School of Engineering and Applied Science (SEAS), Ahmedabad University

B.Tech(ICT) Semester V: Wireless Communication (ECE 311)

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- Base Article Title:

  1) Base Article: [1] X. Qian, M. Di Renzo, and A. Eckford, "Molecular communications: Model-based and data-driven receiver design and optimization,"IEEE Access, vol. 7, pp. 53 555-53 565, 2019.

  2) Optimising the Molecular communication with data-driven approach using LSTM network

1 New Performance Analysis

1.1 System model of ANN:

The Artificial Neural Network can also be known as weighted directed graph, where the nodes are the artificial neuron and the connections between the neuron outputs and neuron inputs is represented by edges with some weight. [1] The artificial neural networks receives the input signal from the external world in the form of a pattern and the image in the form of vector. It can be represented mathematically as x(n) for any number of input. Each of these inputs is then multiplied with the corresponding weights. These weights represents the strength of the interconnections in the artificial neural networks. If the weight of a particular edge is zero, then a bias is added in order to make the output non-zero. The Bias has a weight and the input for it is always 1. The range of the sum of the weighted inputs lies between 0 to infinity. The different types of layers present in the artificial neural networks are as follows:
1. Input Layer : The input layer consists of those artificial neurons which receives input from the outer world.

2. Output Layer : The output layers contain the artificial neurons which receives the output from the model and it is also used to check if has learned any task or not

3. Hidden Layer : The Hidden layer are the intermediate layers between the input layers and the output layers. The hidden layer is used to change the input data into an desired output by using some particular techniques.

The ANN model is trained priorly or is fed with a large amount of data .Training consists of providing input and telling the network about the desired output.Each input is accompanied by the some matching information.By Providing the answers it becomes easy for the model to adjust its internal weightings in order to perform the jobs better. The type of ANN model that we have used is the Feed Forward Neural network . The Feed Forward neural network is the simplest of the various different ANN models. In this type, the information is passed in one direction only, from the input layer towards the Output layer.

1.2 LSTM Network:

One of the most import recurrent neural networks in deep learning is the Long-Short Term Memory network (LSTM). A LSTM based system is used for the detection of the transmitted symbol at the collector in which the past assessed symbols are taken care of alongside the current number of particles so as to expand the presentation of the model expecting no channel information gave at the recipient. It is capable for storing memory and can practice long term dependencies that beats the issue of other neural networks.LSTM has been widely applied in many areas, especially in time series modeling, including speech recognition, natural language processing and sequence prediction. So basically we proposed 2 data-driven models: ANN model and LSTM model. The major difference between these two is that ANN doesn't have any memory elements so that it is not able to store the information.

1.2.1 System Model of LSTM:

LSTM is an extremely efficient tool when the information is sequential. The basic condition of LSTM modeling is that all inputs and outputs are independent of each other.

$$y(k) = \phi[y(k-1), y(k-2),../y(k-n_y), u(k), ..., u(k-n_y)]$$

$\phi(\cdot)$ is an unknown non-linear difference equation representing the plant dynamics, u(k) and y(k) are measurable scalar input and output, ny and nu are the last values of the output and input, respectively, to be considered for the system dynamics. LSTM uses gas cell to remember them. The key to LSTMs is the cell state. The gate in LSTM is a way to permit information to enter. LSTM has three gates to protect and control the cell state: [2]

a) Forget gate

b) Input gate

c) Output gate

Each of these gates are binary gates. Input gate controls whether the memory cell is updated whereas forget gate controls if the memory cell is reset to 0 and finally the output gate controls whether the information of the current cell is made visible or not.

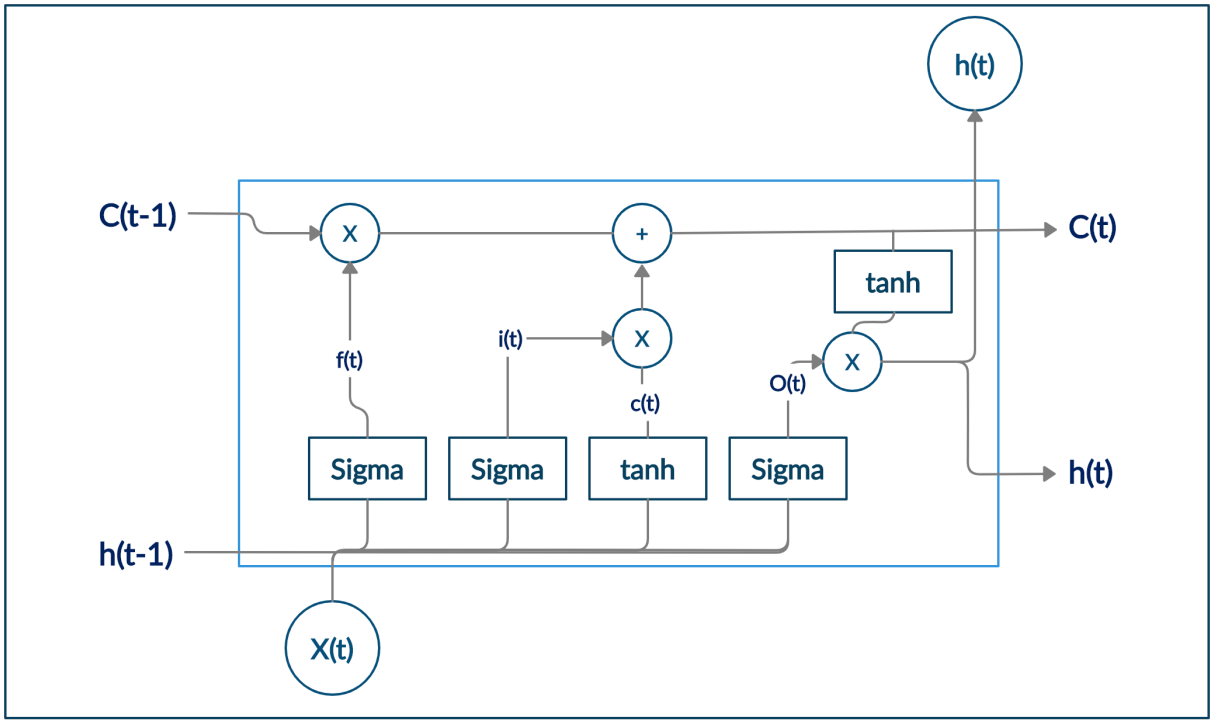


Figure 1: Architecture of LSTM cell

1.3 Performance metric:

Simulation result of the ANN model:

```
157/157 [==============================] - 0s 2ms/step - loss: 1.3772 -accuracy: 0.0804
     At SNR = -20 accuracy: 8.04%

157/157 [==============================] - 0s 2ms/step - loss: 1.3378 -accuracy: 0.0996
     At SNR = -18 accuracy: 9.96%

157/157 [==============================] - 0s 2ms/step - loss: 1.3111 -accuracy: 0.1156
     At SNR = -16 accuracy: 11.56%

157/157 [==============================] - 0s 2ms/step - loss: 1.2599 -accuracy: 0.1538
     At SNR = -14 accuracy: 15.38%

157/157 [==============================] - 0s 2ms/step - loss: 1.1482 -accuracy: 0.2236
     At SNR = -12 accuracy: 22.36%

157/157 [==============================] - 0s 2ms/step - loss: 1.0125 -accuracy: 0.3151
     At SNR = -10 accuracy: 31.51%

157/157 [==============================] - 0s 2ms/step - loss: 0.7725 -accuracy: 0.5051
     At SNR = -8 accuracy: 50.51%
```

```
157/157 [==============================] - 0s 2ms/step - loss: 0.4834 -accuracy: 0.7433
    At SNR = -6 accuracy: 74.33%

375/375 [==============================] - 1s 2ms/step - loss: 0.2345 -accuracy: 0.8937
    At SNR = -4 accuracy: 89.37%

375/375 [==============================] - 1s 2ms/step - loss: 0.1212 -accuracy: 0.9327
    At SNR = -2 accuracy: 93.27%

375/375 [==============================] - 1s 2ms/step - loss: 0.0652 -accuracy: 0.9661
    At SNR = 0 accuracy: 96.61%

375/375 [==============================] - 1s 2ms/step - loss: 0.0389 -accuracy: 0.9794
    At SNR = 2 accuracy: 97.94%

375/375 [==============================] - 1s 2ms/step - loss: 0.0202 -accuracy: 0.9897
    At SNR = 4 accuracy: 98.97%
```

Simulation result of the LSTM network model:

```
157/157 [==============================] - 0s 2ms/step - loss: 1.2731 -accuracy: 0.1336
    At SNR = -20 accuracy: 13.36%

157/157 [==============================] - 0s 2ms/step - loss: 1.2553 -accuracy: 0.1326
    At SNR = -18 accuracy: 13.26%

157/157 [==============================] - 0s 2ms/step - loss: 1.2027 -accuracy: 0.1644
    At SNR = -16 accuracy: 16.44%

157/157 [==============================] - 0s 2ms/step - loss: 1.1507 -accuracy: 0.2010
    At SNR = -14 accuracy: 20.10%

157/157 [==============================] - 0s 2ms/step - loss: 1.0431 -accuracy: 0.2745
    At SNR = -12 accuracy: 27.45%

157/157 [==============================] - 0s 2ms/step - loss: 0.8862 -accuracy: 0.4007
    At SNR = -10 accuracy: 40.07%

157/157 [==============================] - 0s 2ms/step - loss: 0.6776 -accuracy: 0.6097
    At SNR = -8 accuracy: 60.97%

157/157 [==============================] - 0s 2ms/step - loss: 0.4730 -accuracy: 0.7926
    At SNR = -6 accuracy: 79.26%

375/375 [==============================] - 1s 2ms/step - loss: 0.3032 -accuracy: 0.9116
    At SNR = -4 accuracy: 91.16%

```

```
375/375 [==============================] - 1s 2ms/step - loss: 0.2227 -accuracy: 0.9432
     At SNR = -2 accuracy: 94.32%

375/375 [==============================] - 1s 2ms/step - loss: 0.1789 -accuracy: 0.9703
     At SNR = 0 accuracy: 97.03%

375/375 [==============================] - 1s 2ms/step - loss: 0.1562 -accuracy: 0.9837
     At SNR = 2 accuracy: 98.37%

375/375 [==============================] - 1s 2ms/step - loss: 0.1425 -accuracy: 0.9927
     At SNR = 4 accuracy: 99.27%
```

- Evaluation of ANN and LSTM based networks based on the above results:

SNR	**Accuracy (ANN)**	**Accuracy (LSTM)**
-20	8.04	13.36
-18	9.96r	13.26
-16	11.56	16.44
-14	15.38	20.10
-12	22.36	27.45
-10	31.51	40.07
-08	50.51	60.97
-06	74.33	79.26
-04	89.37	91.16
-02	93.27	94.32
00	96.61	97.03
02	97.94	98.37
04	98.97	99.27

2 New Numerical Results

2.1 Simulation Framework

Model 1: ANN model

Shape of input: (1) for ri(receiving particles)

Number of layers: 2 (2nd layer is for output)

Units of each layer: 1st layer - 7 units and 2nd layer 1 unit

Activation function: sigmoid

Optimizer: adam

Model 2: LSTM model

Shape of input: (1,1)

Number of layers: 2 (2nd layer is for output)

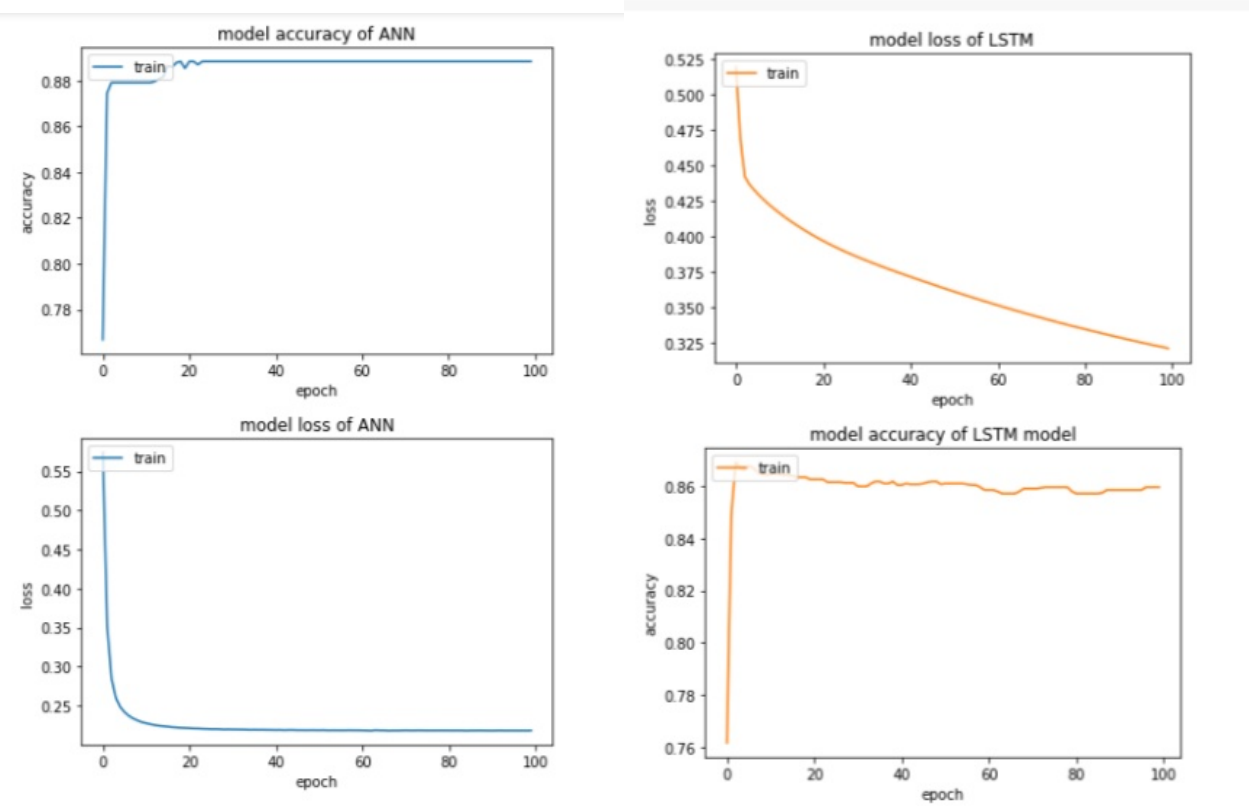
Units of each layer: 1st layer - 7 units and 2nd layer 1 unit

Activation function: sigmoid

Optimizer: adam

2.2 Description of Figures

2.2.1 Accuracy and Loss of ANN and LSTM



- In the first part we try to draw the accuracy and loss of the data set that we generated of received particles and label(predicted bit). Both the models has almost similar accuracy but the loss pattern is different.

2.2.2 Accuracy vs SNR of ANN and LSTM

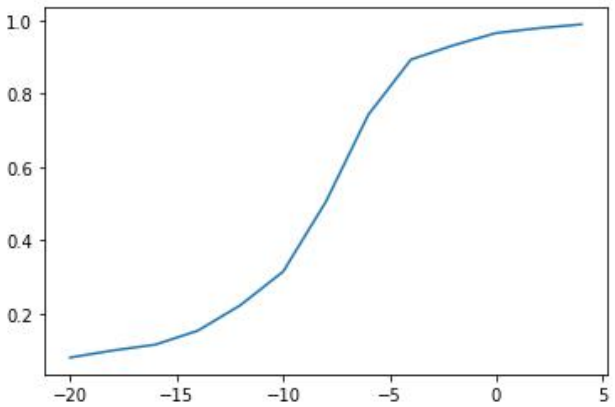


Figure: Accuracy vs SNR for ANN

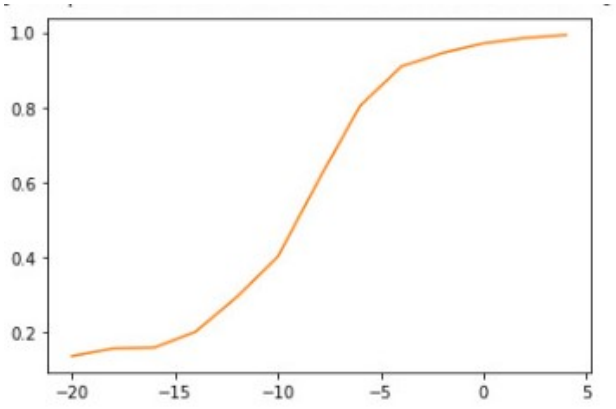


Figure: Accuracy vs SNR for LSTM

- On the left side, it is a graph of Accuracy vs SNR for ANN whereas on the left side, it is a graph of Accuracy vs SNR for LSTM. Here, X-axis is a measurement of SNR and Y-axis determines the value of Accuracy. In the second part we tried to draw the conclusion of Accuracy vs SNR graph by both the models i.e. LSTM and ANN. Here the accuracy of LSTM model is slightly better then that of ANN with respective SNR.

3 Contribution of team members

3.1 Technical contribution of all team members

Tasks	**Samarth Shah**	**Yash Patel**	**Yugamsinh Chavda**
LSTM System Model	+	+	-
Performance Metric	+	-	+
Data generation	+	+	+
Code Analysis and graph plotting	-	+	+

3.2 Non-Technical contribution of all team members

Tasks	**Samarth Shah**	**Yash Patel**	**Yugamsinh Chavda**
Preparing Report	-	+	-
LSTM Architecture	+	-	+
Miro final board	+	+	+
Mind map	+	+	+

References

[1] X. Qian, M. Di Renzo, and A. Eckford, "Molecular communications: Model-based and data-driven receiver design and optimization," *IEEE Access*, vol. 7, pp. 53 555–53 565, 2019.

[2] J. Gonzalez and W. Yu, "Non-linear system modeling using lstm neural networks," *IFAC-PapersOnLine*, vol. 51, no. 13, pp. 485–489, 2018.