Q-SVM APPLIED TO MULTI-USER DETECTION IN DS-CDMA SYSTEMS

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Abstract

Support Vector Machines (SVMs) are an established classical model that use classification algorithms for two-group classification problems. Quantum computers are expected to be able to identify these groups faster than classical hardware. However, quantum hardware is not at a point where the performance exceeds that of classical hardware. This work makes a performance comparison between classical and quantum SVM algorithms in order to construct an multiuser detector (MUD) for direct sequence code division multiple access (DS-CDMA) signals transmitted through multipath channels.

Keywords: Quantum-SVM; MU-DS-CDMA; Multi-User Detection.

Introduction

Quantum computing is a computational paradigm based on the laws of quantum mechanics, which promises to solve problems that would take classical computing too long to compute due to the size of the data set or the computational power required. In quantum machine learning (QML), many quantum algorithms are developed by adapting classical algorithms or their expensive subroutines to run on a potential quantum computer. There are many algorithms of QML such as solving linear systems of equations, principle component analysis (QPCA) and support vector machines [1]. In this paper, we focus on the quantum support vector machine (QSVM) model in particular.

The Problem

A popular and efficient multiple access technique in cellular mobile communications systems is the Multi-User Direct Sequence Code Division Multiple Access (MU-DS-CDMA). In the MU-DS-CDMA, the data signal of each user is multiplied by a code sequence ($\mathbf{U}_i(z)$). The duration of an element in the code is called the "chip time". The ratio between the user symbol time and the chip time is called the spread factor (M). The transmit signal occupies a bandwidth that equals the spread factor times the bandwidth of the user data. A MU-DS-CDMA receiver can retrieve the wanted signal by multiplying the receive signal with the same code as the one used during transmission. Fig. 1 shows the structure of MU-DS-CDMA System [2].

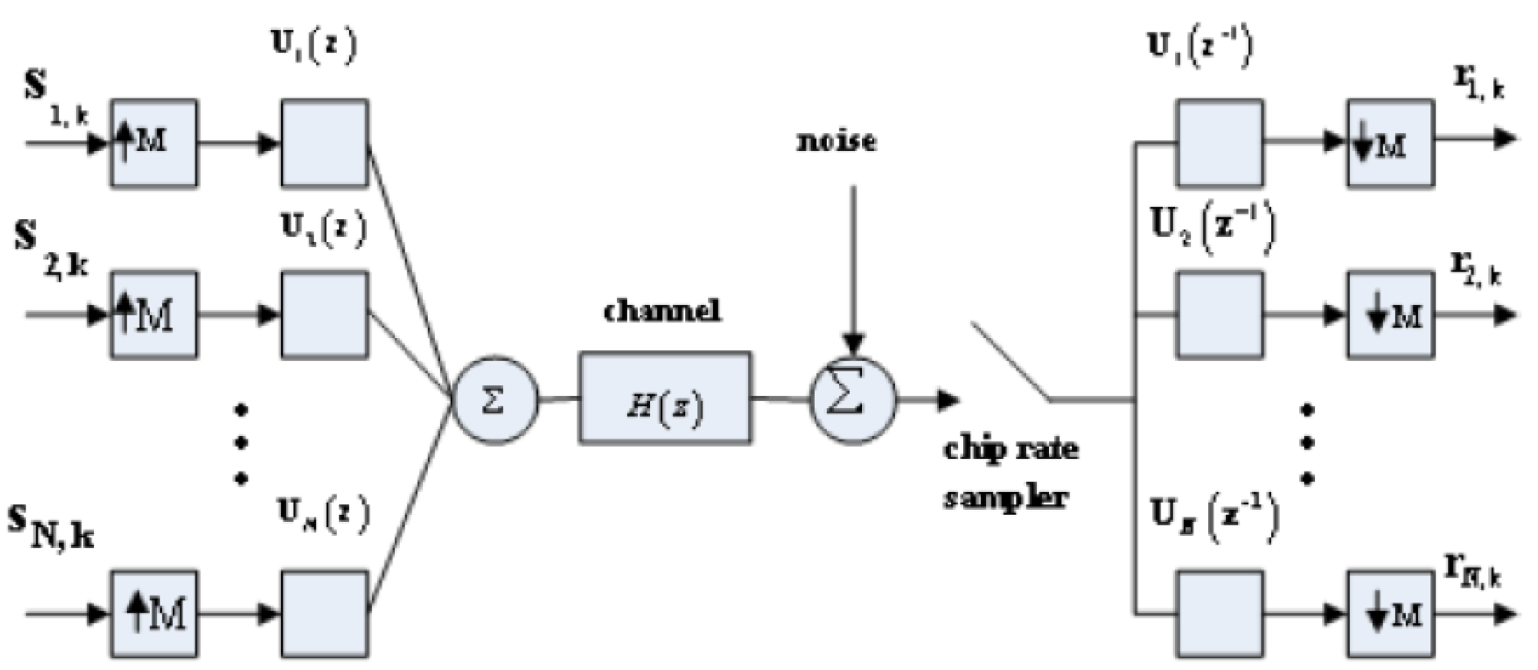

Figura 1: Structure of MU-DS-CDMA System.

The conventional linear detectors, however, fail to achieve good performance when the channel suffers from high levels of additive noise or highly nonlinear distortion, or when the signal-to-noise ratio is poor.

The solution

In order to get around this problem, Quantum Support Vector Machine (Q-SVM) classifier has been considered in implementing of the Multi-User Detector (MUD), because it has the capability of recovering the originally transmitted signals from nonlinear decision boundary cases and explore the quantum parallelism.

Classic SVM uses kernels to handle nonlinearities in dataset classification. However, choosing the SVM tuning parameters and the model that fits the kernel requires experimenting with various parameters and kernel models in search of the optimal model and values. Here we are concerned with kernels that can be evaluated on quantum computers or by quantum simulation [3]. This development is carried out by considering a parameterised quantum circuit $U(\mathbf{x})$ that maps a datapoint $\mathbf{x}$ to the state

$$|\psi(\mathbf{x})\rangle = U(\mathbf{x})\,|0\rangle. \tag{1}$$

The kernel value is then given by the overlap of the associated embedded quantum states

$$k(\mathbf{x}_i, \mathbf{x}_j) = |\langle\psi(\mathbf{x}_i)|\,\psi(\mathbf{x}_j)\rangle|^2. \tag{2}$$

Results

Simulation studies were performed to compare the kernels performance. In order to construct our dataset, we consider two user system with 2 chips per symbol. The chip sequences of the two users were set as (-1, -1) and (-1, 1), respectively [2]. The channel impulse responses used in this simulation is $H(z) = 0.8 + 0.5z^{-1} + 0.3z^{-2}$ and the additive white Gaussian noise (AWGN) has zero mean and variance σ_n^2. The signal to noise ratio (SNR) was set at 10 dB. For Gaussian kernel functions we use the parameter $C = 10$, similar to SNR, and for quantum kernel we make use of regular gradient descent optimization [3]. The Fig. 2 shows the data at the detector input and the performance of each of the tested classifiers. The algorithm was run locally on a quantum simulator provided by PennyLane library for QML[4].

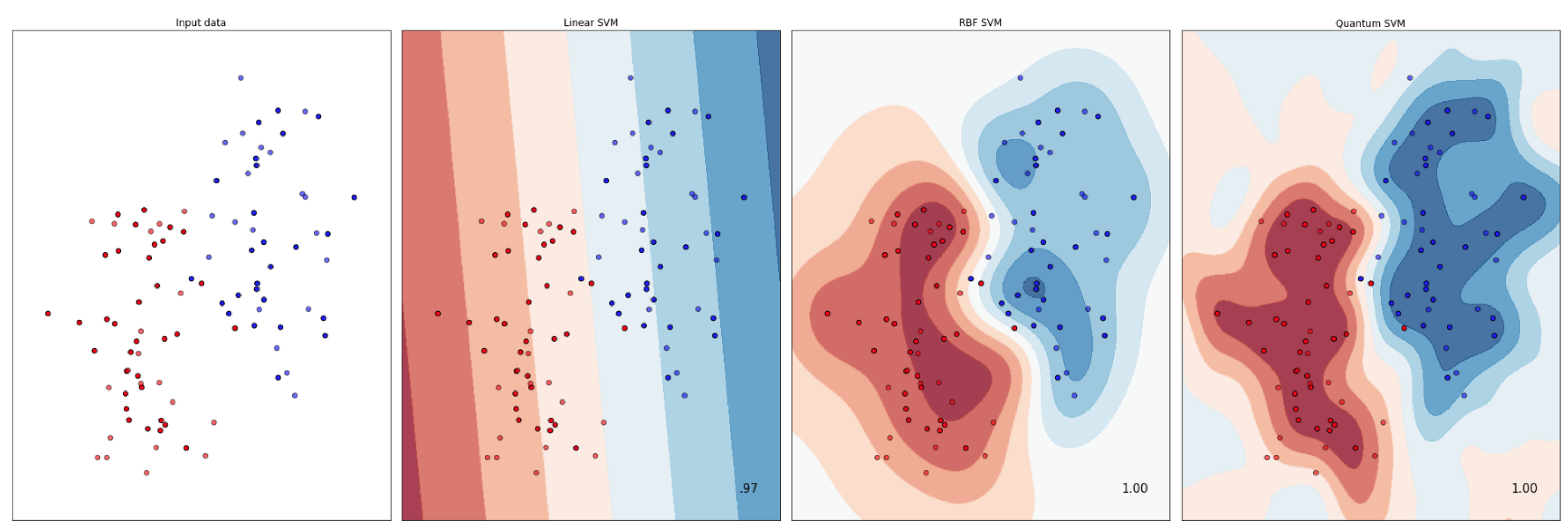

Figura 2: Algorithm performance.

Conclusions

We present a performance comparison between classical and quantum SVM algorithms applied to cellular mobile communications systems Multi-User Direct Sequence Code Division Multiple Access (MU-DS-CDMA). As we can see in Fig. 2, the quantum SVM presents 100% of success in the test set having the same performance of the SVM with RBF kernel, this result confirms the effectiveness of the quantum kernel.

Referências

[1] P. Rebentrost, M. Mohseni and S. Lloyd, *Quantum Support Vector Machine for Big Data Classification*, Vol -14, pp. 3-8, American Physical Society, 2014.

[2] L. Jung-Sik, L. Jae-Wan, H. Jae-Jeong, C. Kyung-Taek. *Multi-User Detection using Support Vector Machines*, The Journal of Korean Institute of Communications and Information Sciences, Volume 34, Pages:1177-1183, year: 2009.

[3] T. Hubregtsen, D. Wierichs, E. Gil-Fuster, P. H. S. Derks, P. K. Faehrmann, J. J. Meyer. *Training Quantum Embedding Kernels on Near-Term Quantum Computers*, arXiv:2105.02276, 2021.

[4] V. Bergholm et al., *Pennylane: Automatic differentiation of hybrid quantum-classical computations.*, arXiv:1811.04968 (2018).

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