Variational Quantum Classifier-based Advanced Anomaly Detection for 6G ORAN

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***Abstract*—The rapid evolution of 6G networks and Open Radio Access Networks (ORAN) faces challenges in ensuring reliability and security. This article proposes an innovative anomaly detection method for 6G ORAN based on a Variational Quantum Classifier (VQC) using 5G-NIDD dataset. The VQC utilizes quantum computing to effectively detect and classify anomalies in dynamic networks. The integration of quantum machine learning with classical techniques enables the VQC to deliver improved accuracy, robustness, and scalability.This model achieved 72% accuracy. The paper presents the architecture, performance analysis based on simulations and real-world data, and a comparison with conventional algorithms, demonstrating the potential of quantum solutions for improving 6G network performance and security.**

***Index Terms*—Anomaly Detection (AD), Open Radio Access Networks (O-RAN), Variational Quantum Classifier (VQC)**

I. INTRODUCTION

A mobile network operator's core network connects mobile devices to a Radio Access Network (RAN), which provides essential radio-related services, like transmitting and receiving data over the airways. A collection of tools and methods known as Open RAN (O-RAN) is meant to increase RAN flexibility, interoperability, and openness. It does so by employing open hardware and software, standard protocols, and open interfaces throughout the RAN [1]. By this method, multiple manufacturers can readily offer compatible hardware and software, thereby enabling mobile network operators to mix different kinds of network components easily. The primary goals of ORAN are the enabling of greater competition, cost reduction, and triggering of innovation in the RAN market [2].

Quanum Machine Learning (QML) models created based on data collected can identify the type of anomaly and trigger a reconfiguration of the network to correct it [3]. One of the major challenges of Anomaly Detection(AD) in the RAN is predicting anomalies so that when they occur, automated action can be taken to alleviate or even avoid service degradation. In order to tackle this problem, in this paper a novel Variational Anomaly Prediction (VAP) framework is proposed that finds possible future anomalies from the forecasted values [4]. A simple workflow diagram shown in Figure 1.

The quantum variational classifier approach offers several advantages over classical methods:

1) Enhanced dimensionality: Leverages quantum superposition to represent complex network states.

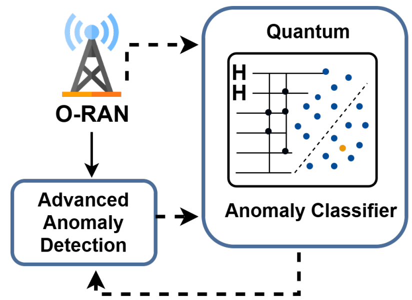

Fig. 1: Systems Workflow Diagram

2) Non-linear classification capabilities: Quantum operations can identify subtle patterns that classical algorithms might miss.
3) Adaptability: The continuous learning feedback loop allows the system to evolve with new threat patterns.

II. SYSTEM ARCHITECTURE

The system diagram represents an architecture for implementing a variational quantum classifier (VQC) approach to anomaly detection in 6G Open Radio Access Networks. The Figure 2 leverages quantum computing advantages while integrating with the O-RAN framework.

1) **6G O-RAN Network Infrastructure:** The O-RU (Radio Unit) handles physical radio equipment and RF signals, while the O-DU (Distributed Unit) processes real-time data and lower layer protocols. The O-CU (Central Unit) manages higher layer protocols and non-real-time functions. The Near-RT RIC optimizes the network in near-real-time, and the Non-RT RIC manages policies in non-real-time for efficient RAN control [5].
2) **Data Collection Preprocessing:** Network telemetry captures performance metrics and traffic patterns. Feature mapping identifies key data for anomaly detection, and data normalization adjusts features for optimal quantum encoding.
3) **Clssical Approach:**
   a) Feature Encoding: Transformation of classical data into quantum states using amplitude or angle encoding techniques
   b) Quantum State Preparation: Creating the initial quantum states for processing in the variational circuit

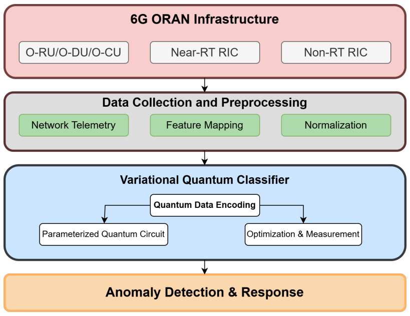

Fig. 2: System Architecture for this proposed model

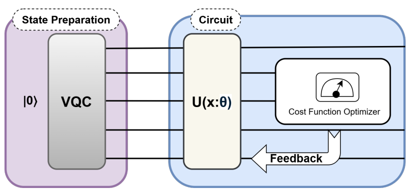

Fig. 3: Variational Quantum Classifier [6]

4) **Variational Quantum Classifier:** Parameterised Quantum Circuit: A quantum circuit for classification uses rotation (Rx, Ry, Rz) and entanglement (CNOT) gates, with multiple variational layers for enhanced expressivity.
   Quantum Measurement: Observable operators provide classification scores, optimized for anomaly detection, with parameters updated via gradient descent in a hybrid classical-quantum training process.
5) **Anomaly Detection & Response:** Anomaly classification identifies potential security threats by analyzing the output of the quantum classifier. The decision engine then determines the appropriate response actions based on the type and severity of the anomaly. Finally, response orchestration implements mitigation strategies through the O-RAN framework, ensuring effective action is taken to address the identified security risks

III. Proposed System

The Figure 3 represents a Variational Quantum Classifier (VQC), where the process begins with the quantum state $|0\rangle$ being encoded using a quantum feature map. The quantum circuit, using the U(x: θ) operator, transforms the data, and the cost function optimizer (classical) fine-tunes the parameters to minimize the model's loss [6]. This hybrid quantum-classical approach allows the model to learn complex data patterns through quantum operations, while classical optimization refines its performance, making it effective for classification tasks.

IV. Result and Analysis

In the Figure 4 optimisation process of a Variational Quantum Classifier (VQC), the plot reflects the typical behaviour of quantum-classical hybrid model training, where fluctuations in the objective function indicate the non-smooth nature of quantum optimisation. VQCs operate in a noisy and non-

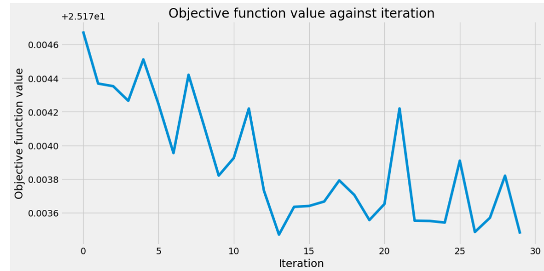

Fig. 4: Optimisation Graph of Variational Quantum Classifier (VQC)

convex landscape, with quantum circuits introducing randomness, leading to instability in the optimisation trajectory. The sharp increase in the objective function suggests a poor update step, likely caused by local minima or saddle points, which is common in quantum optimisation, especially with gradient-free algorithms like COBYLA

V. Conclusion

The Variational Quantum Classifier offers an innovative solution for anomaly detection in 6G O-RAN, achieving 72% accuracy, leveraging quantum computing to enhance network security and performance. Future research will focus on integrating advanced quantum algorithms, improving scalability, and addressing real-time network dynamics. Additionally, advancements in quantum hardware and hybrid quantum-classical systems will further enable practical deployment of VQCs for anomaly detection in next-generation networks.

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