Improving The Energy Efficiency of A 5G Network: The Machine Learning Approach

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Abstract*—5G networks deployment supports large number of devices and requires high data rates, needing too much energy consumption. The need to efficiently manage this energy is a major drive for this work. This work focuses on improving the energy efficiency of a 5G network using machine learning. 5G production dataset generated with G-net track pro was analyzed using Python programming language. The results obtained using the key significant features identified by the significant indicator showed that to avoid over-fitting and for optimal model performance, the number of estimators should not exceed 25 and the maximum depth of gradient descent should not exceed 9. Five algorithms were developed, including random-forest algorithm, gradient boosting algorithm, xgboost algorithm, lasso algorithm and ridge stacking algorithm; the ridge stacking algorithm performed better than the individual algorithms with the root mean square error (RMSE) value of 1.931 and R^2 error of 1.321, being the measure of how best a regression model fits into the data. The xgboost algorithm performed better than all the individual algorithms with RMSE value of 1.943 and R^2 error of 0.114.

***Indexed Terms*—5G, Energy Efficiency, Artificial Intelligence, Machine Learning.**

I. INTRODUCTION

In mobile networks, 80% of the total energy in cellular networks is consumed by base stations and have pivotal importance for energy efficiency improvements (Lahdekorpi, Hronec, Jolna and Moilanen, 2017). Over the past years, technologies such as the Internet of things (IoT) have resulted in billions of connected devices and the generation of an enormous volume of data. It is expected that the traffic volume will increase exponentially and there will be approximately 50 billion devices by 2021 (Panwar, 2016). To improve the coverage and meet capacity requirements, a large number of small cells will be deployed. Small cells make the network denser, which leads to more energy consumption. Furthermore, massive MIMO also increases the power consumption due to more hardware components required for each base station (BS) (Rajoria, Trivedi & Godfrey, 2018). According to (Ericson, 2020), in 2025 the amount of user data will increase four-times compared to today's network. Therefore, there is a need for efficient resource management and spectral sharing for improved energy efficiency. The next-generation networks, such as 5G, are being designed to improve energy efficiency. As a result, energy efficiency will be a significant factor in 5G as compared to earlier generations. (Deepsig.ai, 2022) discussed that a fully operative and efficient 5G network cannot be complete without artificial intelligence (AI) and by integrating machine learning (ML) into 5G technology, intelligent base stations will be able to make decisions for themselves, and mobile devices will be able to create dynamically adaptable clusters based on learned data. This will improve the efficiency, latency and reliability of network applications. (Haidine, *et al*, 2021) stated that AI and ML will unlock the power of software and algorithms that will allow for an efficient deployment of assets and resources.

Several technologies, including software-defined networking (SDN). Ultra-dense networks (UDN), network-function virtualization (NFV). Multi-access edge computing, cloud computing and small cells are being integrated in the 5G network to realize its diverse set of services. These comes with several challenges in terms of energy efficiency, which covers the whole network from the radio access network, core network, data centers and technologies (Mughees, Tahir, Sheikh and Ahad, 2020). Considering the energy constraints and versatile network requirements, traditional approach are not enough for network optimization, hence, machine learning techniques play important roles in assisting in the task of achieving energy efficiency in the network by learning intelligently from data and optimizing the overall operation of the network.

Machine learning are computational systems that are used to learn the discriminative features of a system that cannot be represented by mathematical models. Once a model is trained on the given data, then the model effectively takes decision on unknown data and also performs the tasks based on arithmetic calculations. According to (Sharma, 2022), in machine learning, various kinds of algorithms are used to allow machines to learn the relationships within the data provided and make predictions based on patterns or rules identified from the dataset. AI/ML solutions can help carriers determine where and how to deploy resources to avoid demand crunches and potential service disruptions. Regression is a machine learning statistical technique where the model predicts the output as a continuous numerical value by relating a dependent variable to one or two independent (explanatory) variables, showing whether changes observed in the dependent variable are associated with changes in one or more of the explanatory variables. This is done by essentially fitting a best-fit line and seeing how the data is dispersed around this line (Beers, 2022).

II. MATERIALS AND METHODS

The 5G production dataset of (Raca D., *et al*, 2020) generated from two mobility patterns (static and car) , and across two application patterns (video streaming and file download); composed of client-side cellular key performance indicators (KPIs), comprised of channel related metrics, context-related metrics, cell-related metrics and throughput information was used. These metrics were generated from a well-known non-rooted android network monitoring application, G-Net Track Pro. The Python programming language was used in the analysis.

Given that the dataset is labeled, it will perform the mapping of input function to output function, hence supervised learning as shown in figure 1.

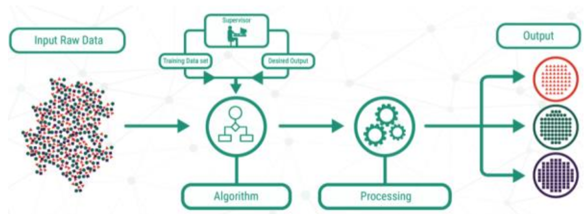

Figure 1: Supervised learning (Kaur, Khan, Iftikhar, Imran & Ul Haq, 2021)

This solves the real-world problem of improving the energy efficiency of the 5G network by first predicting the numerical target values from the 5G production dataset that plays important roles to achieving the set goals.

The dataset which came in thirty-five (35) different sets, were merged together. It was then cleaned by removal of outliers, removal of inconsistent data points, encoding non-numeric data points and descriptively renaming the columns (features).

The production dataset was normalized using the logarithm method in the numpy library. This is because machine learning performs well with normalized data, i.e. data set with no extreme values capable of biasing the decision boundaries of machine learning algorithms.

The statistical distribution of each feature was explored by checking the minimum value, the maximum value, the mean, the standard deviation, the variance, the quartiles and the median points.

The Pearson correlation method was used to investigate the relationships between the variables (features) of the production dataset.
Different regression analysis techniques, including random-forest algorithm, xgboost, gradient boosting, ridge and lasso regression techniques were employed.

III. RESULTS AND DISCUSSION

The Pearson correlation results of (Okpara, Idigo and Okafor, 2023) shows that highest correlation value of 0.78 exists between the reference signal power and the received signal reference power of the neighbouring cells (nrxRSRP). Using the significant indicator, (Okpara, Idigo and Okafor, 2023) showed the seven most important features of the production dataset of (Raca D., *et al*, 2020) and that the signal to noise ratio is the most significant key feature. Furthermore, (Okpara, Idigo and Okafor, 2023) using scatter plots showed that the key features of the production dataset have good linear relationships amongst them.

In determining hyper-parameters for optimal performance in improving the energy efficiency of a 5G network and to avoid over-fitting, we found that the number of estimators should not exceed twenty-five (25) and that the maximum depth of gradient descent should not exceed nine (9) as shown in figure 2 and figure 3 respectively.

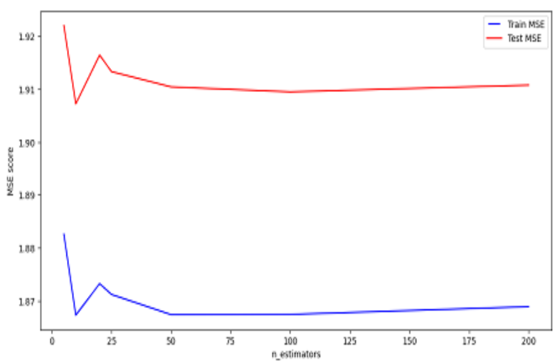

Figure 2: Determination of number of estimators for optimum performance.

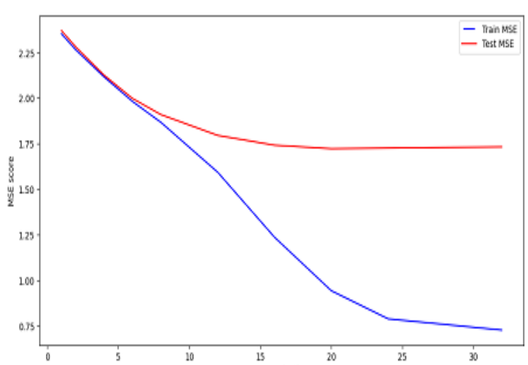

Figure 3: Determination of maximum depth of gradient descent for optimal performance.

The seven most important features determined using the significant indicator were used to train and test the models. The results of figure 4 shows that given the developed algorithms: the random-forest, the lasso, the gradient boosting, the xgboost and the ridge stacking regressor; the ridge stacking regressor which combined all the model outputs performed better than all the individual models with the least root mean square error (RMSE) value of 1.931 and the highest R^2 value of 0.132, being the measure of how best a regression model fits into the data. The xgboost regressor algorithm performed closest to the stacking algorithm, and it is the best of all the individual algorithms with RMSE value of 1.943 and (R^2) value of 0.114.

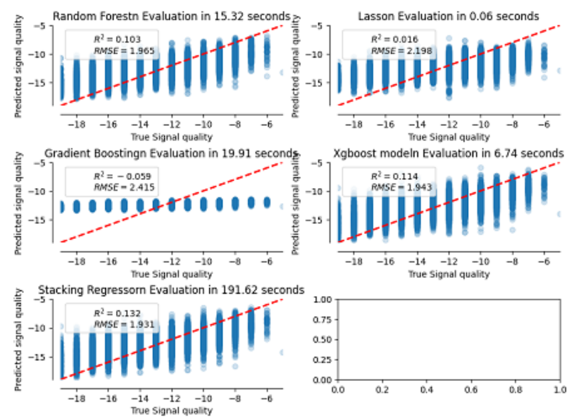

Figure 4: predicted signal vs. true signal quality.

The second-best algorithm is the random-forest algorithm with RMSE value of 1.965 and R^2 value of 0.103.

CONCLUSION

This work sets to answer the question of how to improve the energy efficiency of a 5G network using machine learning. The Python programming language was the tool of use. From the results obtained in choosing the hyper-parameters for optimal performance and to avoid over-fitting during modeling, the maximum number of estimators (trees) should not exceed twenty-five (25) and the maximum number of gradient descent should not exceed nine (9).

Using the identified seven most significant features of the production dataset to train and test various algorithms, including the random-forest algorithm, the lasso algorithm, the gradient boosting algorithm, the xgboost algorithm and the ridge stacking regressor algorithm. The results obtained showed that the stacking regressor algorithm outperforms the individual algorithms, and that the xgboost algorithm proved to be the best out of the individual algorithms.

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