UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

WCSNG
Wireless Communications Sensing and Networking

High-Resolution Spectral Analysis and Signal Segregation Using the Polyphase Channelizer

2022 Asilomar Conference on Signals, Systems, and Computers

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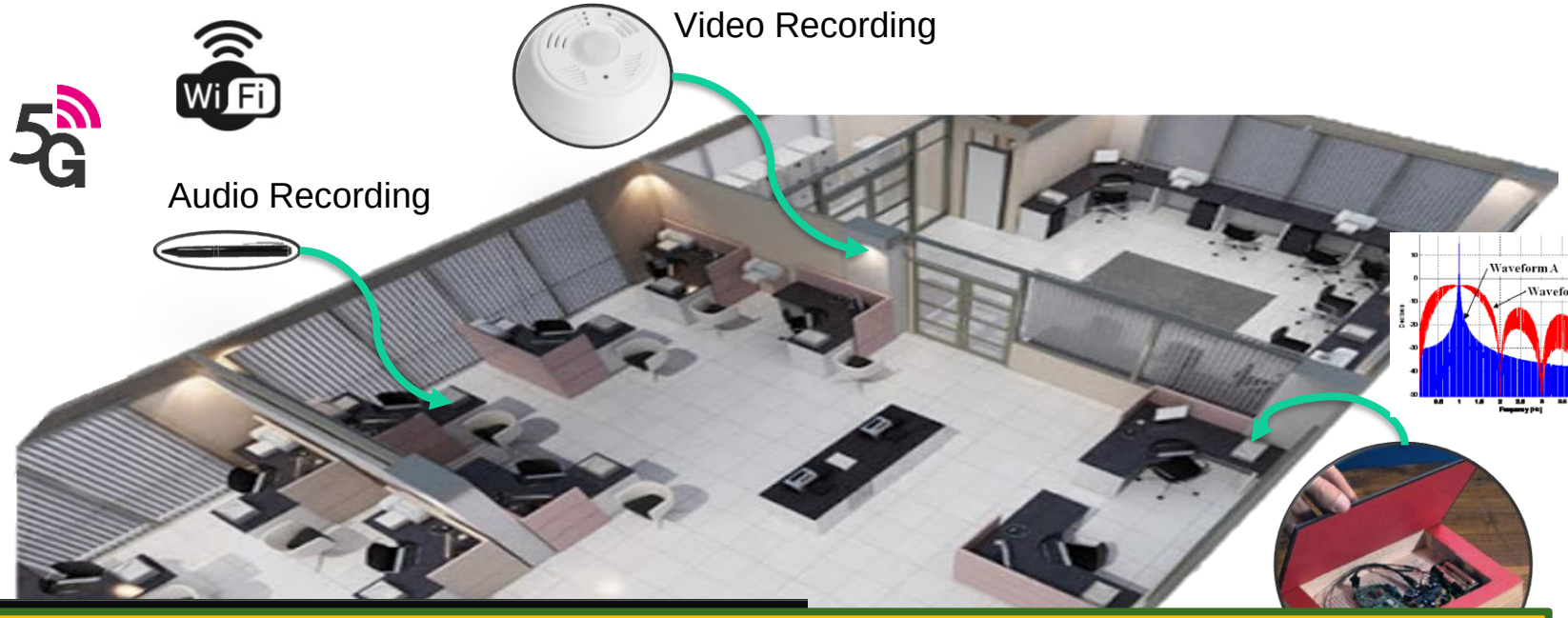
UC San Diego

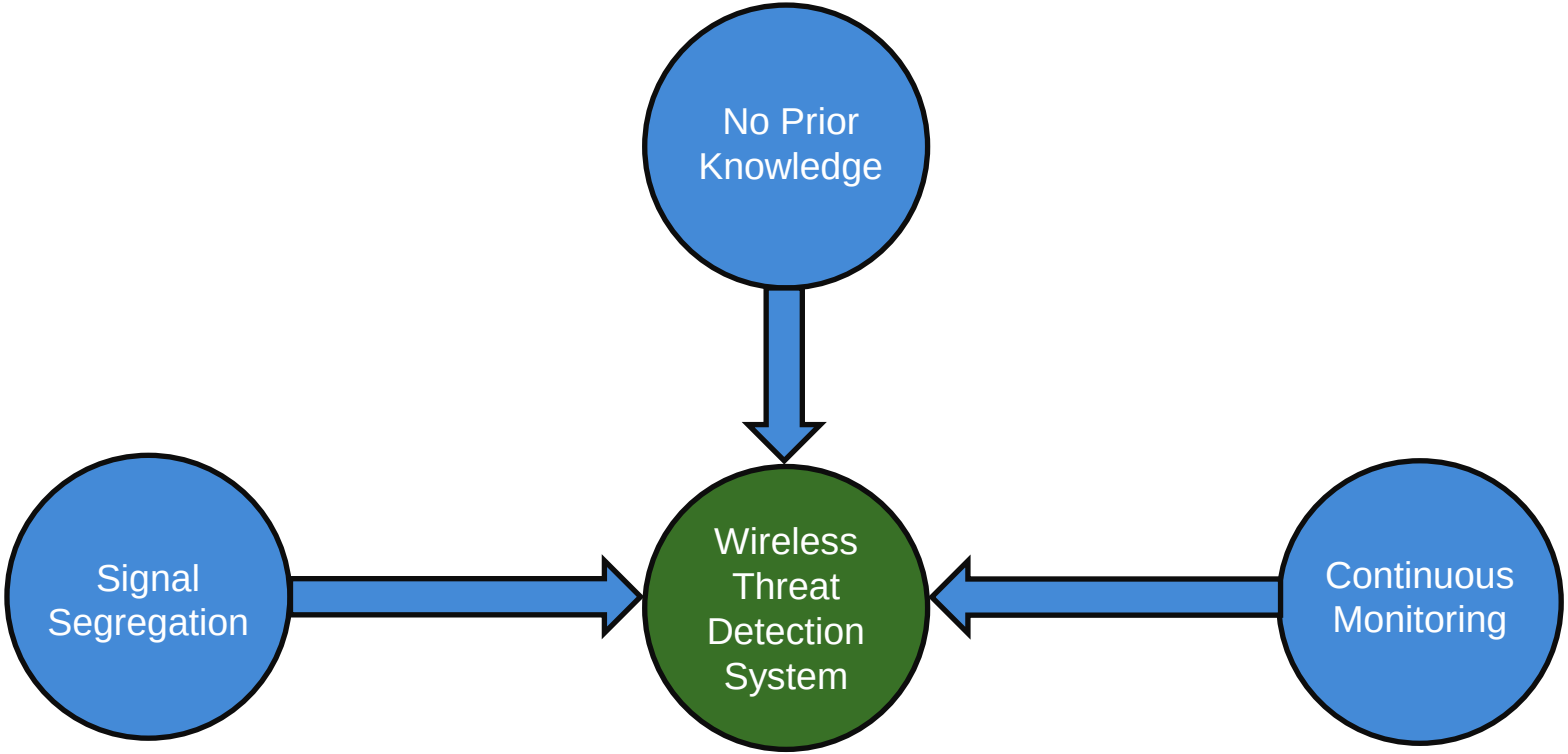
https://wcsng.ucsd.edu/channogram

Motivation: Wireless Security Threats



Goal: An improved spectral estimation technique to enable detection and classification of these types of threats

Three requirements for countermeasure systems that we will present solutions to in this talk



Consumer countermeasures are not sufficient

Entry Level

LM-8 Hidden Camera & Bug Detector
$[illegible]

LNYOSN GSM Wireless Audio Bug Detector
$40

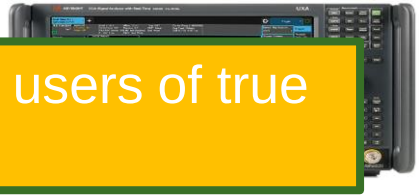
T-9 Specialty Bug

No signal segregation
No continuous monitoring

Professional

Analyzer
$26,500

Signal Hound SM200C
$16,890



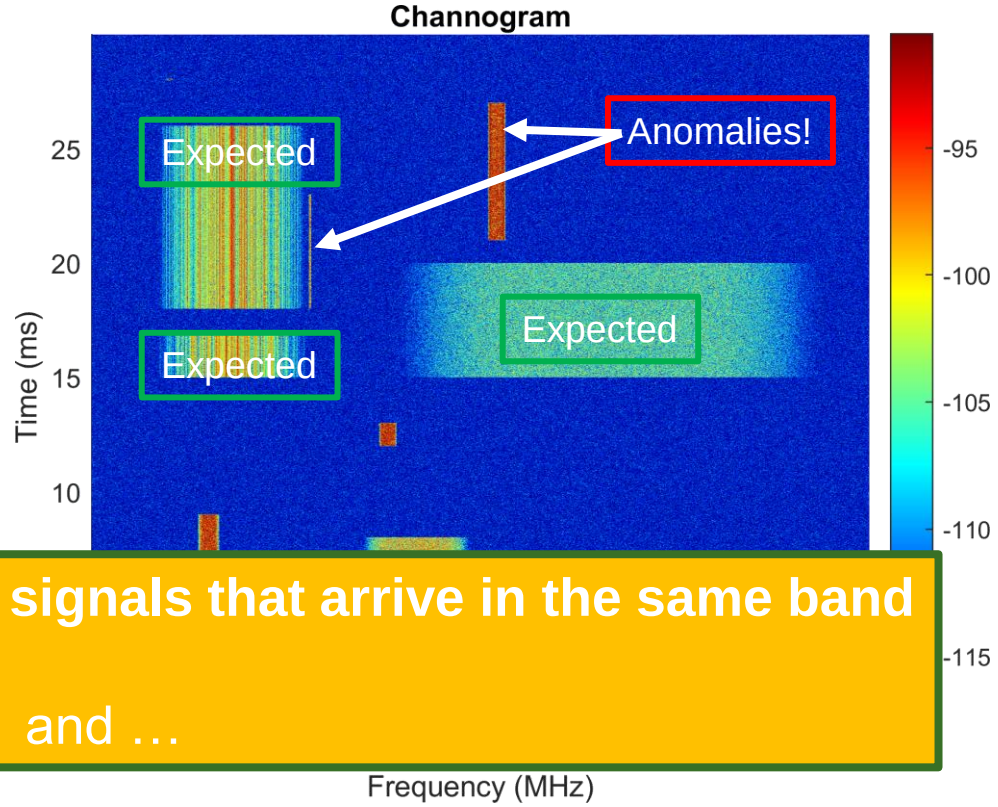
Keysight Agilent N9040B 26.5GHz UXA Signal Analyzer w/ Options
$118,435

No signal segregation

Consumer products lack the features required to alert users of true wireless threats as they occur

Why does the system need to segregate signals?

- The receiver cannot control what signals it collects in band
  - If there are many, all of them will be combined into one time series



The system must segregate signals that arrive in the same band

and …

Why can’t we assume prior knowledge?

- If you are doing something you shouldn’t be, you won’t do it in the open
  - Threats will hide and keep information secret

The system must segregate signals that arrive in the same band

The system should not require prior knowledge to perform well

and …

Why is continuous monitoring required?

- Receivers support wide instantaneous bandwidth (IBW) to support coverage across 6+ GHz of spectrum
  - USRP N210 40 MHz IBW
  - USRP N320 200 MHz IBW
  - Signal Hound SM200C 160 MHz IBW

The system must segregate signals that arrive in the same band

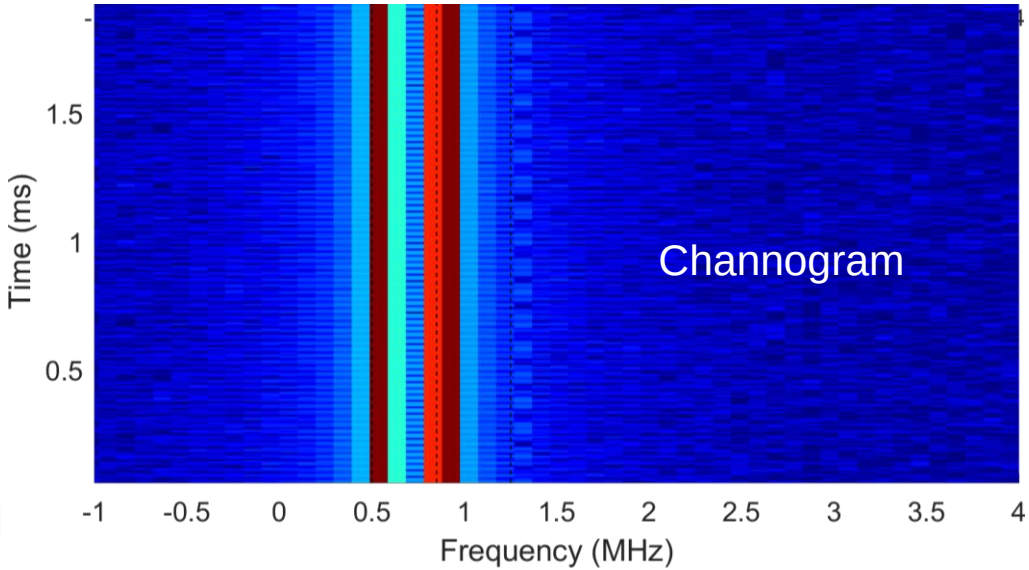
The system should not require prior knowledge to perform well

The system must be efficient and support this kind of throughput!

  - Sparse Bayesian Spectral Estimation – $O(N^3)$
  - MUSIC and ESPRIT – $O(N^{2.3})$

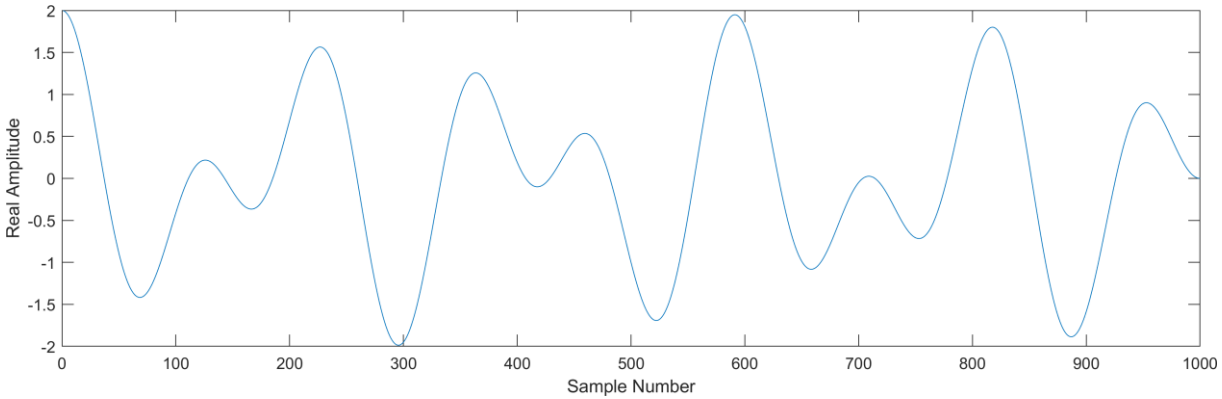
Our solution: Channogram

- Channogram uses the polyphase channelizer to achieve the requirements
- Channogram
  - Complexity scales with O(NlogN)
  - No prior knowledge
  - Supports time/frequency segregation
  - Improves dynamic range and frequency resolution



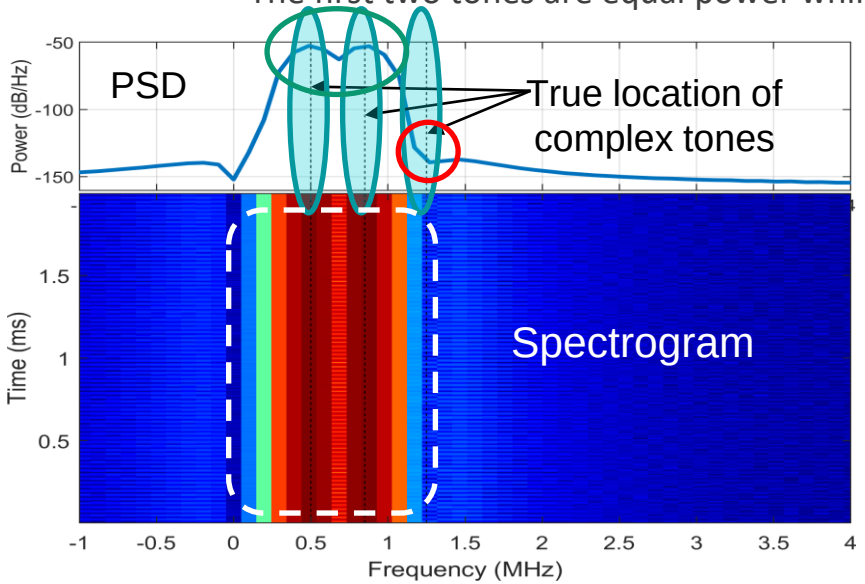
Estimate the number of sine waves, their center frequency and power given time domain samples

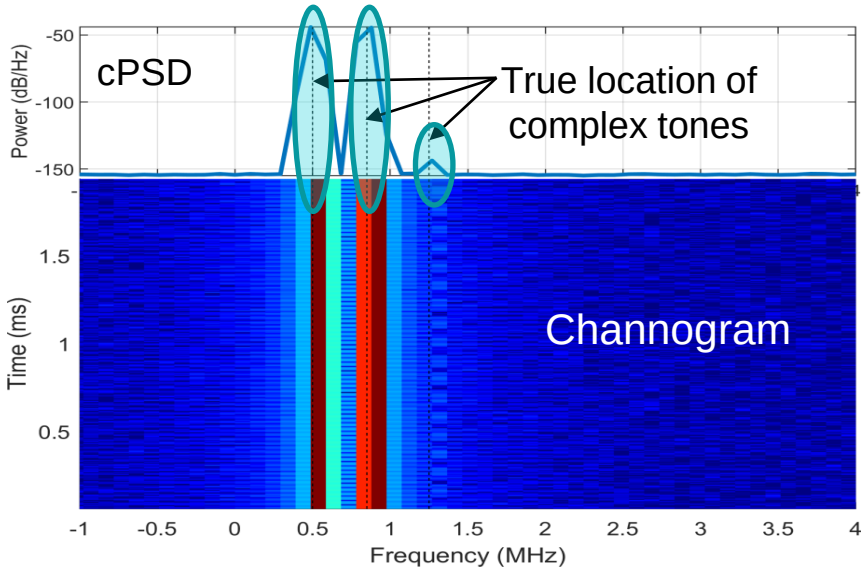
- How many sine waves are there?
- What is the frequency of the sine waves?
- What is the relative power levels of the sine waves?



Channogram provide better resolution and dynamic range than windowed overlapped STFTs

- Three complex tones centered at 0.5 MHz, 0.85 MHz and 1.25 MHz are to be estimated
  - The first two tones are equal power while the third tone has 100 dB less power



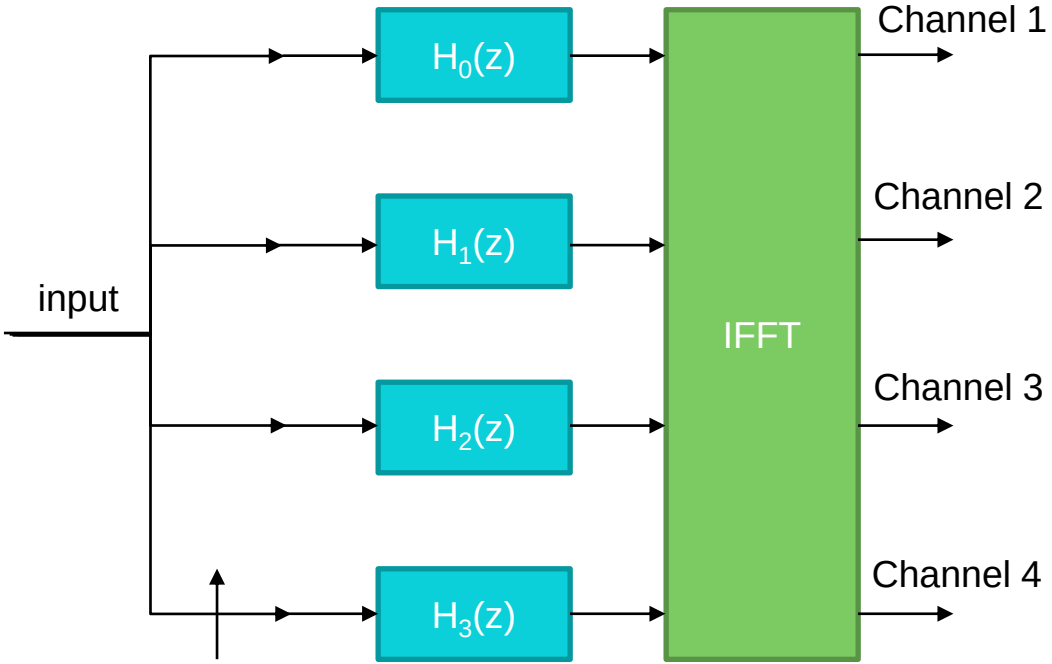


STFT Properties: 1024 Point Kaiser window with beta 10, 50% overlap, 1024 Point FFT

Channelizer Properties: 1024 Channels, 24576 Length Prototype Filter, Beta 5

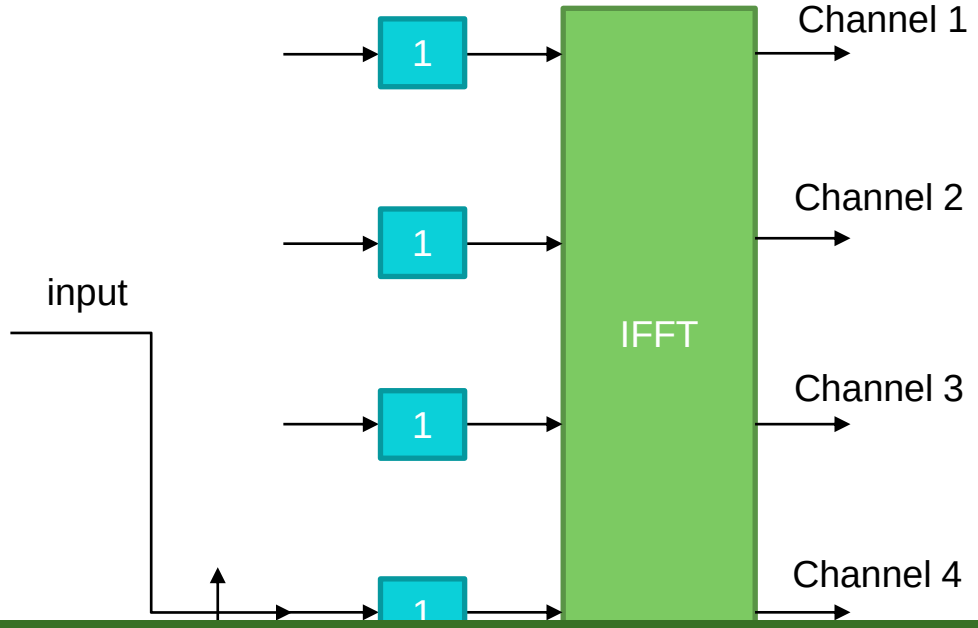
Building Intuition – How the basic polyphase channelizer works

- Standard polyphase channelizer, 4 channels
- Load samples starting at the bottom and work up
- $H_i(z)$ are filters derived from the polyphase decomposition of a prototype filter



The polyphase channelizer with all filters reduced to length one and value one

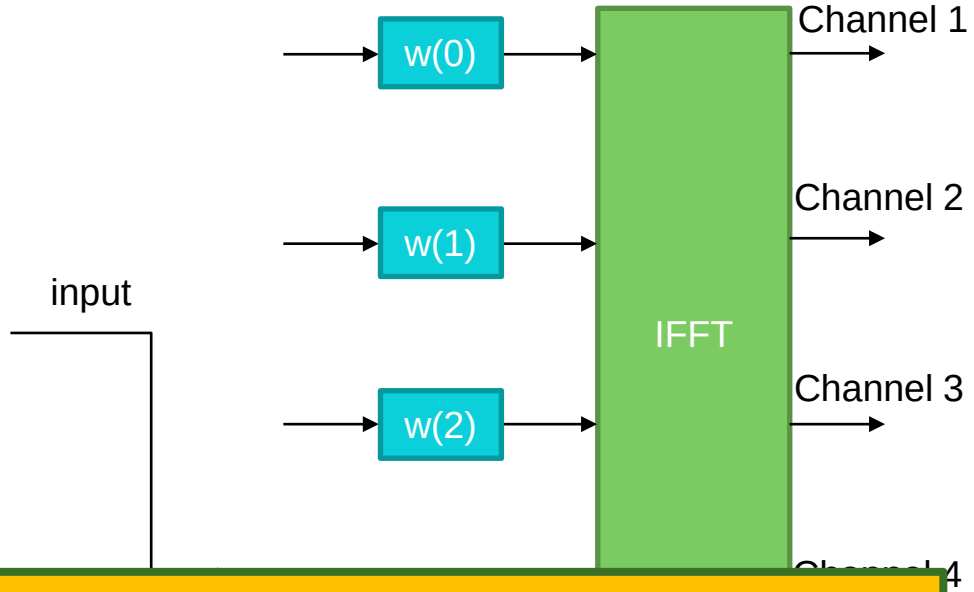
- If the filters are removed, we recover the standard DFT
- Loading from the bottom up into an IFFT is equivalent to an FFT



The FFT is the limiting case of the polyphase channelizer!

The polyphase channelizer with length one filters and coefficients defined by a window function

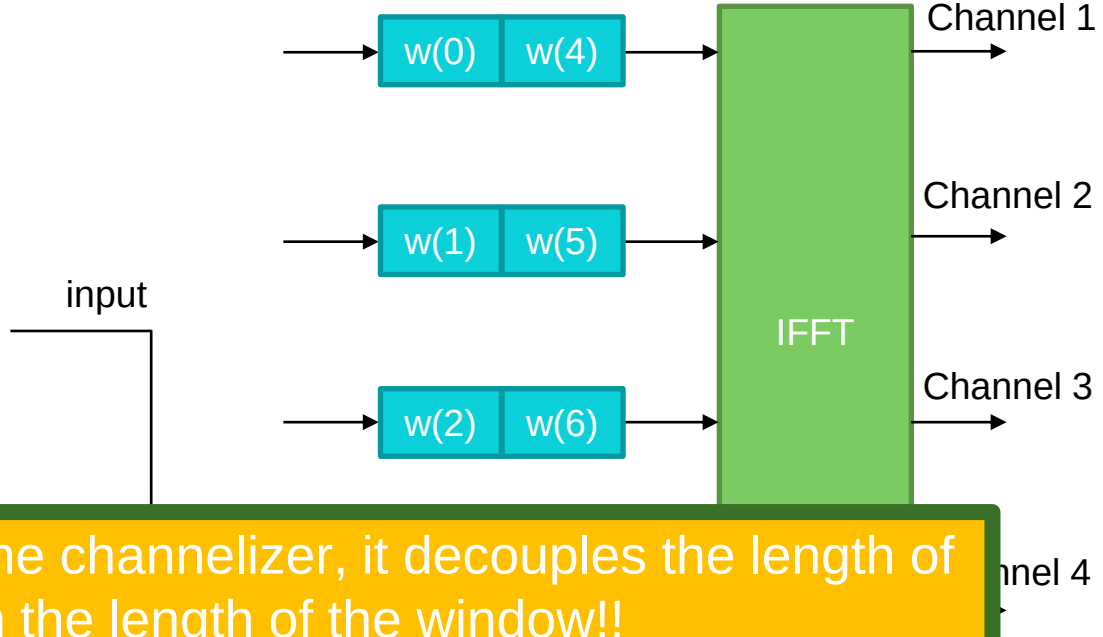
- Suppose we window the time domain samples first
- This is equivalent to using one tap filters, the tap values being equal to the window coefficients



STFT approaches stop here, but we can keep going…

Now let the number of filter coefficients be greater than the number of data points

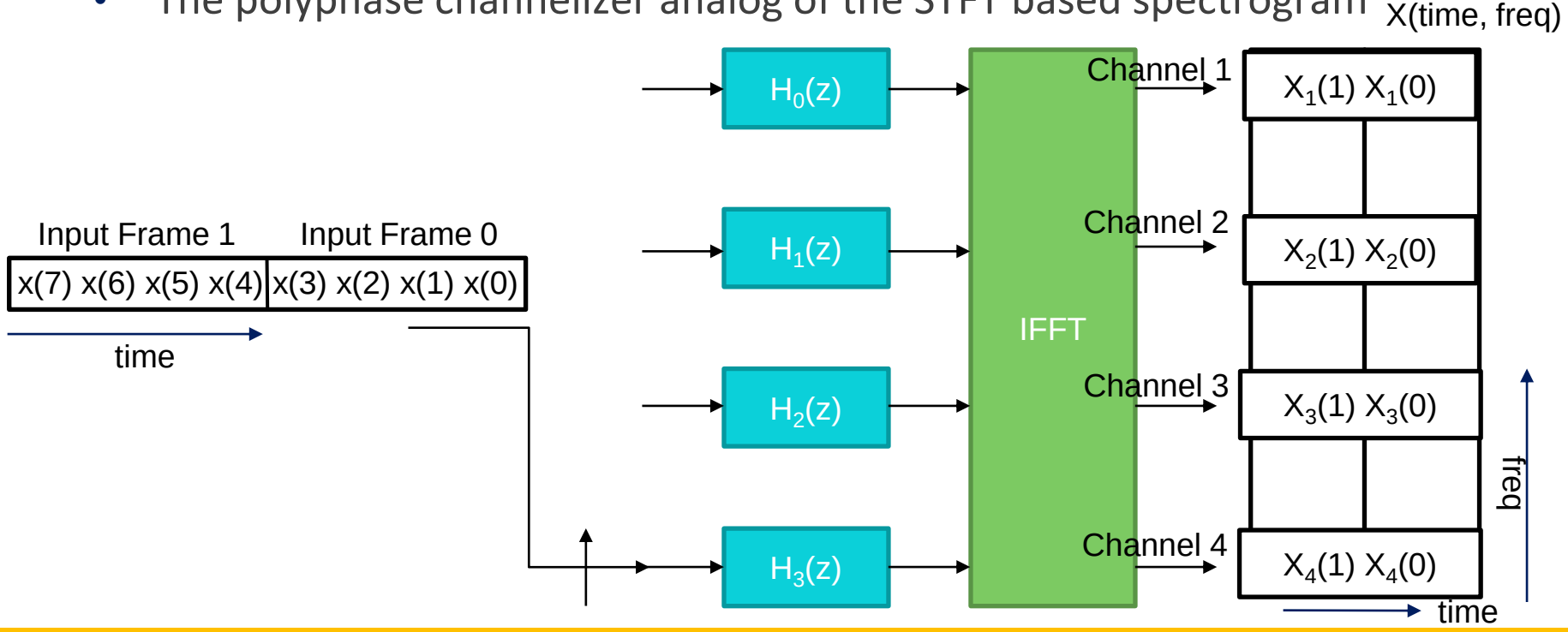
- We are applying an equivalent window with twice as many taps as the number of input samples
- We have decoupled the data length from the window length



This reveals the power of the channelizer, it decouples the length of the data from the length of the window!!

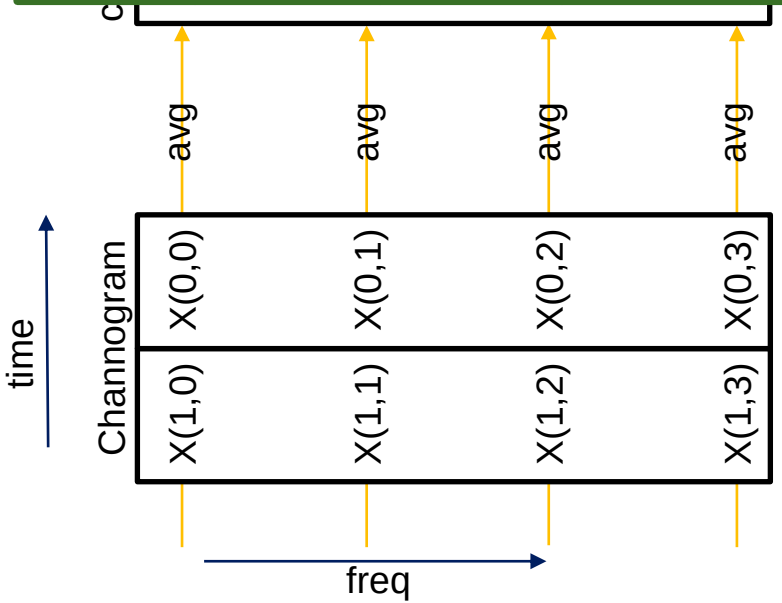
How is the channogram created?

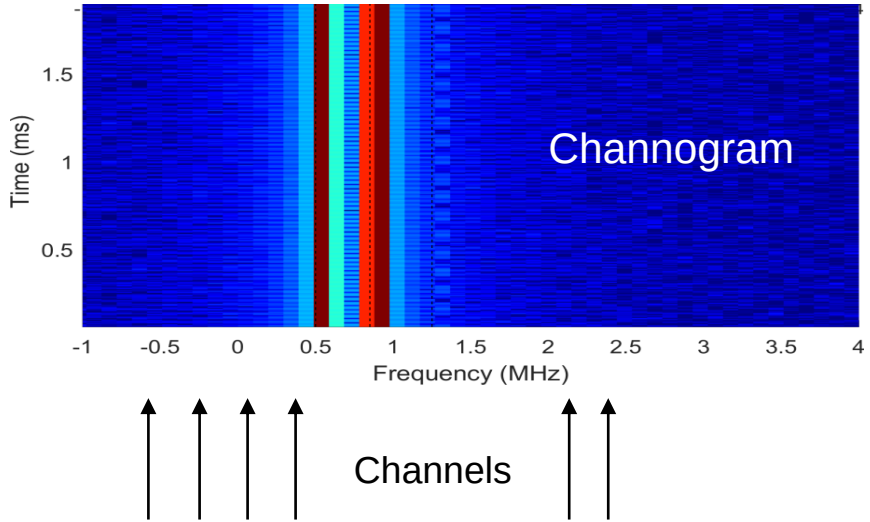
- The polyphase channelizer analog of the STFT based spectrogram



How do we get the channelizer PSD (cPSD) from the channogram?

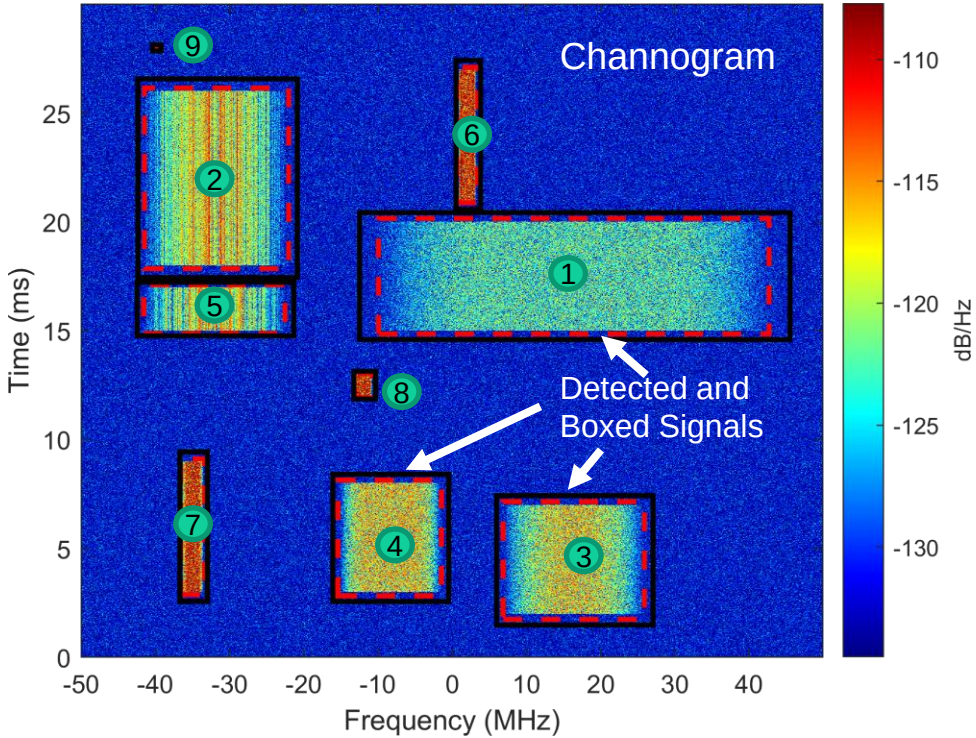
The combination of the channogram and cPSD provide excellent estimates of what is going on in time and frequency



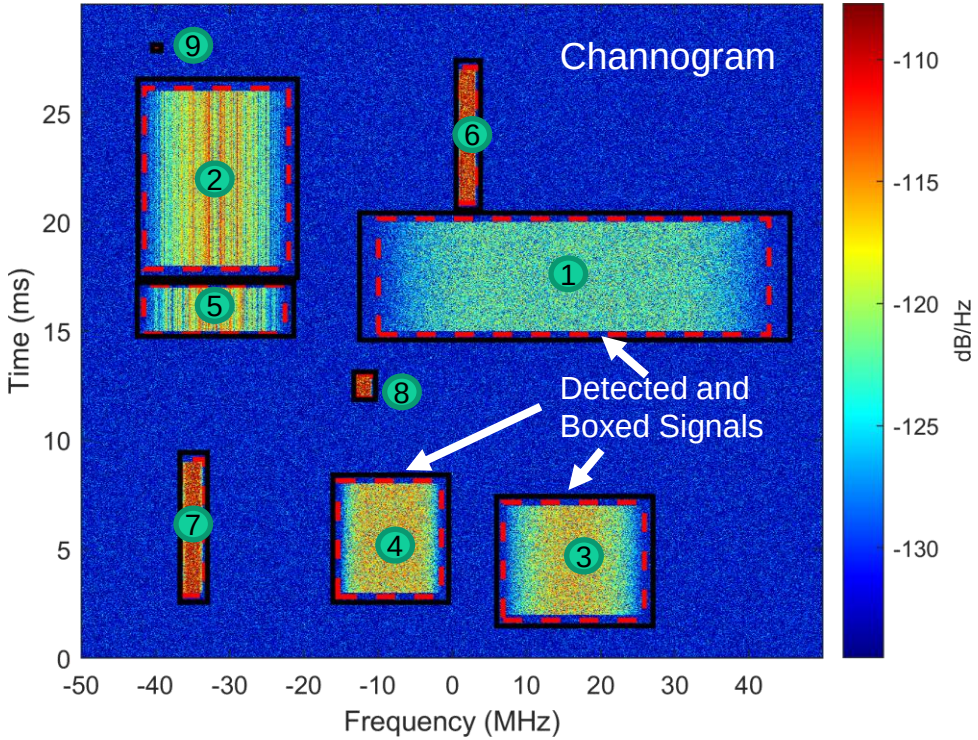


Energy detection using the channogram

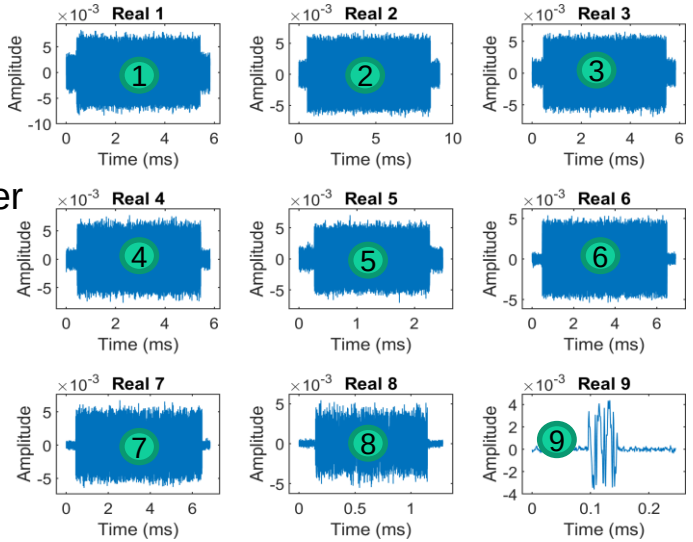
- Optimal: Energy Detector
  - No prior knowledge
  - The noise is AWGN
- Series of 2D convolutions across many different kernel sizes on top of the channogram
- Monitor the rate of power increase within the kernels as the kernels slide across the channogram



Signal segregation using a synthesis channelizer and the channogram

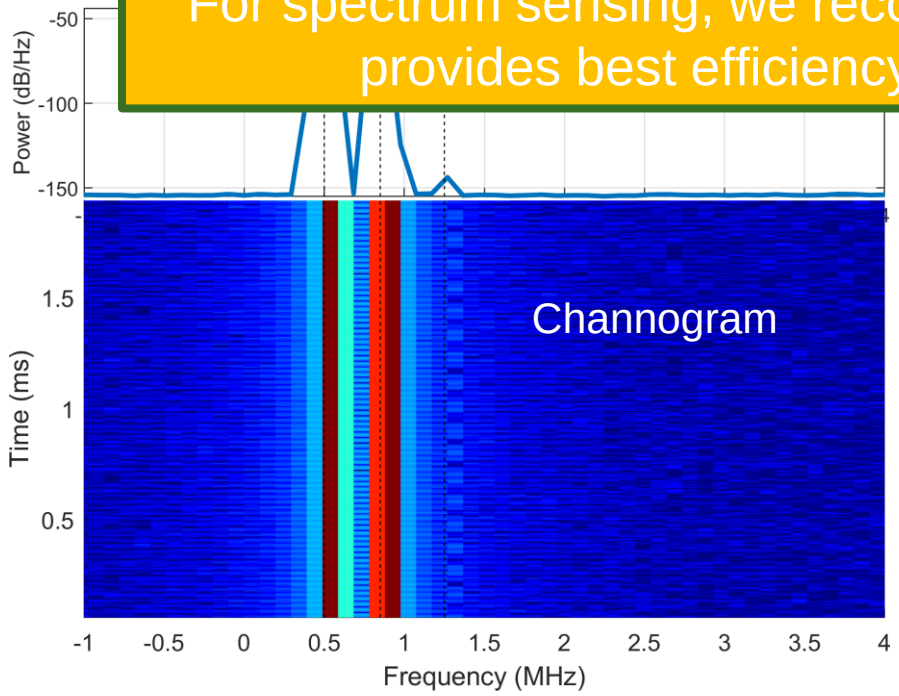


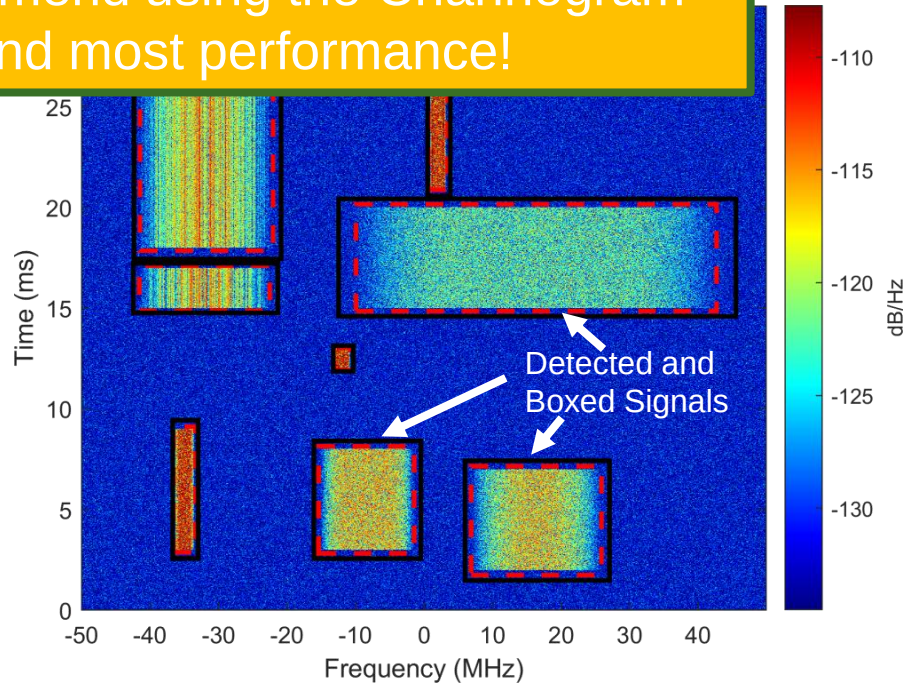
Synthesis
Channelizer



The channelizer provides continuous, high resolution, high dynamic range spectrum analysis and segregation to combat wireless threats

For spectrum sensing, we recommend using the Channogram provides best efficiency and most performance!





Acknowledgement

- https://www.iarpa.gov/research-programs/scisrs

This research is based upon work supported in part by the Office of the Director of National Intelligence (ODNI), Intelligence Advanced Research Projects Activity (IARPA), via [2021-2106240007]. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of ODNI, IARPA, or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for governmental purposes notwithstanding any copyright annotation therein.

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