Propogation model of molecular communication based targeted drug delivery for atherosclerosis disease therapy

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Abstract— Atherosclerosis is one of the major cardiovascular disorder which causes severe health issues in human body. It also ends with patient death, when improper therapy takes place. Conventional therapy measures includes oral statin therapy, skin mode application, Inhalation mode of therapy etc., has their own advantages. But they cannot fully exploits the inflammation because of lower systemic bioavailability. Nowadays, Nano molecular communication provides numerous solutions in the field of targeted drug delivery system. The aim of this thesis is to propose a new analytical model for the propagation process of molecules based on Brownian motion mechanism by formulating the probability density of the Latency in blood medium. This model is analyzed based on crucial parameters such as radius of the propagating molecules, blood viscosity, drift velocity, distance between Nano-Tx and Nano-Rx, temperature of the fluid medium with respect to various blood shear rates. Based on simulation results, the latency is highly affected with molecular radius, distance temperature, shear rate and drift velocity. Our future work is to apply this model for various drug carrying molecules used in the treatment of the cardiovascular diseases and to assess its propagation capacity under various conditions of blood medium.

Keywords—Atherosclerosis, targeted drug delivery, Molecular communication

I. INTRODUCTION

The research and development for Body Area Networks (BAN) has gained maturity in recent years. Hence the researchers are now working for the In body networks using Nano machines [1]. The first useful applications of Nano machines are in medical technology, where they could be used to identify pathogens and toxins from the samples of body fluid. The reduced size of Nano machines translates into higher operational speed. They are designed according to their applications. Specialized Nano machines called nanobots might be designed not only to diagnose, but to treat the disease conditions, perhaps by seeking out invading bacteria and viruses and destroying them. In the field of biomedicine, Drug delivery and health monitoring systems are achieved by biological Nano machines. Targeted Drug Delivery System (TDDS) is an emerging technology that promises to tackle the conventional hurdles in order to achieve a controlled rate of drug release with precise location [2]. A new network Paradigm called IoNT is developed for providing solutions in the drug delivery system. There are four different types of communication in IoNT. The first type is Electromagnetic communication. It enables Nano machines to communicate over electromagnetic waves. The second type is Acoustic, where Acoustic energy is used for communication. The last type is called as Molecular communication. Here, the molecules are used for communication between each other. This MC plays a major role in Nano networks. In this book chapter, focus is put forward on analysis of Diffusion based molecular communication, its propagation model and finally numerical analysis is carried out for MC-TDDS for Atherosclerotic disease therapy.

II. METHODOLOGY

A. General propagation model:
Molecular communication takes place between Nano-transmitters and Nano-receivers. The information molecule is propagated in the blood medium via different process namely walkway-based, flow-based, and diffusion-based. In walkway based, there are pre-defined paths transmitting molecules to the communicating transmitter and receiver. In flow-based and diffusion-based techniques, molecules propagate over diffusion in a fluid medium. Most of the studies in the field of molecular communication done so far feature the diffusion propagation model based on Brownian motion or Brownian motion with drift. The diffusion...
process is explained by Fick’s equations. In the propagation process, propagation medium is a fluid medium (blood) and the propagation path is from sender bio-nanomachine to receiver bio-Nano machine. The propagation of messenger molecules is random, that is to say, in all directions in the fluid medium. These random movements of propagating molecules are modeled by the Brownian motion. The Brownian motion is an important physical process that undergoes random movement of particles in the fluid medium resulting from their collision with the fast moving molecules in the fluid. This motion is generally approximated as a Gaussian model in accordance with the probability theory [3].

B. Mathematical modeling of propagation process in MC-TDDS:

Mathematical models are developed in order to compare the quality of the molecular communication. Propagation period is calculated on the probability basis using Gaussian distribution. For Brownian motion in the blood medium, we apply the Gaussian distribution as follows,

\[ f(t) = \frac{1}{\sqrt{4\pi D t}} \exp \left( -\frac{d^2}{4Dt} \right) \]  

(1)

This is known as the PDF of first hitting time (ie., time when the molecule first hit the Nano-receiver or absorption time.

Where D is the diffusion coefficient of the propagating molecules during the propagation process and d is the distance between the Nano-transmitter and Nano-receiver in a one dimensional interval (-∞, d]. Diffusion coefficient represents the inclination of the propagating molecules during the propagation process through the fluid medium and it can be obtained by the following formula

\[ D = \frac{K_b T}{b} \]  

(2)

Where \( K_b \) is a fixed value called the Boltzmann constant, T is the temperature of the blood medium, and b is also a fixed value representing the drag constant of the molecule in the fluid medium. The drag constant b is derived for two conditions based on the size of the drug carrier molecule \( S_{\text{cm}} \) and the size of the propagating molecule \( S_{\text{fluid}} \) in the fluid (blood) medium,

\[ b = 4\pi \eta r_{\text{nm}} \]  

(3)

When \( S_{\text{cm}} = S_{\text{fluid}} \)

\[ b = 6\pi \eta r_{\text{nm}} \]  

(4)

When \( S_{\text{cm}} > S_{\text{fluid}} \)

\( \eta \) represents the viscosity of the fluid medium and \( r_{\text{nm}} \) is the radius of the propagating molecule in the fluid medium. According to author, liposomes plays a major role in drug delivery systems. At the systemic level, drug bioavailability is increased due to the high relative surface area of nanoparticles and it has been shown that liposomes around 150-200 nm in diameter remains in the blood stream larger than those with diameters less than 70 nm. Liposomes exhibit Brownian motion which is directly proportional to temperature and inversely to the liposome size. Since the diseased vessel has a blood flow with increased velocity, i.e., fluid medium has a medium drift velocity, we go with Inverse Gaussian model as follows,

\[ f(t) = \frac{d^2}{\sqrt{4\pi Dt^3}} \exp \left( \frac{-d^2}{4Dt} \right) \]  

(5)

III. CONCLUSION

Molecular communication, in other words the use of molecules to deliver drugs among Nano machines is new communication paradigm. The most important expectation of molecular communication is to provide new solutions for the treatment of cancer. This thesis provided a novelty by applying molecular communication in Atherosclerosis disease therapy. The proposed mathematical model is evaluated under various conditions and compared with two different radii of the liposome molecules. The results shows that, the latency is highly dependent on parameters such as distance, molecular radius, blood viscosity, blood shear rate and drift velocity. Hence blood becomes an efficient medium at lower shear rates in decreased temperatures. Our future work is to apply this model for various drug carrying molecules used in the treatment of the cardiovascular diseases such as Lipid nanoparticles, polymeric nanoparticles Micelles, CNT etc., and to assess its propagation capacity under various conditions of blood medium.

REFERENCES

