STUDY OF DIVERSITY SCHEMES FOR LEADLESS PACEMAKER SYSTEM USING MOLECULAR COMMUNICATION

[1]Bhagyashree Swain
Guided by: Dr. Anand S
[1]M-Tech, Dept. of Communication Engineering,
VIT University,
Vellore, India

ABSTRACT

Intrabody communication is an emerging research area. One of the novel approaches for intrabody communication is Molecular communication. The communication system model being introduced in this paper is a leadless pacemaker system using the concepts of molecular communication for treating heart related diseases. A concentration model of the flow of molecules within the heart is develop considering the case of pheromone based communication. Diversity schemes such as SISO, SIMO, and MIMO are applied to study their effects and declare a suitable communication model for leadless pacemakers. Performance parameters such a effective signalling rate, the bit error rate, inter-symbol interference are considered to arrive at a conclusion.

Keywords:Molecular Communication, leadless pacemakers, diffusion, pheromone communication, diversity schemes

INTRODUCTION

The number of people suffering fromcongestive heart failures and heart related diseases is increasing drastically due to their sedentary lifestyle. Such diseases lead to the pump action of the heart being impaired, a situation called Arrhythmias. In this disease, the electrical signals from the sinus node does not reach all muscles of heart which lead to improper contraction and expansion of the heart muscles. To treat these congestive heart failures, pacemakers are employed. The pacemakers send an electrical pulse whenever the heart rate gets too low. Traditionally, pacemakers have leads attached to them to provide power source to the pacemaker unit which is placed within the heart. However, leads lead to infections and in some cases, also lead to damaging of the vascular structure. Thus, leadless pacemakers are being widely researched upon. These units are mm-size, thus called nanomachines. They are formed like capsule, containing a sensor, a battery, and a pulse generator. These pacemakers are also less invasive in comparison to the traditional pacemakers.

Molecular communication is an emerging field of research for intrabody communications. It is a technique wherein the information exchange is performed with the help of transmission and reception of information encoded molecules [4]. This type of communication is greatly suited for

48

communication within the body in comparison to electromagnetic or RF communication due to its bio- compatibility [3]. Molecular communication also provides communication possibility in aqueous or fluidic medium like blood and water. The molecular movement amongst these nanomachines is defined using the Brownian motion model [6]. There are a few issues also which are being studied for molecular communication as well. Some of them include slow propagation speed and higher vulnerability to noise [6].

The human heart is divided into 4 parts, the right atrium, the right ventricle, the left ventricle and the left atrium. The natural pacing of the heart occurs when the electrical signals from the sinus node reach all the heart muscles, due to which the contraction of the heart occurs and the blood flow occurs. The blood flow within the heart is of turbulent diffusion type since blood flow within the heart is very quick. To consider the flow of molecules within the heart, the concept of pheromone communication used for communication among plants is considered. In pheromone communication, the alarm molecules or chemicals are bonded along with the carrier molecules which carry this information carrying molecules from the transmitter to the receiver.

The **Fig.1**. shows a molecular communication system model consisting of three parts i.e., the transmitter, the diffusion channel for the molecules to be transmitted in, and the receiver unit. The rest of the paper is divided as follows. In section 2 the system model of the proposed system is explained in detail, in section 3 the various diversity schemes are applied on the system to check for any improvement in functionality of the system, in section 4 the results are discussed and in section 5 the conclusion is arrived upon.
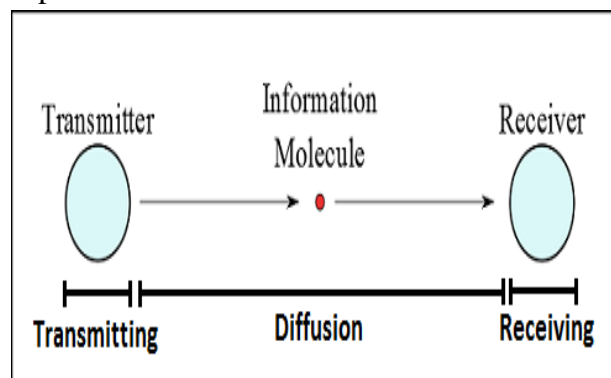

Figure 1. Molecular communication system illustration

EXPERIMENTAL DETAILS

A. *System Model*

The **Fig.2.** shows the system for the model proposed for the case of deterministic Single Input Single Output{SISO] scheme. The system consists of 2 parts, the transmitter sensor (Tx), and the receiver sensor (Rx), the dots between the transmitter and receiver units are the messenger molecules which are used to transmit the information. The Transmitter and receiver units are placed in the right ventricle. These messenger molecules follow a random walk while travelling from the Tx to the Rx unit. The size of a human fist is taken to be the size of the heart which have the values of height, x-max = 7.5 cm, width y-max = 5.5 cm, height z-max = 8 cm. respectively. The blood

49

flow velocity in the right ventricle is taken as the blood flow velocity of the Inferior and Superior Vena Cava which has an average value of 15 cm/s. Here a constant blood flow velocity assumption is made. The pacemaker distance from the closest wall of the heart is set to 7.5mm. Also, the number of molecules emitted is set to an arbitrary value of 500.

B. *Performance Analysis*

The performance analysis was carried out using the concentration model. Using the concept of diffusion, the concentration is dispersed over time and distance. To simplify the analysis, a reference direction for the blood flow is defined in the x-axis, a cylindrical region is defined for the blood flow from the transmitter and the receiver which are assumed to be placed one above the other as shown in **Fig.3**.

The plot of the molecular concentration is then plotted in terms of time and distance.
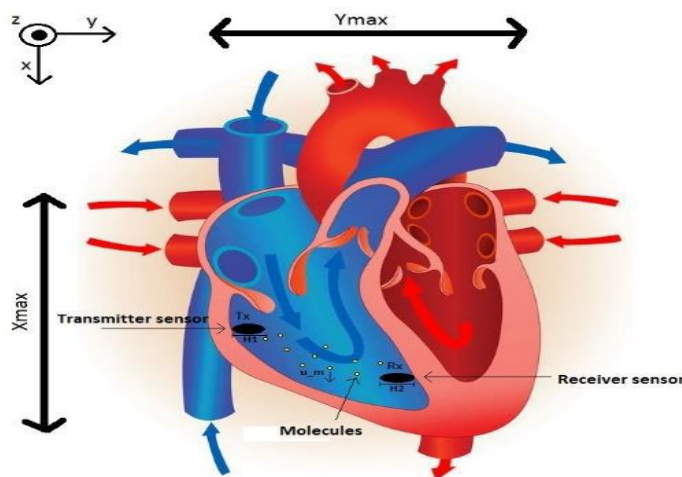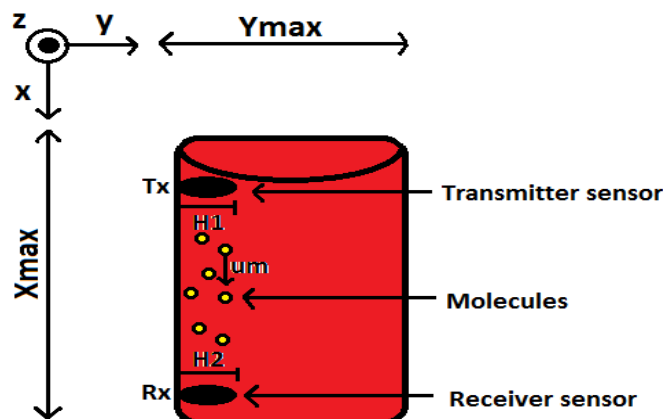
Fig.2. System Model of the proposed pacemaker

Fig.3. Simplified version of the model

In the next step, the stochastic SISO system is modelled by transmitting Q_j number of molecules which are random for every signaling interval. The encoder of the system is designed as On- Off keying type. The OOK Modulation is a very apt modulation technique for communication among nanodevices. Here, if the input signal is 1, then the molecules are transmitted and if the input signal is 0, then the molecules are transmitted, depicting silence. The binary hypothesis testing is applied to find the probability of detection and probability of false alarm. This is depicted in **Fig.4**.
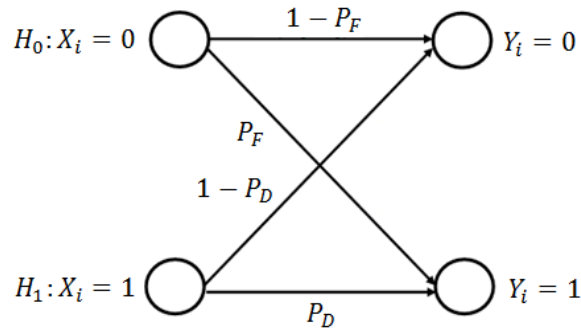

Fig.4. The binary hypothesis testing channel

The detector is designed based on the lines of Information theory approach, using the maximum mutual information. Based on this a optimal detection threshold is decided regarding sending or not sending of molecules. The equation below defines the mutual information.

$$I(X_i, Y_i) = \sum_{Xi=0}^{1} \sum_{Yi=0}^{1} P(Y_i \mid X_i) \, P(X_i) \log \frac{P(Y_i, X_i)}{P(Y_i)} \qquad (1)$$

The probability $P(Y_i \mid X_i)$ is defined using the binary hypothesis testing.

$$P(Y_i = 1 \mid X_i = 0) = P_F \qquad (2)$$
$$P(Y_i = 1 \mid X_i = 1) = P_D \qquad (3)$$
$$P(Y_i = 0 \mid X_i = 0) = 1 - P_F \qquad (4)$$
$$P(Y_i = 0 \mid X_i = 1) = 1 - P_D \qquad (5)$$

The molecules are sent with a priori probability of $P(X_i) = p_1$. Thus, the probability $P(Y_i)$ is given as,

$$P(Y_i) = \sum_{Xi=0}^{1} P(Y_i \mid X_i) \, P(X_i) \qquad (6)$$

It has been proved that the mutual information I is a monotonically increasing function of P_D for a given value of P_F. The Newman Pearson detector is used to calculate the optimal detection using the Maximum likelihood test. The expressions for false alarm probability and detection probability are derived as

$$P_F = \int_{\eta}^{\infty} p(Z_i; H_o) dz = Q\left(\frac{\eta - \mu_{Z_o}}{\sigma_{Z_o}}\right) \qquad (7)$$

$$P_D = \int_{\eta}^{\infty} p(Z_i; H_1) dz = Q\left(\frac{\eta - \mu_{Z_1}}{\sigma_{Z_1}}\right) \qquad (8)$$

The maximum value of the threshold is found by taking the argument of the maximum mutual information

$$\eta_{opt}(p_1) = \arg\max_{\eta} I(P_F(\eta_{opt}), P_D(\eta_{opt}), p_1) \qquad (9)$$

Also, the a priori probability can be controlled by receiver and its maximum value can be obtained.

$$p_1^*(\eta) = \arg\max_{p_1} I(P_F(\eta_{opt}(p_1)), P_D(\eta_{opt}(p_1)), p_1) \qquad (10)$$

The performance parameters tested were the maximum mutual information, the optimal signaling interval, the bit error rate, and the inter-symbol interference. In case of SISO, the distance between the transmitter and receiver is set to 0.03m. In the case of SIMO system, one transmitter and two receiver units are considered, wherein, the second receiver is at a farther distance from the transmitter in comparison to the first receiver. The distances are set to values of 0.03m and 0.04m respectively. For the MIMO scheme, two transmitter units and receiver units are considered. The distance between the 1st transmitter and the 1st receiver, 2nd transmitter and 2nd receiver is 0.02. The distance between the 1st transmitter and 2nd receiver, and 2nd transmitter and 1st receiver is 0.03m.

RESULTS AND DISCUSSION

A. *Deterministic SISO Scheme*

MATLAB R2015 was used to simulate the model proposed. The concentration plot of the molecules spreading out in time and distance is first arrived at, shown in **Fig.5**. Here the darker shades at the center depict more molecule concentration near the transmitter unit and gradually the molecules spread out towards the receiver, and the concentration reduces due to noises and absorption that may occur in the channel path.
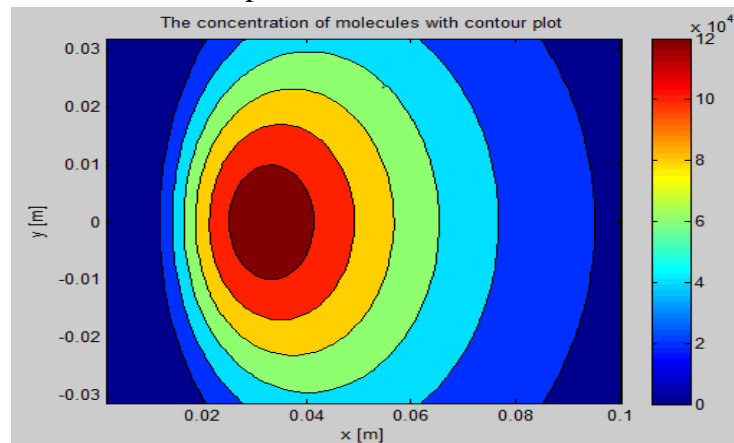

Figure 5. Concentration plot

Next, the Deterministic SISO case was discussed. To prove the correctness of the proposed model, a single signaling interval was considered during which Q_T number of molecules were transmitted from the transmitter to the receiver. The delay and the gain were plotted. As seen from plot in **Fig.6.**, the delay is increasing as we increase the distance between the transmitter and receiver. Also, the highest gain 0 dB when the distance is minimum, with increasing distance the gain experiences a logarithmic decay as shown in **Fig.7**. A plot of molecular concentration versus time is also plotted as shown in **Fig.8**. Here the different curves signify the concentration at different distances. It is seen that the highest curve is for the smallest distance. Another point to be noted here is that, the concentration the molecules is dispersing over time and distance, which decreases as the molecules approach the receiver. The magnitude of the concentration gradually

52

evens out; this is because diffusion reaches equilibrium when the dispersion of molecules is equally distributed at all distances.
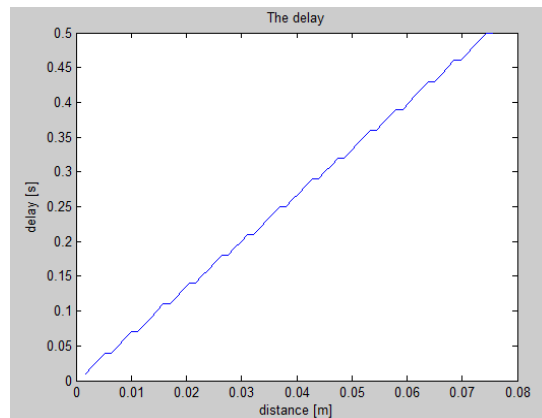

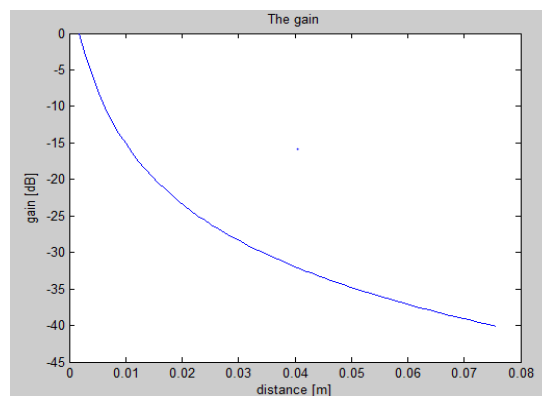Fig.6. Delay vs. distance for Deterministic SISO system

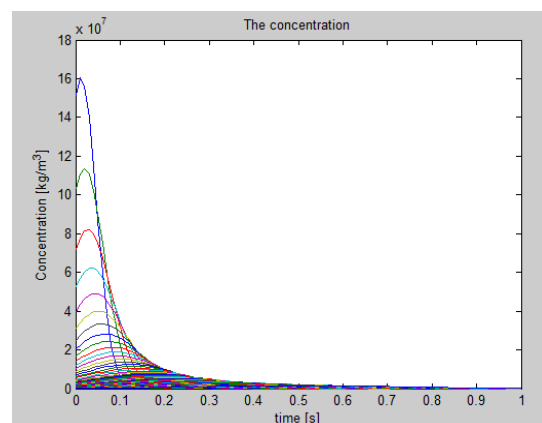Fig.7. Gain Vs. Distance for Deterministic SISO System

Fig.8. Concentration Vs. Time for varying values of distances for Deterministic SISO system.

B. *Stochastic Diversity Schemes*

In the next step, the stochastic SISO, SIMO and MIMO systems were considered one by one. The optimal signaling interval for all the cases were decided based on the amount of ISI occurring in the system for varying amount of signaling interval. By varying the signaling interval for the

53

lowest value of 10s to highest of 500s, the most optimal signaling interval for the case is decided. For the SISO scheme, this value is decided to be 150 seconds, for SIMO it is 200 seconds, and for MIMO, this value is 300 seconds. As a general case, it was observed that the ISI and the bite error rate decreased as there was an increase in the signaling interval. The **Table 1** consolidates all the results obtained for the signaling intervals.

It was observed that contrary to the general belief that increasing the diversity leads to an improvement in the system parameters, the proposed system saw a degradation in the performance parameters. Specially in the case of MIMO system, the inter-symbol interference was more in comparison to SISO and SIMO systems. The bit error rate was 2.41% in comparison to the 0.37% and 0.56% in case of SISO and SIMO respectively. The false alarm probability is the least in the case of SISO system, also the Detection probability is more. One of the reasons for the MIMO system with spatial diversity not being apt for this model is due to the channel which is of diffusion type, due to which the noise along the various paths increases.

Table I. Comparison of parameters for SISO, SIMO and MIMO Scheme

Parameters	*SISO Scheme*	*SIMO Scheme*	*MIMO Scheme*
Signaling Interval	150 s	200 s	300 s
BER	0.37 %	0.56 %	a. 2.41 %
			b. 2.54 %
False alarm probability	0.00134129	0.00191422	a. 0.999594
			b. 1
Detection probability	0.991786	0.397466	a. 0.999636
			b. 1
Optimal Threshold Value	$0.804 * 10^{18}$	479	a. 2
			b. 2
Max Mutual Information	$9.582 * e^{-01}$	$2.348 * e^{-01}$	a. $8.465 * e^{-07}$
			b. $8.466 * e^{-07}$
Max Information rate	$6.388 * e^{-03}$	$1.741 * e^{-03}$	a. $2.822 * e^{-09}$
			b. $2.822 * e^{-09}$
Priori Probability	0.5	0.4	a. 0.4
			b. 0.4

CONCLUSIONS

From the results discussed in the above section it can be concluded that the SISO scheme can be decided to be the best scheme for the pacemaker system, followed by the SIMO scheme. The MIMO scheme is not suitable for the pacemaker system within the heart. If a higher value of capacity is desired, the optimal scheme would be SISO. If a higher signaling interval is desired to reduce the battery consumption the SIMO scheme is more desirable scheme for the system of leadless pacemakers.

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REFERENCES

[1] I.F. Akyilidiz, J.M Jornet, "The internet of nanothings", IEEE Wireless Communication Magazine, 17(6), December 2016.

[2] T. Nakano, "Molecular Communiaction and networking: Opportunities and challenges", IEEE transaction on NanoBioscience, Vol11(2), pp 135- 148, June 2012.

[3] B. Atakan, O.B Akan, S. Balasubramaniam, "Body area nanonetworks with molecular communications in nanomedicine, IEEE communications magazine, January 2012.

[4] S. Kadloor, R. Adve, A. Eckford, "Molecular Communication using brownian motion with drift", IEEE transaction on NanoBioscience, 11(2), pp 89- 99, June 2012.

[5] M. Pierobon, I.F. Akyilidiz, "Noise analysis in ligand binding reception for molecular communication in nanonetworks" IEEE transaction on signal processing, 59(9), pp 4168-4182, September 2011.

[6] M. Pierobon, I.F. Akyilidiz, "Diffusion based noise analysis for molecular communication networks", IEEE transaction on signal processing, 59(6), pp 2532- 2547, June 2011.

[7] M. Pierobon, I.F. Akyilidiz, "Capacity of diffusion based molecular communication system with channel memory and molecular noise", IEEE transaction on information theory, 59(2), pp 942- 954, Feb 2013.

[8] J. Tan, A. Thomas, Y. Liu, "Influence of red blood cells on nanoparticle targeted delivery in microcirculation", Soft matter, pp 1934- 1946, Vol. 8, 2012.

[9] F. Gentile, M. Ferrari, P. Decuzzi, "The transport of nanoparticles in blood vessels: the effect of vessel permeability and blood rheology", Annals of Biomedical Engineering, 36(2), pp 254- 261, 2008

[10] D. Gidaspow, J. Huang, "kinetic theory based model for blood flow and its viscosity", Annals of Biomedical Engineering, 37(8), August 2009.