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Simulation Study of Messenger Molecule Displacement in Communication via Diffusion

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***Abstract*: --- Molecular Communication via diffusion (MCvD) is a new communication paradigm that uses molecules as the information carrier between the nano-machines. The end to end MolecUlar CommunicatIoN (MUCIN) simulator tool is used to explore the characteristics of the MCvD channel. This simulator considered Binary Concentration Shift Keying (BCSK) technique for modulating binary information symbols, support 1-dimensional environment, and send symbols consecutively. The main issues of MCvD system are the Inter-Symbol Interference that arises when the molecules belonging to the previous symbol come into the current symbol. Conventional MCvD system exhibits a long tail of received molecular histogram, results in higher ISI. In this paper, the displacement of a messenger molecule is increased to reduce the amount of stray molecules in the MCvD channel.The proposed technique shows the first hitting time distribution to determine the highest reception of the information carrying molecules by the receiver.We also evaluate the performance of proposed scheme for different values of step length in terms of Inter- Symbol Interference (ISI), symbol detection and communication delay. Our results indicate that introducing proposed technique significantly improves the performance of MCvD system.**

Keywords **— Inter- Symbol Interference (ISI), Binary Concentration Shift Keying (BCSK),MolecUlar CommunicatIoN (MUCIN) simulator,Molecular Communication via diffusion (MCvD),Messenger Molecules (MMs), step length,hitting time distribution.**

I. INTRODUCTION

Nano-technology is a new field of developing and manufacturing of nano-scale materials and machines. Nano-machines are the devices ranging in size from 0.1μm to 10μm that are able to perform simple tasks with limited capabilities such as sensing, storing and actuation. Nano-machines can be interconnected to accomplish complex tasks such as in-body target drug delivery, intelligent disease detection, disease treatment, share location information [1]. Molecular Communication (MC) is the most potential way to interconnect nano-machines and to set up a Nano-network. In MC molecules are used to encode outgoing information, transmit these molecules in the propagation medium and receive these molecules to decode the transmitted information. In MC, the transmitter and receiver nano-machines are located at different distances in the environment. MC involves the exchange of information using chemical molecules called as messenger molecules that physically travel from a transmitter to a receiver nano-machine. In MC, molecules can propagate into two general methods defined as follow:

Passive mode: In this mode, information molecules randomly diffuse in the medium without using chemical energy such as communication via diffusion. It is clear that a high viscosity medium causing slower diffusion of emitted molecules.

Active mode: In this mode, information molecules propagate directionally through the medium by usingchemical energy such as molecular motors. This mode provides better information rate over longer distance between transmitter and receiver nano-machine[2].

Among the molecular transport mechanism, MC is driven by passive mode namedMolecular Communication via diffusion(MCvD). The randomly propagating information molecules are assumed to absorb after hitting the receiver in specific interval of time, which showsan important measurement parameter called as hitting time distribution.

The MCvD system consists of a transmitternano-machine, molecular channel, receiver nano-machineand information carrying molecules. The transmitter is operating in a 1-dimensional bounded medium in which molecules are released and propagate in a way that when a molecule reaches at the boundary, it bounces back into operating environment. The MCvD system model used in this paper is shown in figure 1.The transmitter is a point source of a radius size equal to zero and the receiver is sphere of radius ⟦ r⟧_rwith molecule receptors on its surface. The transmitter is located at a distance r_ofrom the center of receiver node, where⟦ r⟧_o=d+r_r, where d= distance between the transmitter and the receiver. The messenger molecules are released into the medium, where

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they propagate according to Brownian motion and reach at the receiver [3].

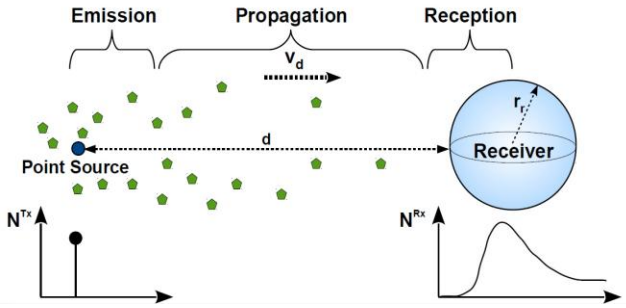

Figure 1: System model of MCvD

The point source releases single pulse of information carrying molecules and these molecules undergo a random walk (diffusion) process in the medium. The propagation these particles are modeled by Brownian motion and this movement of particles utilize zero energy for propagation. After emission from the point source, the time they reach at the receiver is probabilistic. The probability density function of molecule concentration C(x,t)at any point 'x' away from the point source and time't' is given by the equation (1).

$$C(x,t) = (1/(4\pi Dt)^{1/2})\, e^{\frac{-x^2}{4Dt}} \qquad (1)$$

where D is the diffusivity which measures the rate of diffusion [3] and can be calculated as:

$$D = k_b T / 6\pi\eta r_s \qquad (2)$$

where $k_b$the Boltzmann constant, T is the temperature in Kelvin, η is the viscosity of the medium and $r_s$is the Stoke's radius of the particle [2]. It is assumed in that when the number of information carrying molecules in the environment is less than the number of molecules of the fluid, the collisions between these molecules have little effect on the movement of the molecule. Therefore, the propagation model does not consider such collisions.When the propagating molecules hits the boundary of the receiver, the molecules are absorbed and removed from the environment, so each molecule contribute to the signal only once. This process is called first hitting process and it is used to determine therate of receiving the information carrying molecules by the receiver.In MCvD system, time is divided into equal time slots with a duration oft_s in which single symbol can be sent. At the transmitter BCSK modulation scheme is employed. In this technique, the transmitter releases impulse of molecules at the start of time slot to transmit binary symbol 1, while no molecules are released to transmit symbol 0. The encoded information molecules propagate toward receiver through diffusion. The receiver counts the $'N'$ number of molecules received at the end of each time slot and compares the number with pre-specified threshold τ.

$$\begin{matrix} 0, & forN < \tau \\ 1, & forN > \tau \end{matrix} \qquad (3)$$

If the number of received molecules exceed the threshold represents by symbol 1, otherwise 0 [1].Due to the process of diffusion, the information carrying molecules remains for long time in the medium and these stray molecules interfere with the transmitted symbols resulting ISI.This paper also describes the time varying molecular concentration histogram at the receiver end that showing a very long tail of molecular concentration depicting that hitting time of some molecules are very high, causing ISI. This adversely affects the communication system as the possibility of wrong detection of transmitted symbol become high [4]. In order to mitigate ISI, displacement of each information molecule has been increased in the literature. According to this approach the distance covered by the information molecules have been increased and large amount of information molecules reaches at the receiver in short time span. Consequently, the amount of stray molecules in the environment is reduced which leads to reduce ISI significantly. This approach improves the detection of symbols and also reduces the propagation time of information molecules. The paper is organized as follows.Section 2 introduces the proposed technique applied on the MCvD system. Performance evaluation is presented in section 3 and conclusions are drawn in section 4.

1. PROPOSED TECHNIQUE

In this paper the performance of the MCvD system with increased displacement of messenger molecules is analyzed. The information is assumed to be divided into a sequence of symbols that are spread over equal time slots as one symbol in each time slot. Each messenger molecule steps toward receiver once every Δtsecondwhich is the called step time. At each consecutive step time, the random movement of messenger molecule in 1-Dimensional space is given as:

$$r_{t+\Delta t} = r_t + \Delta r \qquad (1)$$

where $r_{t+\Delta t}$is the total displacement of a messenger molecule in after step timeΔt and Δr is the step size [3]. Our approach is to increase the displacement of each messenger molecule by adding steplength(α) value to the $r_{t+\Delta t}$.

$$r_{t+\Delta t} = r_t + \Delta r + \alpha \qquad (2)$$

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The increased displacement of messenger molecules has been regarded as one of the most effective technique to combat the ISI. Hence, the performance of the MCvD system has increased and it can be used for short distances.

II. PERFORMANCE EVALUATION OF THE INCREASING DISPLACEMENT OF MESSENGER MOLECULES IN MOLECULAR COMMUNICATION

To demonstrate the concept of proposed technique, we consider a transmitter nano- machine transmitting a series of symbols in the form of impulse signal.The BCSK modulation uses different number of molecules to represent symbol '1' and '0'. For sending symbol '0', the transmitter node remains inactive and sending symbol '1', it emits 1000 molecules. The probability of hitting symbols '1' and '0' is equal (i.e. 0.5). In 1-Dimensional environment, the messenger moleculesmoveonly in x- direction and at each time step it either moves right or left. The displacement of a single messenger molecule in unit time step is a random variable, which follows normal distribution. The performance evaluation of MCvD system is achieved using human insulin hormone as the information carrying messenger molecules. The displacement of a single messenger molecule (MM) is increased for various values of α [3].The received signal is sampled at sampling intervals oft_{ss}. The detector counts the number of molecules arrives on each sampling interval. Table 1defines the parameters and their ranges used in the simulation.

Table 1: Simulation Parameter

Parameters	Value
Distance (d)	1 μm
Number of MM (s)	1000
Simulation Step Time (Δt)	1 $msec$
Sampling Time (t_{ss})	5 $msec$
Number of Symbols	1
Symbol Duration (t_s)	64 $msec$
Diffusion Co- efficient (D)	79.4 $(\mu m)^2/sec$
Replications	100
Signal to Noise Ratio (db)	5db
Radius of receiver nano-machine	10μm

3.1. Improvement On Molecule Hitting Timedistribution

In MCvD system, hitting time distribution shows the behavior of the channel. Hitting time analysis is a molecule counting process which is used to count the number of hitting molecules at a specific instant of time. The propagation of information molecules across the medium is due to the diffusion process that introduces a high amount of transmitted pulse distortion. This distortion of transmitted pulse within the propagation medium, presents a challenge to their successful pulse detection. From figure 2, we observe that the number of arriving molecules sharply increasing from zero up to its maximum as the value of α increasing. After reaching its peak, the number of arriving molecules slowly decreases, forming a long tail. The infinite tail of molecular pulse creates ISI [5]. Therefore, this paper introduces a technique to minimize the effect of ISI in MCvD system.

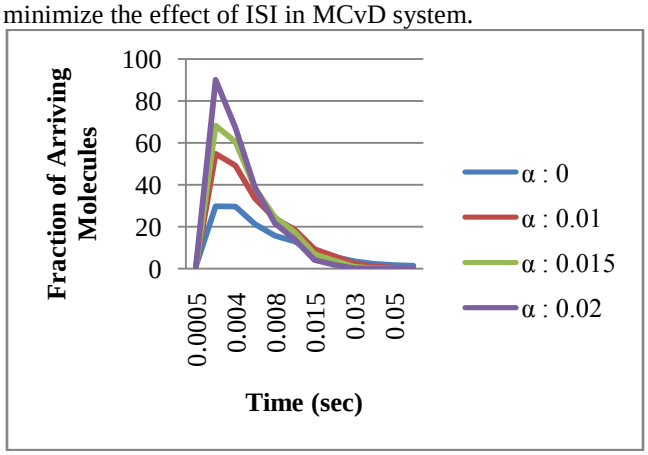

Figure 1: Hitting time distribution for various α values. MCvD system with increasing rate of displacement reach their respective equilibrium points faster and remain less stray molecules than the system with lower rates of displacement.

In figure 2,the x-axis represents single symbol duration and the y-axis shows the number of arriving molecules at each sampling time.From the figure 2, we observe that the large amount of messenger molecules are arriving at a receiver nano- machine in 0.002s, as the value of the molecule displacement is increasing. Notice that in the figure 2, the MCvD system with $\alpha = 0.02$ has no more stray molecules left in the channel after 0.03 seconds, whereas the system with $\alpha = 0$ has sufficient number of molecules remain in the channel.The received signal curves are distorted virtue the presence of diffusion noise in the MCvD channel.

3.1. Improvement On Inter- Symbol Interference

Figure 3(a, b) shows the fraction of molecules arrived in four binary received symbols. The consecutive

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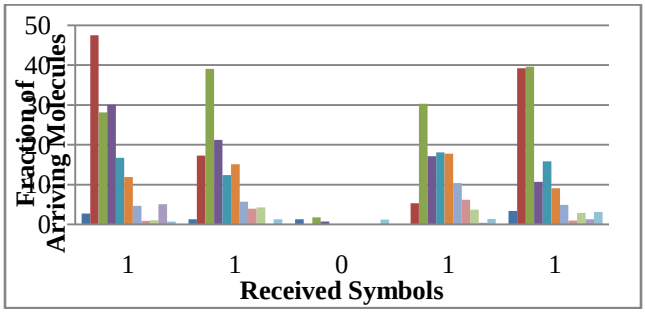
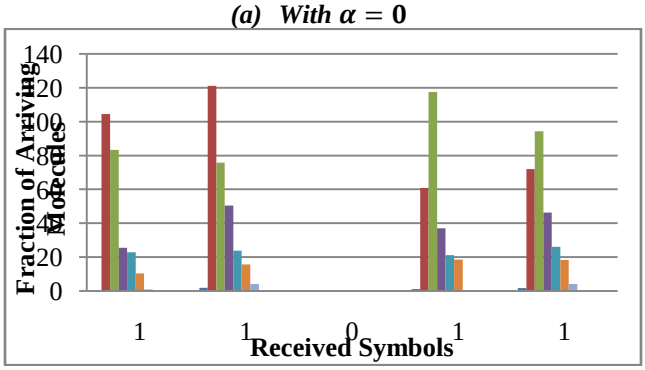
transmission creates ISI at the receiver end. In figure 3(a), we observe that noise causing molecules (i.e., messenger molecules from previous symbols and non information molecules) present in the environment causing high ISI. Figure 3(b), indicates that the receiver nano- machine chemically reacts with the messenger molecules only when a large number of messenger molecules are present around the receiver. The increased total displacement (α=0.02) of messenger molecules accumulates large amount of messenger molecules near the surface of the receiver nano-machine.The receiver nano- machine does not trigger chemical reaction as long as the large amount of messenger molecules accumulates around it.



(a) With $\alpha = 0$



(b) With α=0.02

Figure 2(a, b): Fraction of arriving molecules for received binary symbols (11011). For α=0.02, MCvD system has very less amount of interfering molecules than the system with α=0. Hence, the ISI is significantly reduced in the system.

This increases the robustness of receiver nano-machine toward noise and reduces ISI effectively. Notice that MCvD system with$\alpha = 0.02$, the number of arriving messenger molecules is comparatively higher than that with$\alpha = 0$.

3.1. Improvement On Symbol Detection

In MCvD system, the detection of symbol is performed using a threshold mechanism. If the number of accumulated molecules within symbol duration exceeds a certain threshold, then the output is represented as "1", if not as "0".The probability of error for a transmitted symbol is defined as the number of erroneous reception of that transmitted symbol divided by the total number of transmitted symbols.

$$P_e = N_{ERROR}/N_{TOTAL} \quad (3)$$

where$N_{ERROR} = N(Receivedsymbols - Transmittedsymbols)$. In order to have a reliable communication system, we need to have low probability of error at the receiver side [7].

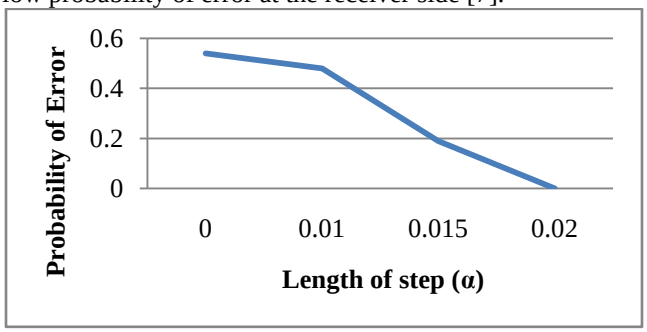


Figure 3: Probability of Error plot for various α values. MCvD system with increasing displacement rates perform better over lower rates of displacement. The MCvD system with α=0.02 has zero error rate.

From figure 4, we observe that when the displacement rate of messenger molecules increases, the probability of error decreases, which indicates better symbol detection.At $\alpha = 0.02$, MCvD system achieves zero error rateswhich show the successful detection of transmitted symbols. These decoded symbols are independent from previous symbol interference and environmental noise.

3.1. Improvement On Communication Delay

The noise presents in the environment cause the propagation of messenger molecules to be fundamentally stochastic and to have a large communication delay (i.e., micrometers per second in a fluidic medium) [6].This creates low speed and large communication delay.From figure 5,we observe that time elapsed in the propagation of information between a pair of devices reduces significantly with increasingα, which indicates better communication performance.The increasing displacement of messenger molecules, the less time elapsed in diffusion process.

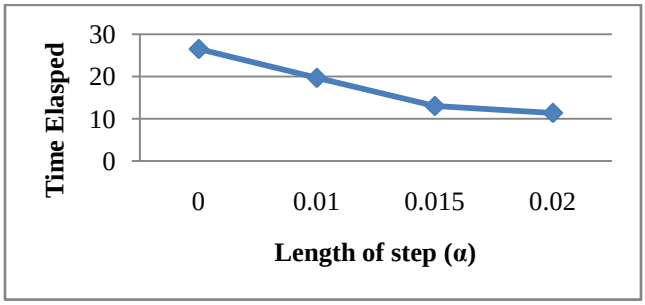


Figure 4: Communication Delay plot for various α values. MCvD system with α=0.02 displacement rate shows less time elapsed than the system with lower rates of displacement.

III. CONCLUSION

This paper explains hows the molecular communication via diffusion system works and proposes a technique that effectively combats inter-symbol interference between consecutive symbols. The proposed technique increases the displacement of messenger molecules in small step lengths.This paper considers a MCvD channel in 1-dimensional environment, BCSK technique for modulation and also provides thresholds for the decoding of received information molecules. This paper evaluates the performance of this technique in terms of hitting time distribution, Inter- Symbol Interference (ISI), symbol detection, communication delay. The histogram of hitting time distribution shows that quickly a sharp peak of molecular concentration reaching at the receiver and no molecules remain after pulse duration. Numerical results show that the ISI get reduced and improves current symbol detection. The speed of messenger molecules increases that result less delay in propagation ofmessenger molecules.

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