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

B.Tech(ICT) Semester V: Wireless Communication (ECE 310)

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- **Group Members :**

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- **Base Article Title:**

  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. 53555–53565, 2019.

- **Abstract:**

In this paper, we consider a molecular communication system that is made of a 3D unbounded diffusion channel model without flow, a point transmitter, and a spherical absorbing receiver. In particular, we study the impact of inter-symbol interference and analyze the performance of different threshold-based receiver schemes. The aim of this paper is to analyze and optimize the receivers by using the conventional model-based approach, which relies on an accurate model of the system, and the emerging data-driven approach, which, on the other hand, does not need any apriori information about the system model and exploits deep learning tools. We develop a general analytical framework for analyzing the performance of threshold-based receiver schemes, which are suitable to optimize the detection threshold. In addition, we show that data-driven receiver designs yield the same performance as receivers that have perfect knowledge of the underlaying channel model.

- **Overview and Introduction**

Molecular communication was introduced when there arose a need for communication in nanodevices, where electromagnetic communication is not possible. In molecular communication, information particles are used to transmit data.Information is encoded into particles, which are then released into the channel and absorbed at the receiver. But, there are some of the major challenges with molecular communication such as controlled propagation of the particles, design of systems devised for transmission and reception and the way encoding or decoding of information particles is done.

Different schemes are proposed for different molecular communications techniques in different articles as per the assumptions done there and possibility of it's success. According to this base article, Concentration Shift Keying (CSK) is the scheme which is used for modulation of the transmitting particles here.The motivation for choosing CSK is that it takes into account the concentration of particles which will help to detect the symbol transmitted using threshold based receivers.CSK encodes the information particles into 0 or 1. Design of the system comprises of a point transmitter and a spherical receiver. The above technique is however utilised for model based detection scheme. A newer approach which is Data-driven approach proves to be more efficient since it does not require any type of foreknowledge of channel state information on the receiver side. Deep Learning methods are used to overcome the above mentioned limitation. Articial Neural Networks is used as a learning framework in our article. ANNs provide same performance as the conventional methods that rely on the perfect knowledge of the system and so they are more feasible to implement in molecular communication system where prior knowledge is not always known. These are kept to be done as future scope for time being.

1 Performance Analysis of Base Article

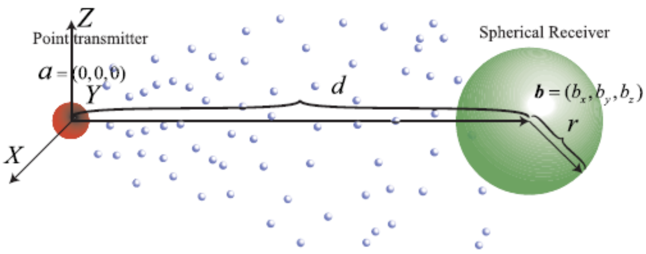


FIGURE 2. **The 3D unbounded molecular channel model without flow including a point transmitter and a spherical absorbing receiver.**

- **List of symbols and their description**

Symbol	Description
d	The distance between the transmitter and the receiver
r	Radius of the receiver
D	Diffusion Constant
N_{TX}	No. of information particles released by the transmitter at the i^{th} time slot
r	Radius of the receiver
s_i	Symbol transmitted i.e either 0 or 1
f_{hit}^{3D}	The hitting rate of each information particles
$P_{hit}(t)$	The probability to absorb one particle after t seconds
C_j	he average received particles at the j^{th} time-slot

Symbol	Description
I_i	The sum of ISI and background noise at i^{th} time slot
λ_0	The background noise power per unit time
r_i	No. of received information particles
$P(r_i \| I_i + s_i C_0)$	The probability of receiving r_i information particles given ISI and background noise
SNR	Signal to Noise Ratio

- **System Model**

  Assumptions:

  - The literature has considered the trasmitter to be a point like transmitter.
  - The particles are assumed to diffuse randomly and independent of each other through the medium.
  - Here as the information particles follows brownian motion, few information particles reach the receiver in subsequent time slot and hence causes the Inter Symbol Interence(ISI).
  - Temperature is assumed to be constant. Viscosity η remains the same throughout the whole transmission. Diffusion constant D is also considered to be constant.
  - As particles perform diffusion freely, no extra energy is required.
  - The model under consideration is 3D diffusion channel model without flow.
  - The transmitter is assumed to release N_{TX} information partlicles in a very minute time due to which the release time effect of the transmitter can be neglected on the recieved signal.

  Working:

  - The System model follows On-Off keying modulation scheme i.e. When '0' symbol is transmitted then the transmitter does not release any information particles and when '1' symbol is transmitted then the transmitter release N_{TX} information particles.

- **Detailed derivation of performance metric**

  - Here, first of all, the hitting rate of of particles can be defined by:

$$f_{hit}^{3D} = \frac{r(d-r)}{4\sqrt{4\pi D t^3}} e^{-\frac{(d-r)^2}{4Dt}}$$

  - Now, the probability of particle hitting the receiver can be defined as follows:

$$P_{hit}(t) = \int_0^t f_{hit} dt$$

  The Error Function is defined as

$$erfc(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{-x^2} dx$$

Here, we consider x=$\frac{(d-r)}{\sqrt{4Dt}}$
dx = $\frac{(d-r)}{\sqrt{4D}} \cdot \frac{-1}{2} \cdot \frac{1}{\sqrt{t^3}}$dt
dt = $\frac{-2 \cdot \sqrt{4Dt^3}}{(d-r)}$ dx

Thus, the probability of the particle hitting the receiver can be defined as follows :

$$P_{hit}(t) = \frac{r}{d} \cdot erfc(\frac{d-r}{\sqrt{4Dt}})$$

– Therefore the probability of hitting particle in (i-1)th time slot is defined as:

$$P_{i-1} = \int_{(i-1)T}^{iT} f_{hit}(t)dt$$

$$P_{i-1} = \frac{r}{d}(erfc(\frac{d-r}{\sqrt{4Dit}}) - erfc(\frac{d-r}{\sqrt{4D(i-1)t}}))$$

– Let $C_j = N_{tx}P_j$ is the number of average particles received at j^{th} time slot.

The no. of received particles at the i^{th} time slot is expressed using Poisson RV:

$$r_i \sim Poisson(I_i + s_iC_0)$$

,where I_i can be gievn as,

$$I_i = \lambda_0 T + \sum_{j=1}^{\infty} s_{i-j}C_j$$

– Thus the probability of receiving r_i particles is:

$$P(r_i|I_i + s_iC_0) = \frac{e^{(I_i+s_iC_0)} * (I_i + s_iC_0)^{r_i}}{r_i!}$$

And the SNR is defined as:

$$SNR = 10log_{10}\frac{C_0}{2\lambda_0 T}$$

On this basis, the SNR the no. of transmitted particles can be defined as:

$$N_{TX} = \frac{2\lambda_0 T 10^{\frac{SNR}{10}}}{P_0}$$

– To optimize the Bit Error Rate Performance in presence of ISI, different threshold based receiver are considered.

– These receiver differ in terms of apriori information received.

– **For Optimal Zero Bit Memory Receiver:**

$$f(x) = \begin{cases} 0, & r_i \leq \tau \\ 1, & r_i > \tau \end{cases}$$

Probability of receiving $r_i$particles:

$$p(r_i|s_i) = \frac{e^{\frac{-\lambda}{s_i}}(\frac{\lambda}{s_i})}{r_i!}$$

$$\text{where,}\frac{\lambda}{s_i} = \lambda_0 T + C_0 s_i + \sum_{j=1}^{\infty} C_j$$

Based on this sub-optimal threshold can be given by:

$$\tau = \frac{C_0}{\ln(1 + (\frac{C_0}{\sum_{j=1}^{\infty}\frac{c_j}{2} + \lambda_0 T}))}$$

– **For Optimal One Bit Memory Receiver:**

$$f(x) = \begin{cases} 1, & r_i \leq \tau|_{s_{i-1}} \\ 0, & r_i \geq \tau|_{s_{i-1}} \end{cases}$$

The BER can be given as:

$$P_e(\tau, s_{i-1}) = \frac{1}{2^{L-1}} \sum_{s_{i-2} \ldots s_{i-L}} P_e(\tau, s_{i-1})$$

2 Numerical Results

2.1 Simulation Framework

Values Of Parameters

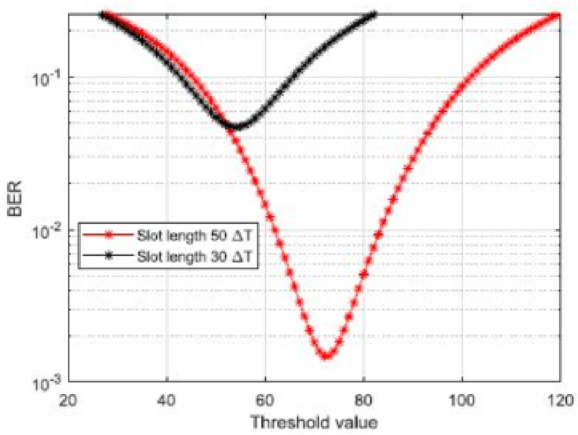
There are a multiple number of parameters adn variables used for the derivation as well as simulation. For that purpose, it becomes necessary to have assumptions for some values and have fixed values as per defined from the derivation. So, here is a list of all values of parmaeters which are used for the simulation framework for the derivation and simulation given in this paper and also for it's use in deriving a new approach for molecular based communications in say enzyme-based degradation, ANN simulation or LSTM in future.

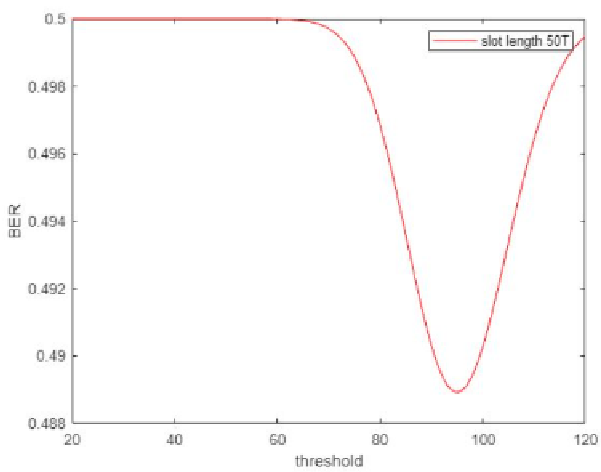
Parameter	Value
λ_0	$100s^{-1}$
Receiver radius r	45 nm
Distance d	500 nm
Diffusion coefficient D	$4.265 * 10^{-10} m^2/s$
Discrete time length ΔT	9 us
Slot length T	$30\Delta T$
Channel length L	5

2.2 Reproduced Figures

- Reproduced Figure-1

  BER in as a function of

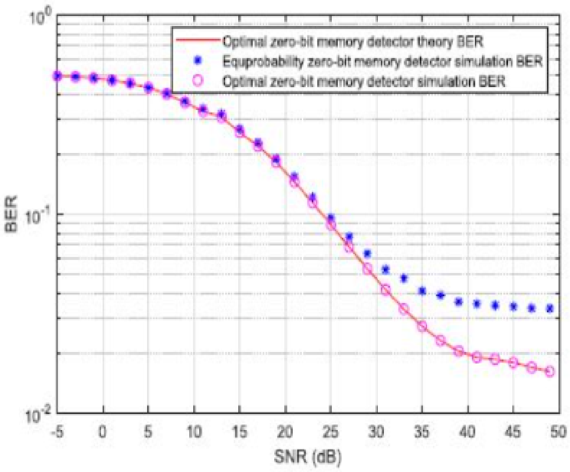


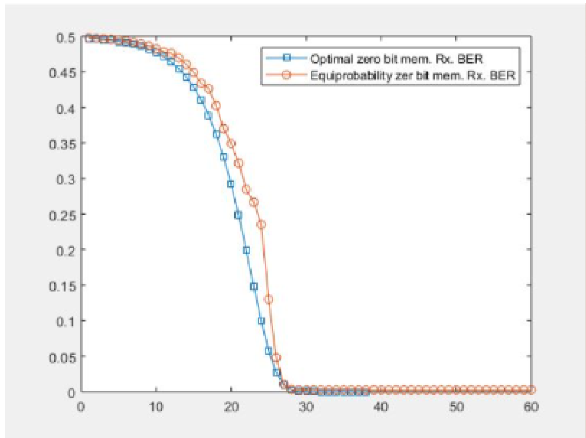


The above graph produced shows the BER in as a function of τ where SNR = 30dB. It depicts the relation between the threshold value and the BER. From the graph, we can say that the optimal threshold can be obtained by looking at the minimum value of the BER to it's corresponding particular slot length. It shows an invers relation i.e. on decreasing the slot length, the BER performance increases and vice-versa.

- Reproduced Figure-2

  The BER of Optimal vs. Conventional Zero-bit Memory Receiver at T = 30 Δ T .

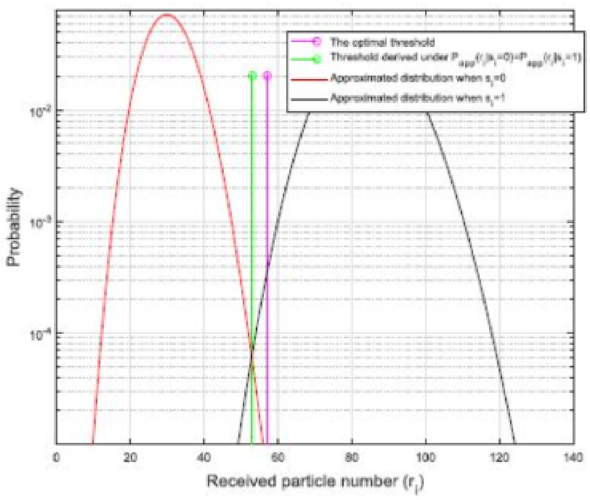


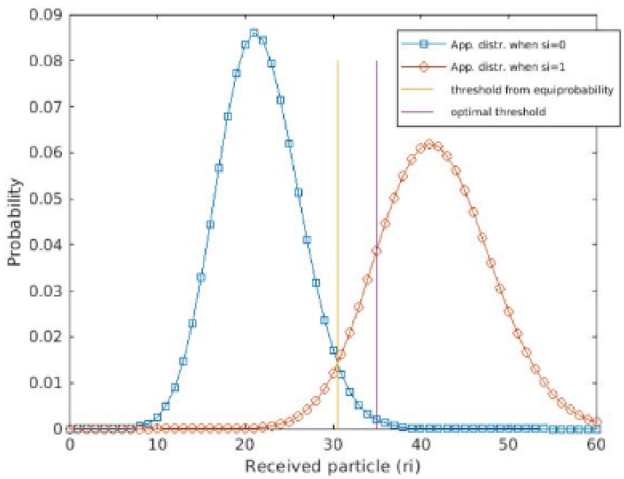


The above graph is for the BER of Optimal vs Conventional with repsect to Zero-bit Mmeory Reciever. It depicts that both the simulated and theory curves of optimal zero bit detector and one additional curve of Equi-probability zero bit memory detector.We observe that the proposed design based on optimizing the detection threshold that minimizes the BER provides us with better performance than the sub-optimal design.It shows that BER performance of optimal threshold is better than BER performance of sub optimal threshold.

- Reproduced Figure-3

  The approximated distributions of the received bits where SNR = 25 dB





First of all, we observe that the theoretical and empirical distributions of the received number of particles are different.The graph shows trends of sub-optimal and optimal thresholds. And the 2 curves show the approximate distribution when the symbol si = 0 and si = 1. It can be observed that the empirical distributions cross each other in correspondence of the estimated optimal detection threshold, while the approximated ones cross each other in a different point.This justifies the reason why our approach yields the optimum and a better BER and the optimal threshold is more idealistic in comparison to sub-optimal threshold.

3 Contribution of team members

3.1 Technical contribution of all team members

Tasks	**Dhruv Shah**	**Yash R Patel**	**Priyank Sangani**
Mathematical Analysis of base article	✓	✓	✓
Analytical Graphs of base article	✓	✓	✓
Performance analysis of base article	✓	✓	✓
System model research	✓		
Flow Diagram and Conclusion	✓		✓
Simulation of Matlab Codes		✓	
Latex Coding		✓	✓

3.2 Non-Technical contribution of all team members

Tasks	**Dhruv Shah**	**Yash R Patel**	**Priyank Sangani**
Introduction and Motivation		✓	✓
Overview and Background	✓	✓	
Leadership and Co-ordination of team	✓	✓	✓
Report Writing and Reviewing	✓		✓
Inference for reproduced results	✓	✓	✓