GHz Spectrum Acquisition in Realtime

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Spectrum Crisis

• The FCC: spectrum crunch started in 2013
• But at any time, most of the spectrum is unused
Dynamic Spectrum Access
Sense to find unused bands; Use them!
How do you capture GHz of spectrum?

Seattle January 7, 2013
(Microsoft Spectrum observatory)
Realtime GHz Spectrum Sensing is Difficult

• Today, sequential scanning of tens of MHz
  ➔ Can easily miss radar signals

• Key Challenge: high-speed ADCs

<table>
<thead>
<tr>
<th>Tens of MHz ADC</th>
<th>A Few GHz ADC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-power</td>
<td>10x more power</td>
</tr>
<tr>
<td>High resolution</td>
<td>Poor resolution</td>
</tr>
<tr>
<td>Cheap</td>
<td>Expensive</td>
</tr>
</tbody>
</table>
Idea: Leverage Sparsity

Sparse recovery show that one can acquire sparse signals using sub-Nyquist sampling.

Compressive Sensing however is difficult:

- Random sampling \(\rightarrow\) Can’t use low-speed ADCs
- Compute million-point FFT \(\rightarrow\) High power
Idea: Leverage Sparsity

Sparse FFT
No random sampling → Use a few low-speed ADCs
Sub-linear algorithm → Computes large FFT cheaply

Occupancy Graph
Seattle January 7, 2013
(Microsoft Spectrum observatory)
How Does Sparse FFT Work?

1- Bucketize
Divide spectrum into a few buckets
→ Can ignore empty bucket

2- Estimate
Estimate the large coefficients in each non-empty bucket

value of bucket = \sum \hat{x}_f
How Does Sparse FFT Work?

Bucketize → Estimate
How Does Sparse FFT Work?

Sub-sampling time ⇒ Aliasing the frequencies

Bucketize → Estimate

Subsample

Time

FFT

Frequency
How Does Sparse FFT Work?

Bucketize → Estimate

Collision → Cannot Estimate

Empty Bucket → Isolated Freq. → Estimate
How Does Sparse FFT Work?

Bucketize multiple times using **co-prime sub-sampling**

Same frequencies don’t collide in two bucketizations.

![Diagram showing bucketization and estimate process]
How Does Sparse FFT Work?

1. **Bucketize**
2. **Estimate**

Identify isolated freq. in one bucketization and subtract them from the other; and iterate ...

Output Result:
How Does Sparse FFT Work?

Repeat bucketization after shifting the signal in time by a **time shift** $\tau$

<table>
<thead>
<tr>
<th>Time-Domain</th>
<th>Freq-Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x(t)$</td>
<td>$X(f)$</td>
</tr>
<tr>
<td>$x(t - \tau)$</td>
<td>$X(f)e^{-j\theta}$</td>
</tr>
</tbody>
</table>

Phase Rotation: $\theta = \frac{2\pi f \tau}{N} \Rightarrow f = \frac{N\theta}{2\pi \tau}$
BigBand: GHz Receiver for Sparse Signals

• Sub-sample the data → Can use low-speed ADCs
• Very fast algorithm → Lower-power consumption

• Used sparse FFT to build a GHz receiver from three tens of MHz ADCs
• Both senses and decodes the spectrum
Realtime GHz Spectrum Sensing

Cambridge, MA January 15 2013

Occupancy from 2GHz to 3GHz (10 ms FFT window)
Realtime GHz Spectrum Sensing

Cambridge, MA January 15 2013

3 ADCs with a combined digital Bandwidth of 150 MHz can acquire a GHz

Occupyancy from 2GHz to 3GHz (10 ms FFT window)
Decoding Senders Randomly Hopping in a GHz
Decoding Senders Randomly Hopping in a GHz

SFFT enables realtime GHz sensing and decoding for low-power portable devices
But, what if the spectrum is not sparse?!

Differential BigBand

- Even if the spectrum is 100% occupied, changes in occupancy are sparse
  → Apply sFFT to Changes/Diffs

- Can’t subtract signals; operate over power

- Realtime GHz sensing; but no decoding
Conclusion

• BigBand provides GHz-wide realtime spectrum sensing and decoding using sFFT

• Differential-BigBand provides GHz sensing using sFFT

• Imagine multi-GHz of unlicensed open spectrum operating with carrier sense (a la WiFi)