Molecular MIMO Communications Platform with BTSK for In-Vessel Network Systems

Changmin Lee(✉), Bon-Hong Koo, and Chan-Byoung Chae

School of Integrated Technology, Yonsei University, Seoul, Korea
{cm.lee,harpeng7675,cbchae}@yonsei.ac.kr

Abstract. In this paper, we propose a molecular multiple-input multiple-out (MIMO) communication platform using binary time shift keying (BTSK) modulation to model in-vessel network systems. A notable prior work introduced a vessel-like communication testbed, yet leaving a challenge to achieve a higher data rate. We suggest an improved version of testbed adding MIMO configurations with modulation techniques. The flow-assist channel model for MIMO systems has been limitedly investigated yet, the feasibility of MIMO systems with timing-based modulation is shown in this paper. The platform uses acid and base molecules as information carriers, and the received output is a set of pH values varying over time. The MIMO platform yields a higher data rate than the single-input single-output (SISO) systems. Furthermore, the system is flexible to any desired configurations, which can illustrate actual blood vessel environments.

Keywords: Molecular communication · In-vessel molecular communication · Molecular MIMO · Flow-assist channel · Testbed

1 Introduction

A decade history of studies on molecular communication managed to build extensive theoretical backgrounds stemming from [1,2], but there is still a long way to go to meet the application targets. The implementation studies started from [3] are aiming to understand and reduce the gap between practice and theory [4,5] of the environment. There had been several individual prototype achievements by different groups; they all commonly proved the feasibility of molecular communication. The remaining challenges are to make the environment closer to its applications while enhancing the communication performances [6].

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The applications of molecular communication include, but not limited to, in-body nanonetwork communications, which can be developed for health monitoring or a drug delivery system [7]. In case, the communication environment locates inside blood vessels where the channel is dominated by microfluidic drift and bounded by thin pipes [8,9]. To the best of the authors' knowledge, the authors in [10] are the only pioneers who implemented a vessel-like molecular communication testbed. Notably, they employed the single-input single-output (SISO) system with concentration-based binary modulations.

In this paper, we show our novelty on demonstrating our testbed by improving both the hardware and the modulations. Note that the system is an upgraded version of our work that is presented in WCNC [11]. We present details of the testbed in Sect. 2, the demonstrations in Sect. 3, and Sect. 4 concludes the paper.

2 Testbed

We develop a macro-scale platform modeling in-vessel molecular MIMO communication. We apply the MIMO system to the testbed to increase the data rate and illustrate complex blood vessel environments. The transmitter consists of multiple circulating pumps controlled by a microcontroller. Multiple pH-sensors work as receivers and connected to the computer through a microcontroller. We build the platform using low-cost parts. Furthermore, the platform is capable of modeling various configurations of communications using modifiable and re-programmable components.

2.1 Hardware Layout

Figure 1 shows the proposed in-vessel molecular MIMO communication platform. A constant flow provided by one of the pumps yields channel medium with drift, while the other pumps induce messenger molecules. In this paper, we expand our claim based on the channel shape, as shown in Fig. 2, while the system is flexible to any configurations. The transmitter consists of 1) four water circulator pumps, 2) a microcontroller to control the transmitter, and 3) reservoirs for chemicals (acid and base). The receiver consists of 1) two pH-sensors to measure a pH value, 2) microcontrollers to convey electrical signals from pH-sensors to a computer, and 3) a computer to detect the received signal and visualize the sequences. The channel comprises 1) length variable tubes with and 2) two types of junction made by a 3D printer. Therefore, we can configure various shapes of complex tube network to mimic a blood vessel network.

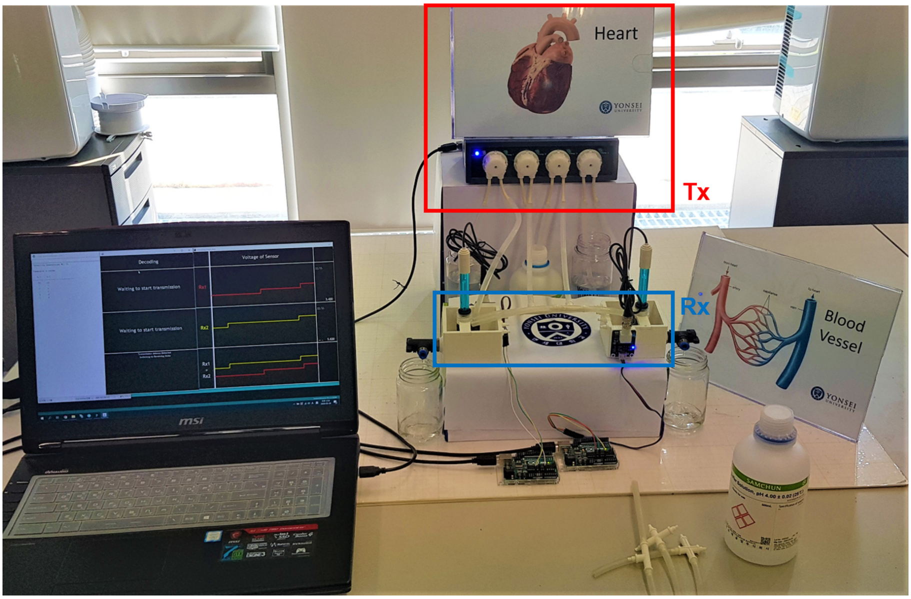

Fig. 1. The tabletop in-vessel molecular MIMO communication platform.

2.2 System Operation

We transmit a sequence of alphabets to verify the communication feasibility. The sequence is divided into two parts for each antenna and encoded into binary bit sequences following International Telegraph Alphabet no. 2 (ITA2). The testbed transmits the coded bits through a transmitter with antennas (pumps) 1 and 2 simultaneously to enhance the data rate. A spatial domain distance allows the signal separation at the receiver side. We suggest binary timing shift keying (BTSK) modulation as a conversion method from bit sequences to physical movements of chemical signals. The BTSK modulation divides a time symbol into two slots and modulates information by the position index of transmission timing. The receiver sensor is capable of interpreting pH values, and we employed a pH 4.0 standard solution as a messenger molecule for both antennas. The transmitter sends molecules at the first slot of the symbol to represent bit ‘1’. Consequently, the second slot transmission represents bit ‘0’. At the receiver, two pH sensors measure pH values over time, and the computer decodes the message from the measured values. The binary bit detection is based on the adaptive thresholding algorithm, where the threshold value is empirically taken from prior experiments with given channel state information.

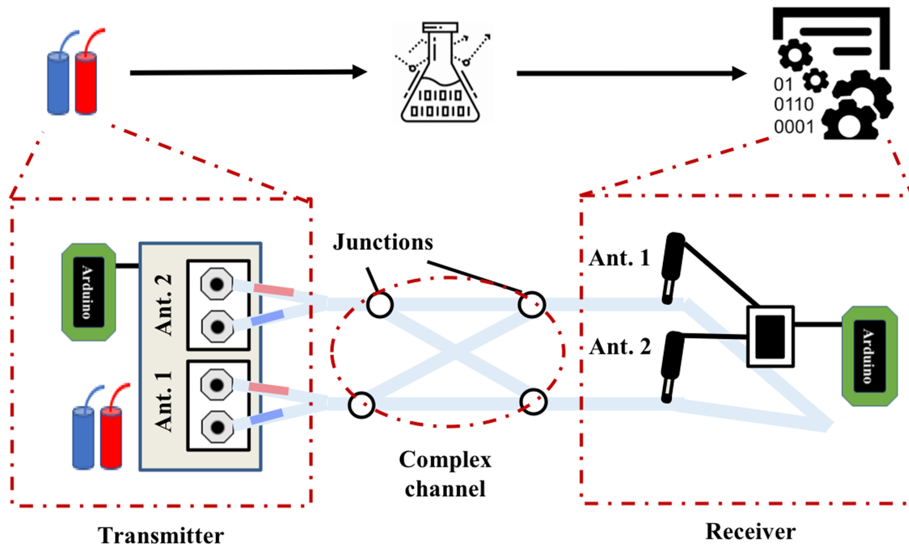

Fig. 2. The complex channel description with MIMO configurations that converts messenger molecules into a message consisting of binary bits.

2.3 Setup

It takes nearly 40 min to set up the in-vessel molecular MIMO testbed. The testbed requires a table with a size of (at least) 1×1 m. We need a minimum of three power plugs for the equipment and a computer to visualize the demonstration output.

3 Demonstration

We plan to demonstrate a short text message transmission with visualization of the signal.

3.1 Text Message Transmission

We demonstrated that we can send text messages via the in-vessel molecular MIMO system in real-time. Most prior work has their focus on the simulation channel model, however, the accurate channel characteristics are hardly achievable. Utilizing the measurement data from our MIMO testbed, it is likely to develop in-vessel molecular MIMO channel models with enhanced accuracy.

3.2 Comparision Transmission Speed

In our platform, the 2×2 MIMO system shows a higher data rate than the SISO system. The data rate gain is lower than double than the SISO system since the system requires compensations of overhead at the signal head and tail due to interference.

4 Conclusion

In this paper, we present that short text messages can be transmitted by the BTSK-based in-vessel molecular MIMO communication system. We develop the platform to show the possibility of utilizing molecular communication at the in-body blood vessel network system. The pump is to model a heart, and the tube network templates the blood vessel network. To enhance the data rate of molecular communication, we apply the MIMO techniques with BTSK modulation. Our testbed is flexible for configurations presenting complex blood vessel networks. We expect our system to be utilized for analyzing the actual complex in-body network systems. Hoping that the testbed study helps advanced molecular communication research and reducing a gap between theory and implementation of molecular communication, our future work will include machine learning coordinated detection techniques as in [12].

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