Session #2 - AI Native 6G

7 July 2026

Towards AI-driven RF Semantics

by

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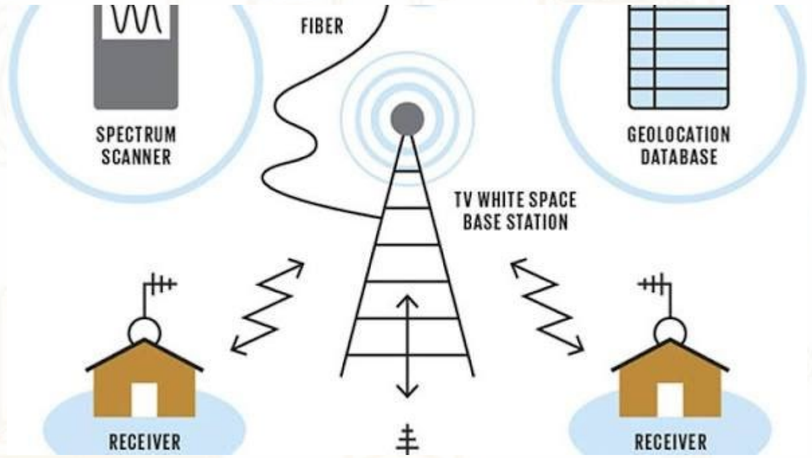
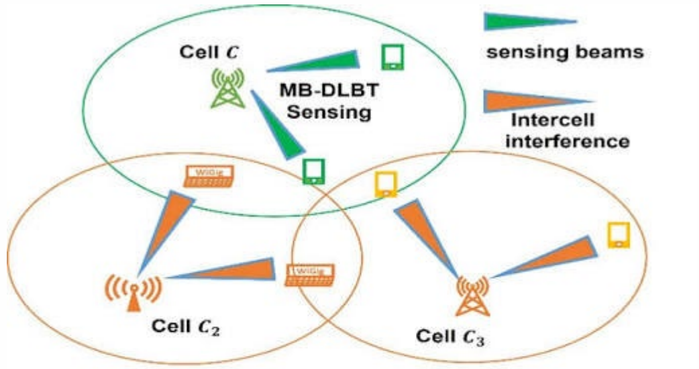
Network Cognition and 6G

- Traditional RF sensing algorithms focus on estimating spectrum occupancy

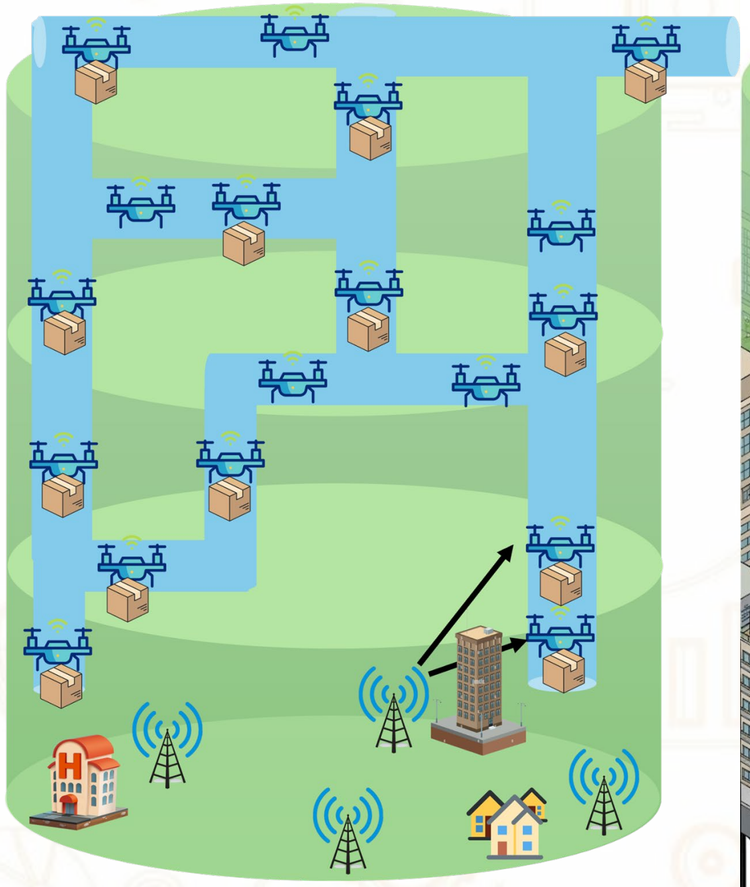




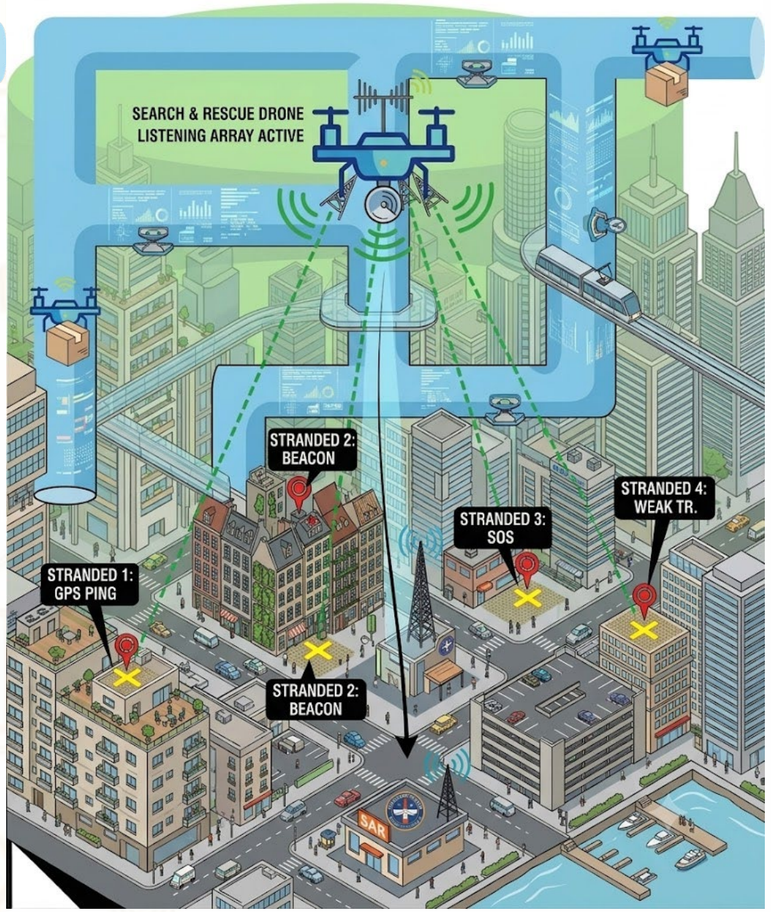
Wireless coexistence of multi-cell cellular and Wi-Fi system, where directional antennua beams are used for joint specturn sensing and communication, and help suppress intercell interferences.

- 6G NTN usecases envisages platforms that require knowledge of their local environment
  - Examples: UAV deconfliction, Autonomous Navigation, Search and Rescue

From Spectrum Sensing to Scene Description



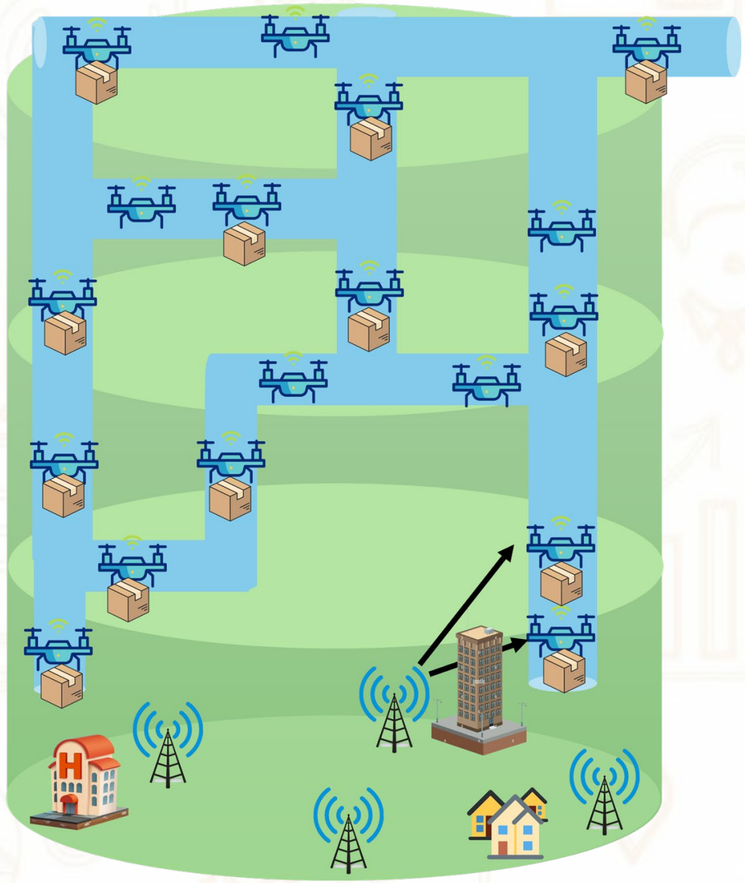
NTN: Aerial Highways



NTN: Search and Rescue

Is there a passive, decentralized, protocol-agnostic approach for each UAV to know the RF scene around itself?

From Spectrum Sensing to Scene Description (contd.)



Some questions:

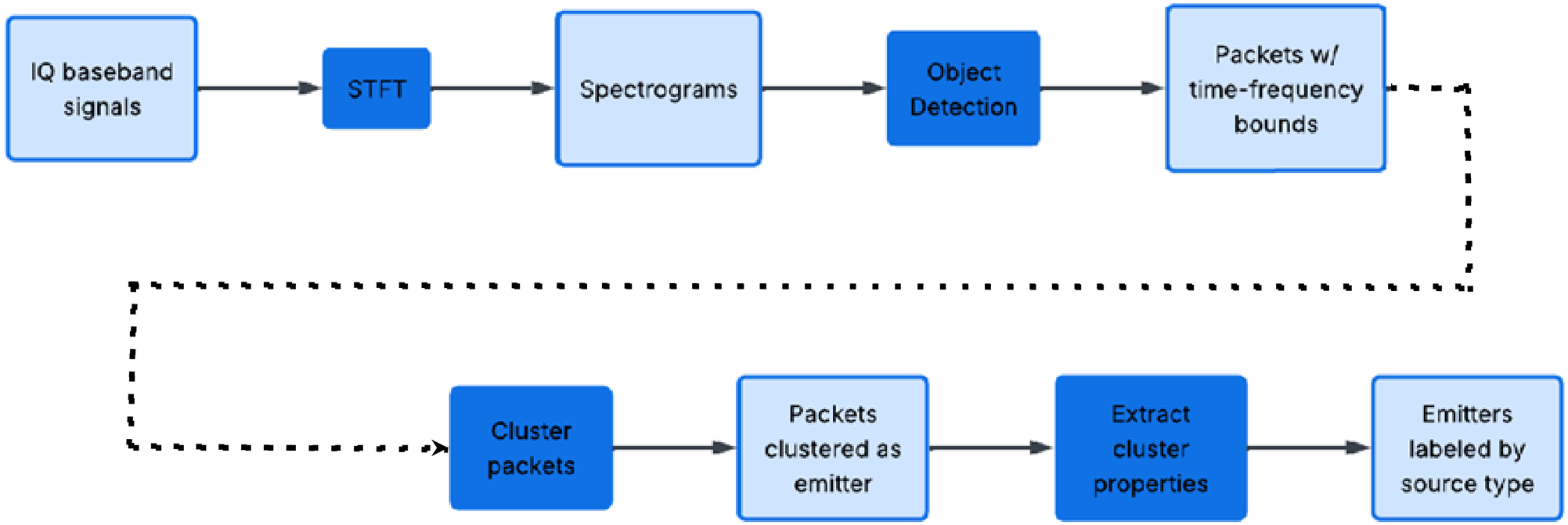
- How many unique transmitters exist in a scene and where are they?
- What protocols are they using?
- In short, we want to move towards **RF semantics**.

Towards RF Semantics

Structured Decomposition of an RF Scene

- Directly processing I/Q samples is difficult, so work with the **spectrogram**
- Treating the spectrogram as an **RF scene**:
  - **Detect individual transmissions**
  - **Form emitter-level representations** by transforming them into a higher latent representation and then grouping related packets together
  - **Extract behavioral and physical characteristics** of each emitter from packet and cluster statistics.
- **Result:** A **structured understanding** of a wireless scene

Data Processing Pipeline



Key Innovations

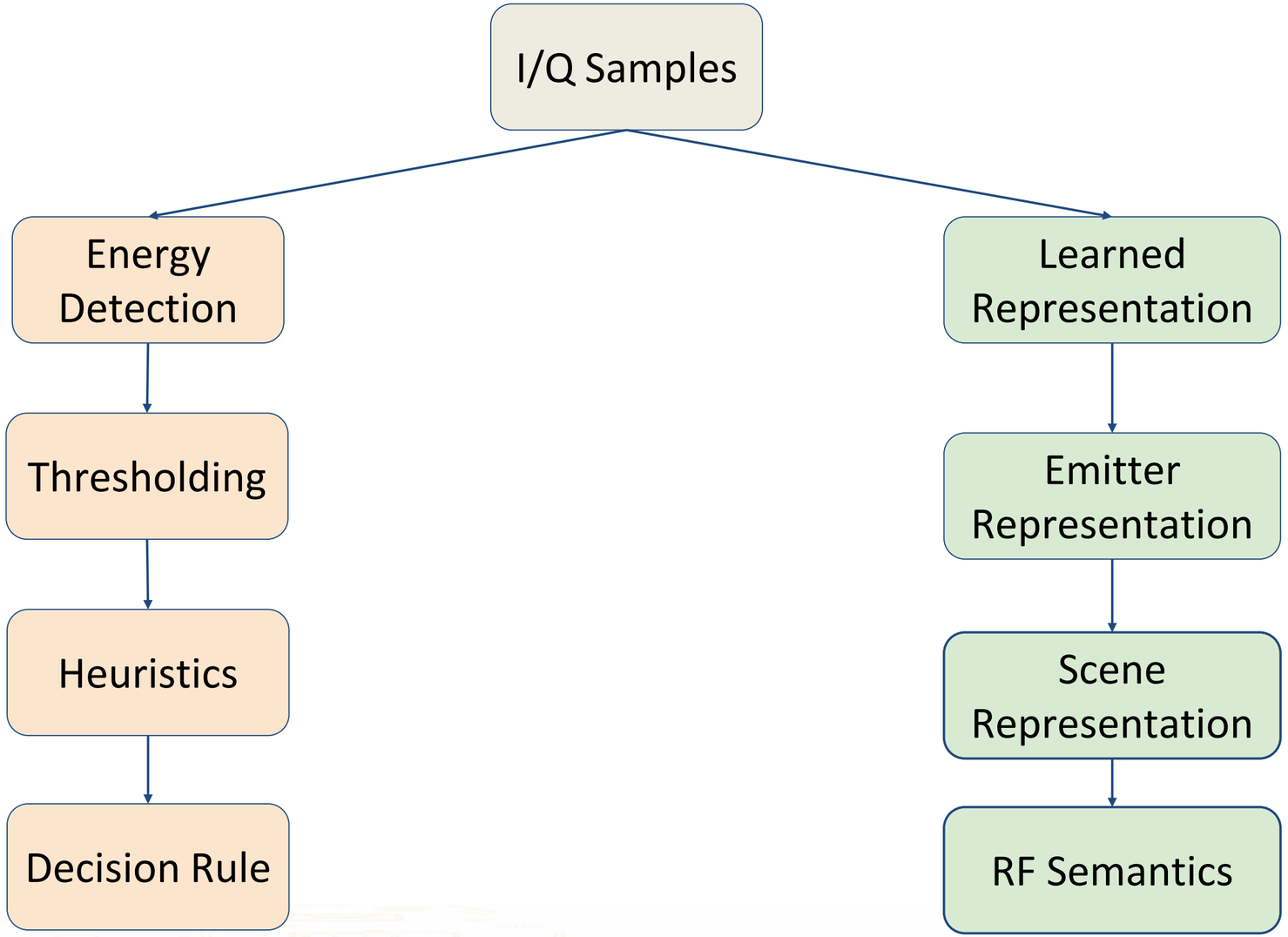
Conceptual:

- Wireless activity as a structured RF scene rather than isolated packets
- Learn transmitter-centric representations instead of **packet-centric representations**
- Build progressively richer abstractions from IQ samples to scene understanding
- Enable protocol-agnostic reasoning over heterogeneous wireless environments

Result:

- Lightweight, domain adapted model
- Modulation, bandwidth, and protocol-agnostic transmitter identification
- Easily pluggable into known protocol analyzers/sniffers

Model-based vs AI Processing



Example

RF Scene and Setup

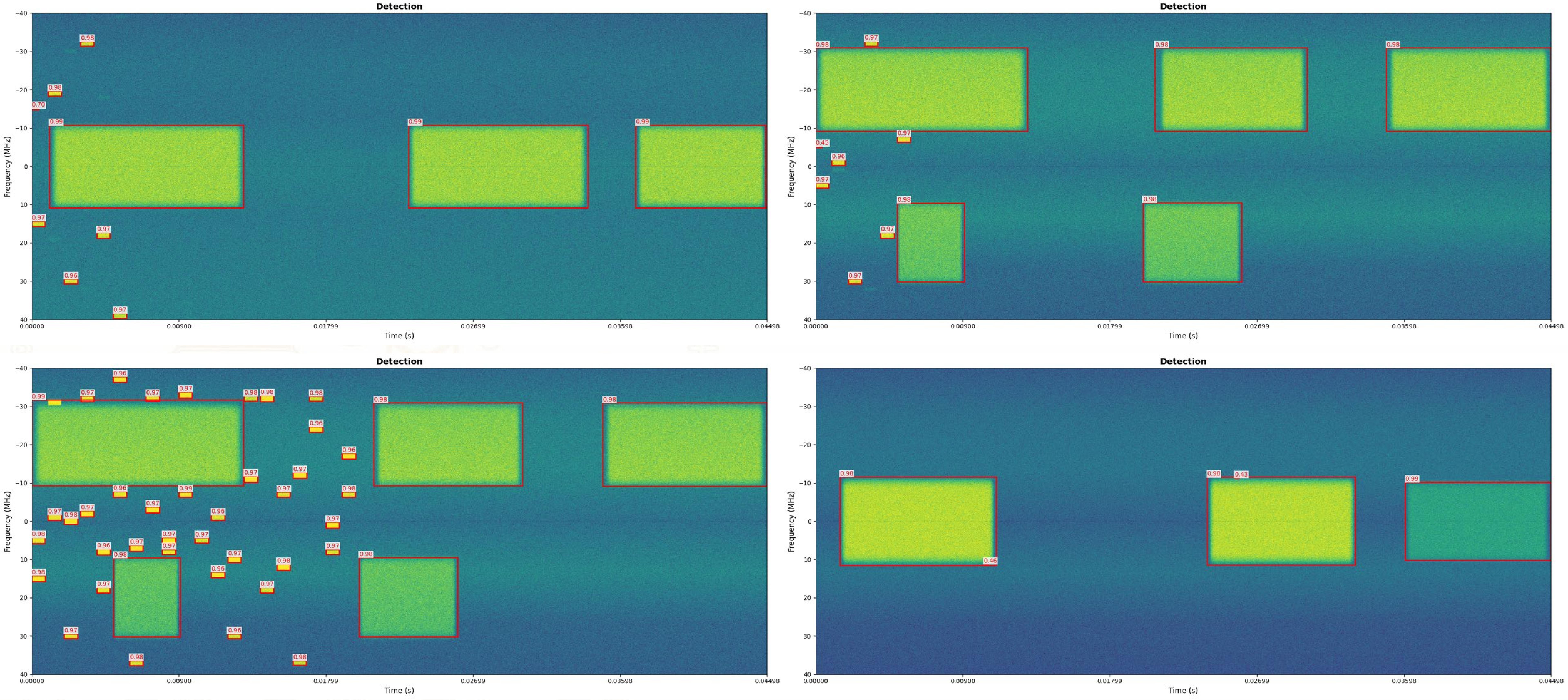
A USRP SDR was configured as a passive receiver to monitor activity in the 2.4 GHz ISM band:

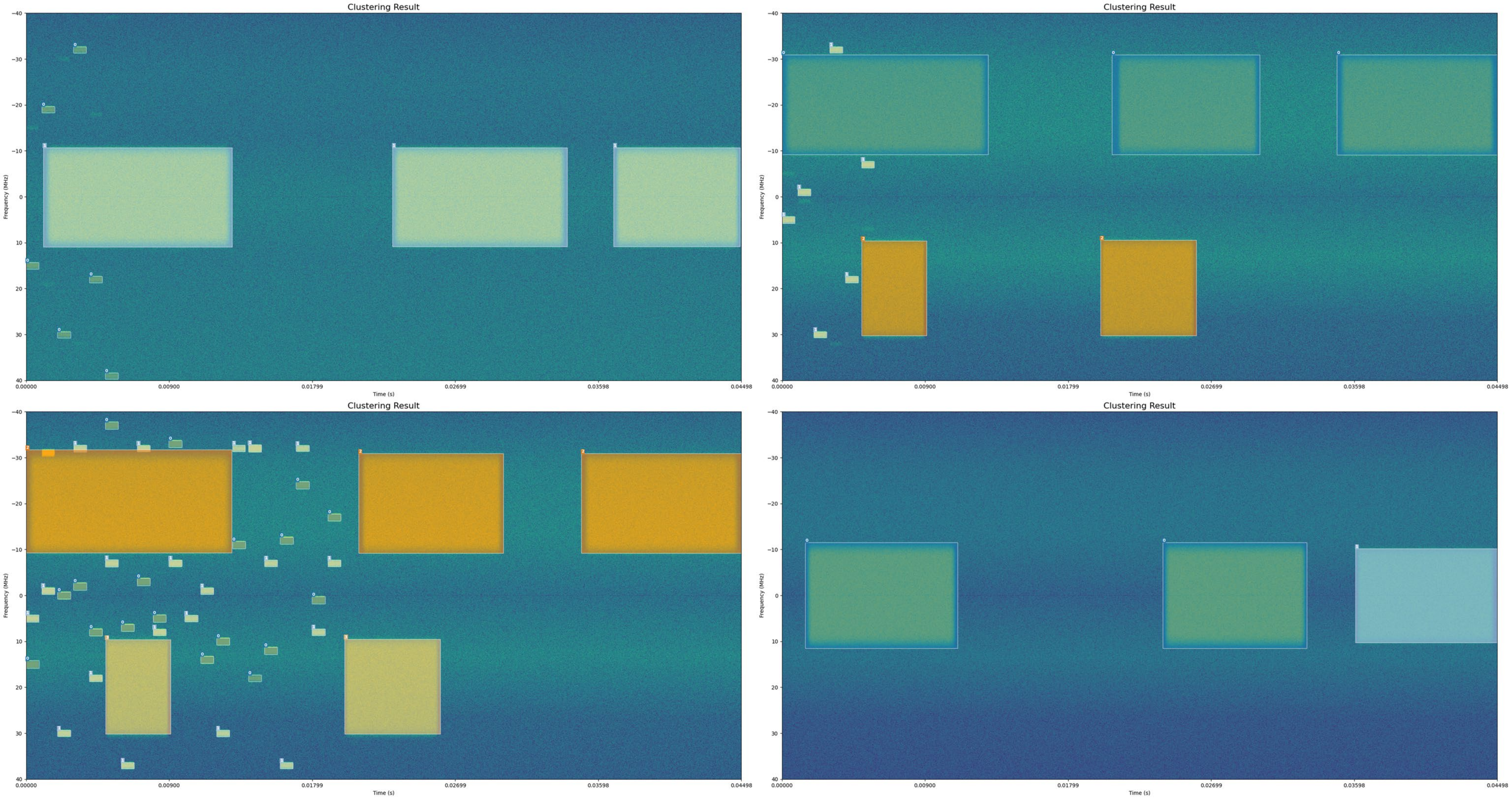
- The environment had an active Wi-Fi network and a Bluetooth device streaming music to a pair of wireless headphones.
- Complex baseband IQ samples were recorded at sampling rate of 56 MHz with the intent to characterize the scene with them.
- Multiple such recordings of 500 milliseconds were made.

USRP board

WiFi network with a router (magenta) and two laptops (red)

Output of the Transmitter Detection Step

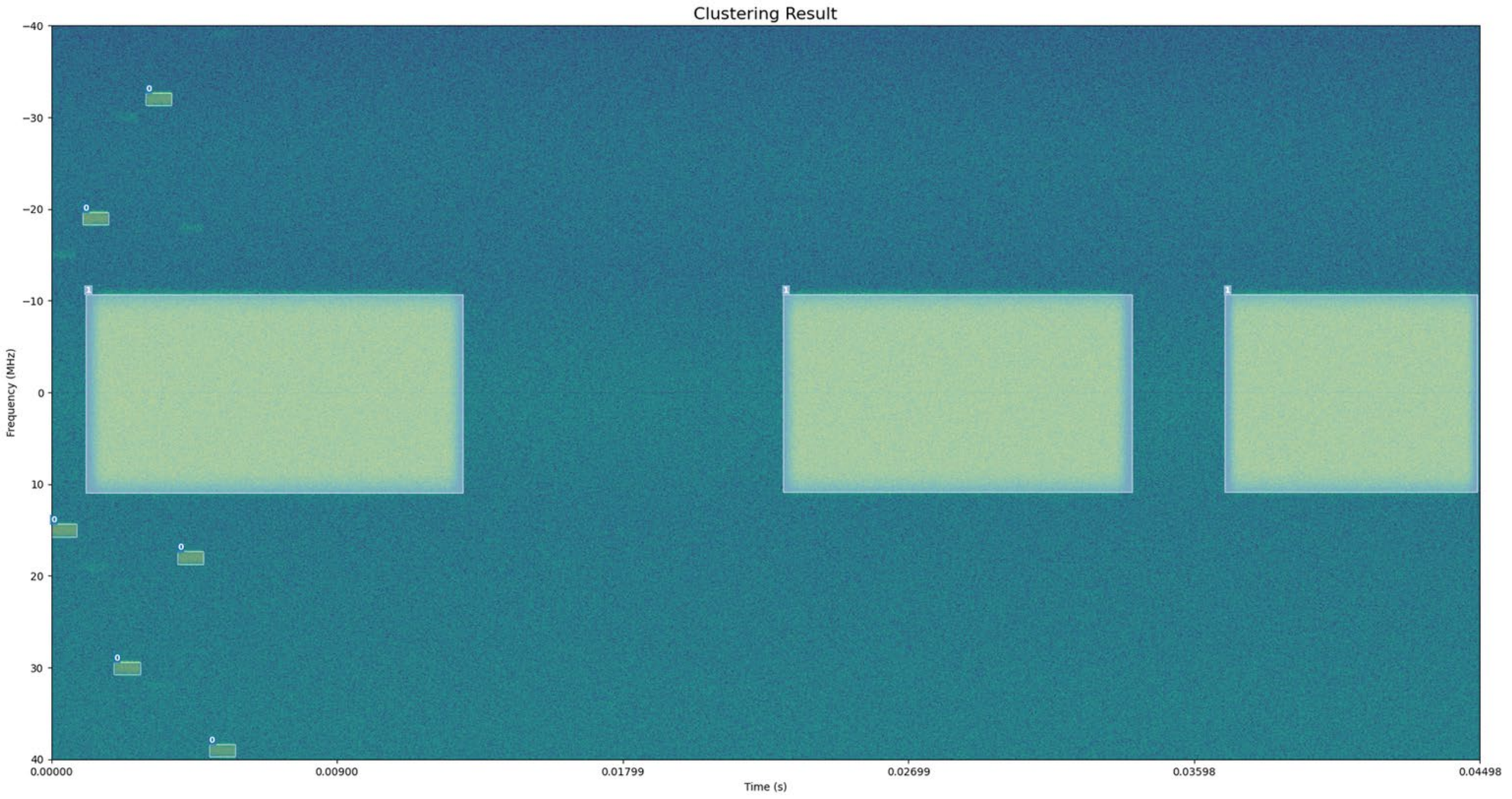




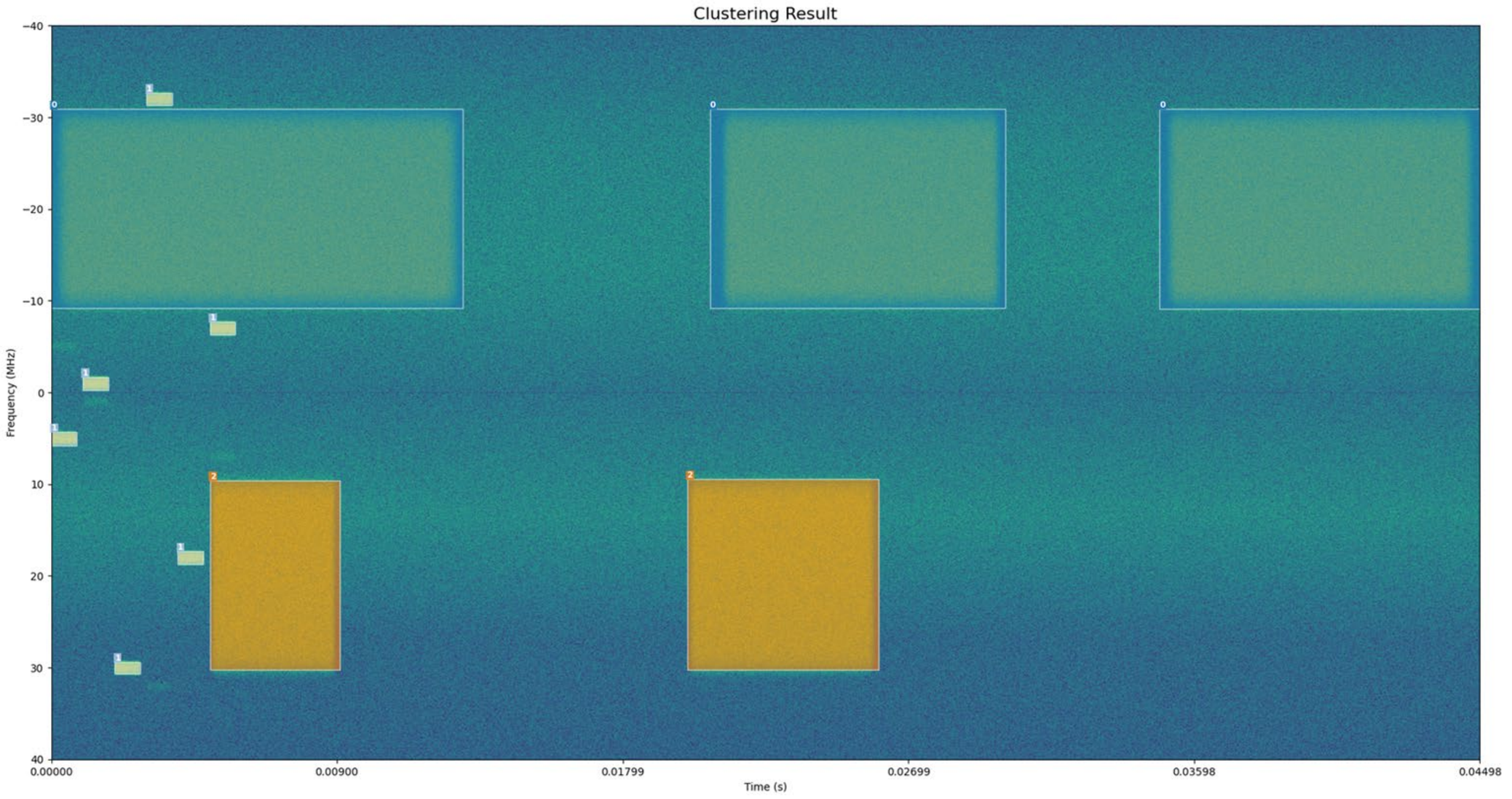
Results from clustering the packets using COP K Means Clustering Algorithm

Statistics from emitters

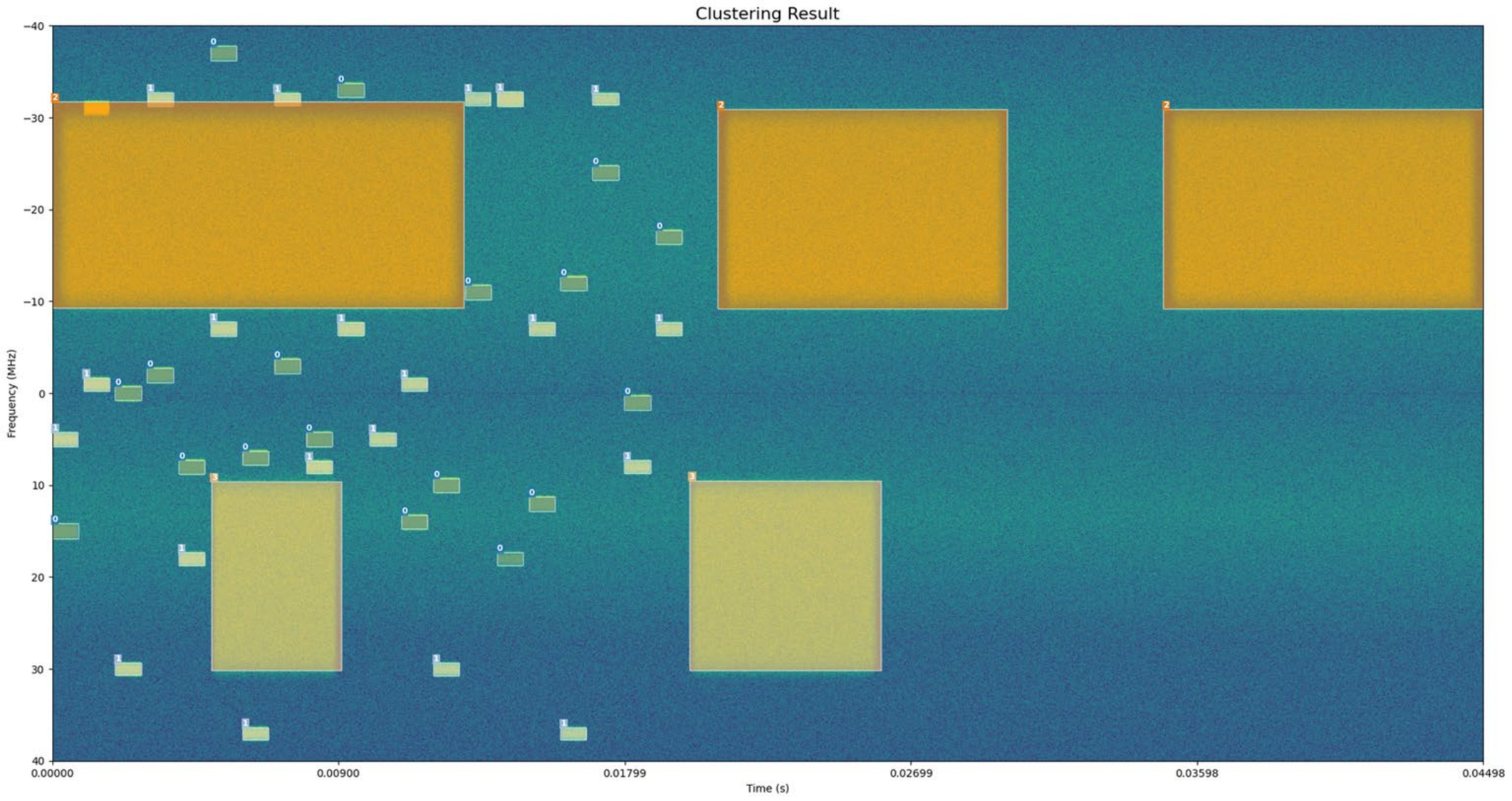
- Now, along with individual packets, properties of these clusters can also be used to characterize the cluster as a type of source
- Dwell time, variance in center frequency of packets, bandwidths of packets in a cluster etc. are some of these features.



Cluster	Type	Packets	Duty Cycle (%)	Avg Duration (s)	Avg BW (MHz)	Center Freq (MHz)	Mean RSSI (dB)
0	BT	6	83.4	0.0008	1.362	8.519	18.7
1	WiFi	3	70.3	0.0103	21.583	0.067	14.8



Cluster	Type	Packets	Duty Cycle (%)	Avg Duration (s)	Avg BW (MHz)	Center Freq (MHz)	Mean RSSI (dB)
0	WiFi	3	71.9	0.0108	21.75	-20.042	12.3
1	BT	6	83.4	0.0008	1.388	2.177	19.5
2	WiFi	2	48.1	0.0051	20.725	19.875	11.3



Cluster	Type	Packets	Duty Cycle (%)	Avg Duration (s)	Avg BW (MHz)	Center Freq (MHz)	Mean RSSI (dB)
0	BT	18	74.5	0.0008	1.546	-2.708	26.5
1	BT	20	82.2	0.0008	1.402	-0.588	20.6
2	WiFi	3	71.4	0.0107	21.933	-20.192	12.2
3	WiFi	2	48.1	0.0051	20.625	19.862	11.3

Takeaways

- For RF semantics, think in terms of RF **scenes**
- Use AI to learn hierarchical representation from I/Q samples
- Develop domain-native AI designs

Thank You

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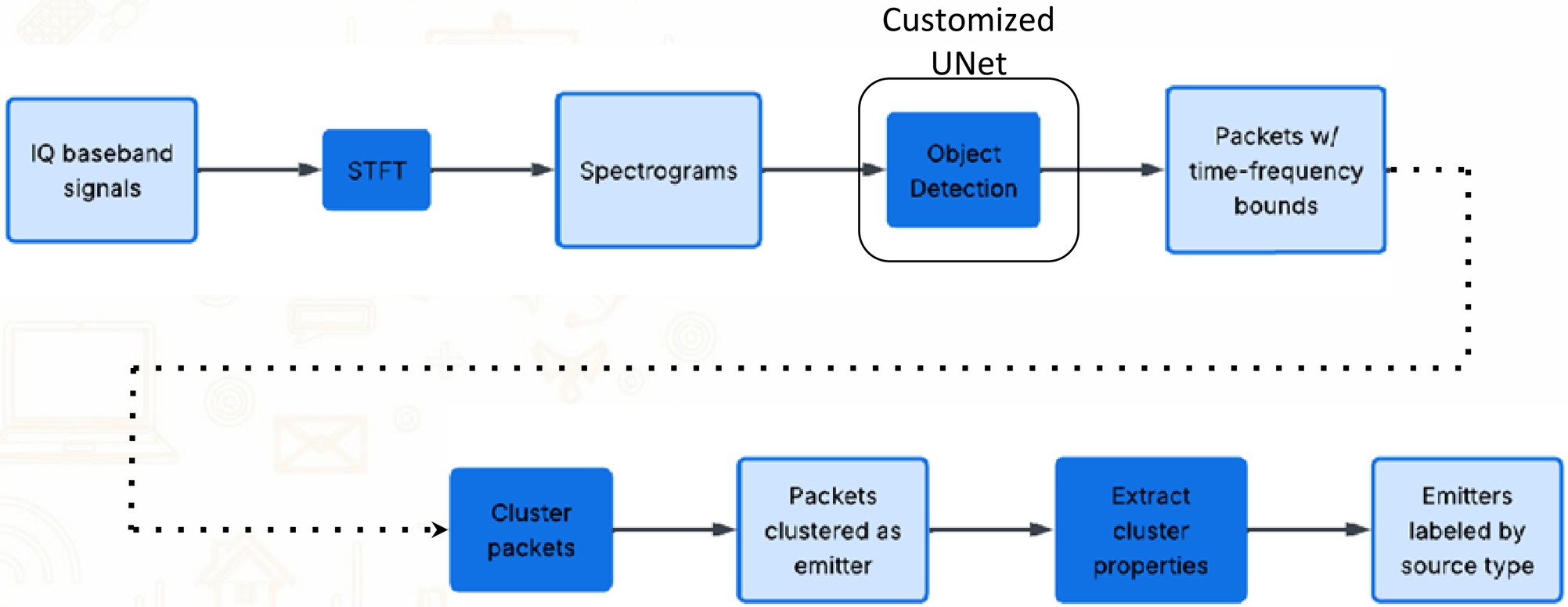
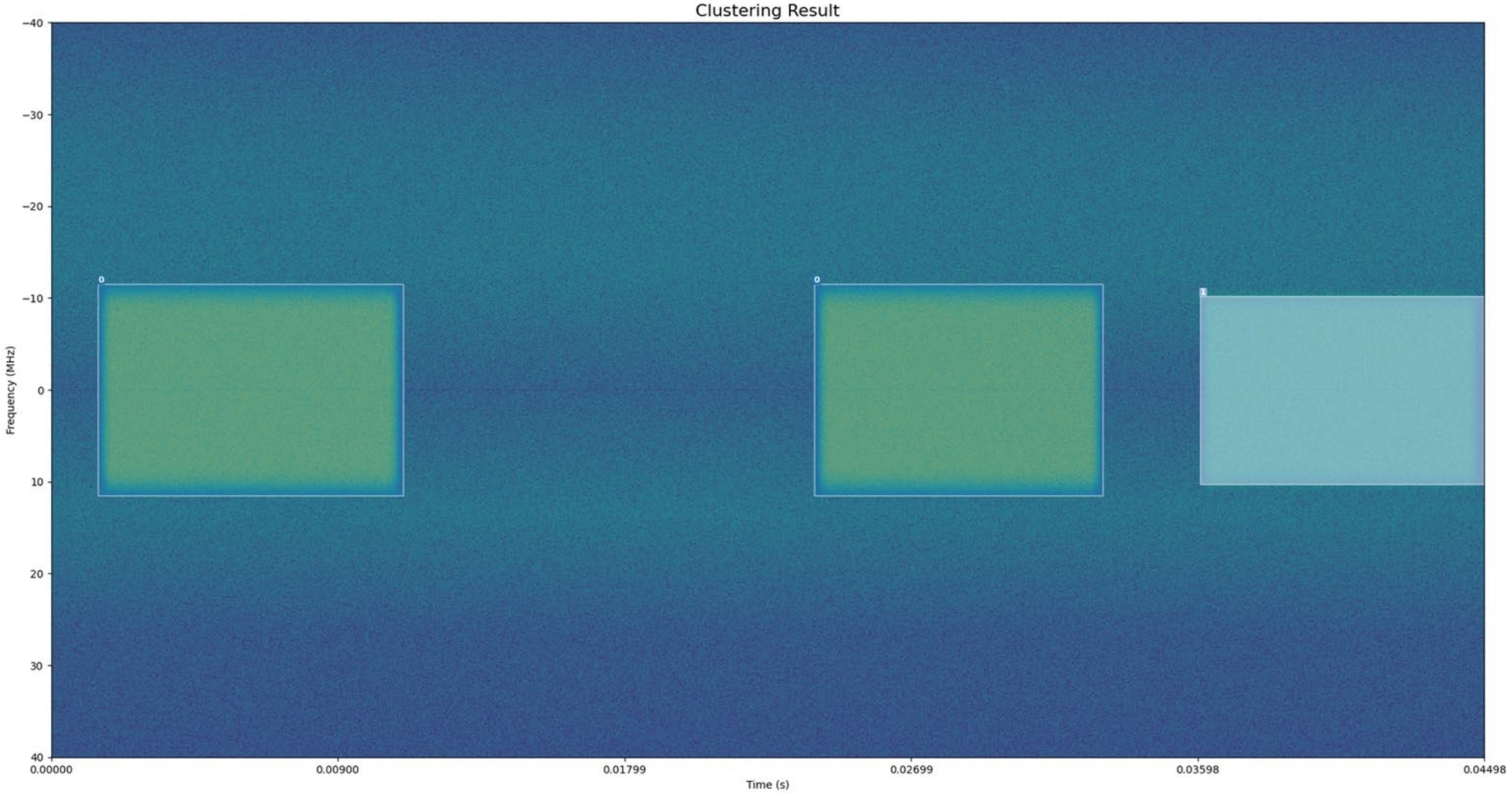
Model Details





Cluster	Type	Packets	Duty Cycle (%)	Avg Duration (s)	Avg BW (MHz)	Center Freq (MHz)	Mean RSSI (dB)
0	WiFi	2	59.1	0.0093	23.025	-0.025	23.4
1	WiFi	1	100.0	0.0089	20.425	0.012	10.1