Energy Efficient Spectrum Sensing using Frequency-Domain Sparsity

Prasun Dutta Gupta, Computer Engineering Technology

ABSTRACT

Spectrum Sensing is very important for cognitive radios which is a terminal that can sense which channels are occupied by users and it is useful to prevent the harmful interference with licensed users and identify the available spectrum for improving the spectrum utilization. **Sparsity** is in the nature of a signal which only contains a small number of non-zero elements compared to its dimension/total signal length which is visible in the Fourier transform. The property of sparsity is useful as this information helps us to understand that even if the signals itself stays in high dimensional space, they only contain only a few natural degrees of freedom.**Compressed sensing** is very useful in this project because it represents an idea where some measurements can be combined with different locations in some way and an algorithm will be in place to sort it out. This allows one to sense the RF spectrum with fewer measurements which makes the approach of combined measurement more efficient. A sample of a signal downloaded from github, is first plotted in the time domain which does not reveal the true nature of the signal. When the signal went through fourier transformation, the domain (x-axis) changed from time to frequency which reveals the sparse nature of the signal very clearly. The spectrum sensing can be formulated as a problem to a system of linear equations **y = Ax** using linear algebra. The sparsity on x makes the problem solving unique and more efficient.

Figure 11.2 Illustration of deployment of LTE-Unlicensed using cognitive ratio (CR) to detect active interferers.

Goals of the project

- Learn about wideband spectrum sensing
- Analyze the properties of signals
- Develop a deeper understanding about the methods and algorithms
- Learn about algorithms and machine learning regarding spectrum sensing
- Transforming the theoretical understanding of spectrum sensing into a more linear system of equations involving matrix analysis.
- Understand and learn about DOA which stands for Direction of Arrival in communication

Results

(Sparsity)

- Sampling frequency of signal x is 52 million samples in 1 sec, which is over **800,000 samples in 16 ms.** The signal can be divided into 16 slots with a slot time of 1 ms in time domain. Each slot in the allocated frequency range of 0.6 Mhz - 26.2 Mhz contains 256 subbands. These are the properties of the signal x.
- **Fourier transform** is a mathematical function that decomposes a waveform, which is a function of time into frequencies that make it up.
- In Frequency domain, each slot of signal x, has a bandwidth of 25.6 Mhz in the positive band of interest.
- In the allocated frequency range, there are 256 subbands and the frequency range of each subband in 100 khz. Since the signal x contains 256 subbands and each subband is 100 khz, 256 times 100 khz equals to be 25.6 Mhz which is the bandwidth of signal x in frequency domain.
- Using the 600 khz as the minimum frequency of the slot and 100 khz as the bw of each subband, the max frequency of the 216th subband is 22.2 Mhz and the minimum frequency is 22.1 Mhz with a center frequency of 22.15 Mhz.
- *The signal which was very noisy and did not show the characteristics became much more clear in the **frequency domain** which was clearly visible through the fourier transformation.*
- ***Nature of the signal is to be sparse and high spikes in power** (db) above the average noise level which is at -25 db shows that the subband is occupied or used by an interferer or another user.*

Figure 1 : Signal X with over 800,000 samples

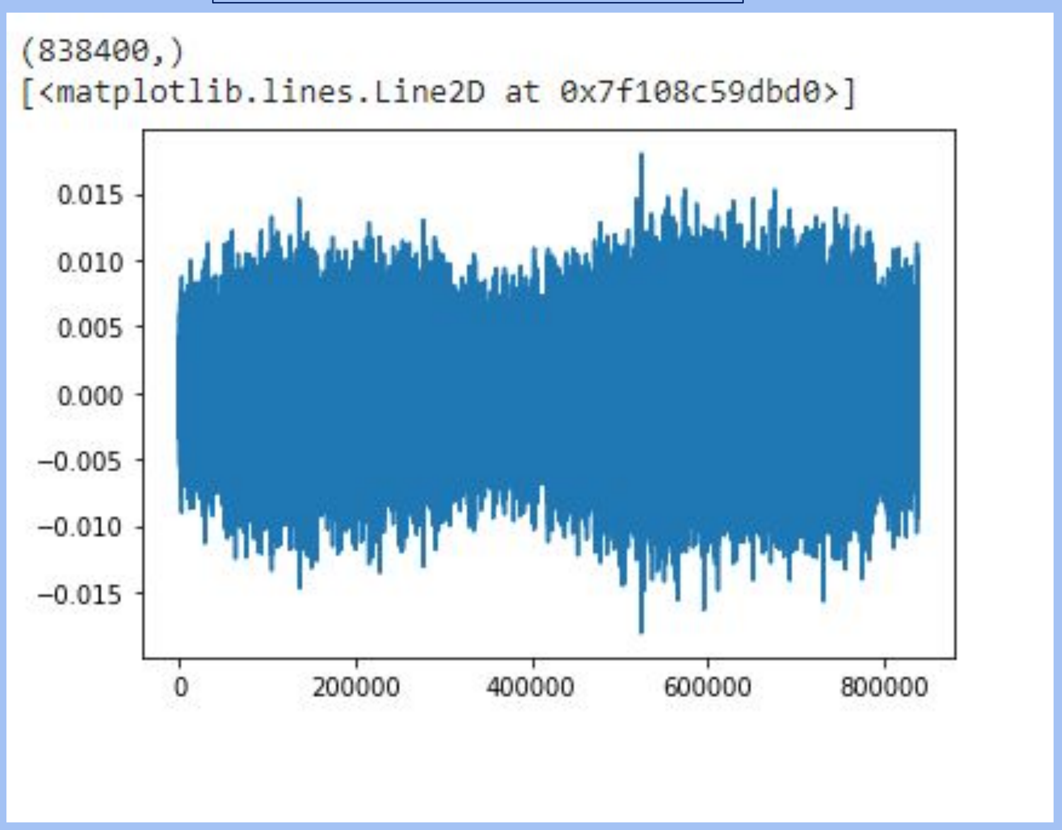


Figure 2 : Signal X in time domain in the first slot which is 1 ms long

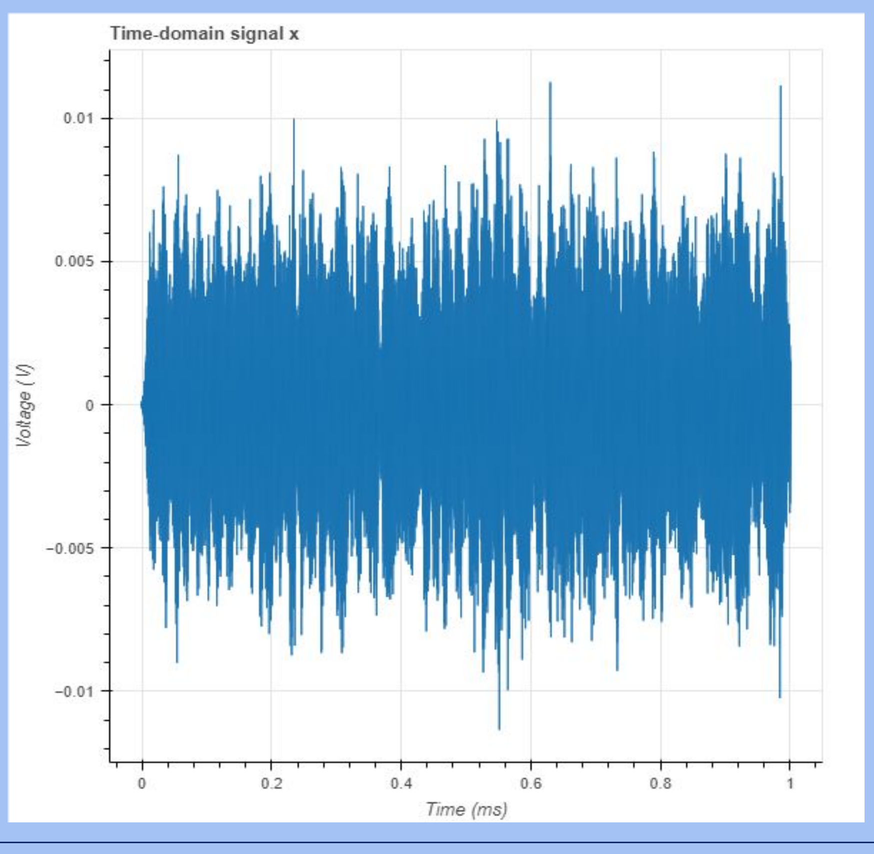


Figure 3 : Signal X in frequency domain in the first slot with a bandwidth of 25.6 Mhz

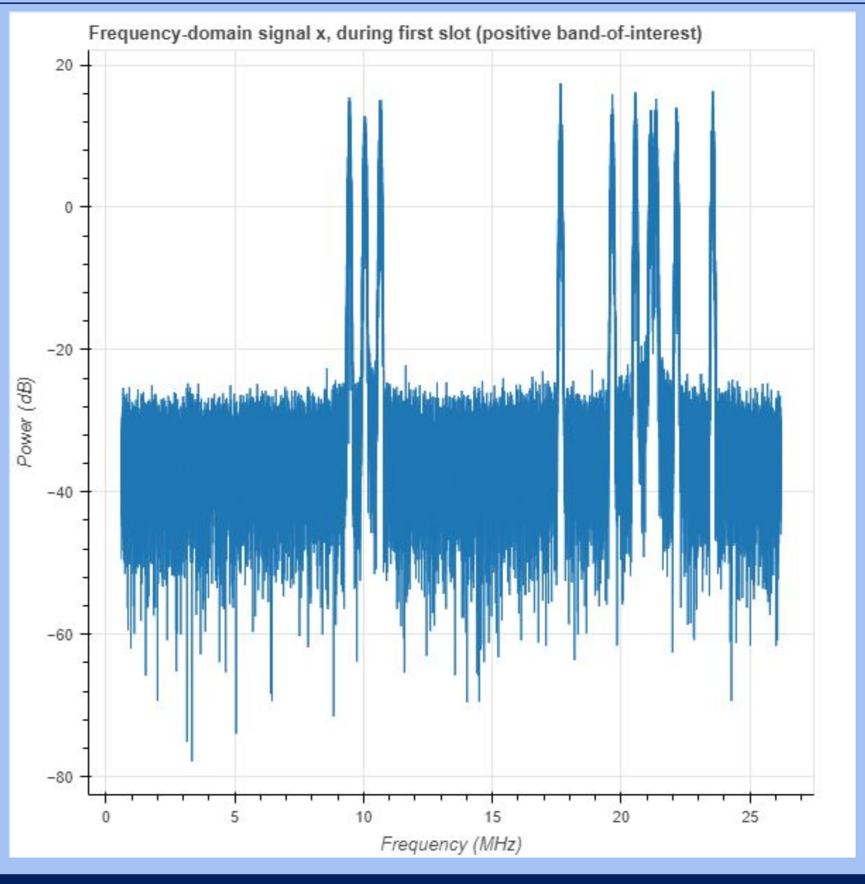
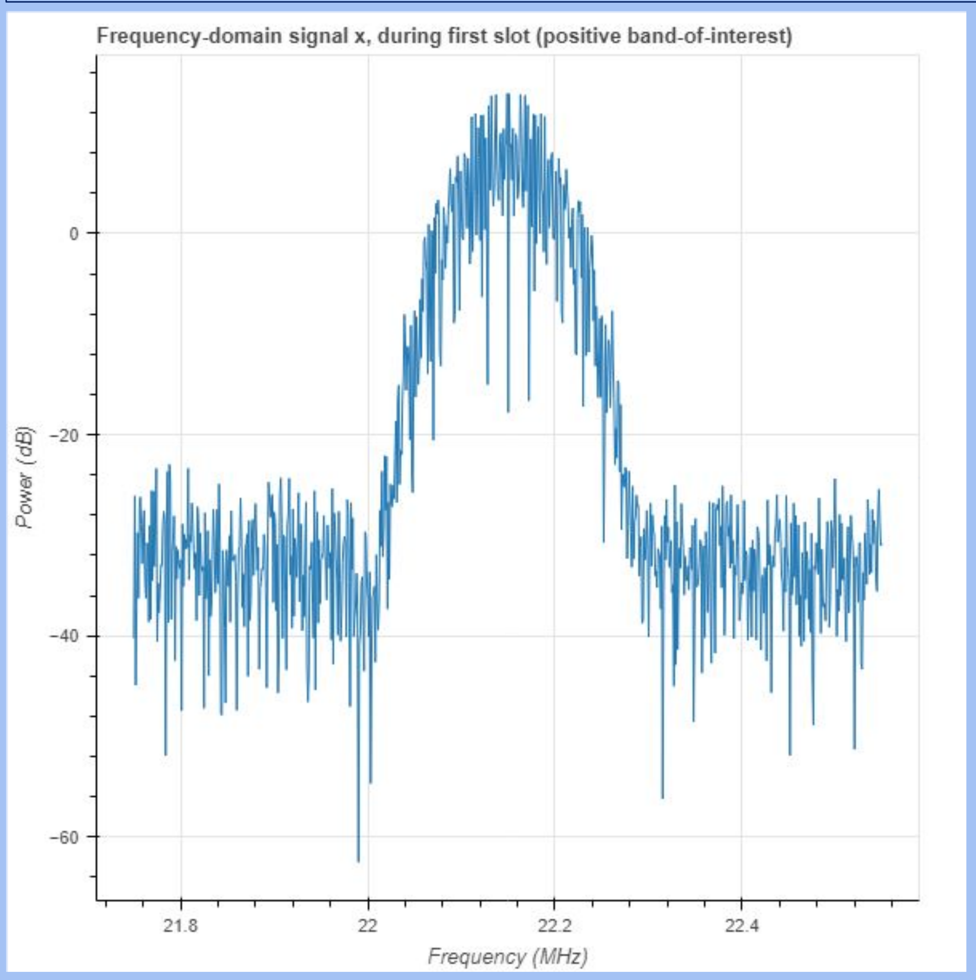


Figure 4 : Frequency domain signal of 216th subband with a wider bandwidth



Conclusion

- **Problem Formulation:** We showed how to formulate spectrum sensing as a problem of seeking a sparse solution x to a system of equations y = Ax, and how to solve this problem using tools from linear algebra.
- **Sparsity:** We observed that RF signals become sparse in fourier domain. This property is useful for energy efficient spectrum sensing – it suggests new sensors and algorithms.
- **Future Work:** Extending this approach to Direction of Arrival (DOA) finding. In DOA finding, the goal is to determine where the signal is coming from, which provides information about the locations of users.

Experimental Design

SPARSITY

1. First the signal is downloaded from Github. Then the signal parameters are loaded into the memory.
2. To sort and graph the signal parameters, python APIs such as bokeh.plotting, numpy, scipy.io
3. We can get a closer view of the signal by looking at the specific band in the first slot (positive band of interest)
4. To calculate the frequency range of a specific subband, we need to compute the formula for max frequency which is (minimum frequency of the slot) + (100 * number of subband) and minimum frequency is (maximum frequency - 100).

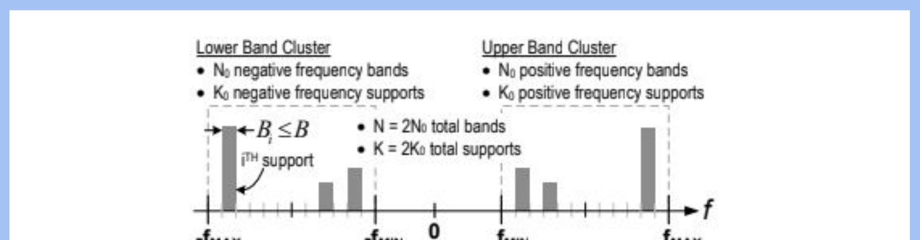
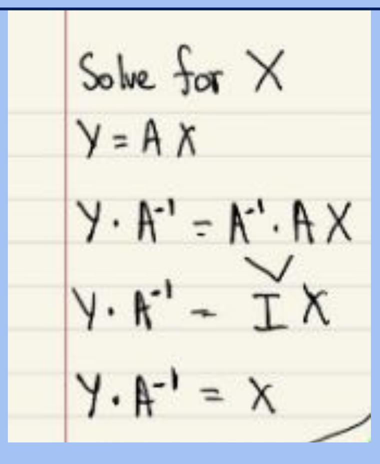
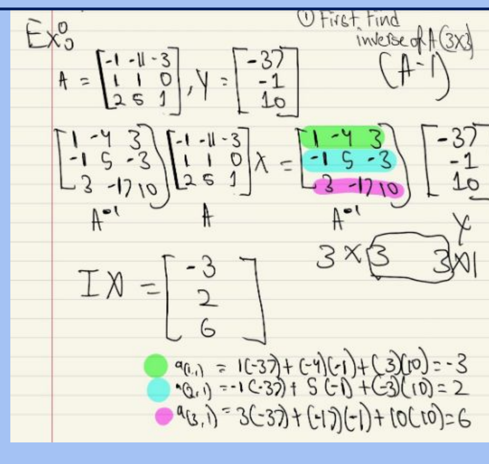


Figure 11.1 A wideband spectrum between (f_{min}, f_{max}) and $(-f_{max}, -f_{min})$ is divided into multiple narrow bands of width B. At any given time a (sparse) number of channels are actively in use.

y = A x

Spectrum Sensing as Linear System of Equations	Solving Linear Systems of Equations
1. Y represents the number of samples/measurements 2. X represents the **signal of interest** which is n dimensional.Since most bands are unoccupied, X is typically **sparse**. 3. A represents the system that takes the measurements which consists of elements y and x. 4. Frequency filter and modulator are part of the system that takes measurements.	1. We can use linear algebra to solve the equation y = Ax to determine the spectrum occupancy x from the measurements y. 2. To solve for x, given y and A, we invert the matrix A, and use that $A^{-1}y = x$. 3. If we have fewer measurements, A will become a wide matrix. In this situation, A has no inverse, but we can still solve the equation Ax = y using sparsity.





Acknowledgements

John Wright
Department of Electrical Engineering
Data Science Institute
Columbia University
Tim Wang
PhD Student, Columbia EE

Scan for my LinkedIn

REFERENCES

- ("High Dimensional Data Analysis with Low-Dimensional Models : Principles, Computation and Applications" by John Wright (Columbia University) and YI Ma (University of California, Berkeley) (CH - 11 with the title)
- Spectrum_Sensing1 (Google Colab : Research Notebook)