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Impact of Regional Weather on PLC-based Data Transmission in Peninsular Malaysia and Nigeria

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ABSTRACT

This paper investigates the potential impact of weather on power line communication (PLC) based systems concerning Throughput. A proposed multi-linear regression-based neural network (MLR-NN) model predicts regional performance of PLC-based data transmission in Malaysia and Nigeria. The paper evaluates the prediction using ITU–T G.9960 which recommends 85–98% Throughput performance for wireline-based technologies like PLC. This paper considers related works from US and China for comparison. The regional performance prediction in Peninsular Malaysia is 71.62%, while Nigeria's regions; Northeast (99.97%), Northwest (79.85%), Northcentral (96.59%), Southeast (81.89%), Southwest (86.32%), and Southsouth (74.46%). Wind analysis in Eastern China showed a high data fitness value (0.995), while in Malaysia (0.985) and Nigeria's regions (0.980–0.989). Thunderstorms analysis in Southwest US showed lower data fitness (0.630) compared to Malaysia (0.970) and Nigeria's regions (0.870–0.980). The data fitness (R-square) describes suitability, and strength for reliable ML-based analysis as utilized in this paper.

Keywords: Power Line Communication (PLC), Weather, Throughput MLR-NN, Malaysia, Nigeria

INTRODUCTION

Power Line Communication (PLC) is a promising technology that supports data transmission over traditional power distribution lines. The primary function of power lines is to supply stable electricity. Power industries can also utilize the lines to deliver reliable communication data. The technology transmits high-frequency through electrical infrastructure. Power lines support waves at higher frequencies and, therefore, when combined with modulating these signals, can give rise to PLC [49]. PLC allows traditional power consumers to enjoy communication data [33]. It utilizes an operating frequency of 30 Hz – 2500 MHz, splitting into 30 Hz –500 kHz and 10 MHz–2500 MHz for narrow and broadband PLC-based data transmission, respectively, while operating data rates of PLC are 120 bps – 1 Mbps and 10 Mbps – 1.8 Gbps for narrow and broadband, respectively [26]. For quality data transmission, practical and industry-specific signal-to-noise ratio (SNR) is 20 dB and above [24]. PLC has several applications, such as in; smart grid system, systems, resource allocation, utility management remote monitoring, metering system, supervisory and control, hybridization, cybersecurity, etc. [11]. The capability of PLC-based transmission depends on a number of factors including; power and data technology, line quality, equipment, line and load capacity, network resources and requirements, modulation and coding schemes, error correction mechanisms, environment, and so on [20]. PLC technology offers a promising future in communication by ensuring stable communication. For effective implementation, it requires several considerations, such as cable type, range, noise, topology, cross-bonding, etc. [21]. The PLC-based transmission system is utilized to provide stable power and reliable data.

The environment has the potential to cause challenges that affect the stability and reliability of power and communication data, respectively, over a PLC-based network system. The environmental challenges are mostly natural; driven by weather. Other challenge-causing factors include; trans- mission distance, construction, industries, pollution, corrosion, existing technologies, licenses, standards, etc.). Adverse weather conditions affect the performance of communication networks; hence, there is a need to investigate such conditions to optimize networks to make them robust to the changing weather conditions [15]. The effect of weather conditions such as solar radiation, humidity, temperature, and rain is important to analyze the impact on propagation [16]. Weather-related events are responsible for about 50 percent of the disruptions of electrical power grid. Such events continue to disrupt power lines [18]. Weather conditions along over-head power lines change significantly, which causes a significant impact on line ampacity [19]. Varying weather conditions affect the conductivity of power lines for effective transmission. These conditions are emergencies (wildfires, rain, humidity, storms, temperature, wind, etc.) that require absolute attention to reduce their impact on communication infrastructures [12]. Scientists expect Malaysia to experience stronger tropical cyclones due to rising temperatures linked to climate change [26]. Apart from technical considerations and due to the concern of transmitting data over high- voltage lines, Malaysia's Tenaga Nasional Berhad (TNB) formalize structure of PLC systems at higher data rates over 1 Mbps [21]. The multiple ecological zones in Nigeria have created a wide range of practices that are affected by climate change [39]. Weather has the potential to influence communication data by causing several transmission-related challenges such as interference, attenuation, loss, and disruption. The challenges vary depending on main and significant weather conditions. Due to differences in climatic characteristics, weather conditions vary in Malaysia and Nigeria, and as such, their potential impact differs regionally.

The contribution of this paper includes;

- Investigation of multiple and significant weather conditions (air pressure, thunderstorm, rainrate, windspeed, relative humidity, temperature, etc.) that potentially influence data transmission rate over PLC- based power lines in Peninsular Malaysia and Nigeria.

- Investigation of network specifications of PLC system regarding data transmission such as operating frequency, Throughput, SNR, etc.
- Proposes an 'MLR-NN', a multi-linear regression based on neural network technique of machine learning (ML) that analyzes impact of weather on PLC system with respect to data transmission rate.

DATA AND METHOD

This paper utilizes a mathematical (regressive) relation- ship between weather conditions to analyze their impact on PLC-based data transmission. It proposes a multi-linear regression-based neural network (MLR-NN) model that explores the influence of significant weather conditions on PLC-based transmission regarding data transmission rate (Throughput). Regional historical weather is obtained from the Universiti Putra Malaysia (UPM) and the Nigerian Meteorological Agency (NiMET) for Peninsular Malaysia and Nigeria, respectively.

Regions of Interest

This paper considers two geographical locations: Peninsular Malaysia, and Nigeria. Malaysia is a Southeast Asian country characterized with Tropical Rain- forest Climate which has extreme weather such as rainfall, thunderstorms, humidity, temperatures, and so on. Malaysia's climate is sub-categorized into Equatorial and Monsoon at Peninsular (West coast) and East coast; respectively [50]. Nigeria, located in the western part of Africa, has six different regional climates with varying characteristics [47]. Nigeria's Northeast region experiences a warm desert (arid) climate character- ized by extreme temperatures, high wind and storms, and low rainfall. Northwest has a semi-arid (semi-desert) climate with features such as; high temperature, high wind/storm, and low rainfall. The Northcentral region has a tropical Savannah climate characterized by moderate weather. The southern regions (Southeast, Southwest, and Southsouth) experience Tropical Rainforest (Monsoon) climate characterized by frequent rainfall and thunderstorms, high air pressure and wind speed.

The figure shows the geographical regions (Peninsular Malaysia and the six Nigerian regions) considered in the paper.

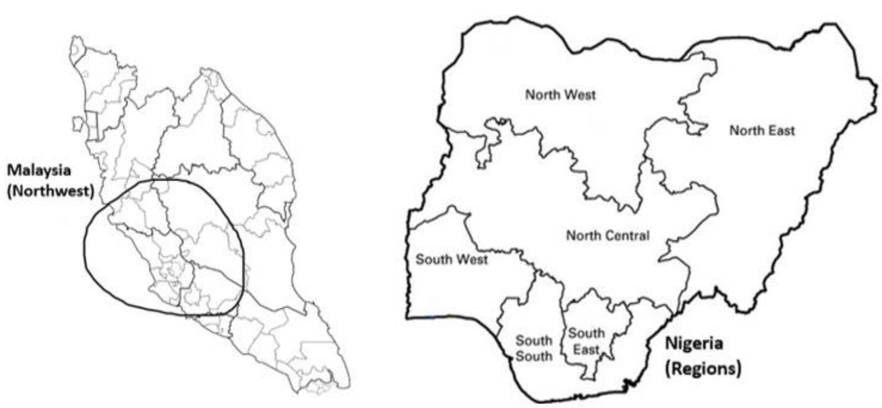

Figure 1: Regions of interest in Malaysia and Nigeria

Malaysian and Nigerian regions have variations in physical and climatic characteristics which have varying impact on data transmission rate (Throughput) over weather-exposed power lines.

Parameters

Relevant parameters were processed using ML to develop the model proposed in this paper. They comprise historical weather conditions, and some adopted PLC-based transmission specifications (operating frequency, Throughput, signal-to-noise ratio (SNR), etc.). Processing of the parameters analyzes their potential impact on PLC-based Through- put. The design and performance parameters are described in Figure 2 below.

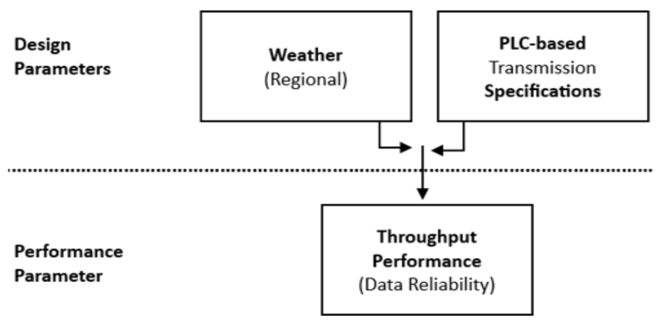

Figure 2: Parameters

The design parameters which consist of regional weather conditions were collected from UPM and NiMET for Peninsular Malaysia and Nigeria respectively. Main transmission specifications of PLC system were also involved in the analysis. The specifications were adopted from existing works that discuss a broad overview of PLC concept and its practical requirements [24, 25].

Table 1: Parameters.

Parameter	Range	Unit
Humidity	20 – 98	%
Air Pressure	953.80 – 1053.80	hPa
Rainrate	0.01 – 64	mm/hr
Temperature	9.00 - 39.20	°C
Windspeed	4.00 – 16.00	km per hour
Thunderstorms	1.00 – 29.00	Thunder-Days per Month
Frequency	0.000003 – 2500	MHz
Throughput	0.00 – 1800	Mbps
SNR	0 - 20	dB

Sources: UPM (2024), NiMET (2024), [24], [25]

Proposed 'Multi-Linear Regression-based Neural Network (MLR-NN)' Model

The proposed model, MLR-NN, is a multi-linear regression-based model developed from the neural network technique of machine learning. It aims to analyze the impact of multiple and significant weather conditions on PLC-based transmission concerning data rate in Malaysia and Nigeria.

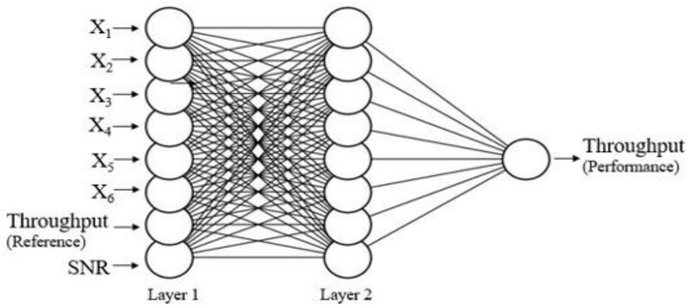

Figure 3: 2-Layer Structure of MLR-NN

Figure 3 shows structure of the MLR-NN describing the design parameters (weather and transmission specifications), ML-based data transformation, and performance parameter (Throughput).

MLR-NN is structured in a 2-layer architecture. The function of each layer is described below;

- Layer 1 takes in the parameters for ML–based task of predicting impact analysis. It consists of the significant weather conditions (represented by X1–X6), and PLC-based transmission specifications (such as Throughput, and SNR) adopted from existing research [24, 25].
- Layer 2 enables the model to learn and train on the parameters to provide reliable prediction.

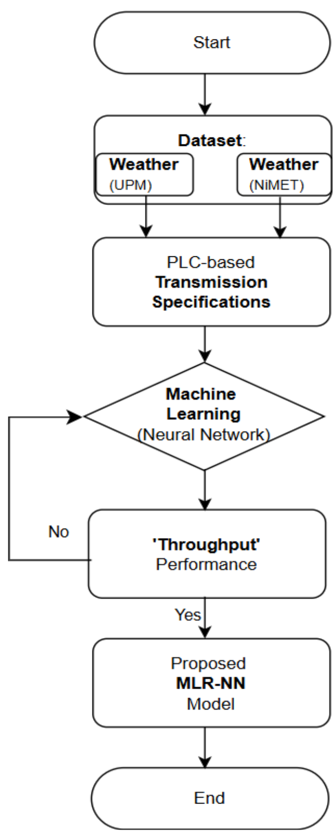

Figure 4: Development Process of MLR-NN model

Figure 4 shows the development process of MLR-NN. Dataset consists of historical weather conditions collected from UPM and NiMET for Malaysia and Nigeria respectively. The dataset also comprises some PLC-based transmission specifications adopted from existing works [24, 25]. MLR-NN analyses the weather impact at each Malaysia and Nigerian region.

The ML aspect of MLR-NN predicts the weights of the parameters (Table 1). The weight quantifies the heaviness of potential impact of each parameter on the transmission. Regression assessment is carried out using the predicted weights to analyze the impact of weather conditions on PLC-based power transmission systems.

Fundamental Equation

The impact of regional weather conditions on PLC-based data transmission is assessed based on the re- aggressive relationship between the parameters (weather and transmission) as described in Equation 1.

$$T = T_o.e^{-}(a_1X_1 + a_2X_2 + a_3X_3 + \ldots + a_nX_n) \tag{1}$$

where:
'T' is a throughput (Mbps) been impacted by weather conditions, 'To' is the reference operational Throughput, 'e' is the transformational function that processes the decaying impact of weather on Throughput, 'X' represents a parameter (weather or transmission), and 'a' represents weight of parameter in impacting PLC system.

RESULTS

Weather analysis aims to assess its regional influence on PLC-based systems with respect to data transmission rate (Throughput). The dataset is validated using real-time weather processing and appropriate electronic equipment. This section provides simulated results on the potential impact of weather conditions on a PLC-based transmission system in selected Malaysian and Nigerian regions. MLR-NN is not limited to Malaysia and Nigeria only; it can be deployed to other communication technologies and regions with additional weather and transmission information. The results are categorized into assessment of regional spread of weather conditions on the PLC system regarding data transmission, and predictions of weights of the parameters utilized in the analysis.

Weather Spread on PLC-based Transmission

Regional regressive assessment is carried out using a MATLAB script to show a prediction on distribution of significant weather conditions on PLC-based transmission systems (with reference to recommended ITU-T G.9960 transmission specifications) in Peninsular Malaysia and Nigeria.

Figures 5 to 11 show prediction on the spread of significant weather conditions on PLC-based transmission. The figures describe distribution of regional weather conditions on PLC-based transmission. The distribution proves that as the conditions spread, they potentially cause impact on the transmission. The spread of the conditions is within the range of PLC-based transmission range.

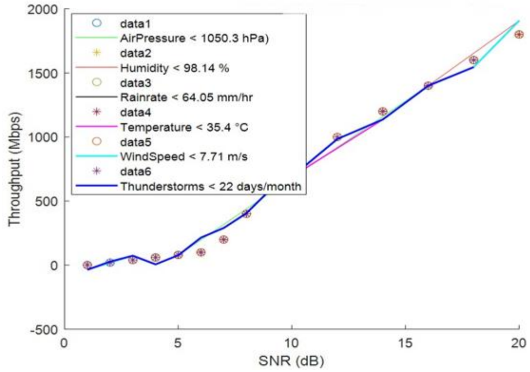

Figure 5: Weather Spread (Peninsular Malaysia)

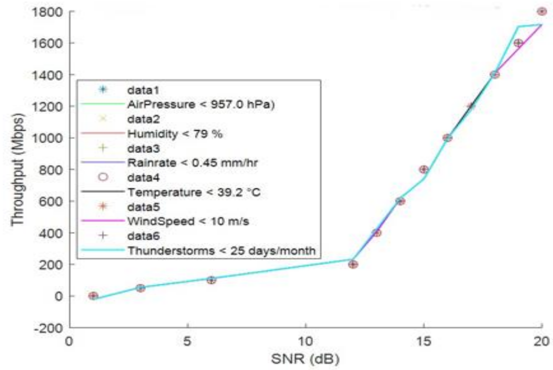

Figure 6: Weather Spread (Northwest, Nigeria)

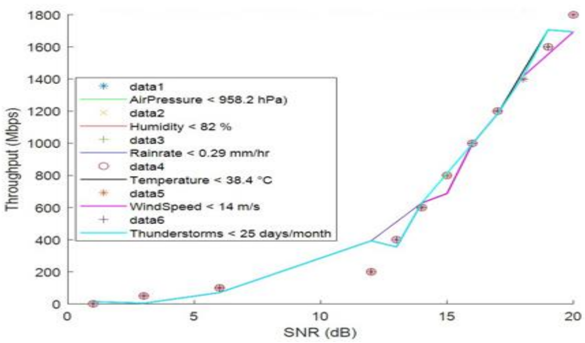

Figure 7: Weather Spread (Northeast, Nigeria)

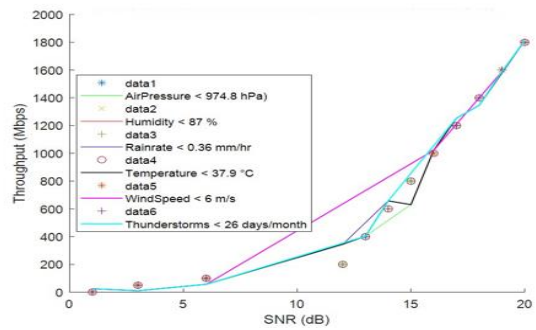

Figure 8: Weather Spread (Northcentral, Nigeria)

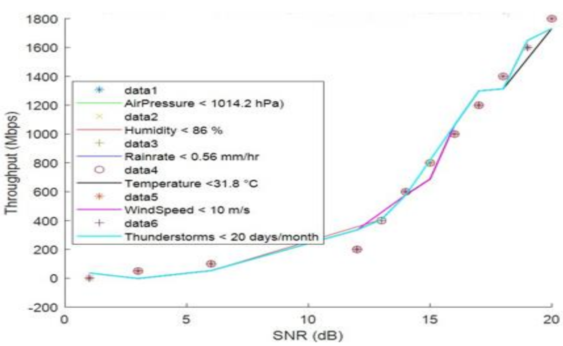

Figure 9: Weather Spread (Southwest, Nigeria)

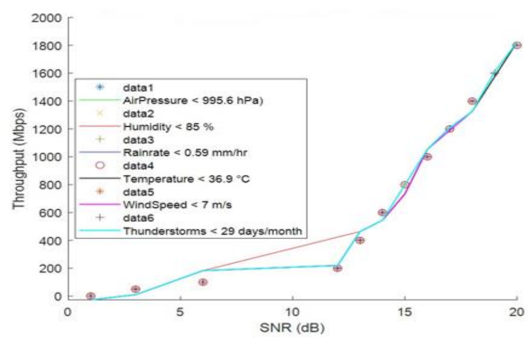

Figure 10: Weather Spread (Southeast, Nigeria)

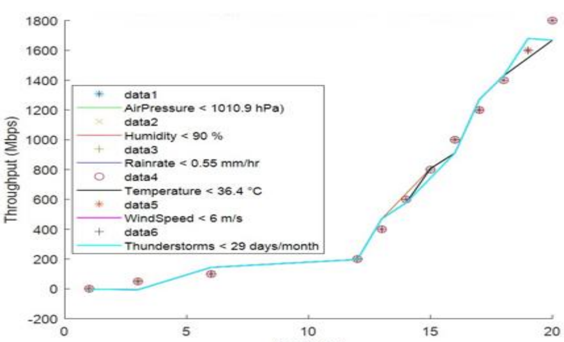

Figure 11: Weather Spread (Southsouth, Nigeria)

Weighting of Parameters

This subsection describes how MLR-NN utilizes ML to predict the weight of parameters (Table 1). The weights are quantification coefficients that indicate the heaviness of parameters (weather and trans- mission specifications) in analyzing their impact on the PLC data transmission. The predicted weights are analytically utilized to regressively assess (Equation 1) the effect of regional weather conditions on PLC-based systems concerning data rate (Throughput) in Peninsular Malaysia and Nigeria. The prediction is developed using a Python script that is supported on the Google Colab.

Figure 3 shows the structure of the proposes MLR-NN model been utilized in this paper. The figure describes ML processing on parameters (weather conditions and transmission specifications). The ridge regression feature is considered during the ML training based (neural network regression) because of its data features' inclusive advantage. The ridge adds a penalty term that shrinks competing data features towards zero without eliminating them, thereby allowing every data feature to contribute in the prediction.

Table 2 provides the predicted weights of the parameters involved in the analysis. A weight describes heaviness and significance of a particular parameter in influencing the PLC-based transmission. In the analysis, the smaller a weight of a parameter is, the significant and heavy such parameter is.

Table 2: Predicted Weights of Parameters.

Parameter		**Weight**
	Peninsular Malaysia	
Rainrate		0.0154
Air Pressure		0.0394
Temperature		0.0123
Humidity		-0.0764
Windspeed		0.1306
Thunderstorms		0.2770
SNR	**Northwest, Nigeria**	-3.4557
Rainrate		4.2566
Air Pressure		-0.0211
Temperature		0.1305
Humidity		-0.1112
Windspeed		-0.1702
Thunderstorms		0.1098
SNR		-8.7479
	Northeast, Nigeria	
Rainrate		2.2184
Air Pressure		0.3464
Temperature		0.1786
Humidity		-0.0350
Windspeed		0.0226
Thunderstorms		0.0169

SNR		-8.1835
	Northcentral, Nigeria	
Rainrate		1.39734
Air Pressure		0.3840
Temperature		0.4553
Humidity		0.0026
Windspeed		0.1447
Thunderstorms		0.0070
SNR	**Southwest, Nigeria**	-7.44705
Rainrate		2.0308
Air Pressure		-1.2101
Temperature		-0.7970
Humidity		-0.1364
Windspeed		0.8421
Thunderstorms		-0.0756
SNR		-8.5439
	Southeast, Nigeria	
Rainrate		-3.4981
Air Pressure		0.0871
Temperature		0.0172
Humidity		-0.0522
Windspeed		0.4994
Thunderstorms		0.1206
SNR		-5.7099
	Southsouth, Nigeria	
Rainrate		-0.0455
Air Pressure		0.3742
Temperature		0.5289
Humidity		0.0097
Windspeed		0.4264
Thunderstorms		0.0062
SNR		-8.0106

Assessment of Weather Impact on PLC-based Transmission Systems

The MLR-NN predicted weights of parameters are regressively processed to assess the overall potential impact of the regional weather conditions on transmission. With reference to PLC-based transmission specifications. Equation 1 is utilized for the weather impact assessment.

Figure 12 shows percentages of regional performance of Throughput as predicted in Peninsular Malaysia and Nigeria.

The ITU-T G.9960 (2009-2023) standard recommends that performance of throughput should be 85- 98% for wireline networks such as PLC system, Ethernet, Telephone, etc. Throughput performance is predicted in Peninsular Malaysia to be 71. 62%, and in Northwest, Northeast, Northcentral, Southwest, Southeast and Southsouth regions of Nigeria is 79.85%, 99.97%, 96.59%, 86.32%, 81.89%, and 74.46% respectively. Prediction below the G.9960 recommendations (85-98%) indicates that weather conditions of a particular region do not support favourable PLC- based data transmission.

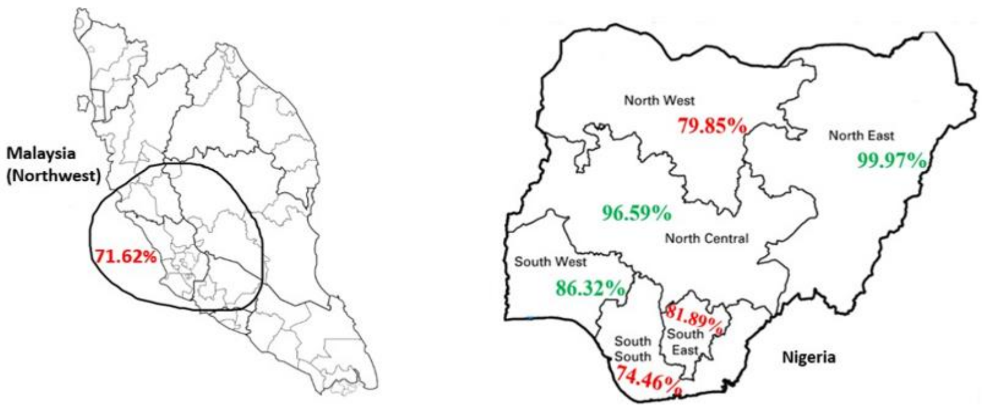

Figure 12: Throughput performance under potential impact of weather in Peninsular Malaysia and Nigeria.

Regressive analysis was carried out to assess impact of wind characteristics on transmission line in eastern region of China [45]. Considering the wind, Table 3 compares computational performance of ML process in China and regions of interest in this paper.

Table 3: ML-based Performance on the Impact of Wind on Transmission Lines

Region	Proposed Model	R-Squared
[45]	RNDA	0.995
Peninsular Malaysia	MLR-NN	0.985
Northwest, Nigeria	MLR-NN	0.953
Northeast, Nigeria	MLR-NN	0.980
Northcentral, Nigeria	MLR-NN	0.966
Southwest, Nigeria	MLR-NN	0.984
Southeast, Nigeria	MLR-NN	0.989
Southsouth, Nigeria	MLR-NN	0.978

where: RNDA: Regressive Nonlinear Dynamic Analysis. MLR-NN: Multi-Linear Regression-based Neural Network.

The R-square describes suitability and fitness, etc. of dataset being utilized in ML process. In both regions, dataset has shown suitability and fit into process (ML) indicated by R-square (0.9), hence; prediction is reliable. Regressive examination was carried out to analyze impact of thunderstorm on power transmission lines in Southwestern US [18]. The analysis shows that thunderstorms cause about 47% potential destructive impact on the transmission. Like in the analysis at Southwestern US, this paper examines thunderstorm by analyzing its potential impact in the regions of interest (Figure 1).

Figures 13 to 19 show prediction on the potential impact of thunderstorms on transmission lines in Peninsular Malaysia and Nigeria.

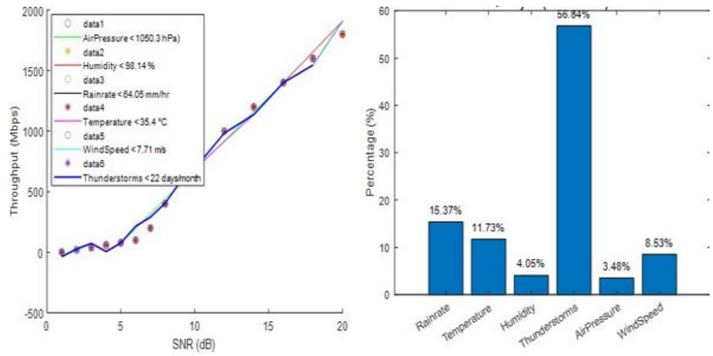

Figure 13: Percentage impact of Thunderstorms on power transmission lines in Peninsular Malaysia (56.84%)

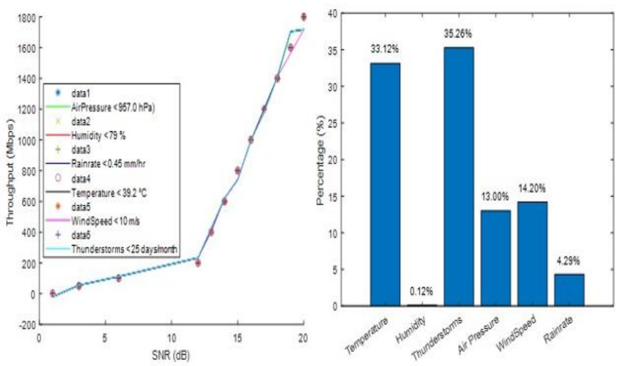

Figure 14: Northwest-Nigeria (35.464%)

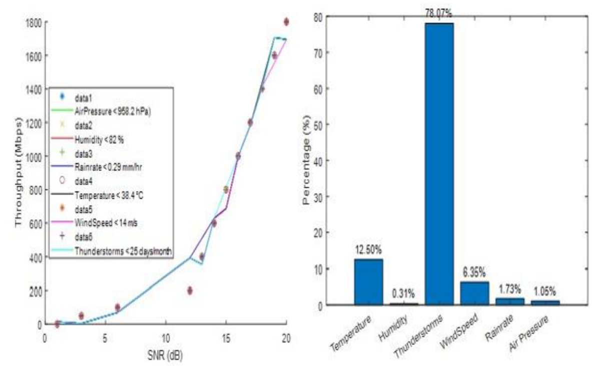

Figure 15: Northeast-Nigeria ((78.074%)

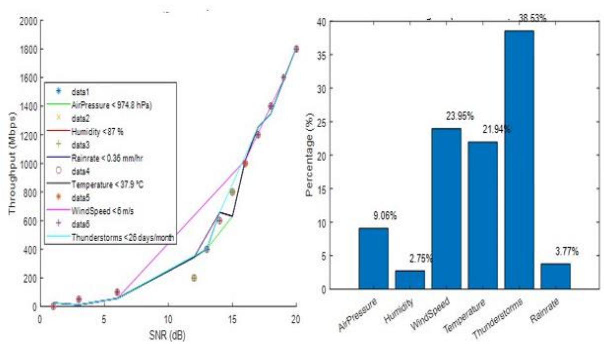

Figure 16: Northcentral-Nigeria (38.53%)

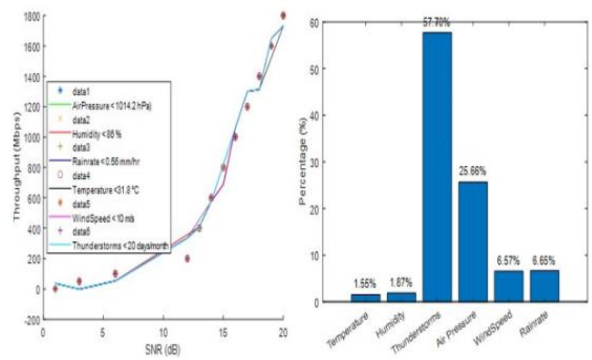

Figure 17: Southwest-Nigeria (57.70%)

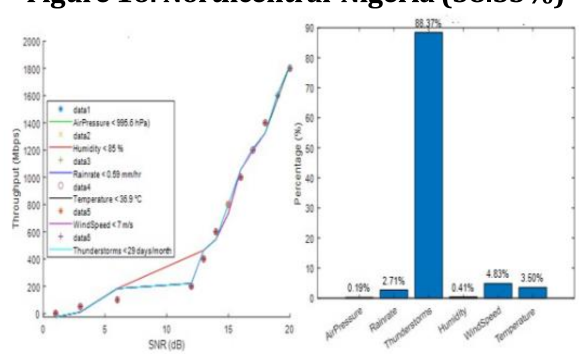

Figure 18: Southeast-Nigeria (88.37%)

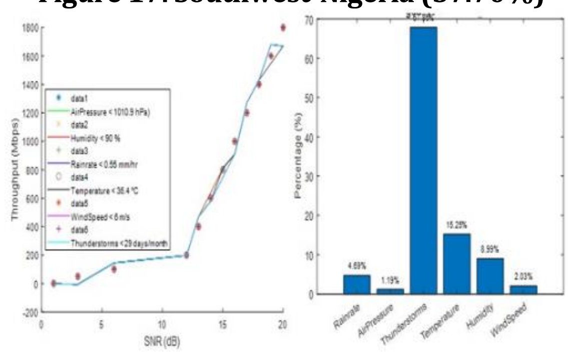

Figure 19: Southsouth-Nigeria (67.85%)

Table 4 below summarizes the percentage of potential im- pact of thunderstorms in the Southwestern region of the United States and regions of interest in this paper (Figure 1). The computational performance of ML, as indicated by the value of R-squared obtained from Malaysian and Nigerian analysis, is higher than that of the US Southwest region. The ML computation carried out by MLR-NN shows strong suitability and fitness of the dataset, therefore, the prediction is reliable.

Table 4: Regional Impact of Thunderstorms on Transmission Lines

Region	Proposed Model	Impact (%)	R-Square
[18]	RE	47.00	0.630
Peninsular Malaysia	MLR-NN	56.84	0.970
Northwest, Nigeria	MLR-NN	35.26	0.870
Northeast, Nigeria	MLR-NN	78.07	0.980
Northcentral, Nigeria	MLR-NN	38.53	0.907
Southwest, Nigeria	MLR-NN	57.704	0.956
Southeast, Nigeria	MLR-NN	88.37	0.971
Southsouth, Nigeria	MLR-NN	67.86	0.940

where: RE: Regressive Examination, MLR-NN: Multi-Linear Regression-based Neural Network.

CONCLUSION

The paper investigates regional weather conditions that potentially impact data transmission of PLC-based systems. PLC is a wireline-based communication technology that supports data transmission over traditional power lines. Climate change changes weather patterns, making them more extreme and adverse, thereby causing a potential impact on transmission systems like PLC. In the paper, an ML-based regressive analysis is carried out to examine the influence of significant weather conditions on PLC-based system in Peninsular Malaysia and Nigeria and assess their impact on PLC-based transmission with respect to data rate (Throughput).

Investigation on main eather conditions and PLC-based transmission specifications was carried out in order to analyze impact of weather on PLC-based transmission system with respect to communication data in Malaysia and Nigerian regions. The proposed model (MLR-NN) considers multiple weather conditions, analyzes their heaviness, and then regressively assesses their impact on PLC transmission. Regional predictions from Malaysia and Nigeria show the influence of extreme and varying weather conditions. Throughput performance is predicted as follows: Malaysia (71.62%), while Nigeria's regions are Northeast (99.97%), Northwest (79.85%), Northcentral (96.59%), Southeast (81.89%), Southwest (86.32%), and Southsouth (74.46%). The predictions were evaluated based on ITU-T G.9960, which recommends 85-98% Throughput performance. Similar works (that analyze single or related weather condition(s)) were also used in the evaluation.

The proposal (MLR-NN) provides weather-based references for implementing, maintaining, and optimizing regional PLC-based network systems. With additional weather and specific transmission information, MLR-NN analysis can Be transferred to other communication technologies and regions beyond Malaysia and Nigeria.

Authorship Contribution

- Muhammad Adamu - conceptualization, investigation, methodology, analysis, and original writing.
- Aduwati Sali - resources, review, editing, supervision, and funding.
- Oussama Messadi - validation, review and editing.
- Nur Luqman Saleh - visualization, review and editing.

Declaration of Competing Interest

The authors have declared no competing interests.

Data Availability

Data will be made available on request.

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