SpecSense: Learning-based Wideband Spectrum Sensing

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Background and Motivation

The use of wireless spectrum is heavily regulated by the FCC (Federal Communications Commission).

However, the monitoring for violations and/or enforcement of these policies is extremely challenging simply due to the shear scale of the problem – Multi-GHz (6GHz) of bandwidth needs to be observed, and in real-time due to the inherent ephemeral nature of the signals. In order to monitor the huge bandwidth in real-time a lot of radio resources are required, which is prohibitively expensive.

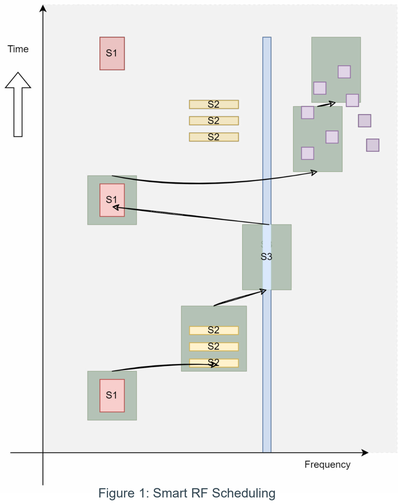
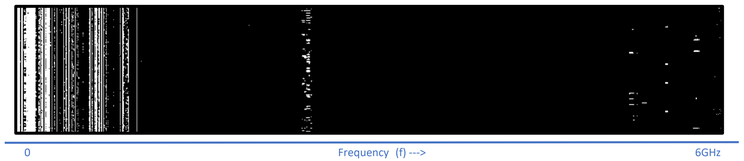


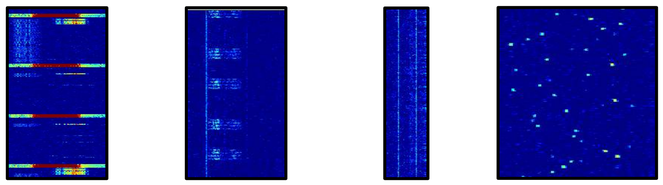
Figure 1: Smart RF Scheduling

Fortunately, the spectrum utilization in the real-world is quite sparse (*Figure 2*), and in this work, we attempt to leverage the sparsity of the spectrum. We explore techniques of smart scheduling using a limited number of radio resources to significantly reduce the cost enabling real-time spectrum awareness capability.

Signals in the wild



a: A look at sparsity in the Sub 6 GHz band



b: Periodic c: Bursty d: Always On e: Frequency Hopper

Figure 2: Signals in the wild

Shown above are some real-world examples signals found in the wild. We see signals that are periodic, bursty, always-on, frequency hoppers, and everything in between.

Proposed Method

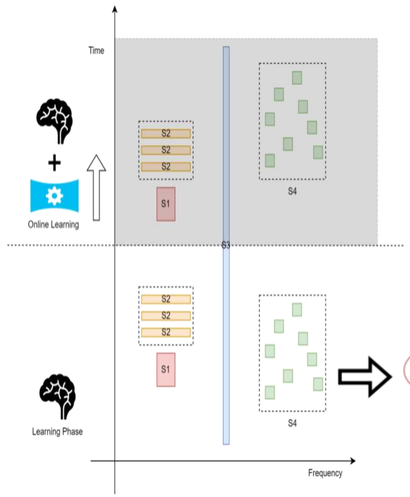
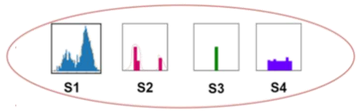


Figure 3: Online learning for real-time spectrum awareness

Smart scheduling enables efficient utilization of the limited radio resources. This requires the understanding of spectrum use in high fidelity, and the ability to predict the regions of interest in real-time.

We realise spectrum awareness using an online learning algorithm. We attempt to learn the joint arrival process of the signals.



Signal Arrival Process

The spectrum awareness is then used to propose regions of interest. The entropy of the signal's arrival process is a good metric for use as an interest function.



Example Signal metrics for use as interest functions

Challenge

Given the limited radio resources, with only about 1-5% real-time coverage of the spectrum under observation, our observations are severely under sampled. This introduces errors in the estimated arrival process, these errors are particularly severe during the initial learning phase. In addition, the spectrum is non-stationary and dynamic.

These issues are severely debilitating for the system, and we tackle them quite effectively using the following three techniques – Cooperative Scheduling, Adaptive Combining and Maximum Likelihood Attribution

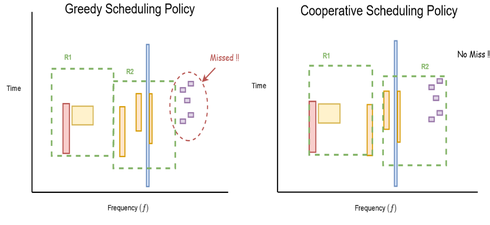


Figure 4: Cooperative Scheduling for optimal radio resource use

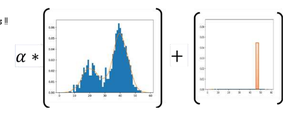


Figure 5: Adaptive combining to combat non-stationary processes

Cooperative Scheduling – is an optimal scheduling strategy to improve efficiency of the limited radio resources, see Figure 4.

Adaptive Combining – places more importance on recent observations making it responsive to change, see Figure 5. Maximum Likelihood Attribution – helps improve reduce the error in the estimation of arrival time by improving accuracy of attribution of an observation to its arrival time, in spite of missing several transmission due to the severe under sampling, see Figure 6.

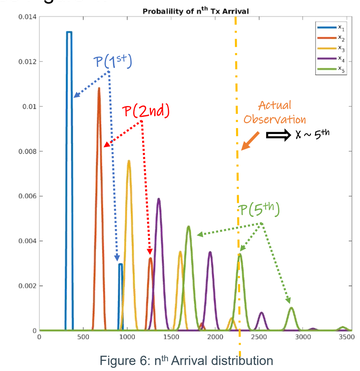


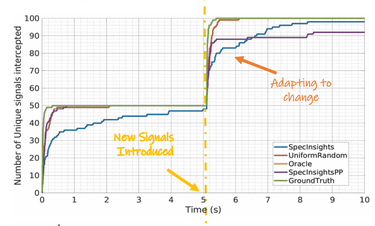
Figure 6: n^{th} Arrival distribution

Results

In Figure 7, we evaluate the algorithm's learning, prediction ability from t=0s to 5s, higher is better, higher indicates better prediction rate and faster learning.

We find that our system has much better prediction rate overall and is significantly more responsive to change.

In Figure 8, we observe that our algorithm has learnt the underlying distribution quite well.



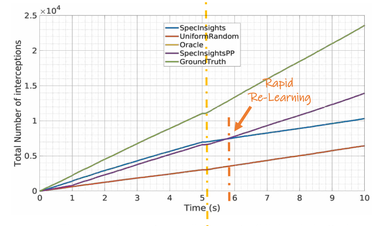


Figure 7: Accurate prediction rate (Higher is better)

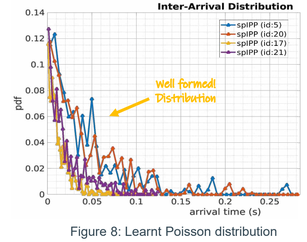


Figure 8: Learnt Poisson distribution

Conclusion and Future Work

We developed an efficient learning-based algorithm for wideband spectrum sensing that provides a cost effective solution for large scale applications such as spectrum monitoring and policy enforcement.

References

[1] L. Shi, P. Bahl, and D. Katabi, "Beyond sensing: Multi-ghz realtime spec trum analytics," in 12th {USENIX} Symposium on Networked Systems Design and Implementation ({NSDI} 15), 2015, pp. 159–172.

[2] P. Kolodzy and I. Avoidance, "Spectrum policy task force," Federal Commun. Comm., Washington, DC, Rep. ET Docket, vol. 40, no. 4, pp. 147–158, 2002.