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KNN-Based ML Model for the Symbol Prediction in TCM Trellis Coded Modulation TCM Decoder

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Abstract—Machine Learning is a booming technology today. In a machine learning set of training, data is to be provided to the model for training and that model predicts the output. Machine Learning models are trained using a computer program known as ML algorithms.The new machine learning-based Transition Metric Unit (TMU) of 4D- 8PSK Trellis coded Modulation TCM Decoder is presented in this work. The classic Viterbi decoder's branch metric unit, or TMU, takes on a complex structure. Trellis coded Modulation (TCM) is a combination of 8 PSK modulations and Error Correcting Code (ECC). TMU is one of the complex units of the TCM decoder, which is essentially a Viterbi decoder. Similar to how the first Branch metric is determined in the straightforward Viterbi decoder, the TCM decoder performs this BM computation via the TMU unit. The TMU becomes challenging and uses more dynamic power as a result of the enormous constraint length and the vast number of encoder states.In the proposed algorithm innovative KNN (K nearest neighbours) based ML model is developed. It is a supervised learning model in which input and output both are provided to the model, training data also called the labels, when a new set of data will come the model will give output based on its previous set experience and data.Here we are using this ML model for the symbol prediction at the receiver end of the TCM decoder based on the previous learning. Using the proposed innovation, the paper perceives the optimization of the TCM Decoder which will further reduce the H/W requirements and low latency which results in less power consumption.

Keywords-Trellis Coded Modulation; Bit Error Rate;Transition Metric Unit, Add Compare Select Unit, Viterbi Decoder Machine Learning

I. INTRODUCTION

The world we live in today is a world of wireless connectivity. There are several online and offline applications that rely on wireless connectivity all over the place. Each and every communication system requires more secure communication with less data loss means low BER. Many online applications become more popular these days just because of modems. Modulator and demodulator, or modems, are one of the many applications for TCM. Smart modems like V.34, V.32, etc. make communication easier and more convenient. Through 1980s and onwards high speed smart modems improves the online system response and made file transfer practical with high data rate services. Rapid growth of online services possible with large file libraries of high-speed modems.

TMU, Viterbi decoder, de-mapper, and differential decoder are the essential building blocks of the TCM decoding system, as shown in the basic block diagram (Refer figure 1). The next section provides thorough description of each included block.

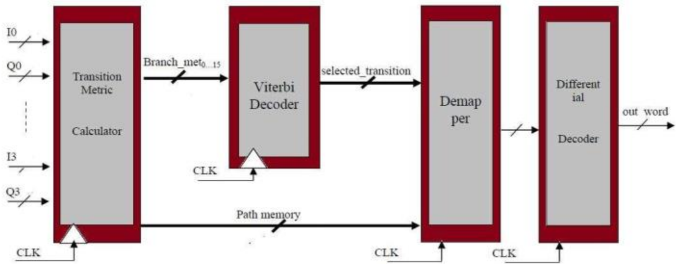

Figure 1: Basic block diagram of TCM decoding system

A. Transition Metric Unit

A 4D 8PSK decoder's transition metric unit and a Viterbi decoder's branch metric unit are identical. The final path metric is created by adding Hamming or Euclidean distances in the VD branch metric unit. The identical actions are performed here in the TMU unit on the metrics from each of the TCM's four dimensions. One of the metrics is chosen from the totaled metrics. While computations for four separate dimensions make TMU procedures exceedingly complex, branch metric operations are straightforward and less complicated. For this reason, TMU was implemented separately from the Viterbi decoder.

B. Viterbi Decoder

Figure 2 depicts the Viterbi Decoder, with the ACSU, PMU, and SMU being its main building components. The ACSU receives the BMs computed in the TMU, after recursive computations of PMs, decision bits are generated for state transitions after every clock cycle. Decision bits from the ACSU were saved in the memory units of the survivors, and these bits were later used by the survivors for decoding. PMs from the most recent iteration are kept in PMU and used for the following cycle. The sections that follow provide information about each block.

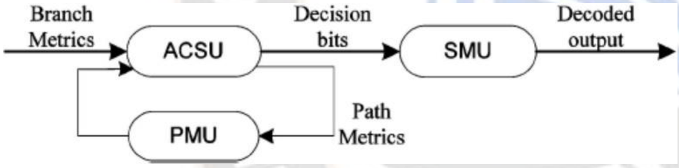

Figure2: Block Diagram of Viterbi Decoder

The ACSU is very complex because at a particular state 8 incoming PMs and 8 BMs are added. Out of these PMs one of the PM with maximum value is to be selected. It is necessary to keep the corresponding 3-bit index, which displays the survival path for the specific condition. Recursive computation makes this unit complex but for high-speed application parallel design can be utilized.

C. Viterbi Decoder

Two strategies can be used to implement TMU.

Memory based strategy

Iterative computations based strategy

The first approach uses memory, which requires more technology and uses more power. The second method uses adders and comparators to streamline calculations and is based on online computations. The second strategy aids in preserving a balance between power and speed. The iterative calculation method is the one we choose to use in our work.

II. EARLIER METHOD OF CALCULATIONS

Following equation demonstrates a streamlined computation of the Euclidean distance between the received symbol and the referenced symbol based on the four dimensions of TCM received symbols (Isym, Qsym) (sym=0,1,2,3,......7 for 8PSK signals).

$$d_{sym}=(I_{rv}-I_{sym})^2+(Q_{rv}-Q_{sym})^2=(I_{rv}^2+I_{sym}^2+Q_{rv}^2+Q_{sym}^2)-2I_{rv}I_{sym}-2Q_{rv}Q_{sym}$$

For all, d_{sym},$(I_{rv}^2+I_{sym}^2+Q_{rv}^2+Q_{sym}^2)$ remains the same.

Finding the maximum of (d0, d1, d2, etc.) would be preferable instead of finding minimum amongst (d0, d1,d2, etc.). Currently equation 2 are used to determine Euclidean distance.

$$d_{sym}=I_{rv}I_{sym}+Q_{rv}Q_{sym}, \qquad (2)$$

From figure 3 we can easily understand that constellation points are equally spaced the phase of $sym\ \pi/4$ (sym=0,1,2,3,……,7 for 8 PSK signals). Constellation points maintain symmetry and satisfy equation 3.

$I_s = -(I_{s+4}) \bmod 8$

$Q_s = -(I_{s+4}) \bmod 8$

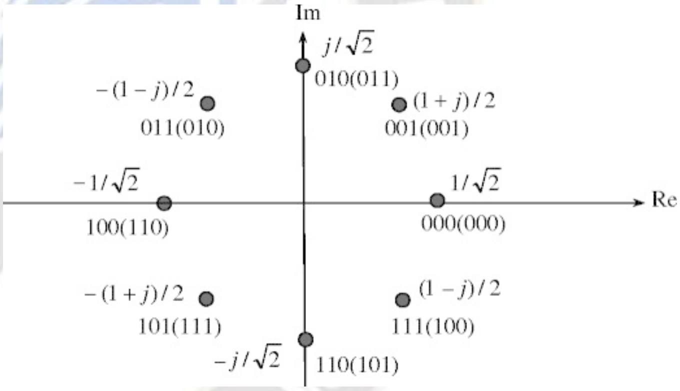

Figure 3: 8PSK constellation

So we need to calculate only four Euclidean distances instead of 8. Equation 4 shows distance calculated by using two multipliers.

$$C_0=|d_0'|=|I_{rv}|$$
$$C_1=|d_1'|=|I_{rv}+Q_{rv}\text{ x } 0.707|$$
$$C_2=|d_2'|=|Q_{rv}|$$
$$C_3=|d_3'|=|I_{rv}-Q_{rv}\text{ x } 0.707|$$

Direct implementation for BM computation necessitates numerous stages of addition and numerous additional comparisons. Repetitive actions are decreased by auxiliary trellis. For BM 0000 calculations, the relationship between the received Euclidean distances is shown in Figure 4. Each step from left to right on the following equation 5 represents the

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Euclidean metrics of the symbol that was received from the four dimensions of the TCM encoder. These received symbols are identified as y0,y1,y2,y3.

$$\begin{bmatrix} y^0 \\ y^1 \\ y^2 \\ y^3 \end{bmatrix} = \left[(4z^{11} + 2z^8 + z^4) \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} + (4) \begin{bmatrix} 0 \\ z^{10} \\ z^9 \\ z^{10} + z^9 + z^7 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \right.$$

$$\left. + (2) \begin{bmatrix} 0 \\ z^6 \\ z^5 \\ z^6 + z^5 + z^3 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} + \begin{bmatrix} 0 \\ z^2 \\ z^1 \\ z^2 + z^1 + z^0 \end{bmatrix} \right]$$

16 BMs for “0000” given by above equation is

Y(0)<=MAX(MAX(C00⊕C10⊕C20⊕C30,C00⊕C12⊕C22⊕C30),MAX(C02⊕C12⊕C20⊕C30,C02⊕C10⊕C22⊕C30));

Y(1)<=MAX(MAX(C00⊕ C10 ⊕ C22 ⊕ C32,C00 ⊕ C12 ⊕ C20 ⊕ C32),MAX(C02 ⊕ C10 ⊕ C20 ⊕ C32,C02 ⊕ C12 ⊕ C22 ⊕ C32));

Y(2)<=MAX(MAX(C01⊕ C11 ⊕ C21 ⊕ C31,C01 ⊕ C13 ⊕ C23 ⊕ C31),MAX(C03 ⊕ C11 ⊕ C23 ⊕ C31,C03 ⊕ C13 ⊕ C21 ⊕ C31));

Y(3)<=MAX(MAX(C01⊕ C11 ⊕ C23 ⊕ C33,C01 ⊕ C13 ⊕ C21 ⊕ C33),MAX(C03 ⊕ C11 ⊕ C21 ⊕ C33,C03 ⊕ C13 ⊕ C23 ⊕ C33));

BM0<=MAX(MAX(Y(0),Y(1)),MAX(Y(2),Y(3))); (6)

Here C00 represents the received value of C0 for the first symbol… and so on.

By applying the simplified Euclidean distance equations (4) number of calculations reduced to 256 out of 4096.

16 BMs divided into odd even manner to find out the maximum of all. Figure 4 shows connections of Euclidean distances from all 4 dimensions. It includes three addition stages and last stage of comparison. If we do straight forward implementation than we need 768(3x16x16) additions while we implemented by auxiliary trellis we need 336(42+43+44) additions [13].

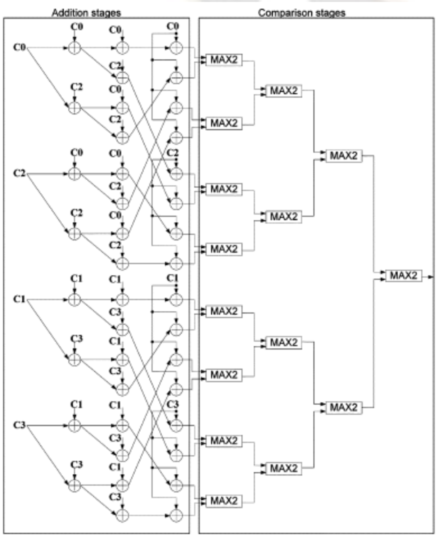

Figure 4: Auxiliary trellis for BM 0000 computations

After this BM calculation stage selected metrics will be sent to PM(Path Metric Unit).In PM unit survival PMs will be come out based on PM purge T or M algorithms. Selected PMs will be send to ACSU(Add Compare Select Unit) and SMU (Survival Metric Unit), Decoded output sent to the De-mapping unit and Differential Decoder unit.

This traditional implementation of the TCM decoder includes lots of mathematical calculation and due to which implementation becomes complex and consumes more dynamic power. New suggested ML method can become one the best suited solution of the above problem

III. WHAT IS KNN

The K-Nearest Neighbor classification is based on supervised learning. Supervised learning can be understood by example such as when a teacher teaches us math’s concepts in our primary education days we never forget it lifelong.

K-NN is a Machine Learning Model (ML model) will be trained using the trained or labelled data. This method is best for classification of the objects. Here data is divided into classes based on unique data available in the dependent training or labels data set. K-NN perform classification based on the value K means neighbors.

K-NN is best understood by this example we have two labels A and B and new data X1 comes and we want to fit X1 in any of the given categories, so K-NN is the solution for the problem. First of all number of neighbours, K has to be decided to choose the nearest neighbour based on the minimum value of the Euclidean distance. A new data point will be assigned to the category where the maximum numbers of neighbors are present.

Figure 5: Before KNN

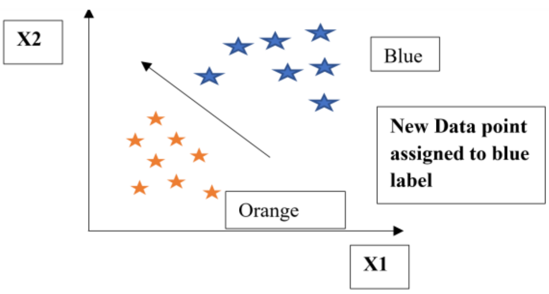

Figure 6: After KNN

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IV. NEW SUGGESTED METHOD

In the earlier method, the Euclidean distance between received symbols from four dimensions of the 4D 8 PSK decoder was calculated. For every single symbol four distances were computed, due to symmetry it will applicable to the rest of the four points. Received symbols are y0,y1,y2, and y3 based on equation no.3.C0, C1, C2, and C3 are the Euclidean distances of the received symbols. Based on the min Euclidean distance the received points belongs to the particular set of class. Due to symmetry, only four classes are here.

In the new approach, KNN based ML model is prepared. KNN is the simplest ML model of supervised learning. KNN works on the classification of input data or available data, New incoming data will be classified based on the similarity with the available category of the data.

KNN is mostly used for classification. Here in the TCM decoder, four sets of symbols will belong to the category of 000,001,010,011,100,101,111 only each incoming symbol will be classified based on the Euclidean distance among the class and symbol. During training, KNN just stores the data set and when it gets the new data then it classifies it accordingly.

Now in this new method, we can find out the Euclidean distance between four incoming symbols to the eight reference symbols. We will predict the best-suited received symbol by using the KNN model. As stated earlier encoded symbols are coming from four dimensions, so at a time 12 bits of data divided into four symbols means the symbol rate is 3.

Encoded symbols are recorded into a CSV file and used as the dataset for the model preparation. Following are the steps involved in the model preparation.

Step 1: For any model preparation we need previous data in .csv format. Data should be authentic and try to avoid duplicates and missing values.

Step 2: Apply EDA to the given data.

Step 3: divide the data into train and test data, generally 80% is the train data and 20% is the test data set. In our case data from four dimensions are the X and Euclidean distance between the received symbol and test symbol is the y. X is the independent variable and y is the dependent variable. We need to compute four sets of Euclidean distances for every set of received symbols. For the experimentation point, only one output variable is selected otherwise we need to create the multi-output model.

Step 4: As stated above y is the distance so it's a float variable most of the ML model works on int data type so the label encoder is going to help us to decide labels.

Step5:if you want to reduce the number of features we can choose between principal component analysis of linear discriminant analysis.

Step 6: Create the KNN model and fit the X_train and y_train data on it.

Step 7: Compute y_pred and check the accuracy score, classification Report and Confusion Matrix.

V. RESULTS

Selection of X, y; where X is the train data and y is test data. X is the independent data and y is known as the dependent data on X. Independent features we can choose from any numbers but generally y is single dimensional because it is output. A multi-output model is also possible but not included here. Table 1 tells about the features and labels used in the paper.

TABLE I. SUPERVISED LEARNING DATA SET

Feature Data				Label Data
Y0	Y1	Y2	Y3	0 ,1, 2, 3
000	110	010	000	0,3,2,0

After the selection of the data as dependent and independent data. Train_test_split method X,y will be divided into x_train,y_train,x_test and y_test. Train_test_split method is present in sklearn library and generally, the ratio of train and test will be 80% and 20% respectively.

TABLE II. X_TEST,Y_TEST, X_TRAIN, Y_TRAIN

```
X_train  # Check the shape

array([[101, 101,  10, 111],
       [111, 101, 111,   1],
       [101,   0,  10, 111],
       [  0, 111, 101,   0],
       [111, 101, 111,   1],
       [101, 101,  10, 111],
       [111, 101, 111,   1],
       [  0,  10, 111, 101],
       [  0,  10, 111, 101],
       [111, 101, 111,   1],
       [  1, 111,   0,   1]])
```

```
X_test

array([[111, 101, 111,   1],
       [111, 101, 111,   1],
       [101,   0,  10, 111],
       [101,   1,   1,   1],
       [101,   0,  10, 111],
       [101, 111,  10, 111],
       [101,   0,  10, 111],
       [101,   1,  10, 111],
       [101,   0,  10, 111]])
```

```
y_test

array([[2],
       [2],
       [1],
       [3],
       [0],
       [3],
       [2],
       [3],
       [3]])
```

```
y_train

array([[1],
       [3],
       [3],
       [3],
       [1],
       [1],
       [1],
       [1],
       [0],
       [0],
       [3]])
```

Table 3 shows the classification Report. It's a performance evolution metric of the ML Model. This is used to display the trained model's precision, recall, f1-score, and support. The ratio of genuine positives to the total of true or false positives is known as precision. The proportion of genuine positives to the total of true positives and false negatives is known as the recall.

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Recall and support are the instances of the class that actually exist in the data set, while F1-score is the harmonic mean of precision.

TABLE III. CLASSIFICATION REPORT

	Precision	Recall	f1-score	Support
1	0.25	1.00	0.40	2
11	0.67	0.67	0.67	3
100	0.00	0.00	0.00	4
110	0.00	0.00	0.00	1
111	0.00	0.00	0.00	1
Accuracy			0.36	11
Macro avg	0.18	0.33	0.21	11
Weighted avg	0.23	0.36	0.25	11

Accuracy score: 73%

Confusion Matrix: It is basically used for the predictive analysis. Its give the relation between the y-pred and y-test data.

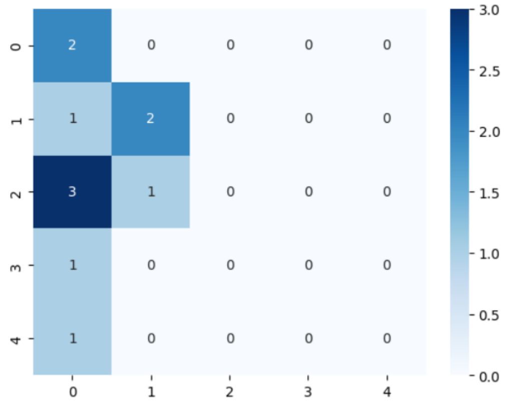

Figure 7: Confusion Matrix

VI. CONCLUSION

In this paper KNN algorithm which is a supervised learning method is used for the symbol prediction at the receiver end of the TCM decoder is presented. This new model of branch metric prediction will give fast results and avoid latency in data decoding. The accuracy of the K-NN model was experimented with for the different values of K (neighbors) and the best-suited accuracy is 73% obtained for K=3. We may conclude that the 4D 8PSK TCM decoder's power-efficient and high-speed design has been realized because the implemented system maintains the speed-to-power ratio.

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