Cognitive Radio Spectrum Sensing and Allocation: A Low-Complexity Deep Learning Approach

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Problem Statement

- Exponential growth in mobile and IoT devices strains 4G, 5G, and future 6G networks [1].
- Licensed spectrum bands are often underutilized, causing congestion and interference [2].
- Resultant spectrum scarcity threatens communication system efficiency [3].

Motivation

- **Cognitive radio (CR)** is a significant and active research topic.
- **Deep Learning (DL)** adapts to various spectral patterns and interference.
- Intersection with research in **Embedded Machine Learning (TinyML)**.
- Addressing challenges in **energy-efficient computing** and **sustainable** spectrum management.

Objectives

- Develop a low-complexity **convolutional neural network (CNN)**-based algorithm for real-time **spectrum sensing (SS)** and allocation.
- Enhance spectral efficiency by optimizing the utilization of available frequency bands.
- Design a hardware setup to simulate a centralized CR network, showcasing the SS algorithm in a practical scenario.

Methodology

- Established hardware setup with a central node, two primary users (PUs), and two secondary users (SUs). PUs are assigned frequency bands using frequency division multiple access (FDMA): 433 MHz and 500 MHz respectively.
- CNN model trained on both an acquired dataset [4] and a generated one to accurately determine the presence or absence of PUs in the spectrum.
- Model quantized using TensorFlow Lite and deployed on a Raspberry Pi (central node).
- Central node runs the CNN-based SS algorithm to detect spectrum holes and allocate them to SUs on a first-come-first-served basis.

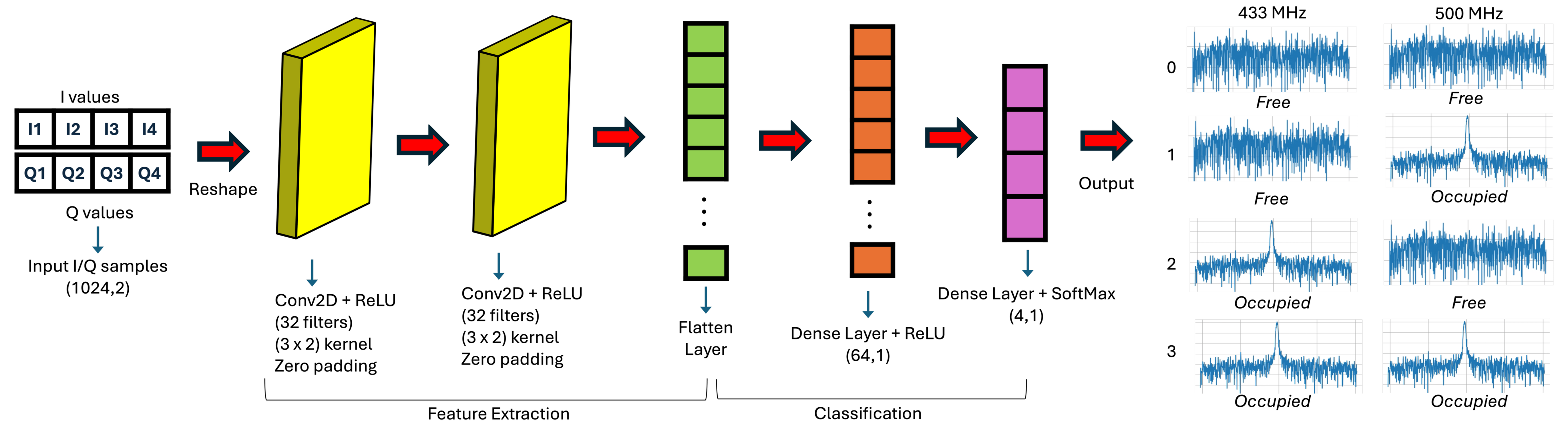

Fig. 1: Network architecture of the CNN model

System Diagram

- Central node monitors 433 MHz and 500 MHz; receives SU requests via 440 MHz.
- SU-1 requests transmission, placed first in FIFO queue.
- RTL-software defined radio (SDR) captures I/Q samples; CNN-SS model outputs [1,0] indicating 433 MHz occupied, 500 MHz free.
- Central node allocates free 500 MHz to SU-1.

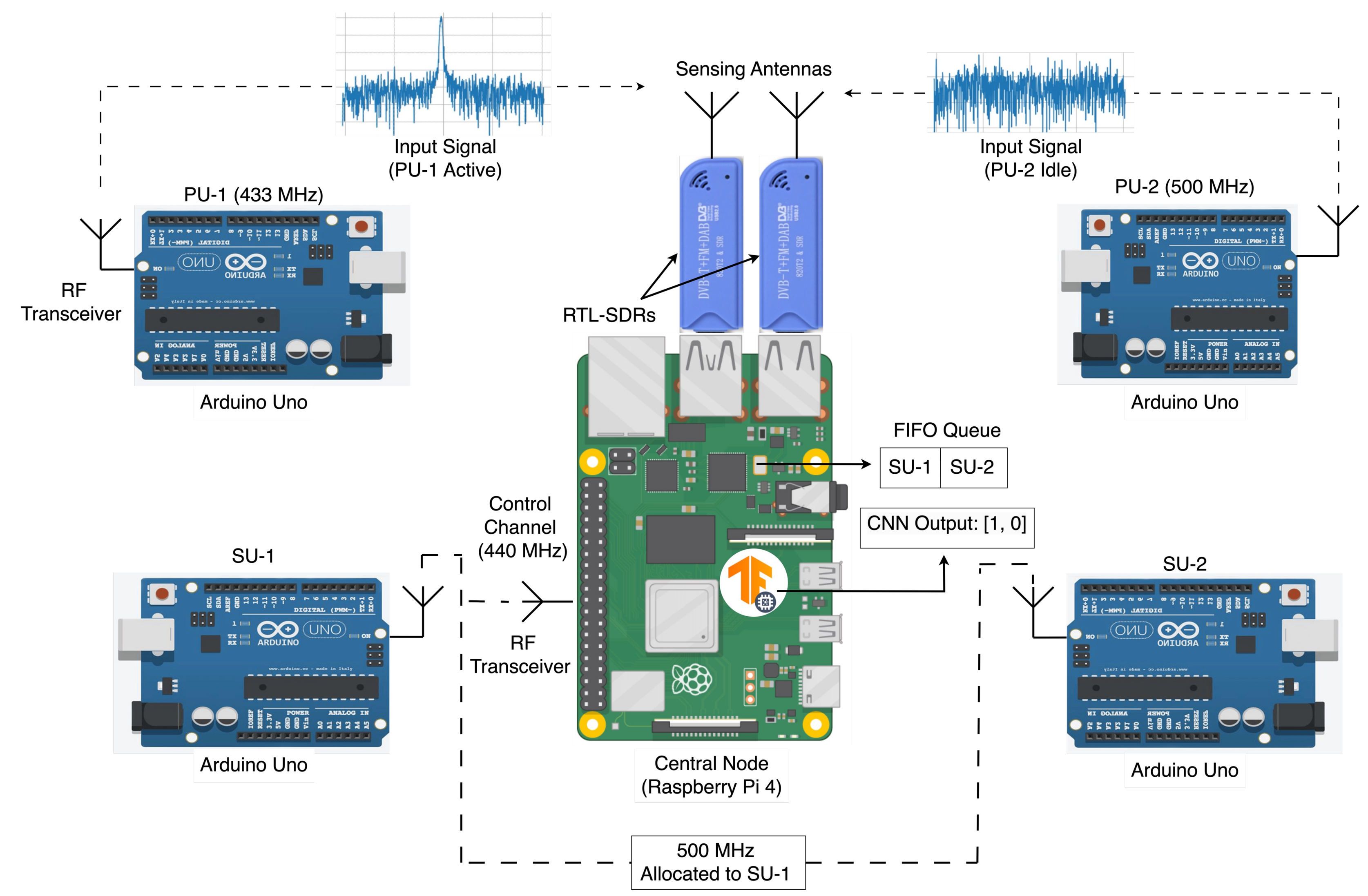

Fig. 2: System architecture and modeled scenario

Results

- Below are the results comparing model performance before and after applying different levels of quantization, presented for both the acquired SDR dataset and our experimentally generated dataset:

Table 1: Performance on acquired SDR dataset

Model	Accuracy (%)	Size (MB)
Baseline (Float 32)	93.73	4.23
Float 16	93.74	2.11
Float 8	91.74	1.06
TF Lite Float 16	93.77	2.02

Table 2: Performance on generated dataset

Model	Accuracy (%)	Size (MB)
Baseline (Float 32)	96.43	16.80
Float 16	96.43	8.40
Float 8	96.40	4.20
TF Lite Float 16	96.18	8.02

- Quantization achieved a **75%** reduction in the model size with no loss in accuracy.
- This ensures **low complexity**, enabling optimal performance for sustainable operation on low-powered devices in real-time applications.

References

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