Performance Enhancement of Diffusive Molecular Communications with an Apertured Plane

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***Abstract*—Molecular communication via diffusion (MCvD) utilizes the free diffusion of molecules to convey information. Brownian motion-induced random propagation of the molecules introduce inter-symbol interference (ISI) into MCvD-based schemes. In this work, the placement of an apertured plane between the transmitter and the receiver is proposed, and its effects on the error performance are analyzed. Overall, our results show that placing an apertured plane yields a promising improvement in the error performance of an MCvD system. The results of the study also link the aperture size to a trade-off between the ISI combating capability of the system and received signal power.**

***Index Terms*—Molecular communication via diffusion, concentration shift keying, apertured plane, bit error rate.**

I. Introduction

Molecular communication via diffusion (MCvD) is an energy-efficient molecular communication approach that utilizes the free diffusion of molecules to convey information [1]. After their emission from the transmitter (TX), the molecules exhibit Brownian motion, which causes them to randomly propagate in the fluid communication environment [2]. This random nature of molecule propagation imposes its well-known inter-symbol interference (ISI) characteristic to the MCvD channel and poses an inhibition on communication reliability as the data rate increases.

Inspired by [3] and [4]'s findings regarding the molecular signal path loss in presence of reflecting entities, this study analyzes the effects of placing an infinite and reflective plane with a circular aperture between the TX and receiver (RX). In the study, it is observed that for the binary concentration shift keying (BCSK) scheme [5], the existence of an apertured plane can help an MCvD system achieve a desirable improvement in terms of the bit error rate (BER). Furthermore, it is shown that the size of the aperture poses a trade-off between received signal power and ISI similar to the findings of [6], which hints to an optimal aperture size in terms of BER.

II. System Model

The system model of this study includes a single point TX and a fully absorbing receiver with radius r_r, whose closest distance to the TX is denoted by d, in a three-dimensional, driftless, and unbounded communication environment. The communication environment is assumed to include a fully and elastically reflective planar surface located at a distance d_a away from the transmitter. The surface is punctured with a circular aperture with radius r_a, whose center is colinear with the point TX and the center of the spherical RX. Overall, the considered system model is presented in Fig. 1.

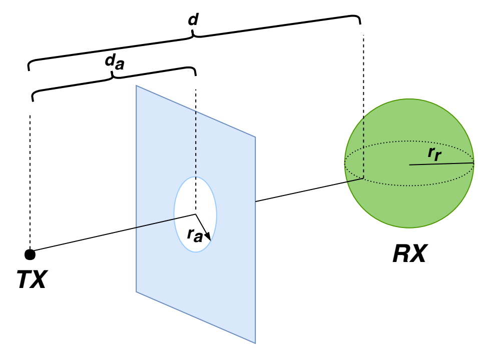

Fig. 1. The system model of interest.

Due to the existence of the reflective plane in Fig. 1, the time distribution of molecule arrivals, denoted by $f_{hit}(t)$, does not have a closed form expression to the best of our knowledge. Instead, the ratio of arriving molecules from time $t = 0$ until time t, $F_{hit}(t)$, is estimated by random-walk-based Monte Carlo simulations. After generating $F_{hit}(t)$, the k^{th} channel coefficient for a time-slotted MCvD channel operating at a symbol duration of t_s can be obtained as

$$h_k = F_{hit}(kt_s) - F_{hit}\big((k-1)t_s\big), \quad k = 1, \ldots, L \tag{1}$$

where L denotes the channel memory. When employing BCSK in which a bit-1 is represented by the emission of M molecules and bit-0 with no molecules, the number of received molecules for the i^{th} symbol slot is shown as

$$R_i = \sum_{k=1}^{L} R_{i,k}, \tag{2}$$

where $R_{i,k}$ is the random variable for the number of received molecules at the i^{th} symbol slot and due to the emission at the $(i-k+1)$th slot. Note that $R_{i,k} \sim \mathcal{B}(M_{i-k+1}, h_k)$, where $\mathcal{B}(n,p)$ stands for the Binomial random variable with n trials and success probability p. Hence, R_i can be approximated by

$$R_i \sim \mathcal{N}\big(\sum_{k=1}^{L} M_{i-k+1}h_k, \sum_{k=1}^{L} M_{i-k+1}h_k(1-h_k)\big) \tag{3}$$

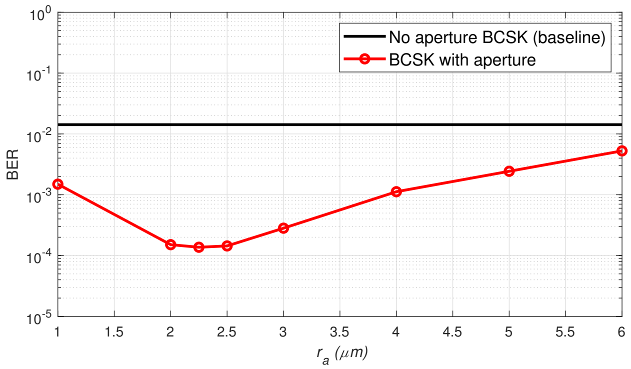

Fig. 2. BER vs. r_a curves for BCSK. $t_s = 0.2\,\text{s}$, $d = 5\,\mu\text{m}$, $r_r = 5\,\mu\text{m}$, $d_a = 2\,\mu\text{m}$, $M = 1500$ molecules, diffusion coefficient $D = 79.4\,\mu\text{m}^2\,\text{s}^{-1}$.

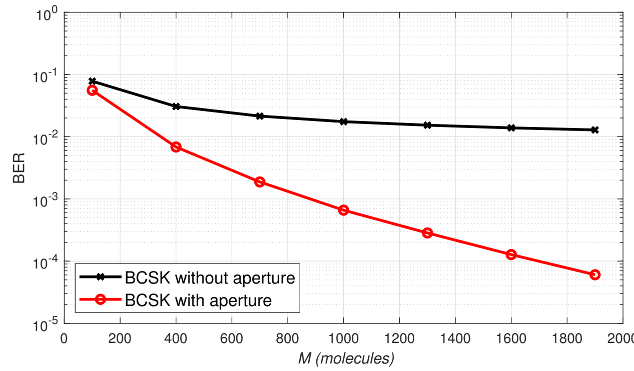

Fig. 3. BER vs. M curves for BCSK. $t_s = 0.2\,\text{s}$, $d = 5\,\mu\text{m}$, $r_r = 5\,\mu\text{m}$, $d_a = 2\,\mu\text{m}$, $r_a = 2.25\,\mu\text{m}$, $D = 79.4\,\mu\text{m}^2\,\text{s}^{-1}$.

following the findings of [7]. Here, M_i denotes the number of transmitted molecules for the i^{th} symbol slot.

III. Numerical Results and Discussion

This section presents the comparative BER performance of an MCvD system with a single point TX and a single absorbing RX [8], with and without the considered apertured plane. The symbol sequence used for the comparison is BCSK-modulated with equal probability of transmitting a bit-1 and bit-0, and demodulated using a single threshold detector. To generate $F_{hit}(t)$ values for the apertured plane model, random-walk-based Monte Carlo simulations are performed on a custom simulator implemented using MATLAB with 10^5 molecules, an incremental time step of $\Delta t = 1 \times 10^{-4}\,\text{s}$, and a total duration of $10\,\text{s}$. Fig. 2 and Fig. 3 present the BER curves corresponding to both with and without the apertured plane with respect to r_a and M, respectively.

The results of Fig. 2 show that for a given d_a, the error performance of the apertured plane scenario varies with r_a. When the aperture is too small (small r_a regime), the molecules that arrive at the RX mostly consist of those who take shorter and more directed paths towards the RX. These molecules are much more likely to arrive at the RX in shorter times, hence ISI reduces with decreasing r_a. However, since these molecules consist of a small portion of all emitted molecules, having a small r_a causes fewer number of molecules to arrive at the RX (reduced received signal power). Note that as r_a increases, ISI combating capability is traded for received signal power, which suggests that there exists an r_a value that yields the lowest BER for a given topology. For the system considered in Fig. 2, this value is roughly $r_a = 2.25\,\mu\text{m}$. It is also worth mentioning at this point that promising preliminary results are obtained for finding close to optimal r_a points analytically via signal-to-interference difference (SID) metric ([9]), which will be analyzed in future studies. In order to visualize the improvement in the BER vs. M curve when operating at $r_a = 2.25\,\mu\text{m}$, Fig. 3 is provided.

IV. Conclusion and Future Work

In this study, we have investigated the effects of the placement of an apertured plane on a molecular communication via diffusion system. We have presented that a desirable error performance improvement can be obtained by placing an apertured plane between the TX and RX, and we have shown the existence of a best aperture radius that minimizes BER.

The primary future work to this study is an analysis on analytical cost functions such as signal-to-interference ratio and SID, considering the aforementioned promising results. Furthermore, consideration of more practical scenarios with similar topologies and other issues such as mis-alignments and time variations are also future research directions.

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