OFDM Modulation Order Detection With Convolutional Neural Networks

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Abstract

We study the application of convolutional neural networks to the problem of modulation classification. We compare the efficacy of radio modulation classification using simulated data as well as real data generated with software-defined radios. Using a MATLAB model, we generated OFDM with BPSK, QPSK, 16QAM, 64QAM, 128QAM, and 256QAM modulated subcarriers and added white Gaussian noise at SNRs ranging from 0 dB to 20 dB. This data was used to train a deep convolutional neural network in the Google TensorFlow framework. Subsequent testing resulted in a percent correct of 100% for the simulated dataset at 0 dB SNR. Similar OFDM data was generated using GNU radio's OFDM and then transmitted and received via USRP N200's. The received data was used to train and test the same network, resulting in a percent correct of 93.3%.

Introduction

A large area of research in radio communications is finding ways to increase the efficiency, adaptability, and flexibility with which devices access and operate within the same spectrum. These methods include dynamic spectrum access (DSA), the opportunistic access and sharing of spectrum, as well as cognitive radio, radio optimization with learning algorithms. One of the biggest challenges facing these methods is providing spectrum users with sufficient awareness of their surroundings to avoid creating or being harmed by radio interference with other users. Modulation recognition is this identification of noisy received radio signals, specifically what types of communications schemes are being used, and thus what types of spectrum users are present that may cause interference or may need to be protected from interference. Modulation recognition could also be useful in a cognitive radio underlay - that is, if the modulation order of the underlying OFDM is known, one could potentially determine how much interference a user could introduce without adversely affecting the primary user.

It has been shown in [1] that convolutional neural networks are capable of outperforming cumulant based modulation recognition for digital modulation schemes including BPSK, QPSK, and 16QAM. We wanted to investigate if this performance of convolutional neural networks extended to OFDM modulated signals, as differences in these signals are harder to discern from temporal and spectral characteristics as seen in figure 1.

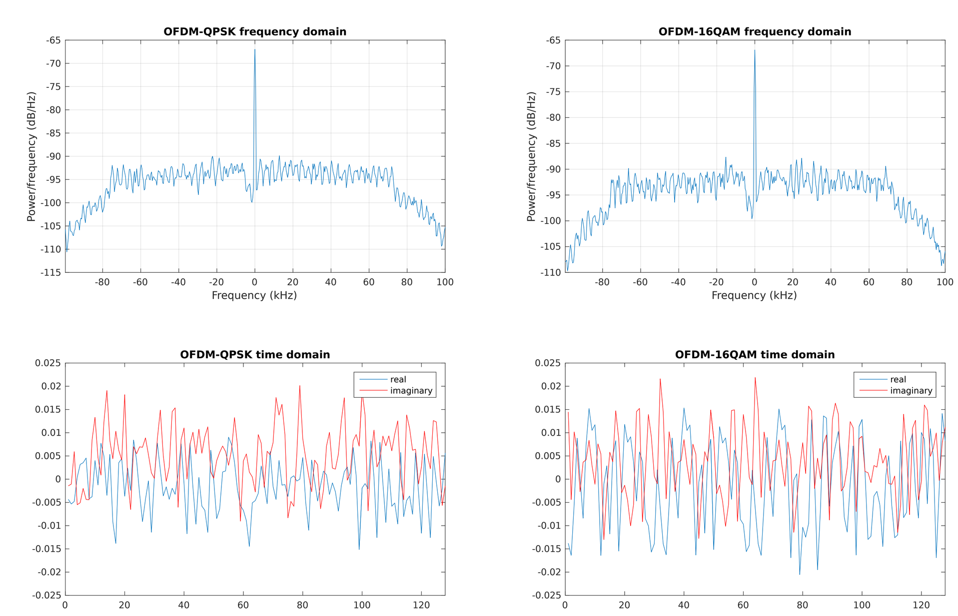

Figure 1: Time and Frequency Domain of QPSK and 16-QAM

Methods

The method under evaluation in this case is a convolutional neural network provided with data generated using a MATLAB model. We focus on a dataset consisting of 64 pt OFDM with 6 digital modulations: BPSK, QPSK, 16QAM, 64QAM, 128QAM, and 256QAM.

The data was used to train against a 4-layer neural network with two convolutional layers and two dense fully connected layers. We use an exponential linear activation function for the first four and a Softmax activation on the final layer to determine the output class. This network is similar to the network used in [1]with a few minor modifications, namely the use of ELU in place of ReLU. We train our network with a 15000 samples training set in batch sizes of 10.

We found that 128 sample inputs were sufficient for good performance using the MATLAB simulated data, while 128, 256, and 512 sample inputs were tested to determine the best sample length for the received data.

It was determined that a 256 sample input yielded the most accurate results for the transmitted data. We created a MATLAB model to generate OFDM with the various modulation schemes at SNRs ranging from 0 - 20 dB as a result of additive white Gaussian noise (AWGN). This data was used to train and test the network to ensure its viability. Once we were satisfied with the performance of the network when trained with noisy simulated data, we turned our attention to real data. Similar data was generated using GNU radio's OFDM block, then transmitted and received using USRP N200's. The network was trained and tested using this received data.

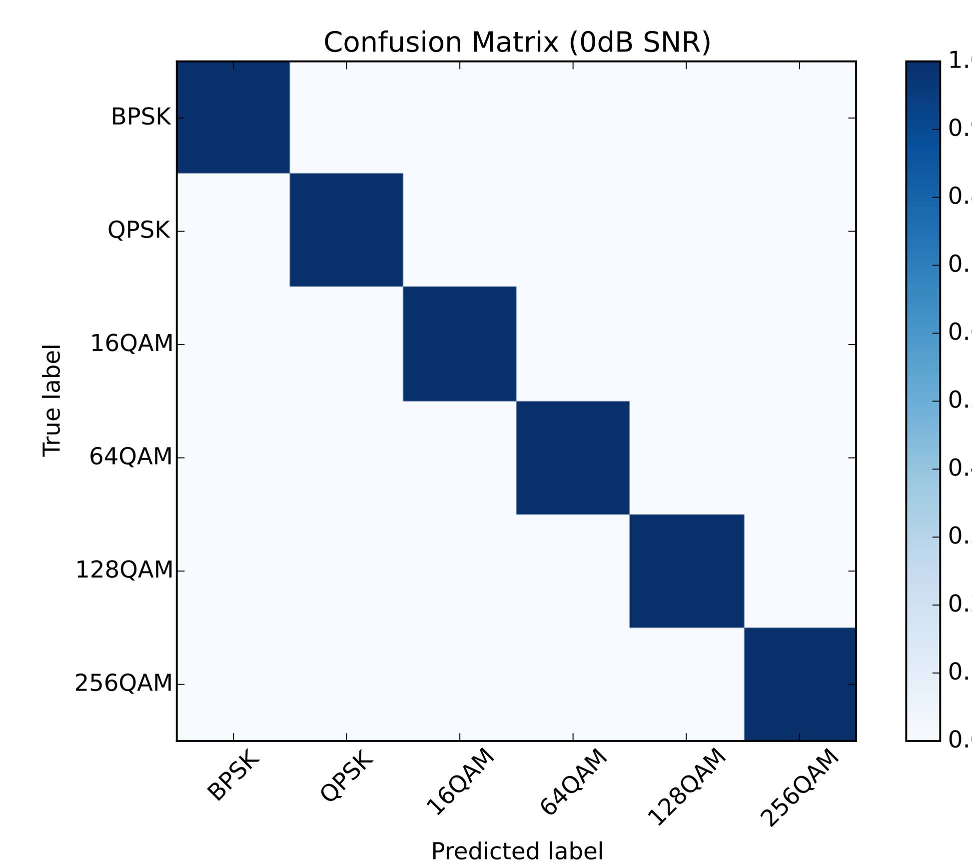

Figure 2: Performance of MATLAB generated OFDM data (0dB SNR)

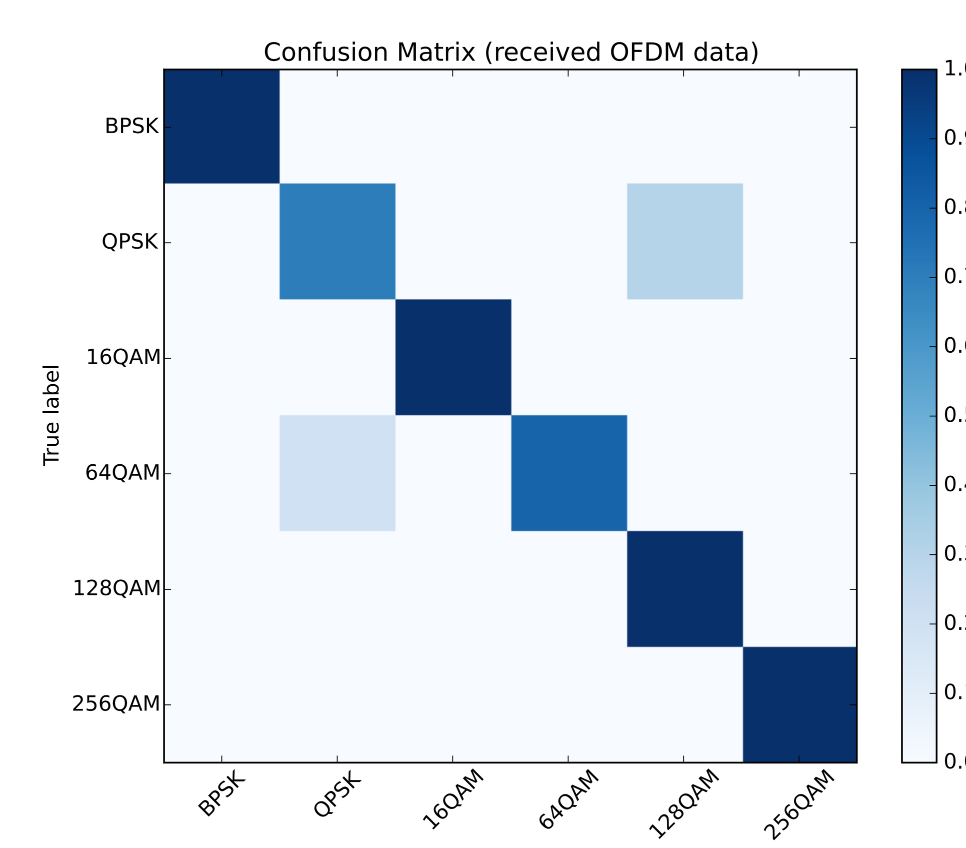

Figure 3: Performance of GNU radio generated OFDM data

Results

After training with the simulated test dataset, we achieve a classification accuracy of 100% for 0 dB SNR as shown by the confusion matrix in figure 2. We also achieve a 93.3% classification accuracy while training and testing with live data captured from the N200s and the corresponding confusion matrix is shown in 3.

Conclusion

We showed that convolutional neural networks can perform well in detecting and classifying modulation order of different OFDM signals despite the fact that temporal and spectral characteristics are seemingly quite similar.

Future Work

In later work, we hope to:

- Reconcile the MATLAB model we used with live data, possibly by including time and frequency offsets in the model
- Determine the feasibility of using MATLAB generated simulation data as training for real transmitted signals
- Incorporate frequency selective Rayleigh fading channel
- Consider OFDM MIMO transmission schemes
- Compare these methods against cumulant based modulation recognition for OFDM
- Create a dataset from a large scale testbed to determine the robustness of modulation classification using convolutional neural networks.

References

[1] Timothy J. O'Shea and Johnathan Corgan. Convolutional radio modulation recognition networks. *CoRR*, abs/1602.04105, 2016.

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