SLIM-Detector for Undersampling Preamble in Underwater Acoustic Communications

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ABSTRACT

The preamble is the signal to trigger the receiver to change from the standby mode to the working mode. Preamble detection is a very important part for underwater acoustic communications, since if the preamble signal is not detected or the receiver is triggered wrongly by inteferences, the whole communication will fail[6][7].

Matched filter (MF) [5] is widely used for sonar detection. It correlates the transmitted with received waveform to determine whether and when a target appears. The MF has a very simple formulation, and is optimal in additive white noise in probing a stationary target since it gives the highest output signal-to-noise ratio (SNR) among all FIR filters in White Gaussian Noise (WGN). The Page test (PT)[1] is used to improve the detection performance in the nonstationary underwater channel with the slowly changing noise level and multiple echoes for active sonar systems. Besides, the normalized matched filter (NMF)[3] relies on the matching of the signal shapes for detection, minimizes the influence of unknown SNR which is more practical than the MF in complicated underwater environments. Other anti-interference detectors for preamble in underwater multipath channel are proposed [7][4][9] to further improve the detection.

All the above traditional detectors are based on assumption that the Nyquist frequency is absolutely met. However, the underwater systems usually need to be low power-consuming, especially in standby mode. And undersampling processing can lower the power, cost and even storage for preamble in standby mode. Hence undersampling preamble detection calls for studying for underwater acoustic modems. Undersampling makes signal aliasing and lose much feature, hence it leads traditional detection failure.

Doppler-insensitive waveforms[10] such as hyperbolic frequency modulation (HFM) or linear frequency modulation (LFM) are often used as the probing waveforms for target detection in radar and sonar applications and preambles in communications. Undersampling processing can seriously weaken the detection of these wideband signals.

In this work, we propose a new detector named Sparse Learning via Iterative Minimization(SLIM)-detector. SLIM is proposed for sonar location in [8]. It can collect echoes from Multiple-Input Multiple-Output (MIMO). In our work we use this principle to collect and strengthen energy from underwater multipath channel. With SLIM-detector, energy of preamble is strengthened after iterations in SLIM, then collected. Even if the undersampling makes the signal aliasing, we can still separate preamble from different interferences and noise.

SLIM-detector works different from SLIM. The initialization part of SLIM-detector is similar to NMF which presents a rough model for detection. The iterative part of SLIM-detector is the main part of SLIM estimator. In this part, the strongest paths become stronger after each iteration and the weak paths become weaker. This can also help us distinguish real paths of preamble signals from false alarms under aliasing caused by undersampling. One of the challenges to put this detector into practical use is that the original assumption for SLIM is under WGN. Therefore interferences can bring outliers which can lead the detection into failure. As we know, normalization can lower the false matching for MF. Here we add another normalization step after the iterations to further lower the false alarms of interferences. Another challenge to make the detector practical is that a reasonable signal template is crucial. The iterations make the matching very sensitive. This is a benefit if the template is good enough, but can also be a weakness when the template is too rough. A good template should try to cover all the possible delays and Doppler-shifts of preamble signals. However this will lead to a large dimensional signal template and low efficiency. Here also comes to why we choose HFMs as our preamble signals: it is Doppler-insensitive, and the Doppler-shift in it can be converted into a time-delay. Hence we only need to consider the coverage of the possible delay in signal template. Besides, the threshold is also difficult to obtained in practice. The normalization step helps us to limit it into a small range. Empiric value can be recommended from simulations and experiments.

The experimental results show the performance of SLIM-detector under undersampling condition. In the experimental data, the HFM signal with 5kHz bandwidth comes from the test in Qiandao Lake, Zhejiang, China, in 2017, full of multipath. The impulsive interference data sets were collected from the sea experiment conducted in May 2013, in the South China Sea, near Kaohsiung City, Taiwan.Other data sets of interferences are collected from the Mobile Acoustic Communication Experiment (MACE10), which was held in June 2010 off the coast of Martha?s Vineyard, Massachusetts. After downsampling, the sampling frequency of received preamble becomes 5kHz. It is much lower than Nyquist frequency. SNR is −6 dB. In Figure 1, SLIM-detector is robust against undersampling, while other conventional detectors totally fail in some interferences due to the aliasing effect. Results show SLIM-detector can be used as an efficient detector for the undersampling preamble signal.

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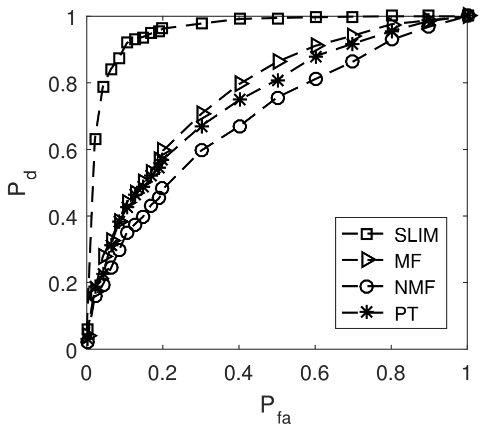
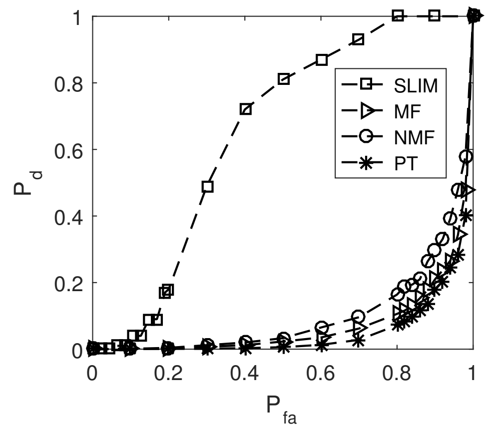
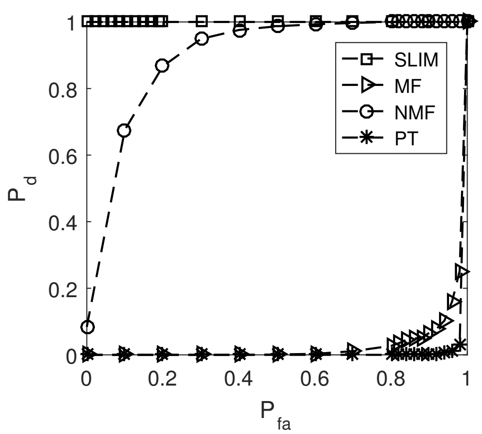


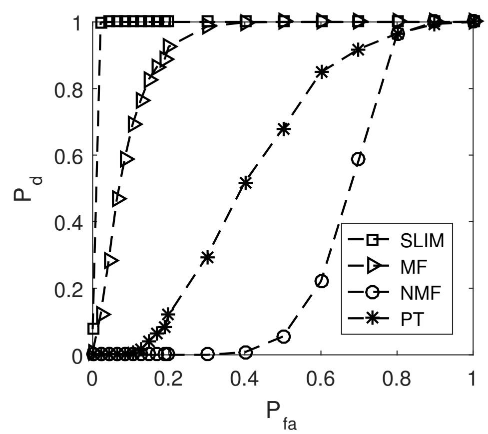
(a) White Gaussian Noise



(b) PBPD interference



(c) Narrow-band interference



(d) Impulse interference

Figure 1: the ROC curves under different interferences with experimental data. The bandwidth of preamble is $5k$Hz. The sampling frequency is $5k$Hz. SNR= -6 dB.

KEYWORDS

Underwater acoustic communications, preamble detection, undersampling, SLIM

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