CNN-Based Signal Modulation Classifier for Shared Spectrum in Cognitive Radio Networks

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Introduction

According to a survey by McKinsey Global Institute, there are over **two billion devices** connected to the internet, and e-commerce activities have reached $8 trillion annually [1]. This massive increase in connected devices and the demand for very fast and high-data-rate applications put a lot of pressure on the wireless frequency spectrum, especially in densely populated city centers.

The electromagnetic (EM) spectrum used for radio communications ranges from 30 MHz to 300 GHz. However, a large portion of wireless communication occurs at frequencies below 6 GHz, which support wide coverage, deep indoor penetration, and high data rates. Despite this, usage of frequencies below 6 GHz is only about 10 to 20%, showing very **low utilization** [2].

Spectrum reframing and millimeter wave technology are two proposed solutions to meet the growing demand for wider bandwidth and higher data rates. Spectrum reframing, which involves reallocating spectrum licenses, is very complex, while millimeter wave technology is still not fully developed. The potential for **shared spectrum** in the <6 GHz bands represents a significant opportunity for more efficient spectrum use to meet the increasing need for mobile connectivity.

Objectives

This project aim to give an holistic yet concise view of the role of **deep learning** in future cognitive radio networks that implements **Shared Spectrum** for high **spectrum utilization**:

- Comprehensive review of exiting spectrum sharing and sensing techniques.
- Develop a CNN-based signal modulation classification system.
- Develop a Deep Learning Processor (DLP) for a custom Deep learning Network and evaluate implementation and timing costs.

Methodology

We used MATLAB Deep Learning and the Deep Learning HDL Toolbox to develop a CNN-based signal modulation classification system as demonstrated in Figure 1. We trained four CNN networks to investigate how filter size affects classification accuracy. Model parameters are summarized in Table 1. Finally, we created a deep learning processor IP block (see Figure 2) for a Xilinx MPSoC board and evaluated the model's resource utilization.

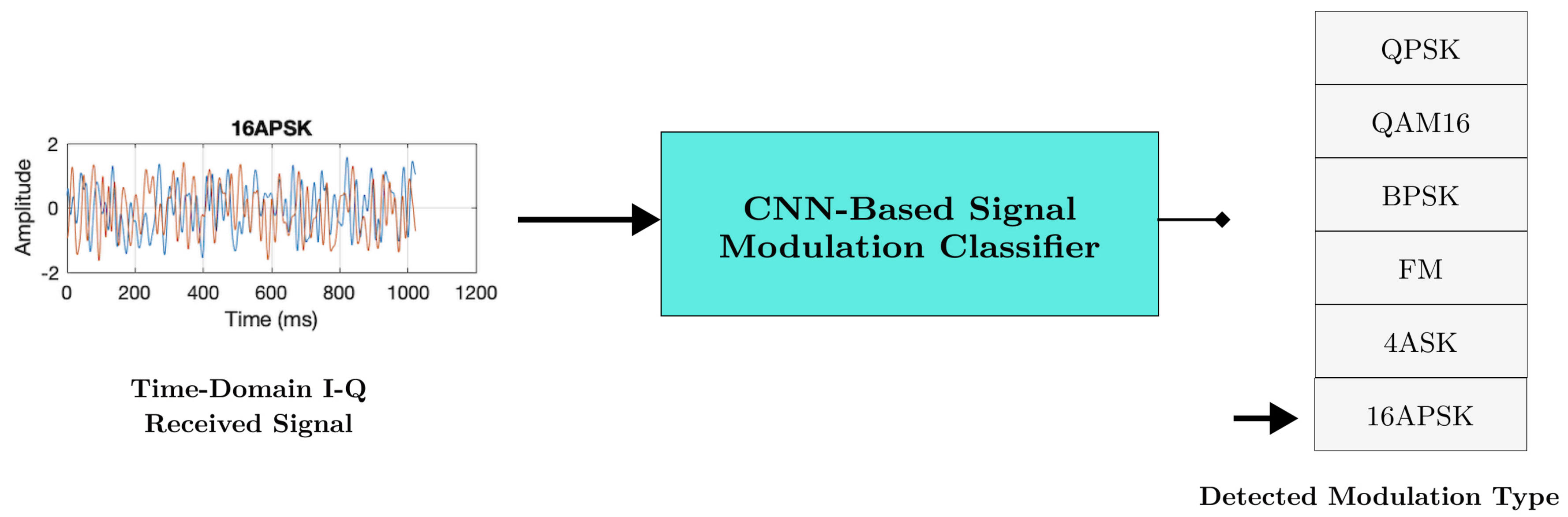

Figure 1:High-level System Architecture

Models	Filter Size	Epochs	Layers
Model I	1x2	20	6CONV 1FC
Model II	1x4	20	6CONV 1FC
Model III	1x8	20	6CONV 1FC
Model IV	1x16	20	6CONV 1FC

Table 1:Trained CNN Models Parameters

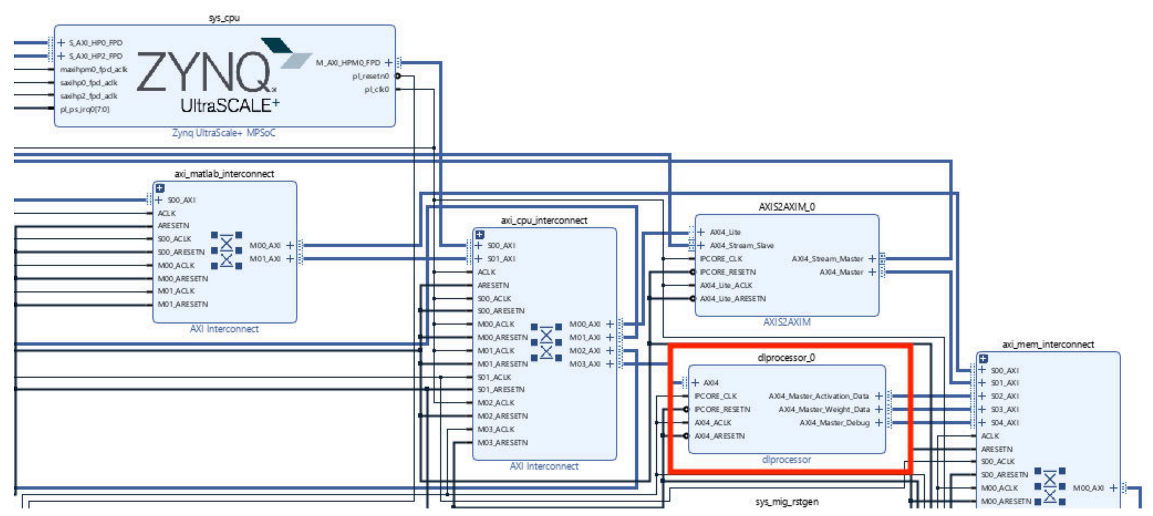

Figure 2:Deep Learning Processor IP

Results

- Experiments have established that CNNs, are **effective** for modulation classification of radio signals (see Figure 4).
- Our investigation revealed a **negative correlation** between the CNN's receptive field and classification accuracy: increasing the receptive field led to poorer results, as shown in Figure 3.
- Best-performing model achieved **91.8%** classification accuracy and was optimized for implementation on the Xilinx Zynq Ultrascale+ MPSoC. All timing constraints for a clock speed of **100 MHz** was met. A summary of the Vivado implementation and timing reports is provided in Table 2.

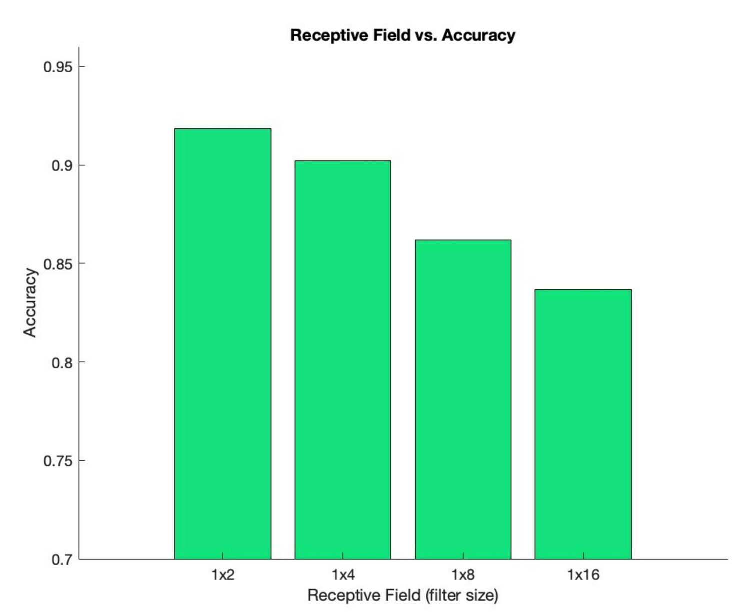

Figure 3:Model Accuracy Vs Receptive Field

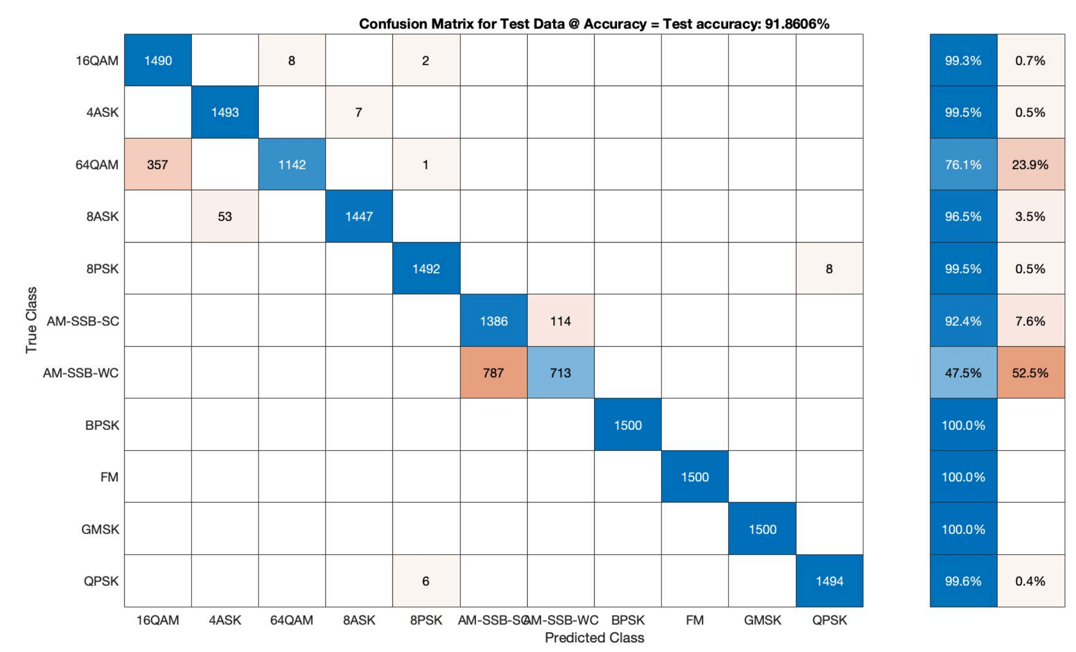

Figure 4:Best Model Performance on Test Set – 91.8%

	LUT	FF	LUTRAM	DSP
Utilization	236554	250539	33290	382
Available	274080	548160	144000	2520
Percentage	86.31%	47.71%	32.12%	15.16%

Table 2:Resource Utilization Report

*All user specified timing constraint was met 100MHz clock speed

Conclusion & Future Work

Shared spectrum has the potential to greatly improve the current underutilization of a large portion of the radio spectrum. The application of CNNs to spectrum sensing and signal classification has proven to be feasible, with further opportunities for improvement in model accuracy, resource utilization, and classification speed (latency).

References

[1] J. Manyika and C. Roxburgh. *The great transformer: The impact of the internet on economic growth and prosperity.* McKinsey Global Institute, 2011.

[2] S. Shi et al. Challenges and new directions in securing spectrum access systems. *IEEE Internet of Things Journal*, 8, March 2021.