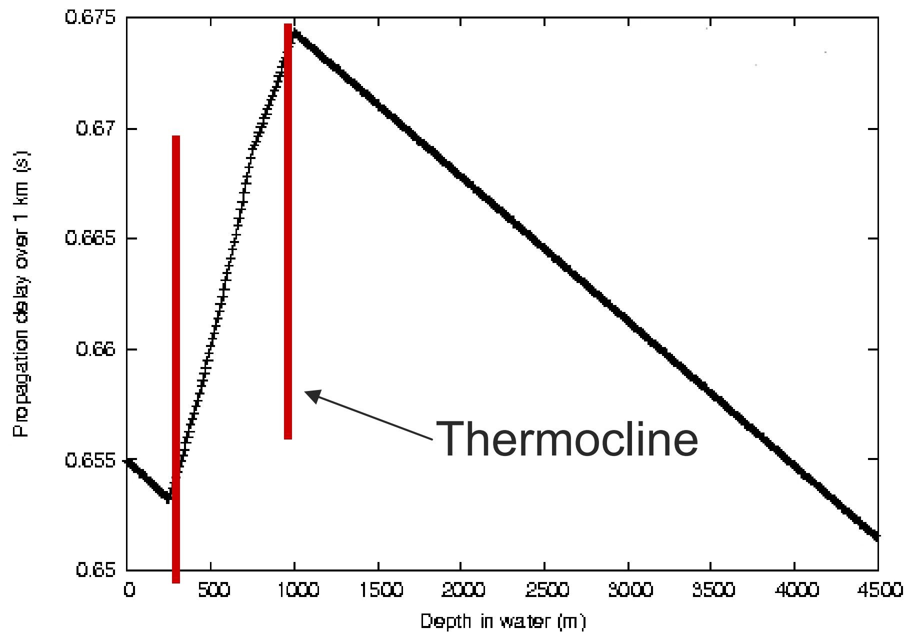


Knee in curve appears at < 3 km

Underwater Acoustic Propagation Speed

- Speed
  - $c \approx O(T^3)+O(T^2S)+O(z^2)$
  - Temperature (*T*)
  - Salinity (*S*)
  - Depth in water (*z*)
    - T is dependent on z
      - Value
      - Rate of change
- Average speed in water
  - 1,500 m/s

Consider nodes 1 km apart



Varies by 20 ms over a depth of 4 km

Model - Summary

- Accounts for
  - Distance bandwidth
    - Attenuation model
  - Four component noise model
  - WHOI modem interface model
  - Simple orientation-based fading
    - Requires improvement

Case Study: Energy-efficient Transmission

- Shorter transmission distances
  - Increased hop count between source and sink
- Larger transmission distances
  - Smaller bandwidth
  - Longer transmission times
  - Longer delays

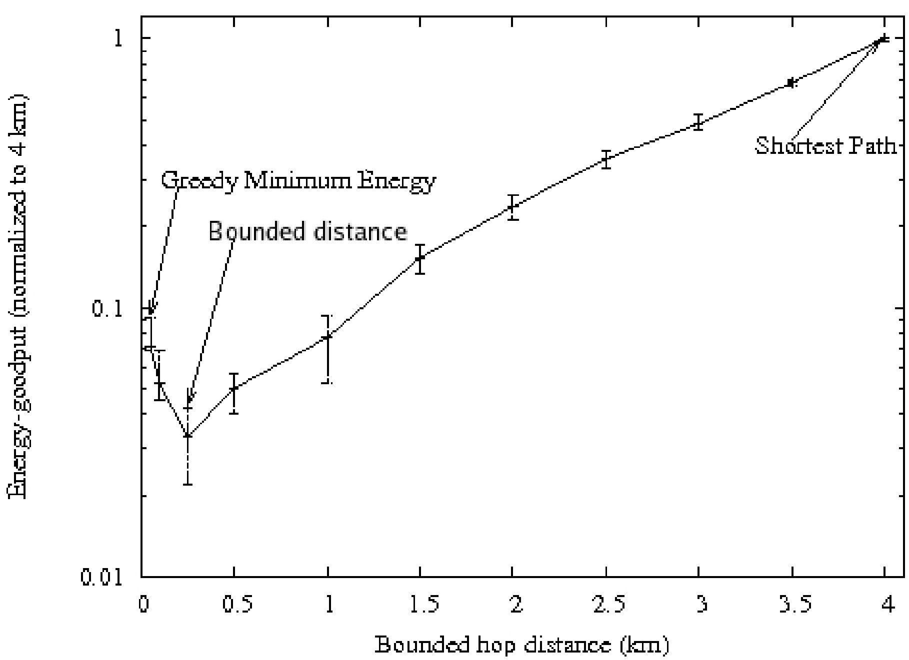
- Metrics
  - Total path energy consumption
    - Number of nodes in path (number of transmissions)
    - Retransmissions
    - Collisions
  - Delay

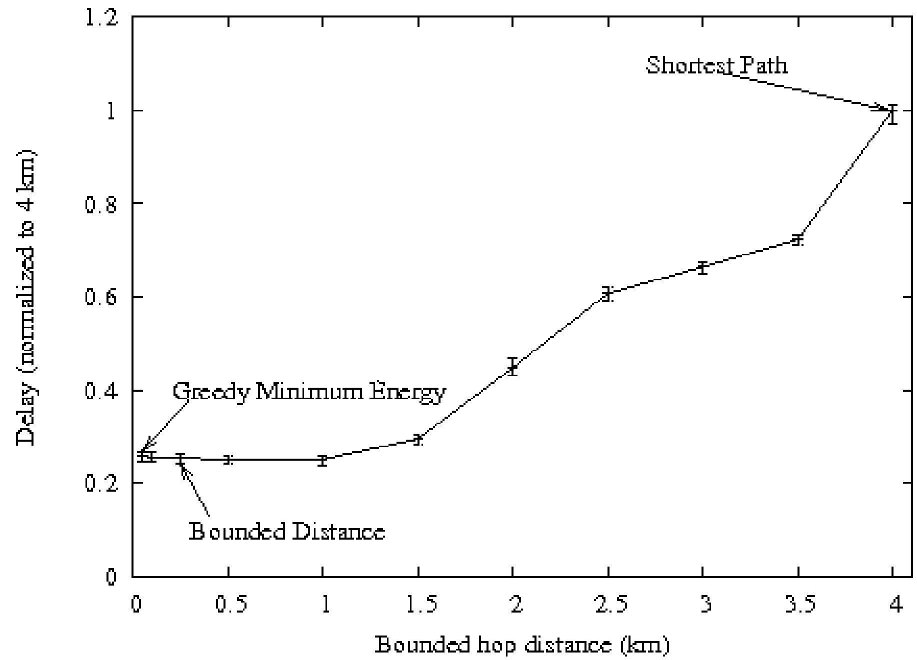
Question: When choosing routes, what is the effect of path and hop length on energy consumption

Energy-efficient Route Selection

- Observation
  - Optimal transmit distance (**X**)
    - Better to fall short of this distance
- Approach
  - Choose farthest node < X meters away
    - Geographic routing protocol
    - Augment with bounded distance
- Comparison
  - Greedy shortest distance (shortest transmit distances)
    - This is theoretically the best for radio-based (without interface costs accounted for)
  - Shortest hop count (longest transmit distances)
    - Research shows that this is best in radio-based networks
- Evaluation
  - Vary X to simulate other protocols
    - $X = 0$: greedy minimum energy (shortest hop)
    - $X = \infty$: shortest path
    - $X = 250$: Bounded distance based on analysis
  - Metrics
    - Total path energy consumption
    - Delay

Energy Savings via Bounded Distance





- Bounded Distance outperforms greedy minimum energy by at least 5%
- Delay is minimized due to topology control

Conclusions and Future

- Significant progress towards standard underwater simulation toolset
- Use of incomplete models may lead to incorrect conclusions
- Future Directions
  - Complete fading model
    - Ray-tracing to complex for large network simulations
  - Doppler effect
  - Mobility must be hand-coded
    - Current-based mobility model is desirable