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Reliability and delay analysis of multicast in binary molecular communication

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ABSTRACT

Molecular communication is a new and promising communication technology. However, we consider that molecular communication easily suffers from high unreliability and long delay due to the stochastic behavior of the molecules in a biological environment, thus it is essential to investigate the characteristics of reliability and delay in molecular communication. In this paper, we analyze the reliability and delay in multicast topology based on binary molecular communication model. First, we give the mathematical expressions of reliability and delay in different scenarios including a single link, a single path and multicast topology, respectively. In particular, we use retransmission mechanism for transmission failure. Then the numerical results derived from the simulation performances show how the parameters including diffusion coefficient, the distance between transmitter nanomachine and receiver nanomachine, the number of molecules emitted in each time slot, the number of slots and each time slot duration have impacts on reliability and delay. More importantly, under the same reliability, lower delay can be theoretically realized by binary molecular communication model compared to the concentration model of virus-based nanonetworks.

1. Introduction

The rapid development of nanotechnology enables the manufacture of devices in the nanometer scale, ranging from one to few hundreds of nanometers [1]. A nanomachine is considered as the basic function unit which can be used to execute simple tasks. Several nanomachines can be interconnected to share information and perform more complex tasks in a collaborative manner by nanonetworks [2,3]. Molecular communication is a new communication technique to realize nanonetworks [4]. In molecular communication [5], the information is encoded in molecules which are released by the transmitter nanomachine, and propagated in biological environment, and finally arriving at the receiver nanomachine. Some promising applications of molecular communication are being used in drug delivery [6,7], modeling populations of microrobots [8], and body area nanonetworks [9].

However, the development of molecular communication poses a number of opportunities and challenges [10–12] mainly due to the characteristics of the molecules with stochastic behavior in a biological environment. In recent years, the field of molecular communication has been investigated deeply and has attracted attentions from many researchers. The survey papers [13,14] extensively overview the other current researches of molecular communication. Furthermore, there have been growing interests and efforts dedicated to the performances analysis of different molecular communication models.

Atakan et al. [15] designed a mobile ad hoc molecular nanonetwork and evaluated the performance of the

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nanonetwork, such as average delivery delay and throughput. Akan et al. [16] first proposed a new messenger-based molecular communication model, and then investigated the trade-off between the rate and delay by using a simple network coding mechanism. Nakano et al. [17] discussed issues concerned with transmission rate control which was explored to maximize the throughput and efficiency among biological nanomachines. In [18], a molecular uni-cast communication system based on molecular motor on a microtubule topology was designed. Balasubramaniam et al. [19] analyzed various characteristics of multihop molecular nanonetworks that utilize bacteria as a carrier, such as the reliability of message delivery with different topology shapes. Walsh et al. [20] studied the reliability and delay of multihop molecular nanonetworks which used virus particles as information carrier based on molecular concentration model.

On the basis of traditional electromagnetic communications, molecular communication systems use digital signaling, such as binary signaling and multi-amplitude signaling [21,22]. A binary molecular communication model is proposed to transmit binary digital information between transmitter nanomachine and receiver nanomachine by releasing multiple molecules [23]. Atakan [24] proposed optimal transmission probability to maximize the molecular communication rate by using binary molecular communication model. The binary modulation scheme was also used to improve the capacity performance [25,26].

The binary molecular communication model is used to analyze the reliability and delay of multicast topology in our paper based on the following considerations:

First, to the best of our knowledge, no study has concentrated on the performances of reliability and delay of multicast using binary molecular communication model. In particular, multicast has a more complex network topology which has more significant effect on reliability and delay. Our paper addresses this gap.

Second, the expected number of absorbed particles for a transmission between two nodes is only an approximate value in [20] which largely affects the reliability and delay. For the binary molecular communication model, the delay experienced by any molecule to reach receiver nanomachine obeys the probability density function which is an exact equality. In such case, the exact mathematical expressions of reliability and delay in different scenarios can be derived to better analyze reliability and delay performances.

Third, the number of the molecules needed in the binary model is theoretically smaller than the concentration model in [20] to achieve the same delay under the same reliability.

The main contributions of our paper are summarized as follows:

(1) Based on the binary molecular communication model, the mathematical expressions of reliability and delay in different scenarios including a single link, a single path and multicast topology are derived for successful transmission, respectively. The transmission failure is also considered which needs to use retransmission mechanism.
(2) The numerical results are provided to prove how the parameters including diffusion coefficient, the distance between transmitter nanomachine and receiver nanomachine, the number of molecules emitted in each time slot, the number of slots and each time slot duration have impacts on reliability and delay in these different network topologies.
(3) More importantly, under the same reliability, lower delay can be theoretically realized by binary molecular communication model compared to the concentration model of virus-based nanonetworks in [20].

The rest of this paper is organized as follows: Section 2 will describe binary molecular communication model. Section 3 analyzes reliability and delay in different scenarios including a single link, a single path and multicast topology, respectively. Numerical results are given in Section 4. Section 5 presents our conclusion.

2. Binary molecular communication model

In this paper, we examine the binary molecular communication model between Transmitter Nanomachine (TN) and Receiver Nanomachine (RN) in the biological environment. TN and RN refer to the sender and receiver as in the traditional communication, respectively. We consider a time-slotted system model with molecules diffusion and assume all events occur at some discrete time $T = n\tau$. Here n is an integer which is the number of time slots, and τ is one time slot duration. We also assume that TN and RN are perfectly synchronized in terms of time. The mechanism of transmission over a single link between two nanomachines TN and RN for the binary molecular communication model is described as follows:

The binary channel is used to transmit binary information from TN to RN in time T. Both input and output are bit 1 or 0 in each transmission. We use two different types A_1 and A_2 molecules to represent the bit 1 and 0, respectively. We assume that the movements of different type molecules are independent. The five main processes of binary communication model include information encoding process, transmission process, propagation process, reception process, and information decoding process which can be implemented in a biological environment.

When the transmitter nanomachine TN wants to transmit a single message of one bit 1 or 0 to the receiver nanomachine RN, TN should prepare to generate the corresponding type of N molecules at the beginning of each time slot k ($1 \le k \le n$) in the information encoding process. Each molecule can have the information of the bit and the extra information which includes the address and the time-slot index in its DNA sequence. The address indicates the logical address of the destination which is to arrive at. The time-slot index represents the time slot in which the current bit is transmitted. The information with time-slot index is used to avoid the interference between the same type molecules. In the transmission process, TN instantaneously emits N molecules at the beginning of each time slot.

In the propagation process, the movement of molecules is assumed to be governed by a Brownian motion. The