



Effect of the Viscosity on Molecule Reception Ratio for Mobile Nano Systems

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Abstract: Studies regarding communication of the nano-devices/machines are considered to highly contribute to the developments in the field of nano-technology. Therefore, in this study, software-based a new model using nano-machine that could potentially be used in nano-scale systems was developed and analyzed in terms of communication performance. The information about the carrier particles used in such communication systems consists of biological components such as DNA and protein components. MC model that can possibly be used in nano-scale systems is analyzed in terms of channel performance of communication model such as viscosity of the medium. The physical properties of the proposed channel model such as viscosity is analyzed with respect to the ratio of received molecules in the duration of first symbol slot and number of received molecules using the mobile point transmitter and spherical receiver. As a result, the probability of a molecule reception of the receiver and number of received molecules increase with decreasing viscosity.

Hareketli Nano Sistemler İçin Viskozitenin Molekül Alınma Olasılığına Etkisi

Anahtar Kelimeler

Hareketli nano sistemler, Viskozite, Molekül alınma olasılığı

Öz: Nano cihazların/makinelerin iletişimine yönelik çalışmaların nano teknoloji alanındaki gelişmelere büyük katkı sağladığı düşünülmektedir. Bu nedenle önerilen çalışmada, nano ölçekli sistemlerde potansiyel olarak kullanılacak nano makine teknolojisi ile yazılım tabanlı yeni bir model geliştirilmiş ve bu model iletişim performansı açısından analiz edilmiştir. Bu tür iletişim sistemlerinde kullanılan taşıyıcı parçacıklar hakkındaki bilgiler, DNA ve protein bileşenleri gibi biyolojik bileşenlerden oluşur. Nano ölçekli sistemlerde kullanılacak model, ortamın viskozitesi gibi iletişim modelinin kanal performansı açısından incelenmiştir. Önerilen kanal modelinin viskozite gibi fiziksel özellikleri, hareketli noktasal verici ve küresel alıcı kullanılarak alınan moleküllerin ilk simge aralığı süresindeki oranı ve alınan moleküllerin sayısına göre analiz edilmiştir. Sonuç olarak, alıcının molekül alma olasılığı ve alınan molekül sayısının azalan viskozite ile arttığı görülmüştür.

1. INTRODUCTION

Many study have been carried out about communication of nano-devices in recent years [1]–[3]. The transmitter (Tx) and receiver (Rx) parts are investigated to analyze transmitted and received molecules in a fluid media. However, generally the Rx entity and the received signal are considered to analyze molecular communication (MC) systems. In [4], channel transfer function by using a fully absorbing spherical receiver and point transmitter for molecular communication via diffusion (MCvD) is

presented with analytic and simulation studies. In this study, in a 3-dimensional (3-D) environment, propagation delay and attenuation are studied for channel of MCvD model. Pulse amplitude and pulse peak time are investigated regarding distance between receiver and transmitter. Finally it is found that when the distance and pulse peak time increased then pulse amplitude decreased. Moreover molecular antenna models for MCvD are also studied in the literature.

In MC, chemical transceiver models can be used for the implementation subjects to send information from

receiver to transmitter. It is known that this models can be applied to many fields such as defense, environmental monitoring, bio-medical, industrial and dentistry purposes [1]–[6]. In these studies, because of their parallel structure to the digital antennas usually receptors have been considered as the molecular antenna. It is known that all biological cells have receptors which is placed at the surface of their receiver to receive nutrient, proteins or other substances. In [5], the hitting probability of MCvD system for a point transmitter and spherical receiver is analyzed by changing the parameters of density and size of these receptors. The absorption rate of receiver is also analyzed analytically by using hitting probability versus the number and the size of receptors. It is concluded from [5] that deployment of small receptors on the receiver instead of larger receptor, the hitting probability is obtained higher when the total receptor deployment area remains the same. The minimum sufficient surface area of receptor is also investigated in this study and finally it is found that displacement of the receptors on the receiver should be as little as 1% of the surface area of the receiver to have a comparable signal energy with a perfectly absorbing spherical receiver.

In [7], a receiver model with ligand receptors that contains holders for molecules to start signaling and interrupt inside the cell is proposed. The receiver of the system model is proposed to hold a great number of binding places and the molecular absorption over each of these places is considered using Markov Chain model in this study. The whole reception ratio of a receiver is estimated via calculating the mean of concentrations on all binding places [7]. The molecules are released by transmitter at either low or high absorptions to get “high” and “low” signal levels related to binary generators to test the system for realizing higher reception ratios. Finally, the facility of ligand receptors which increase with increasing number of receptors is obtained. As a result, it is concluded that percentage of absorptions are avoided at the transmitter side not reason of any ambiguity as neither “low” nor “high”. CNTs (carbon nanotubes) and GNRs (Graphene Nanoribbon) based molecular receptor antenna models using graphene and its derivatives are also analyzed due to their prominent sensing capabilities in nano sensor networks [3]. In another model [8], a molecular antenna model is proposed and some coding techniques are introduced for the proposed system. In [9], a new antenna model, which generally consists of a spherical receiver and reinforced with a completely reflective spherical or cylindrical shell concerned with on or nearby the receiver in Molecular communication, has been introduced to increase the ratio of reception. Different shape of a shell such as sphere and cylinder which is placed on the receiver is considered as antenna and numbers of absorbed molecules are increased with these shells.

In this study, a novel architecture of receiver model by using different channel environment parameters such as viscosity of the diffusion constant for MCvD is introduced. It is proposed that the use of different values of the viscosity in the environment increase the

communication quality of the proposed model instead of the same value of it used in the literature. Through Monte Carlo simulations it is obtained that the effect of viscosity on the reception ratio which suggests better channel parameter possibilities in terms of reception probability. The proposed system model is given in Fig. 1. As shown from the figure, molecules which carry information from transmitter to receiver, transmitter and receiver are mobile in a diffusion environment.

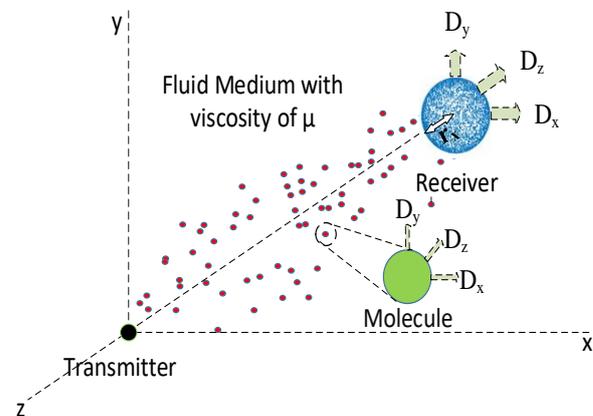


Figure 1. The proposed system model

2. MATERIAL AND METHODS

In this study, physical properties of the channel of nano-machine model are analyzed using a mobile point transmitter and spherical receiver by considering receptors on it. It is known that information transfer between transmitter and receiver occurs in the medium by carriers such as molecules. The physical properties of the carriers and density of medium is very important for information transfer.

The number of current density that can be an atom, hole, electron and molecule determine the current that is the rate of charge flow. The current flowing can also be calculated since it is known as the number of charge carriers. There are two current mechanisms which are drift and diffusion that cause the charges moving. Charge moves under the influence of an electric field since the applied field exerts a force [10],

$$F=qE, \quad (1)$$

on the charge carriers where E represents applied field and F represents force. This movement results a current which is known as drift current,

$$I_d=nqV_dA, \quad (2)$$

where I_d , V_d , A , n and q are drift current, drift velocity of charge carrier, area of the medium, number of charge carriers per unit volume, charge of electron respectively. Carrier mobility, μ decides how mobile the charge carriers and how certainly charge carriers transfer under the effect of an applied field [10],

$$V_d=\mu E \text{ or } \mu=V_d/E. \quad (3)$$

If the medium is at thermodynamic equilibrium (there is no applied field) the carrier have a thermal energy of $\frac{k_B T}{2}$ per degree of freedom and in 3D the thermal energy of electron,

$$E = \frac{3k_B T}{2} \text{ and } V_{th} = \sqrt{\frac{3k_B T}{m^*}}, \quad (4)$$

where V_{th} , k_B , m^* and T refer to thermal velocity of electron, Boltzman Constant ($1.38 * 10^{-23} J/K$), the effective mass and temperature of the medium (Kelvin), respectively. If there is no applied field, the movement of the molecules will be completely random and this randomness result no net current flow. Molecules move in the system due to its thermal energy or applied field but they collide each other. The average time taken between collisions is called as relaxation time or mean free time, τ . So we can define the mobility as,

$$\mu = \frac{q\tau}{m^*}. \quad (5)$$

Diffusion current is due to the movement of the carriers from high concentration region towards to low concentration region. As the carriers diffuse, a diffusion current flows. The force behind the diffusion current is the random thermal motion of carriers. A concentration gradient produces a pressure gradient which produces the force pressure gradient and the force on the molecules causing to move them [10]. According to electrical mobility equation, diffusion constant for charged particles is defined as follow,

$$D = \frac{\mu k_B T}{q}. \quad (6)$$

It is known that the transfer of information generally takes place in the form of free diffusion movement of molecules in the environment. The feature of transmission medium is determined with diffusion coefficient; D for diffusion of spherical uncharged particles through a liquid is given,

$$D = \frac{k_B T}{\zeta}, \quad (7)$$

where ζ drag coefficient and it is defined as follow,

$$\zeta = 6\pi\eta R_H, \quad (8)$$

where η and R_H refer to viscosity and the hydraulic radius of the information particle. The diffusion coefficient of some molecules in water obtained at 25°C are shown as in Table 1 [3], [11].

Table 1. Diffusion coefficient of some molecules in water

Molecule	D ($\mu\text{m}^2/\text{s}$)
DNA	0.81-53
human serum albumin	61
Insulin	150
Sucrose	520
Glucose	600
Glycerol	930
Nitrate	1700
Water molecule	2100

In the literature, it is clearly stated that the properties of the environment and the density difference between the regions directly affect the performance of molecular communication since molecules transport information between nano-devices (machines) using the free diffusion medium. Diffusion, also known as flux, is expressed as the movement of particles from a very dense medium to a less dense medium due to the difference in density between two regions. Considering that the molecules are released into the transmission channel with a certain emission rate from the transmitter nano-machine, the density $C(x, t)$ formed by these molecules at time t and at a distance x is expressed according to the certain boundary (boundary) and initial conditions of the following partial differential equation. This equation is derived based on the equation of $\frac{\partial C}{\partial t} = D_i \nabla^2 C_i$, which is known as Fick's second diffusion law in the literature. Here i denotes the substance type and C denotes the substance density. The change in the density in the x direction of the emitted molecule depending on time is expressed as in Eq. 9 [12].

$$\frac{\partial C(x,t)}{\partial t} = D_i \frac{\partial^2 C(x,t)}{\partial x^2} \quad (9)$$

The number of hitting molecules until time t , $N_{hit}^{3D}(t)$ is given below,

$$N_{hit}^{3D}(t) = \frac{r_x}{r_x + d} \text{erfc}\left(\frac{d}{\sqrt{4Dt}}\right) \quad (10)$$

where erfc , r_x , and d refer to error function, radius of receiver and distance between transmitter and receiver respectively. In an MC system, the number of received molecules in the first symbol duration to the number of transmitted molecules, in other words, the ratio of received molecules in the duration of first symbol slot is given as follow,

$$h_0 = \frac{N_{rx}(0)}{N_{tx}(0)}, \quad (11)$$

where $N_{rx}(0)$ and $N_{tx}(0)$ refer to total number of molecules received by the receiver and total number of molecules released from the transmitter during the first symbol duration. As given above formulas, the definition of the viscosity and mobility are briefly explained, and diffusion constant and viscosity are observed to be inversely proportional.

3. RESULTS

In this study, the proposed MC model is analyzed by changing the viscosity of the medium. System parameters of the proposed model are given in Table 1. Effect of viscosity on receiver models are analyzed by using the ratio of received molecules in the duration of first symbol slot which is h_0 metric. Shape of the transmitter is chosen as a point source and shape of the receiver is chosen as spherical with receptors on it. Firstly we analyze sphere receiver model for different viscosity values which are 67, 45, 34 and 27 nkg/ms to obtain the best result for the proposed model. As shown in Fig. 2 maximum number of molecules is obtained for

$\eta = 27 \text{ nkg/ms}$ and the maximum value of h_0 is also obtained for $\eta = 27 \text{ nkg/ms}$. It is concluded that, probability of received molecules in the receiver increases with decreasing viscosity of the fluid. Since an environment with a high diffusion constant or low viscosity would have little effect on the spreading rate of the molecules in the medium. Viscosity has also a reverse relationship with diffusion constant as given in Eq. 7. The proposed model is also analyzed for h_0 value in Fig. 3. As seen from the figure, when the viscosity increase, h_0 value also decrease as expected. Since value of the diffusion constant decreased, the spreading rate of the molecules in the medium decreased as shown in Eq. 7 and 8.

Table 2. System parameters

Radius of receiver, r_x	3.1 μm
Distance between receiver and transmitter, d	5 μm
Radius of receptor, r_s	0.02 μm
Number of receptor	5000
Number of transmitted molecules	20000
Viscosity of the fluid, η	67-27 nkg/ms
R_H	2.86 nm
T	298 K
Number of simulation	100

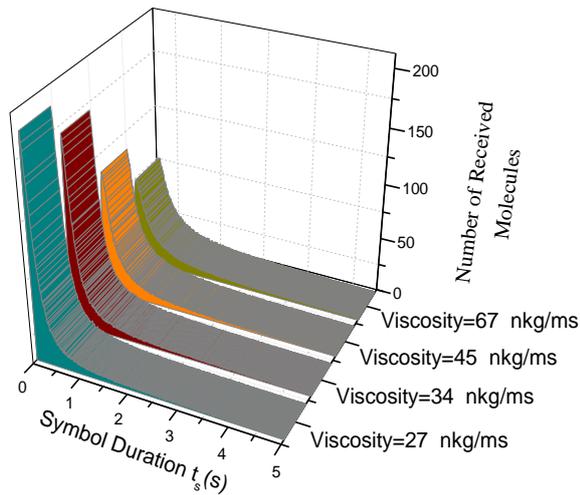


Figure 2. Number of received molecules versus symbol duration graph with changing of viscosity

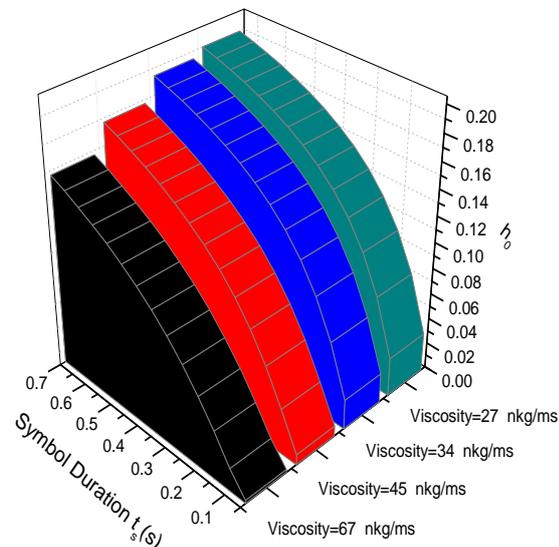


Figure 3. h_0 versus symbol duration graph with changing of viscosity

4. CONCLUSION

In this study, the number and reception ratio of the received molecules are analyzed by changing the viscosity of the environment. A software based model is developed with mobile point transmitter and spherical receiver. It was observed that when the viscosity of diffusion coefficient increase the number and probability of receiving molecule decrease. Due to the collision of molecules, carriers may be move slowly or lost their energy to move. Therefore when the symbol duration increased, the number of received molecules decreased. According to the Fig. 2 we observed that the relaxation time of molecules is about 1.5 s as shown from the Fig. 2. Because after 1 s, the number of received molecules decreased sharply. As a result, the viscosity of the medium can be changed in order to increase information transfer with lower error.

As a future work, we plan to find new antenna models to increase hitting probability and to decrease effect of environment on diffusion of molecules.

REFERENCES

- [1] Tadashi N, Eckford AW. Molecular Communication. Cambridge University Press, 2013.
- [2] Akyildiz IF, Brunetti F, and Blázquez C. Nanonetworks: A new communication paradigm, Comput. Networks, vol. 52, no. 12, pp. 2260–2279, 2008.
- [3] Farsad N, Yilmaz HB, A. Eckford, Chae CB, and Guo W. A Comprehensive Survey of Recent Advancements in Molecular Communication. 2014.
- [4] Yilmaz HB, Heren AC, and Tugcu T. 3-D Channel Characteristics for Molecular Communications with an Absorbing Receiver, IEEE Commun. Lett. 3-D, pp. 1–4, 2014.
- [5] Akkaya A, Yilmaz HB, Chae CB, and Tugcu T, Effect of receptor density and size on signal reception in molecular communication via diffusion with an absorbing receiver, IEEE Commun. Lett., vol. 19, no. 2, pp. 155–158, 2015.
- [6] Er MB and Aydilek IB, Music emotion recognition by using chroma spectrogram and deep visual features, Int. J. Comput. Intell. Syst., vol. 12, no. 2, pp. 1622–1634, 2019.
- [7] Einolghozati A, Sardari M, and Fekri F. Capacity of diffusion-based molecular communication with ligand receptors, IEEE Inf. Theory Work. ITW 2011, pp. 85–89, 2011.
- [8] Singh S, Singh HR. Molecular Receptor Antennas for Nano Communication: An Overview, vol. 9028, pp. 13–16, 2016.
- [9] Felicetti L, Femminella M, and Reali G. Directional receivers for diffusion-based molecular communications, IEEE Access, vol. PP, no. c, p. 1, 2018.
- [10] Walter H, Vreebur J. Fluid Sciences and Materials Science in Space - a European Perspective, vol. 50. 1989.
- [11] Search BioNumbers - The Database of Useful

Biological Numbers, 2011. [Online]. Available:
<https://bionumbers.hms.harvard.edu/search.aspx>.
[Accessed: 05-May-2015].

- [12] Schulten K, Kosztin I, and Street NM. Lectures in Theoretical Biophysics, 2000.