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Research paper

Evaluation and modeling of HIV based on communication theory in biological systems

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ABSTRACT

Some forms of communication are used in biological systems such as HIV transmission in human beings. In this paper, we plan to get a unique insight into biological communication systems generally through the analogy between HIV infection and electrical communication system. The model established in this paper can be used to test and simulate various communication systems since it provides researchers with an opportunity. We interpret biological communication systems by using telecommunications exemplification from a layered communication protocol developed before and use the model to indicate HIV spreading. We also implement a simulation of HIV infection based on the layered communication protocol to predict the development of this disease and the results prove the validity of the model.

1. Introduction

Biological communication is one kind of communication which is an exciting new platform that engineers are willing to research. The latest developments in biotechnology spawned many new areas, such as gene therapy and drug delivery in nanoscale, and they are essentially form the basic method for the biological level communication (C.M. Roth and Sundaram, 2004; R.A. Petros and Ropp, 2008; M. Moore et al., 2007). With the right modeling and understanding of the basic principles of biological communication, it is possible to build a complete biological system. Such a system would provide enormous benefits. Gene therapy, drug delivery and imagings in cellular-level and other areas will benefit from a robust designed system greatly. From this kind of system, it will likely provide from nanoscale to macroscale feedback, essentially taking shape of two-way communication between the nanoscale level and macroscale level.

In biological systems, transmission of information is meaningful. Anti-cancer-drugs transmission system, attempts to provide information which will result in the destruction of cancer cells. Also, the gene delivery vector containing information encoded from DNA, attempts to repair abnormal or variable genes. Once infected by virus, such as HIV virus, the biological system continues the malicious dissemination of information contained within the virus. Although information or delivery by a specific system may be rather different, the way of transport keeps similar. For example, most of the communication system using some kind of biological protective capsule to protect the information carried (N. Nasongkla et al., 2004; K.K. Upadhyay et al., 2009), similar to a packet data unit. Similarly, many of these systems also includes methods based on physical characteristics of the particles to route (M. Lerdrup et al., 2007; E.S. Seto and Bellen, 2002), similar to any type of system used in electrical communication with a packet routing. There are many such similarities, and it is clear that no matter how different their physical configurations are, the existence of a unique part of the biological system helps to accomplish a specific goal.

For these reasons, we chose to use our layered communication protocol (A. Sharp et al., 2010) in biological communication and study one example of the system in communication. In order to start this layered communication protocol's application, we first consider a simple system. Equally important, there are already a large number of experimental data can be provided to the underlying simulation. Therefore, we chose to apply our layered protocol model to HIV infection, which is already a well-studied subject. In this way, we will accurately relate principle and communication terminology in communication with HIV spreading. The protocol will help simplify the complex process of HIV infection, and let us focus on the system's communication level. We are going to use this layered protocol to establish an HIV infection simulation from the perspective of communication. Our simulation will prove the validity of the protocol, and will in turn establish a platform for biological experiments and simulations for natural and synthetic communications systems.

2. Background

In the basic biological level, information exchange system has been deeply studied by biologists for many years (Lai, 2014). As we all know, most of the biological systems are using some form of

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communication. Build a complete communication system now may be out of reach, tools needed to conduct research and testing of biological communication are easy and available. One of the simplest forms of communication is DNA exchanged between different organisms. DNA itself may in fact simply be considered an information container or packet. By modeling regarding biological systems as a communication network, we can quickly use communication technologies and paradigms that have been studied in depth. In this manner, communications engineers can eventually develop a bio-communication network which would be likely the electrical communication networks. Prior to this, it is necessary to understand the fundamental aspects of biological communication. Layered communication protocol is a simple method to quickly understand the abstract communication process which can also be used effectively to understand bio-communications. Therefore, we will apply our protocol to one specific examples of biological communication.

We chose the proliferation of HIV. Despite the simple form of biological communication, seldom of them are researched deeply as HIV. Therefore, we will apply the protocol to HIV. The goal of the virus is to replicate itself in the communication channel to maximize proliferation. This greatly resembles a multicast communication network, and there are many receivers (cells), and they are able to receive packets (virus). The difficulty of determining constants will be reduced because of the research in this specific infection. While the focus of our current efforts is the HIV, we hope to expand this model to many different types of biological communication systems.

2.1. HIV reproduction

The spreading of HIV in a human body is studied by researches for years, the process is relatively clear in some degree. HIV infects human T-cells and these infected cells produce more viruses, thus helping the spreading. Especially in the initial stage of spreading, the host immune responses may even help HIV spread (K. Wendelsdorf et al., 2011). The ultimate goal of a virus is to infect target cell's nucleus, where it can be changed to produce more copies of the genetic material for the virus, though early interventions can interfere the natural immune processes (M. Joly et al., 2016). If a virus successfully enters into a nucleus, the cell must traverse to complete reverse transcription and nuclear infection.

However, HIV must first enter and penetrate into the cell then infect the target cells. There are two ways for the virus to enter into cells. The first is fusion, and it means cell membrane and virus itself get fused, and the virus injects the viral contents into the cell cytoplasm. The second method used to enter into cells called Endocytic pathway. Endocytosis is used by cells to engulf and eventually absorb external material. Extern substances are surrounded by vesicles formed by cells and the vesicles are pulled into a cell to complete endocytosis process. Virus can escape from the vesicle to get into the channel. If the virus fails to escape from the vesicle, it will finally be destroyed.

Once the virus enters into a cell, it must build viral material (RNA) in DNA, a process called reverse transcription. Reverse transcription is very prone to mutation, which often enhances virus resistance to treatment (J. Vercauteren and Vandamme, 2006). Our research ignores the impact of virus mutation.

After the virus enters the cell and reverse transcription is completed, it must enter the cell nucleus to breed viruses. If the nucleus of target cells is infected, the virus often reprograms the normal nucleus, and begins to use resources to produce more viruses (Gu, 2010). Copied viruses are released into the interstitial fluid, and then repeat the whole process again. If there is no interventions from antiviral drug, one infected cell can produce 10–100 viruses per day (S.L. Butler and Hansen, 2001).

3. HIV communication

3.1. Biological layered communication protocol

We have described the macro to the micro-level system of layered communication protocol (A. Sharp et al., 2010). The protocol for communication will take place when sending information from the macro world to the micro-world and an example is delivery of drug. We improve this model to be used in general biological communication systems, in particular, how the HIV spreading in a biological system. So we need state clearly the model assumptions.

Although HIV infection is a seemingly deep-studied process, we still need to break down the model in a variety of ways to study further. For example, when a new generation of virus escapes from an infected cell, the route is formed in order to correctly pump virus into plasma. This route is considered as an external process that occurs in many physical structure of the system. Therefore, we chose such a routing system to be modeled as an additional communication gateway and we just consider external process rather than inner spreading process, that is, the activity from external gateway to nucleus. Thus, the virus must go through a number of communication layer information. And we only consider the initial stage of infection, so drug interference, like drug chemotherapy, is overlooked. We do not consider the reinfection of HIV infected cells by free virus (the reasons are explained in Section 3.2). During simulations, target cells' number will not decrease by other reasons except virus consumption and T-cells' number increase linearly in initial stage. Virus number in data channel equals to the number in our simulation. Besides, an infected cell produces new viruses at a constant speed and receives new incoming viruses simultaneously. Errors of reverse transcription are simulated with appropriate noise, though the errors enhance virus resistance, we ignore it because viruses in initial spreading stage are relative few and weak, thus, no viral spike in current model. Similar to multicast communication, there are many different tools to determine and control the flow of data in the system. The layered protocol model is shown in Fig. 1 (Algorithms are shown in Fig. 2 and Fig. 3).

Flow path of the protocol is simple. The path of HIV propagation presents many joints, leading a route based on the features of virus. These features help to form a sort of control error, which is represented by the transport layer (Algorithms are shown in Fig. 4). In essence, the ultimate goal of the virus is to infect the receiver (host cells) which can be switched to the mode that copy more viruses and send them to the channel (A.S. Perelson and Nelson, 1999; Li and Shu, 2010b).

The protocol forms a communications link so that the recipient will try to send the output packets into different host cells. And we have used our protocol to describe the full path of HIV communication, which starts and ends with an application layer which is responsible for messages sending and receiving (Algorithms are shown in Fig. 5).

3.2. HIV infection layered protocol

Fig. 1 illustrates the layered communication protocol of this system. Many process in the system can be rather complex, however, they eventually form a single, clear function. This protocol helps us quickly understand the role of a particular procedure, even if some certain physical principle or the implementation process at the molecular level is not well understood. Using this case, we are aware that HIV infection and multicast communication network is very similar with each other. In essence, each individual virus is transmitted to a data channel, and each target cell is the receiver that is able to receive this packet. There is a certain probability that a given cell is infected and begins to produce new viruses at a constant speed (called effective infected cells). At this time, the cells change behavior patterns, not only receive the packet, but also copy and send the packet to the channel. Effective life cycle of infected cells is significantly shorter than non-infected cells because the virus uses cell materials to quickly proliferate (A.U. Neumann and Markowitz, 1996). Thus, in the system, one receiver randomly breaks down at any point of time. This phenomenon has not been clearly demonstrated in the protocol, but it impacts theoretical and simulated results.

The protocol describes that a new virus go through a communication network to infect another cell, that is, the packet must pass through the