GNU Radio Blocks for Long-lasting Frames in Mobile Underwater Acoustic Communications

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1 Introduction

We have implemented new blocks to support mobile underwater acoustic communications. We focus on long distance, i.e., low frequency, weak signals and extremely narrow bandwidth. We build upon previous publications [1, 2, 3, 4]. This paper focuses on the GNU Radio implementation of the work.

2 New Blocks

Algorithm 1 Main operations of the protocol decoder

```
for loop #1 // (s)lope search
  for loop #2 // (v)elocity search
    for loop #3 // (p)osition search
      // find & store candidate tuples as array [s, v, p]
      // use [s, v, p] during energy & frequency search ...
      // ... to identify candidate signals, then use them ...
      // during time resolution & signal demodulation.
    end for
  end for
end for
```

Figure 1: Protocol decoder.

The design consists of four new blocks: Sliding Window Stream to PDU, FDR, Sync and Demodulate and WSPR Unpacker. *Sliding Window Stream to PDU* accepts a continuous stream of time-domain samples. When a window of 120 seconds of samples is obtained, it becomes the payload of a Protocol Data Unit (PDU) that it posted on the output port. The window slides nine seconds forward. *FDR* (Frequency Domain Representation) takes in input that PDU and constructs a frequency domain representation. Leveraging a frequency domain search, it produces a PDU containing indices of candidate frequencies. *Sync and Demodulate* attempts to resolve time delays and demodulate signals at the candidate frequencies. It takes into account Doppler frequency shift. Two Doppler forms are considered, linear and non-linear. The linear form is handled considering the maximum shift over a frame interval. The non-linear form is handled making hypotheses about the two communicating objects, i.e., their positions and velocities. A decision is made on appropriate frequency shifts by exploring a given set of candidate values for positions and velocities These values are defined to best contain all probable Doppler variations. The linear and non-linear forms are simultaneously considered to cover all possible variations, see Figure 1. The block chooses the form with higher correlation when searching for a frame. If successful, output frame payloads (i.e., packets) are posted, as PDUs.

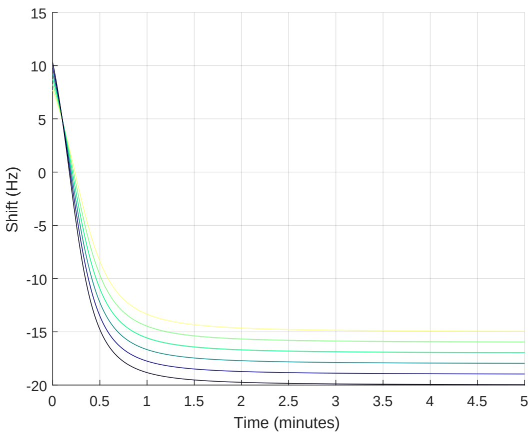

Figure 2: Doppler plot over 5 minutes interval.

Figure 2 illustrates an example of linear and non-linear Doppler curves. The figure shows six curves, where velocity of a transmitter varies from 5 m/s to 10 ms/s (light yellow has lowest velocity, as color gets darker velocity increments by 1 m/s). Each curve can be divided into two parts: from start to the 1:30 minute time point there is non-linear Doppler; from the 1:30 minute to the end, the Doppler is linear. *WSPR Unpacker* parses packets in the WSPR format and outputs text content.

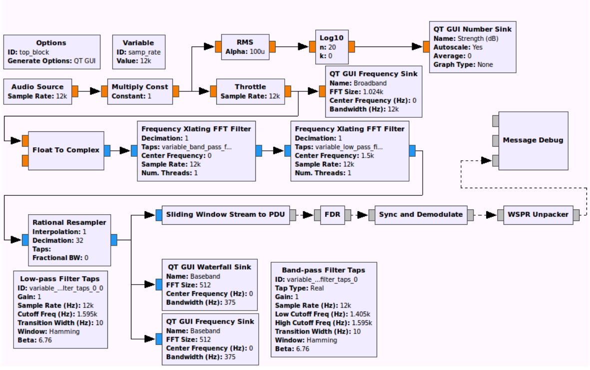

Figure 3: Flow graph of the audio decoder.

Figure 3 shows the flow graph of a complete decoder. It embeds instances of the aforementioned four new blocks.

3 Example Application

We have conducted several simulations and experiment in various bodies of water, including canals, lakes and coastal waters. An example application is discussed hereafter. A transmitter sends two frames, 110 seconds each at 1.46 baud. The transmitter moves with a constant speed of 8 m/s, leading to a Doppler shift that starts as non-linear and, as the separation distance increases, becomes linear during the transmission of the frames.

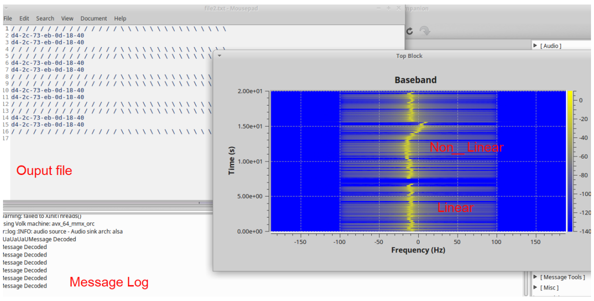

Figure 4: Decoding a two frames sent repeatedly.

Figure 4 shows as function of time (vertical axis) the resulting frequency drift (horizontal axis). The decoder is successful at decoding the frames.

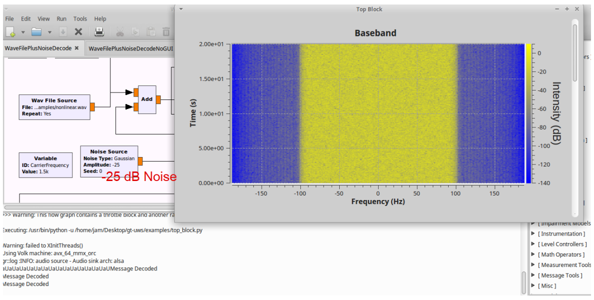

Figure 5: Decoding a two frames with noise.

In Figure 5, the experiment is repeated, but with AWGN (Additive White Gaussian Noise) such that the resulting is SNR (Signal to Noise Ratio) of -25 dB . Due to the low SNR, the trace of the signal becomes confused with noise. Although, the decoder is still successful at decoding the frames.

4 Conclusion

We have demonstrated how our four new blocks are capable of decoding frames in an underwater environment, while being subjected to very high noise levels (-25 dB SNR) and linear and non-linear frequency shifts. They are also capable of handling Doppler due to mobility of the transmitter (both linear and non-linear).

References

[1] Abdel-Mehsen Ahmad, Michel Barbeau, Joaquin Garcia-Alfaro, Jamil Kassem, Evangelos Kranakis, and Steven Porretta. Doppler effect in the underwater acoustic ultra low frequency band. In *Proceedings of the 9th EAI International Conference on Ad Hoc Networks*, Niagara Falls, Canada, 2017. Springer.

[2] Abdel-Mehsen Ahmad, Michel Barbeau, Joaquin Garcia-Alfaro, Jamil Kassem, Evangelos Kranakis, and Steven Porretta. Doppler effect in the acoustic ultra low frequency band for wireless underwater networks. *Mobile Networks and Applications*, 2018. https://link.springer.com/article/10.1007/s11036-018-1036-9.

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