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: Molecular Communications: Model-Based and Data-Driven Receiver Design and Optimization [1]

1 Performance Analysis of Base Article

- **List of symbols and their description**

Symbol	**Description**
λ_o	Background noise power per unit time
r	Receiver radius
d	Distance between Tx and Rx
D	Diffusion Coefficient
ΔT	Discrete time length
T	Slot length
L	Channel length
N_{TX}	No of released particles
P_j	Probability of a particle hitting Rx ith time slot
C_j	Average no of received particles at the jth time-slot if N_{TX} particles are released
τ	Demodulation threshold
$\bar{s}_i$	Estimate of symbol s_i ith time slot
I_i	Sum of ISI and background noise
r_i	No of received particles

- **System Model:**

Transmitter - Transmitter is assumed to be small enough to be a point. It generates the information particles, which are released into the channel using ON/OFF Keying modulation. At the ith slot, the transmitter releases N_{TX} information particles into the environment when the symbol is $s_i = 1$, otherwise the transmitter does not release any particles. The information particles are assumed to diffuse randomly and independently of each other through the medium (Brownian motion).

Channel model - Channel is a 3D unbounded diffusion channel model without flow, where temperature and viscosity is constant during the whole transmission process. Therefore, diffusion coefficient D remains constant as the particles diffuse freely and no extra energy is needed.

Nature of noise - A large number of information particles are emitted not all of which reach the receiver in the considered time-slot. The information particles that remain in the channel and reach the receiver at a later time-slots causing Inter Symbol Interference (ISI). Background noise λ is also considered during calculations.

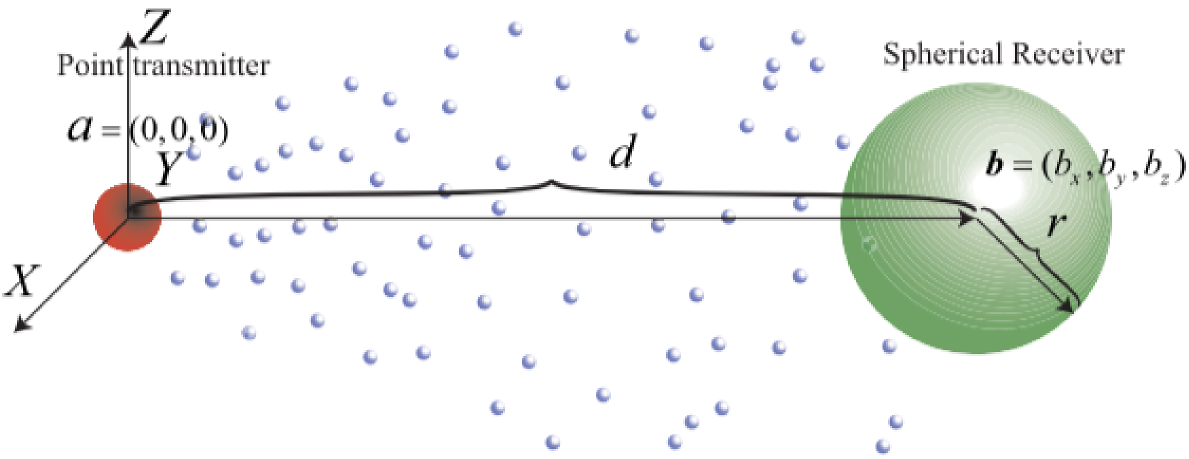

Figure 1: **The 3D unbounded molecular channel model without flow including a point transmitter and a spherical absorbing receiver.**

- **Detailed derivation of performance metric**

  Proposition 1: The optimal threshold that minimizes the BER of the zero-bit memory receiver is as follows:

$$(\tau^*, P_e^*) = arg_\tau min \quad P_e(\tau) \tag{1}$$

where $P_e(\tau)$ is the BER as a function of τ:

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

and:

$$P_e(s_{i-1}, \tau) = \frac{1}{2}[Q(\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j, \lceil \tau \rceil) + 1 - Q(\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j + C_o, \lceil \tau \rceil)] \tag{3}$$

Proof. The BER is defined as follows:

$$P_e(s_{i-1}, \tau) = \frac{1}{2}[P(r_i \geq \tau | s_i = 0, s_{i-1}) + P(r_i < \tau | s_i = 1, s_{i-1})] \tag{4}$$

$$\begin{aligned}
P(r_i \geq \tau | s_i = 0, s_{i-1}) &= P(r_i \geq \tau | \lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j) \\
&= \sum_{k=\lceil \tau \rceil}^{\infty} \frac{e^{-(\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j)} (\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j)^k}{k!} \\
&= Q(\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j, \lceil \tau \rceil)
\end{aligned} \tag{5}$$

where $Q(\lambda, n) = \sum_{k=n}^{\infty} \frac{e^{-\lambda} \lambda^k}{k!}$ is the incomplete Gamma function and $Q(\lambda, 0) = 1$. Similarly, we have:

$$\begin{aligned}
P(r_i < \tau | s_i = 1, s_{i-1}) &= P(r_i < \tau | \lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j) \\
&= \sum_{k=0}^{\lceil \tau \rceil - 1} \frac{e^{-(\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j)} (\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j)^k}{k!} \\
&= 1 - \sum_{k=\lceil \tau \rceil}^{\infty} \frac{e^{-(\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j)} (\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j)^k}{k!} \\
&= 1 - Q(\lambda_o T + \sum_{j=1}^{L} s_{i-j} C_j + C_0, \lceil \tau \rceil)
\end{aligned} \tag{6}$$

From equation (5) and (6), we obtain equation (4). Finally, the BER is obtained by averaging (4) with respect to the vector $s_{i-1} = s_{i-1}, s_{i-2}, ..., s_{i-L}$. □

2 Numerical Results

2.1 Simulation Framework

Table 1: Simulation Parameters

Parameters	**Value**
λ_o	$100\,\mathrm{s}^{-1}$
Receiver radius r	45 nm
Distance d	500 nm
Diffusion Coefficient D	$4.265 \times 10^{-10}\,\mathrm{m/s}^2$
Discrete time length ΔT	9 µs
Slot length T	30 ΔT
Channel length L	5

2.2 Reproduced Figures

For smaller slot lengths, there is a higher BER value, as visible in Figure 3. Choosing an appropriate demodulation threshold becomes important because it affects our ability to detect a bit correctly. The traditional approach is to take $P(r_i = \tau | s_i = 0) = P(r_i = \tau | s_i = 1)$ and find the appropriate value of τ, but this approach is especially sub-optimal for shorter slot lengths. This paper, instead of equating probabilities adds them, $P_e(s_{i-1}, \tau) = \frac{1}{2}[P(r_i \geq \tau | s_i = 0, s_{i-1}) + P(r_i < \tau | s_i = 1, s_{i-1})]$, and hence optimizes the demodulation threshold which consequently gives a better BER curve for the zero bit memory receiver.

Figure 5 shows the BER vs SNR curves of zero bit memory receiver for optimal and equiprobability BER equations. As seen in the figure the optimal curve gives better BER value for SNR than the equiprobability curve. Hence, this paper improves upon the BER performance metric for diffusion based molecular communication system by optimizing the demodulation threshold.

Reproduced Figure 1

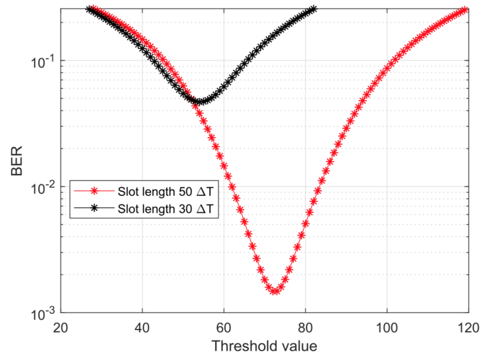

Figure 2: BER vs τ, reference figure [1].

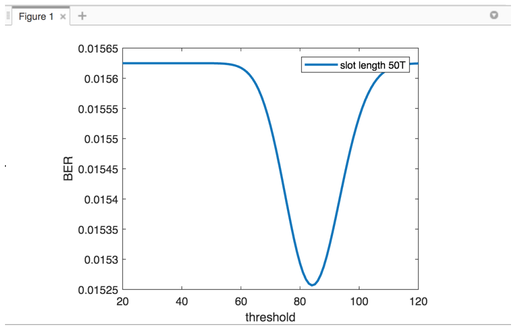

Figure 3: BER vs τ, simulation.

Reproduced Figure 2

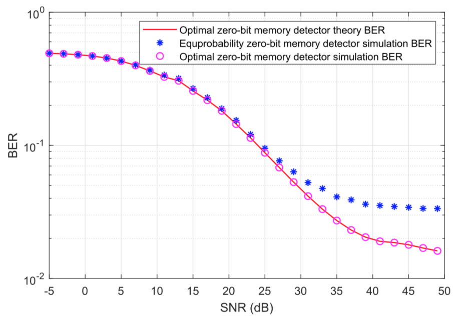

Figure 4: BER of optimal vs. equiprobability zero-bit memory receiver, reference figure [1].

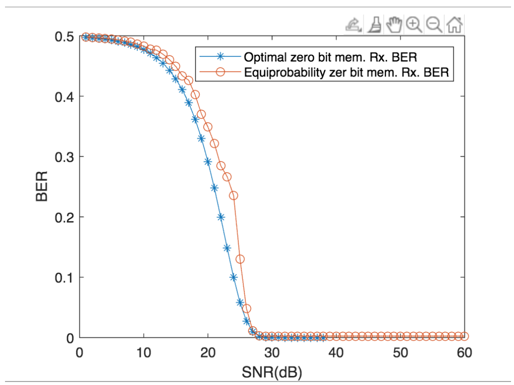

Figure 5: BER of optimal vs. equiprobability zero-bit memory receiver, simulation.

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.