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

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

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- Base Article Title:

  X. Qian, M. D. Renzo, and A. Eckford, "Molecular Communications: Model-Based and Data-Driven Receiver Design and Optimization," IEEE Access, vol. 7, pp. 53555–53565, Apr. 2019. [1]

  Innovation on the Data Driven Model

1 New Performance Analysis

1.1 Brief Introduction to the Innovation

- Innovation in Analytical Model

  For the improvement of of the BER performance,we have tried to implement two methodologies:
  - By the use of molecular communication via diffusion with flow, by including the flow of the molecules in the calculation for the hitting probability, for lower values of velocity we get the results that the number of received particles remains constant and after some higher value the number of particles received decreases. [2]
  - On including the weighted sum detectors, along with enzymes present, it provides an easier implementation along with a slightly higher BER and more throughput. [3]
- Innovation in Data Driven Model
  - For improving BER performance, the ANN model can have some memory based system in it, which leads to the idea of implementing the LSTM data model in place of the ANN model. [4]
  - By the use of LSTM we are able to consider the long term dependencies of the data, which was not there in ANN. Because LSTM uses previously stored information and new information both inorder to predict the output, so that way we can model long term dependencies of the data.

1.2 List of symbols and their description

Symbol	Description
λ_0	background noise power per unit time
r	Receiver radius
d	Distance
D	Diffusion coefficient
ΔT	Discrete time length
T	Slot length
L	Channel length

1.3 System Model/Network Model

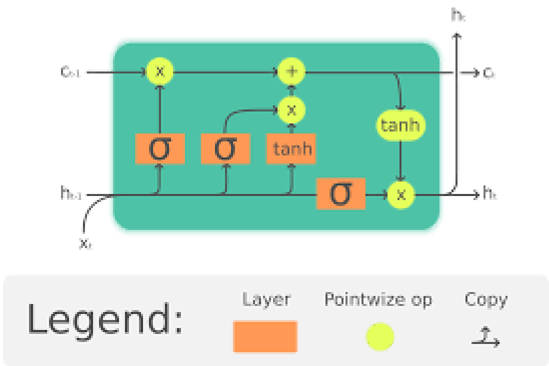


Figure 1: Network Model

- As previously mentioned in the neural network model, the network model doesn't need a perfectly known system model.
- We implemented the network model with ANN(Artificial Neural networks) and LSTM (Long Short Term Memory networks) both the models.
- Now RNN(Recurrent Neural Network) is a powerful model for sequential data and LSTM belongs to the class of RNN.
- It is specially designed to learn long-term dependencies and overcome inherited problems of RNNs.

1.4 Detailed derivation of performance metric-I

Performance matrix will be the same as the ANN data driven approach. It consist of three types of receivers:

Parameter	Description
Training Dataset Size	Size of the data for training
Hidden Layers	Number of layers for training the model
Neuron Per Layer	Neuron inside each layer
Epochs	Number of times model is trained
Batch Size	Number of values given to model for training
Validation Set Size	Size of the data for testing/validating

- **Zero-bit Memory Receiver**:

  It is a system whose input is received information particles r_i at i-th time slot, and the output are the probabilities that the transmitted bit is 0 or 1, $Pi(si = 0|ri)$ and $Pi(si = 1|ri)$, respectively. [4]

  And also, $Pi(si = 0|ri) + Pi(si = 1|ri) = 1$

  ∴ We have to find any one of them, so

$$\bar{s_i} = \begin{cases} 0 & , \mathrm{P}_i \leq 0.5 \\ \\ 1 & , \mathrm{P}_i \gneq 0.5 \end{cases} \tag{1}$$

- **One-bit Memory Receiver**:

  In this case, ANN not just depend on received particles at ith time slot, but also on previous one estimates symbol at (i-1)th slot as $\bar{s}_{i-1}$.

  ∴

$$\bar{s_i} = \begin{cases} 0 & , \mathrm{P}_i(S_i = 1|\mathrm{r}_i, \bar{s}_{i-1}) \leq 0.5 \\ \\ 1 & , \mathrm{P}_i(S_i = 1|\mathrm{r}_i, \bar{s}_{i-1}) \gneq 0.5 \end{cases} \tag{2}$$

- **K-bit Memory Receiver**:

  By extending the logic on one bit receiver to k bit receiver the decision rule is describe as,

$$\bar{s_i} = \begin{cases} 0 & , \mathrm{P}_i(S_i = 1|\mathrm{r}_i, \bar{s}_{i-1}, \bar{s}_{i-2}, ..., \bar{s}_{i-K}) \leq 0.5 \\ \\ 1 & , \mathrm{P}_i(S_i = 1|\mathrm{r}_i, \bar{s}_{i-1}, \bar{s}_{i-2}, ..., \bar{s}_{i-K}) \gneq 0.5 \end{cases} \tag{3}$$

2 New Numerical Results

2.1 Simulation Framework

- Data Generation

  The parameters used in the simulation work are as follows.The simulation of the data modelling is done in the Google CoLab files

Symbol	**Description**	**value**
λ_0	background noise power per unit time	$100s^{-1}$
r	Receiver radius	45 nm
d	Distance	500 nm
D	Diffusion coefficient	$4.265 * 10^{-10} m^2/s$
ΔT	Discrete time length	9 us
T	Slot length	$30\Delta T$
L	Channel length	100

  We have considered the range of the SNR to be [-5,50), so the number of values possible are 55.
  And the channel length is considered to be 100.
  So, the data points generated for the data model is 5500(55*1000) particles.

- Model Parameters

Parameter	**ANN Value**	**LSTM value**
Training Dataset Size	3000	3000
Hidden Layers	1	1,1
Neuron Per Layer	1,7,1	1,max(input data),1000,1
Epochs	50	60
Batch Size	100	100
Validation Set Size	33.33%	33.33%

2.2 Description of Figures

- Figure-1

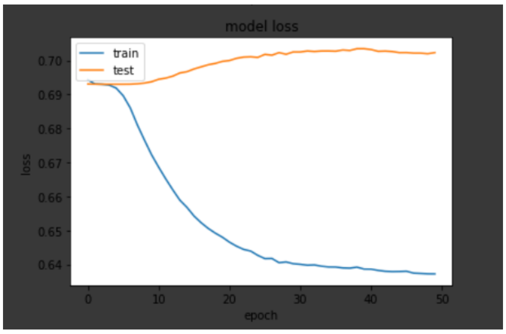
  The below figures are about the train-test accuracy and loss v/s epoch graph for both ANN and LSTM model.

  The optimizer used is **adam optimizer**

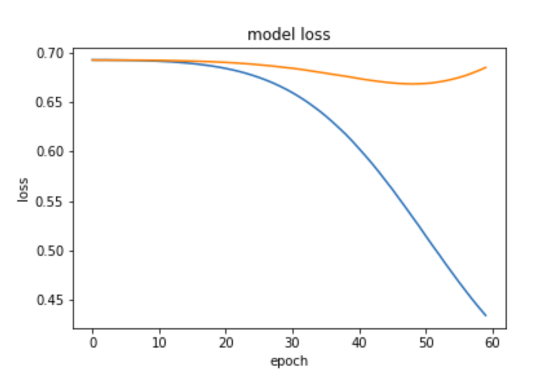
  The loss method used is **binary crossentropy**

  For training, we have used SNR range of [20,50) i.e. 3000 particles.

  For testing/validation, we have used SNR range of [-5,50) i.e. 5500 particles.

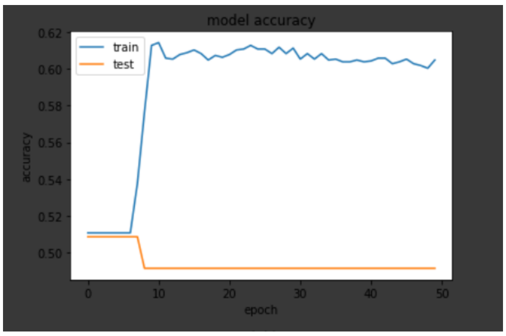


(a) Figure 2A

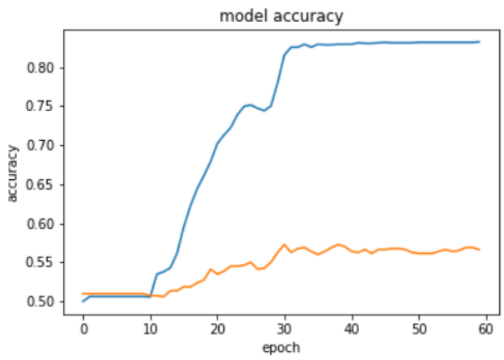


(b) Figure 2B

Figure 2: Comparison of loss for ANN model and LSTM model



(a) Figure 3A



(b) Figure 3B

Figure 3: Comparison of accuracy for ANN model and LSTM model

- Figure-2

  Below is the comparison for the BER vs SNR plot of analytical, data driven and the LSTM model.(For zero-bit reciever design)

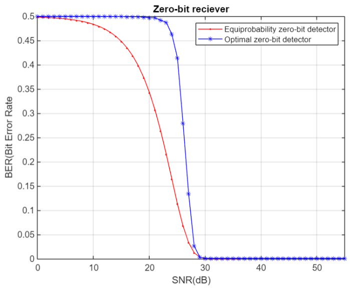


Figure 4: Analytical Plot

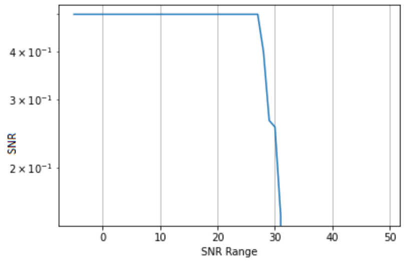


Figure 5: ANN(Data) Plot

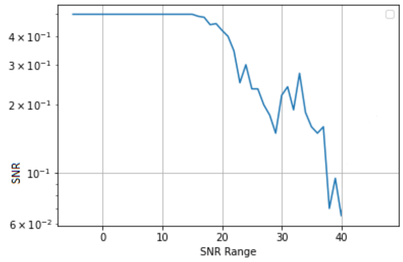


Figure 6: LSTM Plot

Figure 7: Comparison of BER vs SNR

The table for comparison of the values is as follows:

SNR	**ANN BER**	**LSTM BER**	**Analytical BER**
-5	0.5	0.5	0.5
0	0.5	0.5	0.5
10	0.5	0.5	0.47
20	0.5	0.4	0.5
30	0.25	0.1	0
30+	0	0	0

We can say from the result above is,

- The analytical and ANN zero bit memory receiver is almost similar.
- With the help of LSTM model we can get improved result for the data-driven model (As we are not able to get smooth curve after 20 db SNR, but this result is comparatively better than ANN(as its become less after 30 db)).
- By the graph of train-test accuracy vs epoch of ANN and LSTM , the LSTM model gives better accuracy compared to ANN (72.75% and 57% respectively).

3 Contribution of team members

3.1 Technical contribution of all team members

Tasks	Aanshi Patwari	Dipika Pawar	Miracle Rindani	Mithilesh Thakkar
Analytical Innovation	✓		✓	
Data Innovation Search	✓	✓	✓	✓
Data Innovation Model	✓	✓	✓	✓
Data Innovation Simulation		✓		✓

3.2 Non-Technical contribution of all team members

Tasks	Aanshi Patwari	Dipika Pawar	Miracle Rindani	Mithilesh Thakkar
Innovation Report	✓		✓	
MIRO mind mapping	✓	✓	✓	✓
Project Video	✓	✓	✓	✓

References

[1] X. Qian, M. D. Renzo, and A. Eckford, "Molecular communications: Model-based and data-driven receiver design and optimization," *IEEE Access*, vol. 7, p. 53555–53565, Apr 2019.

[2] A. E. P. T. T. Bayram Cevdet Akdeniz, H. Birkan Yilmaz, "Impulse response of 3-d molecular communication via diffusion and flow channel with an absorbing receiver."

[3] R. S. Adam Noel, Karen C. Cheung, "Optimal receiver design for diffusive molecular communication with flow and additive noise," *IEEE Transactions on Nanobioscienc*, vol. 13, pp. 350–362, Sep 2014.

[4] H. L. S. J. N. L. Z. L. Caihong Hu, Qiang Wu, "Deep learning with a long short-term memory networks approach for rainfall-runoff simulation," *Access*, OCt 2018.