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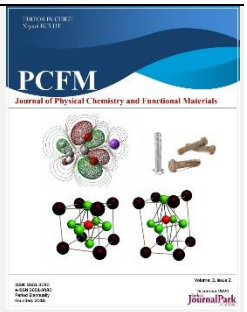

Analysis of Half Sphere Receiver Model in Molecular Communication Through Diffusion

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ABSTRACT

The area where the chemical signals are used as carriers in transporting information is known as the Molecular Communication (MC). The information particles which are used for communication in the MC systems consist of biological components such as proteins and DNA. Recently, together with the spread of nanotechnology, the number of publications related to MC also increases. Various researchers propose new methods and techniques for the science of nanotechnology to be used more efficiently in various fields such as medicine and nanorobot. These methods rather address solving the inter-cellular communication problems today. In this study, in contrast with the literature, the half sphere receiver model in a different topology has been analysed. This is due to the potential of different receiver models instead of micro strip or patch antenna in the digital communication systems. For this reason, different forms of the receiver have been tried and the signal transmitting ratio is tried to be increased and the intermolecular interference to be decreased.

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1. INTRODUCTION

In digital communication systems, when hardware based antenna is used for more efficient transmission of information from the transmitter to the receiver, in MC systems, molecule based antennas are used. In the literature, studies may be found where molecule based antenna models are elaborated. [1-3]. Akkaya *et al.*[1], made about the probability of the molecules to successfully reach the receiver, they proposed a simulation based analytical model. The receptors over the receiver in biological creatures are thought of as molecular antennas in the study, and by changing the size of the receptors and their intensity over the receiver, the probability of the molecules that are released from the transmitter to successfully reach the receiver has been analyzed. As a result of the analysis, it was seen that the smaller size receptors with the same intensity on the receiver acquired the released molecules with a higher probability of success. Einolghozati *et al.* [2], proposed the Ligand receptor model. For the capacity increase of this proposed model, the Markov chain model was preferred. Felicetti *et al.*[3], in their study, examined the directed receiver models which are mentioned as the equivalent of the antennas in the digital communication systems in MC systems. In the study, by placing spherical and cylindrical shaped structures, called cover, over the receiver at a certain distance from the receiver, the probability of the receiver to acquire molecules has been tried to be increased. If the molecule sent from the transmitter did not enter into the receiver but entered into the cover placed over the receiver, such molecule is resent from the transmitter and the probability of the receiver to acquire that molecule is increased. The authors had analysed the probability of the receiver to acquire molecules by assuming that the spherical and cylindrical shaped structures defined over the receiver have been placed with

different sizes and angles over the receiver. As a result, it was found that the cover model with a cylindrical shape and six times larger than the receiver is the model that most increases the probability of acquiring molecules by the receiver.

Yilmaz *et al.* [4], have preferred the Channel transfer method. By using a point transmitter and sphere receiver model, the interference and transmission delay paradigms at a 3-D plane have been achieved. Also, the time-molecule acquisition probability representing the probability of the molecules that are assumed to be released from the transmitter by the receiver has been graphically obtained with the simulation study. The graphics were analysed depending on the distance between the receiver and the transmitter, and it is seen both analytically and through simulation that, as the distance increases, the probability of molecule acquisition has decreased. Deng et al. [5] analysed reversible adsorption and desorption receiver models by the density shift switching method. In the system where communication through diffusion is used, some analytical studies are made for diminishing the inter-symbol interference (ISI) which is one of the biggest problems in MC. In the model where the molecules hitting the receiver during the symbol period are adsorbed, and the molecules remaining from the previous symbol period are desorbed, the bit error ratio (BER) values are calculated by using the Skellam distribution method. In another study where the adsorption and desorption receiver model is used, the system has been numerically analysed in 3-D space for different adsorption and desorption ratios [6]. As a result of the analysis made, it has been observed that the excepted number of the adsorbed molecule at the receiver increases by the adsorption ratio increasing and desorption ratio decreasing.

In this study, the MC model which is constructed by using a point transmitter (a sphere with a radius assumed to be very little) in 3-D space and a half-sphere receiver model as given in Figure 1 in MATLAB simulation environment has been analysed for various parameters. As shown in Figure 1, the receiver unit is placed to the origin of the 3-D space and the transmitter unit at a d distance from the receiver. The receptors on the receiver are randomly distributed. Supposing that the data transfer between the transmitter and the receiver is made by the molecules that are released from the transmitter, the acquisition probability of these molecules by the receiver, its amount, and the effect of the interference appearing with the intermixing during the symbol durations are examined.

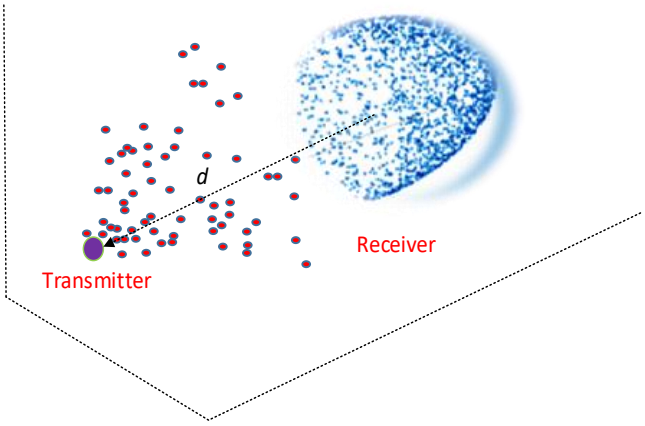

Figure 1. Half-sphere receiver model

2. MATERIAL AND METHOD

The reason for testing the half-sphere receiver model with different topologies is the potential of different receiver models to be used instead of micro strip or patch antenna in the digital communication systems. For this reason, by testing different forms of the receiver, the signal transmission ratios are tried to be increased and the intermolecular interference to be decreased. It was assumed that the molecules used for information transportation act in accordance with Fick's second law among the *Diffusion* laws and Brownian form in a fluid environment [7], [8]. In this process, like it is in the neuronal communication mechanism in the biological creatures, among the molecules that are released from the transmitter and reach the receiver, only those molecules that attach to the receptors placed on the receiver were considered. For the analysis of the molecules that attach to the receptors and that are perceived by the receiver, the probability of acquisition of the molecules that are released from the transmitted by the receiver is analysed. As in the digital communication systems, also in the MC, intermolecular interference is one of the biggest problems in data transfer. Therefore, the intermolecular interference was also analysed during the entire analysis here. All system parameters that are used during the analysis in the proposed model are given in Table 1.

Table 1.System parameters used in the proposed model

System Parameter	Value
Diffusion constant	79.4 $\mu m^2/s$
d	3-5 μm
r_r	2.87-4.92μm
Receptor radius, r_s	0.01-0.1 μm
Receptor number	7200-72

The molecules that reach from the channel to the receiver unit are taken into the environment by the receptors, by chemical reactions or by direct absorption [9]. The reach of the molecules to the receptors is called as (first

hitting). The formula of this first hitting at a 1-D plane is expressed as [10],

$$f_{hit}^{1D}(t) = \frac{d}{\sqrt{4\pi D t^3}} e^{-d^2/4Dt}, \quad (1)$$

And its 3-D space formula, as,

$$f_{hit}^{3D}(t) = \frac{r_r}{(r_r+d)} \frac{d}{\sqrt{4\pi D t^3}} e^{-d^2/4Dt}, \quad (2)$$

here *d* represents the distance between the transmitter and the receiver.

For the analysis of the software based MC model based on the above equations, two equations are used. The first of these equations is the h_0 equation which shows the acquisition probability of the molecules sent from the transmitter at the receiver, and the other is the signal to interference ratio (SIR) where intermolecular interference is taken into consideration. This ratio is often defined as inter-symbol interference (ISI) in the literature. However, it was thought that the definition made here by taking into consideration the formula expression will be more appropriate. As in the digital communication systems, also in the MC systems, inter-symbol interference is one of the biggest problems in data transfer. Inter-symbol interference or SIR concept in terms of distribution concepts are shown as examples in Figure 2. As seen in Figure 2, the molecules remaining from the first symbol duration continue to come to the receiver through the first symbol duration has ended and the second duration has started. These molecules causing the interference are shown in red, in Figure 2. Here, since taking the symbol duration longer will enable the secreted molecules to reach the recipient cell for a signal transmission this will decrease the percent of error in the communication, however, as the number of symbols sent during the unit time will decrease, the data transmission pace will decrease. On the other hand, since taking the symbol duration shorter will enable the molecules of that symbol to remain in the environment even after the perception time of the sending molecules and since this will cause interference due to the inclusion of these molecules in the molecules that require to reach the receiver during the next symbol duration, this will increase the percent of error in communication and the number of symbols sent in unit time and hence increase the pace of transmission. For this reason, when choosing the duration of the symbol, a balanced choice should be made between the data transmission pace (capacity) and percent of error [11].

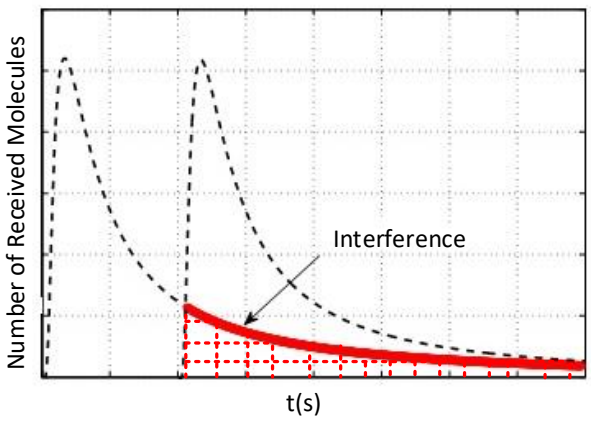

Figure 2. Representation of the intermolecular interference with the time graph of the number of molecules taken at a time of two symbols

In an MC system, the ratio of the number of molecules that the receiver acquires during the first symbol time to the number of total molecules sent by the transmitter, in other words, the molecule acquisition probability of the receiver is expressed by h_0 (Equation 3). The ratio of molecule probability h_0, reaching the receiver in the first symbol period, which is generally expressed as ISI in the literature, to the probability of the molecule reaching the receiver after the first symbol period is expressed here with SIR (Equation 4).

$$h_0 = \frac{N_{rx}(0)}{N_{tx}(0)}, \quad (3)$$

$$SIR = \frac{h_0}{\sum_{k\in(1,\ldots son)} h_k}, \quad (4)$$

$N_{rx}(0)$: The number of molecules reaching the receiver during the first symbol period

$N_{tx}(0)$: The number of total molecules released from the transmitter receiver during the first symbol period.

3. RESULTS OF ANALYSIS

Contrary to the literature, in the proposed MC model, the results were obtained by distributing the receptors not on the entire sphere on the receiver but to its half surface. h_0 and *SIR* analysis were made with the flat side of the half-sphere looking to the transmitter. Here the reason for using the defined half sphere receiver model is to increase the receptor intensity of the side that is closer to the transmitter and thus, to enable more molecules to be caught by the receptors.

In Figures 3 and 4, a comparison of half and full sphere models is made. Among the half and full sphere receiver models with the same system parameters including the total number of receptors, it was seen that the half sphere model, as seen in Figure 3, has a higher molecule acquisition probability and a higher *SIR* ratio, as seen in

Figure 4. Thus, it may be thought that instead of distributing the receptors on the entire sphere, distributing the same amount of receptors on the half of the sphere will give a better result.

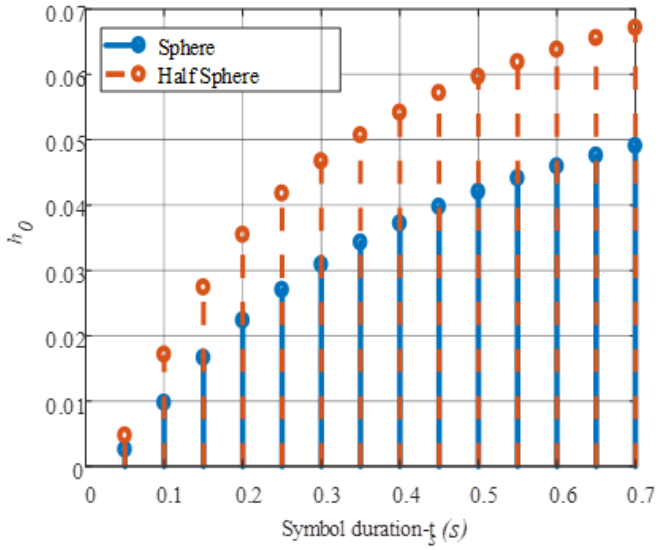

Figure 3. h_0 - symbol duration analysis for distributing receptors to the full sphere and half of the sphere

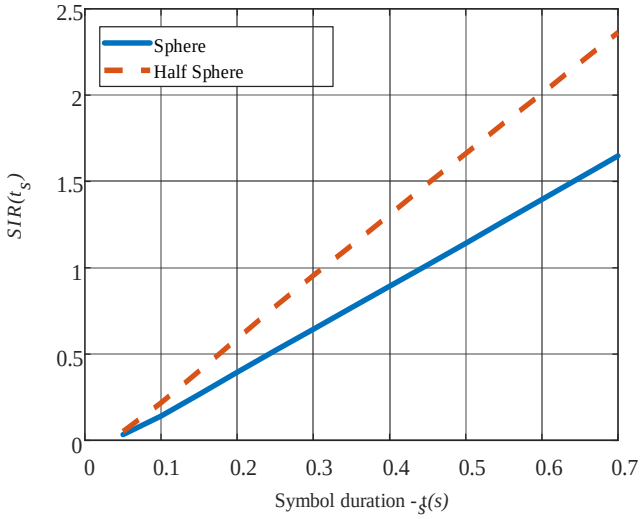

Figure 4. SIR- symbol duration analysis for distributing receptors to the full sphere and half of the sphere

Also, a better result is obtained by placing the transmitter facing the flat side of the half sphere model. As it is thought that in this situation, the probability of the molecules released from the transmitter to contact with the receptors over the receiver increases. And this shows that half sphere model may be preferred instead of full sphere model. Also, 100, 500 and 1000 μm^3 models of the half sphere model with different radiuses (volume) are analysed. As the result of the analysis, as seen in Figure 5, the amount of receptors in the receiver with a smaller volume is higher, when the distance between the transmitter and the receptor centres are kept equal in the half sphere receiver model. The average distance between the transmitter and the receptor centers is calculated as 5.6303, 6.1633 and 7.1956 μm for half sphere model with 100, 500 and 1000 μm^3 volumes respectively. When the average distance values calculated for full and half sphere receiver models are compared, it is seen that the average distance between the transmitter of the half sphere receiver model and receptor centers are shorter. And this shows why the half sphere model gives better results than the full sphere receiver model.

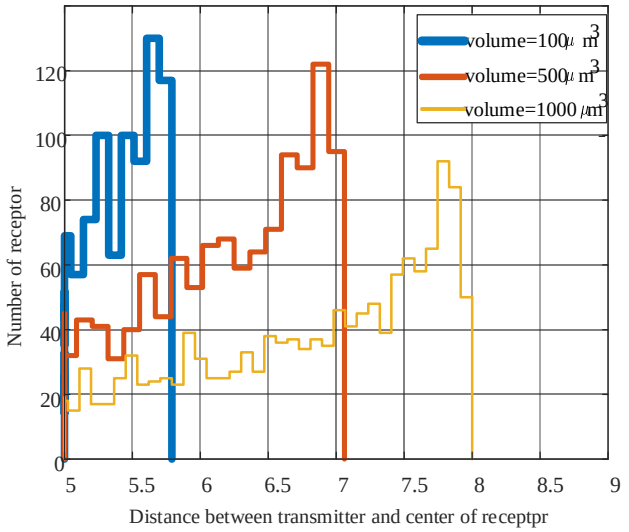

Figure 5. Relationship between the number of receptors and the distance of receptor centers to the transmitter for the half sphere receiver model.

The size of the receiver has been changed during the process obtaining this data, in a manner where the distance to the closest point of the receiver will be kept equal. In this case, while the position of the transmitter is kept constant in 3D space, the positions of the receiver and the receptors change.

4. CONCLUSION

In this study, a simulation based MC model has been designed in a MATLAB environment, and for the sphere and half sphere forms of the receiver over this designed model, the probability of the receiver to acquire molecules was tried to be increased. In the literature, the studies on this subject is made rather with sphere receiver model and the models proposed not by changing the form of the receiver but by changing the other system parameters such as the number of the receptors on the receiver and their sizes, and the distance between the transmitter and receiver have been analysed over these models. However, in this study, in addition to the previous studies in the literature, the MC model is analysed for different topologies of the receiver. Receiver models with different topologies like the patch antenna structures in the digital communication systems are tested. When the full sphere and half sphere receiver models with the same volumes and features are compared, it is seen

that the half sphere receiver model has the probability of acquiring lower interference and higher molecules.

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