Performance Analysis of LDPC Code for Atmosphere Laser Communication Channel under Rainy Condition Using FWFE

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***Abstract* — Owing to the lack of appropriate data analysis tools, study on the performance of Low-Density Parity-Check (LDPC) code has been rarely done or published in atmosphere laser communication channel (ALCC), especially under rainy conditions. Forward Weights Feature Extraction (FWFE) is proposed to solve the problem, which is a new way of extracting feature information from trained Multi-Layer Perception Network (MLPN). Firstly, raw experimental data sets, which are obtained from ALCC under rainy condition adopting LDPC code, are transferred into training data sets of MLPN in a pre-processing stage. Secondly, we construct MLPN according to the size of training data sets and choose initial weight sets matched with training data sets using Optimal Weights Initialization Technology (OWIT). Thirdly, we train the MLPN with error back-propagation algorithm until total error is qualified. Finally we extract feature information from the trained MLPN using FWFE, which can achieve the correlations for each element over the performance of LDPC. Experiments show that: i) rain density has the biggest impact on the LDPC code's performance (its correlation R_e is 39), which is consistent with the result from intuitive analysis of the experiment data; ii) season element has the second biggest impact (its R_e is 24); iii) channel quality element has the third impact (its R_e is 19), and iv) the rainfall has the least impact (its R_e is 18).**

Keywords - low-density parity-check (LDPC) code, atmosphere laser communication channel (ALCC), forward weights feature extraction (FWFE), multi-layer perception network (MLPN), optimal weights initialization technology(OWIT)

I. INTRODUCTION

Free-space optical (FSO) communication is a useful communication technology where the physical connections are infeasible due to high costs or other difficulties. In FSO communication system, air (or atmosphere) is utilized as transmission medium, which is vulnerable for terrible meteorological condition. To improve the reliability of ALCC, forward error correction (FEC) schemes are generally adopted in actual FSO communication system. LDPC code is a kind of FEC widely applied in ALCC [1-3].

LDPC was proposed by Gallager in 1962. It is a sparse matrix based, high efficiency linear block coding scheme with its performance approaching Shannon Limit. Due to the high data speed in ALCC, forward error correction coding is one of the most suitable schemes for laser communication. Study on the LDPC code's application is received attention, which has its strong anti-jamming performance in ALCC [4].

The performance analysis of LDPC code is focused on coding gain and bit error rate in coded system [1,3,5]. However, LDPC code's performance under rainy condition was rarely concerned by researchers in ALCC.

At present, the study on LDPC code's performance generally limits on specific application condition. LDPC code's performance on atmospheric turbulence channel is studied in [1], which is suitable for multiple input multiple output (MIMO) configuration under strong and weak turbulence. An orbital angular momentum based on LDPC coded modulation scheme is proposed, which can operate under strong atmospheric turbulence regime [6]. An analytical approach is presented to evaluate the bit error rate performance of a FSO link, which adopts LDPC coded Q-ry optical pulse position modulation (PPM) over atmospheric turbulence channel for MIMO configuration [5].

On the other hand, the study on ALCC is only focused on building accurate mathematic model in the process of analysis. Some researchers carry out their study on ALCC in specific applications. A numerical expression and simulation modeling of a Wavelength Division Multiplexing (WDM) FSO communication system have been achieved [7]. Rain intensity and raindrop distribution are most important features of the rain. Different raindrop size distributed in space is called raindrop spectrum. Study on precise law parameters of rain attenuation received much attention [8-11]. However, in [8], the ultimate result is more applicable to the case of heavy rain. A rain attenuation prediction model is proposed to represent tropical weather condition in [9]. However, the proposed values are only derived from data measured in Malaysia. In [11], rain attenuation has been found higher in the pre-monsoon period than in the monsoon months for identical rain rate.

Several contributions are accomplished in the project:

(1) A workable architecture is presented, which can achieve direct analysis in raw experimental data sets of ALCC under rainy condition.

(2) A novel method, called FWFE, is proposed, which can extract key information from trained neural network.

II. FWFE IN MLPN

A. Main Idea of Performance Analysis of LDPC Code for ALCC under Rainy Condition

BER is an important parameter of communication quality. Generally speaking, BER is available in actual experimental system, including LDPC coded system and uncoded system. In addition, specific date, rainfall and rain intensity are recorded as raw experimental data sets in ALCC under rainy condition.

Researchers want to know the relationships inside raw experimental data sets, which are helpful to improve communication quality.

From the information of raw experimental data sets, there are no direct relationships between individual elements, which cannot be presented by traditional mathematical expressions. Therefore, artificial intelligence technology is more suitable for the problem. MLPN is adopted in the solution. Fig. 1 shows the main architecture.

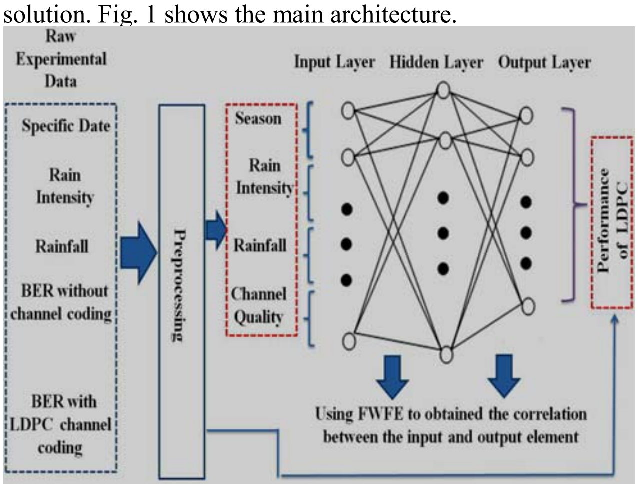

Figure 1. Solution to obtain correlation with FWFE from trained MLPN

The specific steps are as follows:

(1) Transfer raw experimental data sets into training data sets of MLPN.
(2) Load the training data sets on MLPN.
(3) Choose initial weight sets matched with training data sets using optimal weights initialization technology (OWIT) [12].
(4) Train MLPN with back propagation algorithm until total error is qualified.
(5) Extract the correlation using FWFE from trained MLPN .

Through artificial intelligence method, the correlation strength between the various elements and the performance of LDPC can be obtained without involving complicated calculation. The result will provide the foundation on improving the quality of ALCC under rainy condition.

B. *Theoretical Basis of FWFE*

MLPN is a widely used artificial neural network, which has been applied successfully to solve some difficult and diverse problems by training them in a supervised manner with highly popular algorithm known as the error back-propagation algorithm.

After learning, MLPN will have the functionality of pattern recognition. In other word, the training data sets' information has been stored in the form of weights in the whole neural network. From this aspect, the weights of the MLPN can be used to obtain the correlation inside the training data sets. This is the theoretical basis of FWFE.

C. *The Implementation of Optimal Weights Initialization Technology*

In (3) listed above, an optimal initialization technique can used to assess the matching degree between the initial weight sets and training data sets, so that good initial weight sets can be achieved. The implementation of the algorithm can be described as follows (Fig. 2):

① Load a group of initial weight sets and training data sets on MLPN
② Utilize OWIT [12] to calculate the matching degree of current weight sets
③ Store the initial weight sets which have big matching degree
④ Exit the algorithm if the optimal times reach preset value, or jump to ①

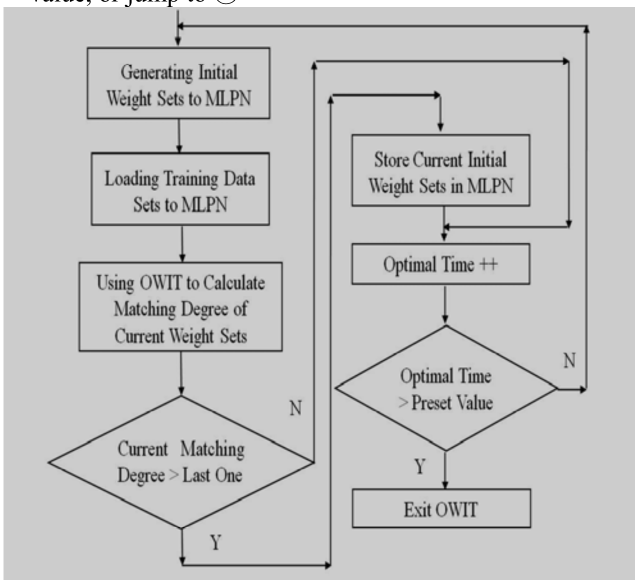

Figure 2. The specific steps of OWIT

D. *The Implementation of FWFE*

In (5), the detailed FWFE algorithm can be described as below:

If the number of related target element is single, the correlation between the input and output elements can be calculated by the following formula:

$$R_{ef} = \sum_{i=m}^{n} \left(\sum_{o=1}^{O} \sum_{h=1}^{H} \left| f(f(w_{ih}) * w_{ho}) \right| * C_o \right) \quad (1)$$

$$R_{eT} = \sum_{i=1}^{N} \left(\sum_{o=1}^{O} \sum_{h=1}^{H} \left| f(f(w_{ih}) * w_{ho}) \right| * C_o \right) \quad (2)$$

$$R_e = T^{-1} \sum_{f=1}^{T} (R_{ef} / R_{eT}) * 100 \quad (3)$$

Whereas the *f()* is the activity function of the perceptron node, *O* the output node number of MLPN, *H* the hidden node number, N the input node number, T the sampling times of the initial weights, R_{ef} the correlation of the specific input element, R_{eT} the total correlation, R_e the normalized correlation of the specific input element, m~n the node range of input element, C_o the encoding weights of the output node which is calculated as below:

$$C_o = \begin{cases} 1 & \text{orthogonal coding} \\ N^q & N\text{-ry coding} \quad q \text{ is output node code weight} \end{cases} \qquad (4)$$

If the number of related target element is multiple, the correlation between input and output elements can be calculated by the following formulas:

$$R_{ef} = \sum_{i=m}^{n} \left(\sum_{o=m'}^{n'} \sum_{h=1}^{H} | f(f(w_{ih}) * w_{ho}) | * C_{o'} \right) \qquad (5)$$

$$R_{eT} = \sum_{i=1}^{N} \left(\sum_{o=m'}^{n'} \sum_{h=1}^{H} | f(f(w_{ih}) * w_{ho}) | * C_{o'} \right) \qquad (6)$$

Whereas m'~n' is the node range of specific output element, and C_o' the output node encoding weight which is calculated as below:

$$C_{o'} = \begin{cases} 1 & \text{orthogonal coding} \\ N^q & N\text{-ry coding} \quad q \text{ is output node code weight} \end{cases} \qquad (7)$$

A bigger value of correlation indicates a stronger connection between input and output elements, while a smaller correlation means a weaker connection. Based on this, the relationship among various elements can be achieved.

III. THE PREPROCESSING OF RAW EXPERIMENTAL DATA SETS

A. *The Composition of Raw Experimental Data Sets*

In the experiment on ALCC, system's BER is normally used as an important parameter on channel quality. Apart from this, the experiment also records specific date (season), rainfall, rain intensity, the bit error rate without channel coding (channel quality) as well as the bit error rate with LDPC channel coding.

TABLE I. PART OF LDPC CODE'S RAW EXPERIMENTAL DATA SETS IN ALCC UNDER RAINY CONDITION

Index	Specific Date	Rainfall (mm)	Rain Intensity	BER without channel coding(10^{-4})	BER with LDPC channel coding(10^{-6})
1	2007-4-23	0.2	Light rain	2.2	3.3
2	2007-7-5	34.1	Violent rain	24	42
3	2007-9-27	7	Light rain	2.6	4.2
4	2007-9-29	3	Light rain	3.5	4.3
5	2007-10-9	1.6	Light rain	2	3.2
6	2007-10-10	6.6	Light rain	2.6	3.5
7	2007-10-11	12	Moderate rain	4.8	6.6
8	2007-5-13	13.6	Moderate rain	5	6.6

From Table 1 above, raw experimental data sets cannot be directly loaded on MLPN. Therefore, it is necessary to employ a specific method to transfer the data sets in preprocessing stage, which can achieve the transformation from raw experimental data sets into training data sets of MLPN

B. *Transformation of Raw Experimental Data Sets in Preprocessing Stage*

Specific date is another expression form of season. Generally speaking, different season has its unique weather, ecology, and hours of daylight. Therefore, the characteristics of rainy weather maybe vary greatly in different seasons, which have influence on ALCC. Naturally, specific date will be transformed into season degree in preprocessing stage, which represents the key information of season.

The detailed algorithm has two steps: firstly, transforming specific data into Han Calendar according to conversion rules; and then coding the date as season degree according to Han Calendar. Season degree is a part of training data sets of MLPN.

The level of rainfall is sometimes reported as inches or millimeters. The rainfall data can be directly quantized in preprocessing stage. In most cases, rainfall intensity is classified according to the rate of precipitation. BER can be quantized directly in preprocessing stage.

IV. CONCLUSION

A. *Performance Analysis of LDPC for ALCC under Rainy Condition*

To compensate the fluctuation of initial weight sets, several weight ranges are adopted in the initialization process, including ±1,±0.9 … ±0.1.

A full connection model is adopted in MLPN. According to detailed algorithm of FWFE, ultimate result is achieved. Fig. 3 gives the correlation of all elements under different initial ranges of weights.

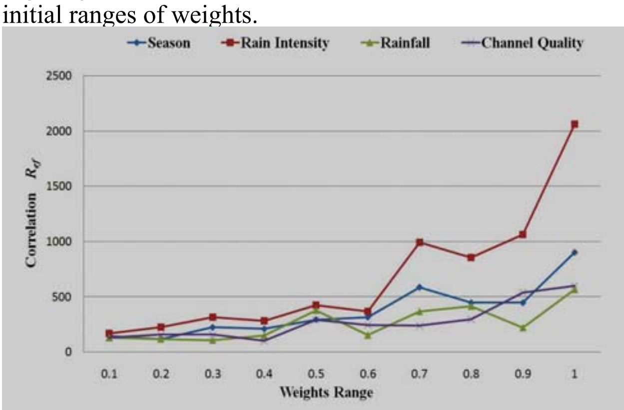

Figure 3. Correlation R_{ef} in different initial weights range

From Fig. 3, it can be observed that the R_{ef} of rain intensity is obviously bigger than the others. Following FWFE algorithm ((1)-(7)), the normalized correlation R_e can be achieved.

The ultimate results show that rain density has the most significant impact on LDPC's performance (with a R_e of 39), which is consistent with the result from intuitive analysis of the raw experiment data sets. The second most significant element is season (with a R_e of 24). The third most significant element is the channel quality (with a R_e of 19), and the least significant element is rainfall (with a R_e of 18).

B. Summary and Prospect

Traditional mathematic methods cannot be directly adopted in many applications of real world, where many uncertain elements are difficult described by mathematical formulas. In many circumstances, researchers want to know the relationships inside the data sets, rather than precise mathematical expressions.

In ALCC under rainy condition, there are many uncertain elements which are not recorded in raw experimental data sets, such as wind, humidity and so on. It is difficult and unnecessary to built respective mathematical formulas to describe individual elements.

Therefore, FWFE is a good option for such situation. For this data analysis method, it requires the learning rate to match with MLPN's training data sets, weight sets and size. On the other hand, for a complicated MLPN with large number of nodes, it needs more training data sets and more iteration to guarantee that sufficient feature information is learnt and stored inside the neural network.

The method, which utilizes FWFE in trained MLPN for correlation analysis, can not only be used for the performance investigation of LDPC, but also be utilized in other similar circumstances. It is a fast and efficient solution to extract feature information from raw data sets.

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