Optimization of an Acoustic Communication Protocol for Underwater Wireless Communication
Final Presentation

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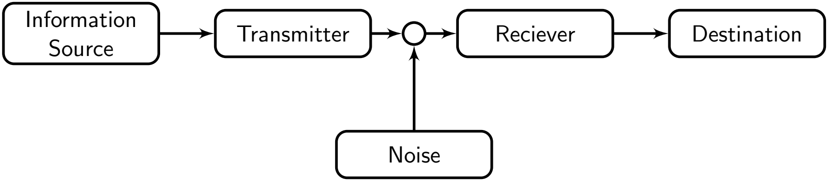
eProuplsion Ltd.

Underwater communication between Divers + Submarines

Small Diving Group[1]

Presentation Outline

Model of Communication[2]



Waves in Water

- Doppler Shifting
  - Acoustic waves in water, $\frac{f}{f_0} = \frac{(c + v_r)}{(c + v_s)} \approx 0.5\%$
  - Negligible with EM waves
- Multipath
  - More important as distance increases
- Noise
  - White noise
    - Constant power waves across all frequencies
  - Random noises
    - Unavoidable
    - Error correction
- Attenuation
  - High frequency EM waves attenuate quickly
    - Microwaves!
  - Low frequency radio antenna are not practical

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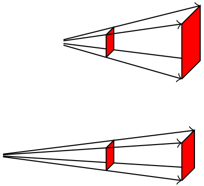
Acoustic Attenuation

- Inverse Square Law
  - $I = d_0^2/d^2$



- Many non-linear effects,[3]
  - $V = V_0 - \alpha d$
    - $3 < \alpha < 40$ in air
    - $\alpha \approx 0.05$ in water
- $I = 10^{(V_0 - \alpha d)/10} \cdot \frac{(d_0)^2}{d^2}$
- $V = V_0 - \alpha d + 20 \log_{10}\left(\frac{d_0}{d}\right)$

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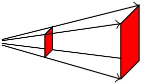

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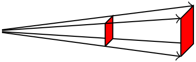

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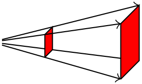

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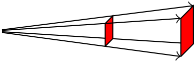

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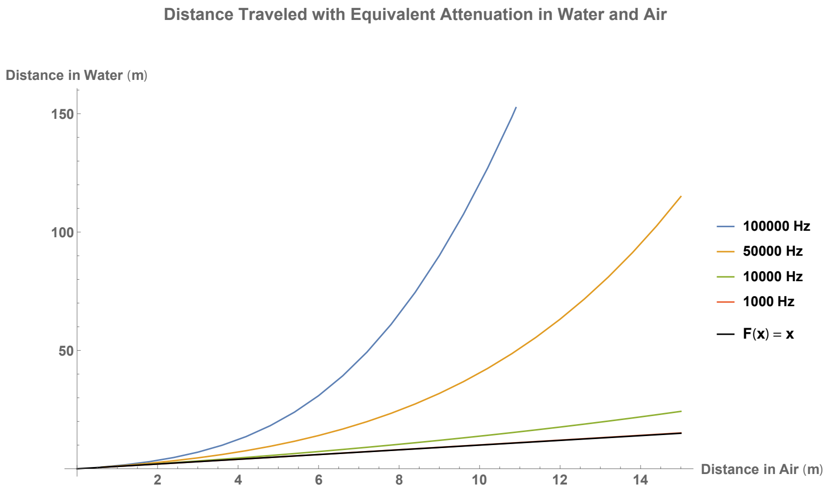
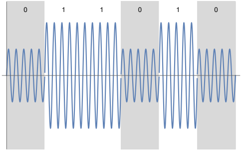
Attenuation - Equivalent Distances in Air and Water

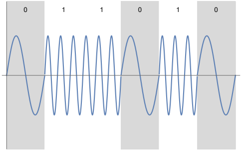


Modulation

- *Modulation: the process of converting information into a form that can be conveyed across a physical channel*[4]
  - Style of Information
    - Analog Modulation
    - Digital Modulation/Keying
  - Domains
    - Frequency
    - Amplitude
    - Phase



Digital Amplitude Modulation



Digital Frequency Modulation

Orthogonality

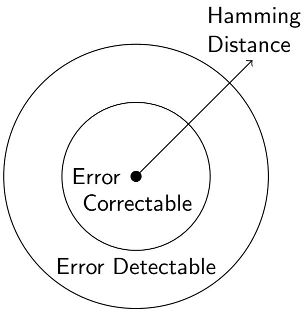
- Over interval of length T the following are orthogonal:
  - $\cos(2\pi \frac{m}{T} t)$
  - $\sin(2\pi \frac{m}{T} t)$
  - $\cos(2\pi \frac{n}{T} t)$
  - $\sin(2\pi \frac{n}{T} t)$
- Vector space of signals sampled over some interval ($\mathbb{R}^N$)
- Discrete Fourier Transform
- Orthogonal Frequency Division Multiplexing (OFDM)

Doppler Shifting

- How can Doppler shifting be accounted for?
  - Solve linear system of equations for shifted basis
    - basis vectors are no longer orthogonal
  - Adjust length of DFT
    - now none of our original basis vectors are in the new basis
    - but they can be pretty close

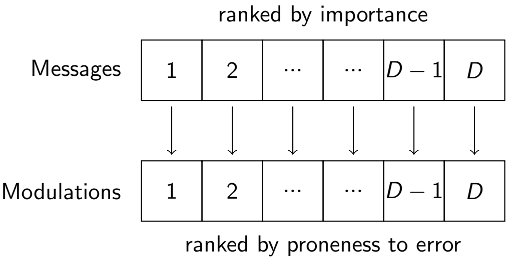
Informational Accuracy : Linear Codes

- Word-Wise
  - Bicydle $\Rightarrow$ Bicycle
  - Hamming Codes
- Sentence-Wise
  - "I Live You" $\Rightarrow$ "I Love You"
  - Reed Solomon Codes[5]



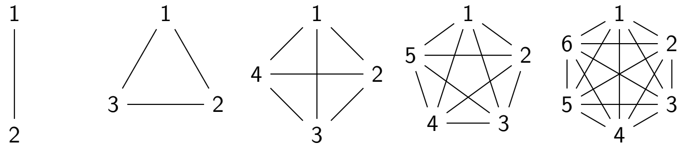
Informational Accuracy: Effective Dictionary Creation

- Some channels are more error prone than others
  1. Weight each modulation by its error.
  2. Construct a dictionary of D words (each word of length $\log_2 D$)
  3. Rank dictionary by importance of message
  4. Linearly assign



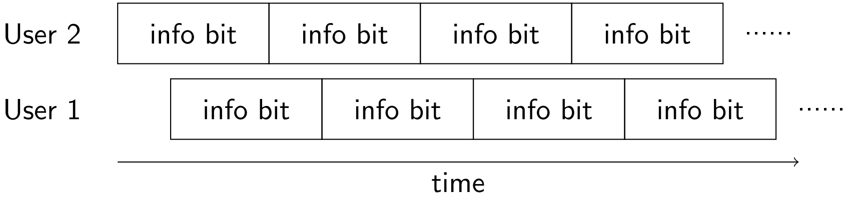
Multiple Access

- Given N users there are $N(N-1)$ directed pathways



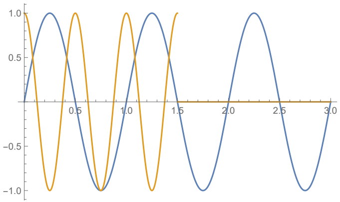
- How should such pathways be allocated?
  - Where and when should users transmit
  - Medium Access Control (MAC) protocols

Orthogonality of time shifted signals

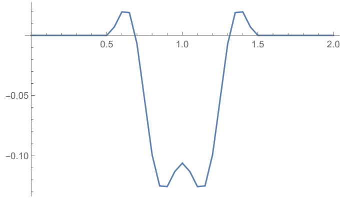


Orthogonality of time shifted signals

- Over time T sinusoidal functions with frequencies in $\mathbb{N}/T$ are orthogonal to one another



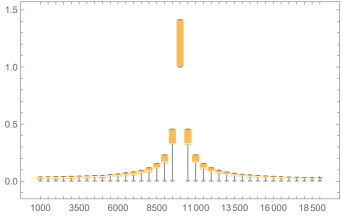
two signals on orthogonal frequencies



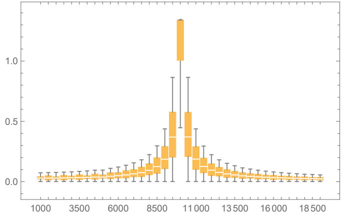
value of inner product over possible intervals

- What is the effect at phase and amplitude changes?

Frequency Response



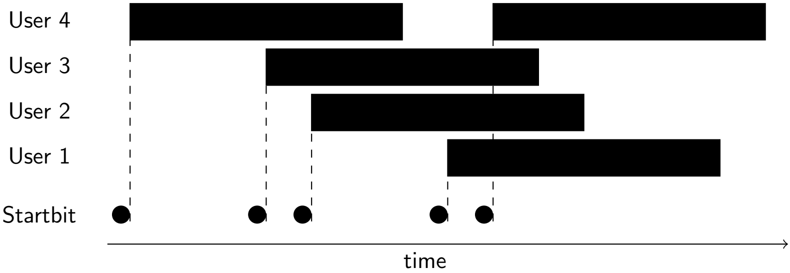
FSK/OFDM



QAM-16

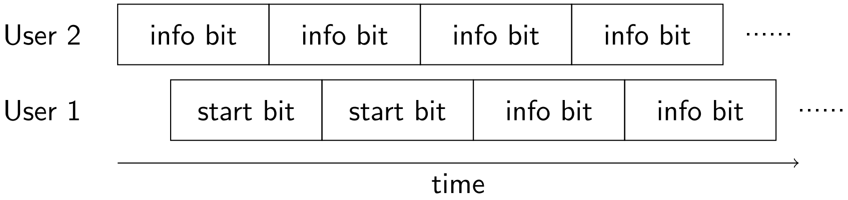
- How does the difference in frequency affect how “orthogonal” two frequencies are when time shifted?

Overview of our Implementation



Multi-access of 4 users using FDMA

Main Difficulty of Multi-Access

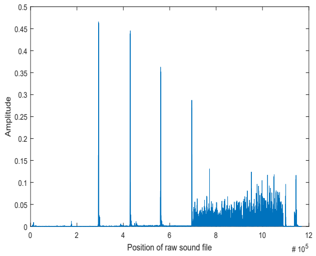


Example of an asynchronous bit pattern

- Interference from other users
- Finding correct starting point

Our solution: Convolution

Step 1: Apply convolution on recorded sound pattern and sinusoidal wave of the start bit frequency to approximate the starting point position



Convolution Result

Our solution: Convolution

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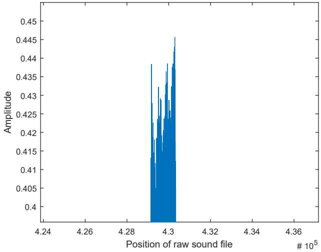
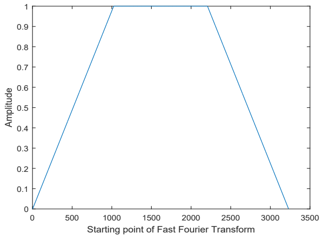
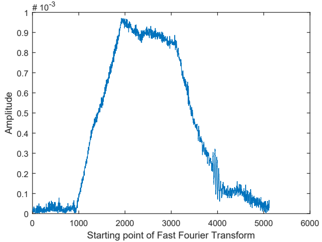


Magnified Second Peak

Our solution: Convolution

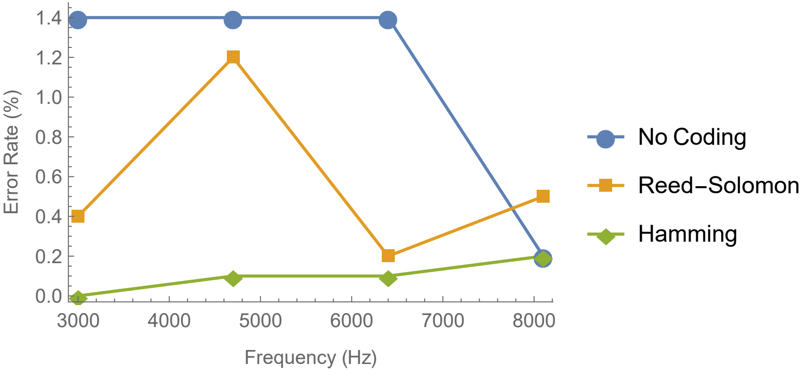
Step 2: Apply convolution on standard start pattern and that in the recorded sound file to determine the exact starting point position





Experimental Results - Linear Codes

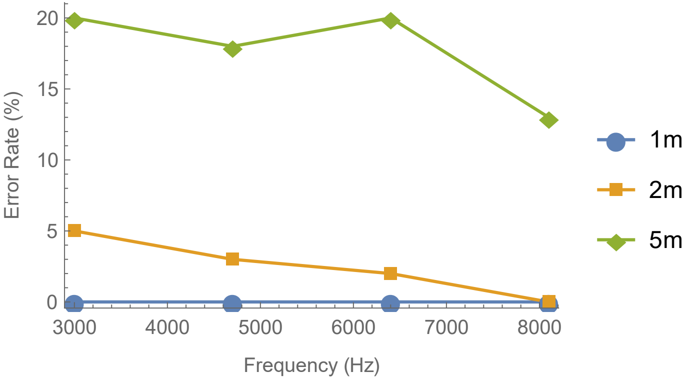
Transmission Error Rate vs. Frequency (1.7 kHz bandwidth) at 1 meter



The experiment is done using iPhone recorder and computer speaker.

Experimental Results - Distance

Transmission Error Rate vs. Frequency (1.7 kHz bandwidth) using Hamming Codes



The experiment is done using iPhone recorder and computer speaker.

Conclusion

- Muti-access protocol is developed successfully, though the starting bits are intolerant of noise.
- Hamming code outperforms Reed-Solomon code. However, both linear codes fail to correct most errors when the error rate is higher than 10%.
- The error rate is generally lower in higher frequency channels. Developing dictionary entropy encoding is a good choice.

References

[1] "Lykia world diving center - small diving group." Web. http://lykiaworlddivingcentre.com/.

[2] W. W. Claude E. Shannon, "The mathematical theory of communication." Book. University of Illinois Press.

[3] "Calculation of absorption of sound." Web. http://www.npl.co.uk/acoustics.

[4] C. L. Henrik Schulze, "Theory and applications of ofdm and cdma." Book. John Wiley & Sons, Ltd.

[5] O. Pretzel, "Error-correcting codes and finite fields." Book. Oxford Applied Mathematics and Computing Series.

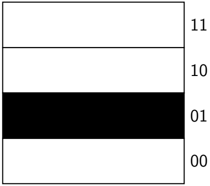
Thank You!

Special Thanks to:

- Our Academic Mentor, Avery Ching
- Our Industrial Mentor, Andreas Widy
- People who made this program possible: Stacey Beggs, Jorge Balbas, and Albert Ku

MFSK and OFDM

- Given M frequency bands...



MFSK signal: 01

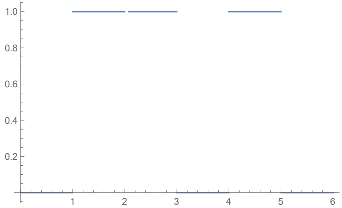
OFDM signal: 1011

- $\log_2 M$ bits per step
- Intensity per band $= I_0$

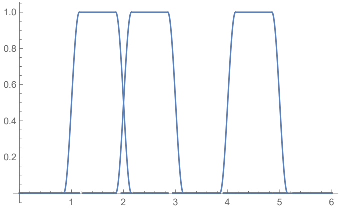
- M bits per step
- Intensity per band $= \frac{I_0}{M}$

Digital Modulation

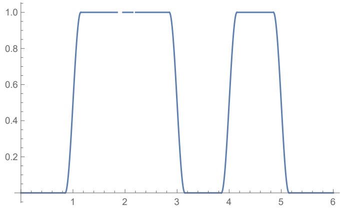
- Why we choose it
  - Computers!
- Problems:
  - Discontinuities



Digital Signal

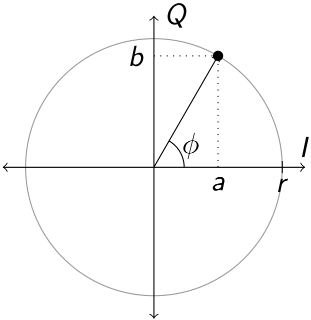


Smoothed Bits



Final Smoothed Signal

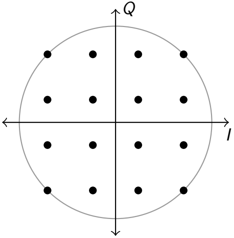
Constellations



Arbitrary sinusoidal signal $r\cos(2\pi ft - \phi)$ on the I-Q plane (the dot)

- $r\cos(2\pi ft - \phi) = a\cos(2\pi ft) + b\sin(2\pi ft)$
  - $a = r\cos(\phi)$
  - $b = r\sin(\phi)$

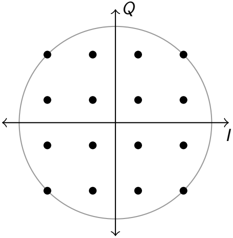
QAM



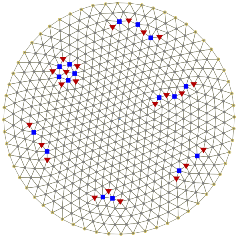
QAM 16 constellation

- Assign symbols to points on the I-Q plane
- How do you decode a signal?

Soft Body Packing Problem Of Dictionary Creation



QAM 16 constellation



Soft-Body Packing Problem
(Wigner Crystal)

- The closer nodes are, the higher the error
  - *error* $\propto \frac{1}{\langle \Delta d \rangle}$
- The farther from the center, the higher induced error on other channels
  - *error* $\propto r$