Demo: Molecular MIMO with Drift

Changmin Lee, Bonhong Koo, Na-Rae Kim, H. Birkan Yilmaz, Nariman Farsard†,
Andrew Eckford†, and Chan-Byoung Chae
Yonsei Institute of Convergence Technology, School of Integrated Technology, Yonsei University, Korea.
†Dept. of Electrical Engineering and Computer Science, York University, Toronto, Canada
cbchae@yonsei.ac.kr

ABSTRACT

In molecular communication information is transferred with the use of molecules. Molecular multiple-input multiple-output (MIMO) system with drift (positive velocity) at macro-scale will be presented and the improvement against single-input single-output (SISO) molecular communication systems will be verified via our testbed. Until now it was unclear whether MIMO techniques, which are extensively used in modern radio frequency (RF) communications, could be applied to molecular communication. In the demonstration, using our MIMO testbed we will show that we can achieve nearly 1.7 times higher data rate than SISO molecular communication systems. Moreover, signal-to-inter-link-interference metric for one-shot signal will be depicted for a given symbol duration.

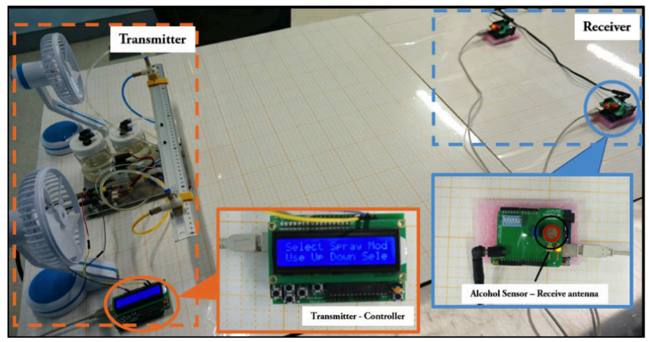

Figure 1: The tabletop molecular MIMO communication platform.

1. BACKGROUND

With the development of nanobots and micro machines, a new research domain, which focuses on communication requirements and techniques for these scales has emerged [10]. In small scales, electromagnetic communication is challenging because of constraints such as the ratio of the antenna size to the wavelength of the electromagnetic signal [1, 10]. Inspired by nature, one possible solution is to use chemical signals as carriers of information, which is called molecular communication [6]. It can be utilized where radio based communication fails or is inefficient: for example, city infrastructure monitoring in smart cities at macro-scale [11], and body area nanonetworks for health monitoring and targeted drug delivery at micro-scale [2].

Mostly, literature on molecular communication has focused on micro-scale systems such as diffusion-based communications [2, 7, 9]. Most of these works have been theoretical, and only recently some experimental implementations of molecular communication systems are proposed at macro-scale [3]. More recently, nonlinearity in diffusion channel at macro-scale is modeled as noise [5].

MobiCom'15, September 7–11, 2015, Paris, France.
ACM 978-1-4503-3619-2/15/09 .
http://dx.doi.org/10.1145/2789168.2789181 .

In prior work, a pioneering single-input single-output (SISO) macro-scale molecular communication link was demonstrated [3, 4]. We also demonstrated a simple molecular MIMO (without drift) at IEEE INFOCOM 2015 [8] and got the Best Demo Award for this work. In this demonstration, we will show the world's first molecular multiple-input multiple-output (MIMO) communication link with drift, where an artificial flow exists in the environment. MIMO is a technique, which is used in modern radio communication to increase transmission data rate. The feasibility of using MIMO technique in macro-scale molecular communication will be demonstrated.

2. TESTBED

Our testbed is a macro-scale version of the molecular MIMO communication system at micro-scales. The transmitter and the receiver are equipped with multiple sprays and sensors to further increase the data rate. The system is inexpensive, and the platform is available as a modifiable and re-programmable research testbed.

2.1 Hardware Layout

In Fig. 1, the main components of the testbed are shown and consist of molecular MIMO transmitter and receiver. The propagation channel in between is several meters of free-space. With using standard fan, the environment may have flow that assists the propagation. The transmitter consists of: 1) a simple user interface for text entry, 2) a microcontroller for executing transmitter algorithms, 3) two reservoir for chemicals, and 4) two chemical release mechanism (i.e.

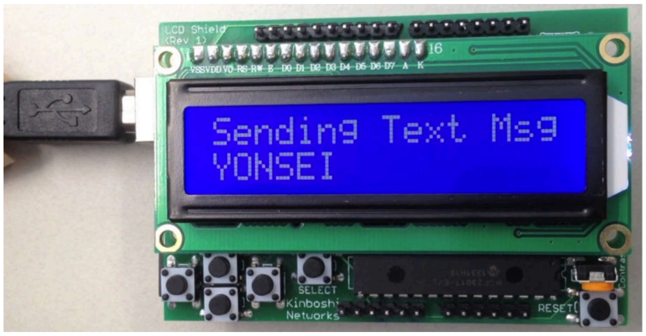

Figure 2: Sample text message entered at the transmitter.

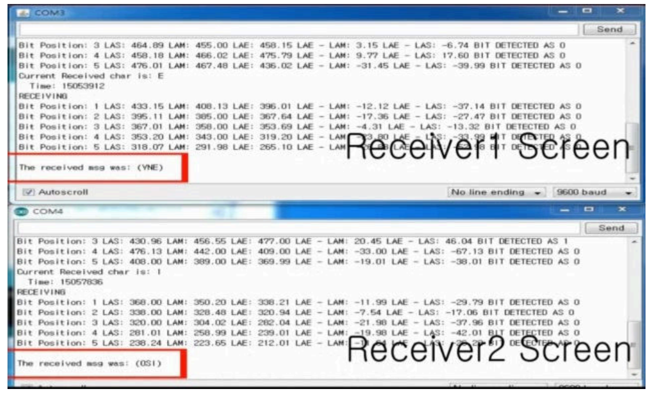

Figure 3: On the receiver screens the decoded characters are seen.

two sprays with adjustable separation). At the receiver, the hardware consists of: 1) two chemical sensors for MIMO operation, 2) two microcontrollers that forward electrical signal that originated from chemical sensors to computer, and 3) a computer for demodulating, decoding the signal, and visualizing results.

2.2 System Operation

Basically, the transmitter separates the strings into two parts and converts them to bit sequences via using international telegraph alphabet no. 2 (ITA2). The molecular MIMO system feeds the coded bits to the transmitter antennas (sprays) one and two independently. Which can be considered as utilizing spatial domain for increasing the transmission data rate. At the receiver site, molecule concentrations at two antennas are recorded as voltage readings from sensors and demodulator detects the intended symbol at each symbol duration. Unlike prior work in RF communication, non-coherent detection is required since the coherent time of the molecular channel is zero.

2.3 Setup

Setup time for the molecular MIMO testbed is nearly 40 minutes and the testbed requires a table with size (at least) 76×260 centimeters. We also need at least 6 power plugs for the equipments and a big monitor to visualize the demonstration output.

2.4 Health and Safety

As part of the demonstration low volumes of alcohol will be diffused in open air. There will not be any chemical risks since the alcohol used will be safe for humans and of a small quantity. Moreover, we will put the testbed equipment behind a transparent shielded screen to respect religious sensitivities and avoid any unwanted alcohol odors at the demo hall.

3. DEMONSTRATION

There will be mainly two types of demonstrations: one is text message (any number of characters) transmission and the other is visualizing the signal and interference for one shot signal.

3.1 Text Message Transmission

The main goal of the demonstration is to show that text messages can be continuously and reliably carried via molecular MIMO system. In Fig. 2, the sample text is depicted at the transmitter and Fig. 3 illustrates the receiver screen. Molecular MIMO system divides the sample text into two and sends independently. As can be seen from the figure, three character strings are decoded independently at the receivers. Table 1 compares the transmission time and the data rate of SISO and MIMO systems, from which we observe that the MIMO system show 1.7 times higher data rate than the SISO system.

Table 1: Experiment results of the macro-scale SISO and MIMO molecular communication testbed.

Type	TX time (s)	Data rate (bps)
SISO w/ Drift	74	0.41
MIMO w/ Drift	44	0.68

Most mathematical models developed for molecular communication have relied on Fick's diffusion equation and been validated via Monte-Carlo simulations [12]. Moreover, most prior work has assumed perfect transmission, propagation, and reception [7]. These assumptions, however, do not hold in practice, and more realistic models based on experimental data are necessary [5]. Measurement data, which are obtained from our MIMO platform, may play a crucial role in developing more accurate molecular MIMO channel models.

3.2 Interference Measurements

In molecular MIMO setup inter link interference (ILI) is an important metric to measure and it depends on the separation distance between the antennas. We denote the separation between the transmitter antenna-1 (Tx1) and Tx2 by h. In Table 2, signal-to-ILI (S-ILI) ratios are measured and given for distance of $90\,cm$, different symbol durations, and antenna separation distances.

During the demonstration, we will visualize the signal and the S-ILI ratio metric for one shot signal without demodulation. S-ILI ratio is evaluated by sending bit-1 at Tx1 and bit-0 (silence) at Tx2 and evaluating

$$\text{S-ILI Ratio} = \sum_{t=0}^{t=t_s} s_{\mathrm{Rx1}}(t) \Big/ \sum_{t=0}^{t=t_s} s_{\mathrm{Rx2}}(t) \qquad (1)$$

where t_s and $s_{\mathrm{Rxi}}(t)$ denote the symbol duration and received signal at receiver i (Rxi), respectively. As can be

Table 2: Measurement data of S-ILI Ratios (without drift).

Symbol Duration	$h = 30\,cm$	$h = 40\,cm$
$t_s = 1\,s$	10.18	11.03
$t_s = 2\,s$	24.09	26.70
$t_s = 3\,s$	39.78	59.31

seen from Table 2, increasing the symbol duration and the antenna separation increase S-ILI ratio, which makes the signal easier to detect.

4. CONCLUSION

In this demonstration, we present the first macro-scale molecular MIMO communication system with drift that can reliably transmit short text messages. We also demonstrate the interference measurements due to independent Tx1 and Tx2 antenna (spray) transmissions. Our goal is to show that molecular communication can be used as an alternative to radio communication in challenging environments. To improve the low transmission rate of molecular communication, we implement novel molecular MIMO detection algorithms. The main challenge in our design was implementing a signal separation algorithm for the molecular MIMO channel, since MIMO detection algorithms for classical RF communications could not be directly applied. We hope to motivate researchers, and fill a gap between theory and practice of molecular communication.

5. DEMO VIDEO

The demo video is available at http://www.cbchae.org.

6. ACKNOWLEDGEMENT

This research is funded by the MSIP (Ministry of Science, ICT & Future Planning), under the "IT Consilience Creative Program" (IITP-2015-R0346-15-1008) and by the Basic Science Research Program (2014R1A1A1002186) funded by the MSIP, through the National Research Foundation of Korea. The authors would like to thank C. Kim for his help in implementing the hardware.

7. REFERENCES

[1] I. F. Akyildiz, F. Brunetti, and C. Blazquez. Nanonetworks: A new communication paradigm. *Elsevier Comput. Netw.*, 52(12):2260–2279, Aug. 2008.

[2] B. Atakan, O. Akan, and S. Balasubramaniam. Body area nanonetworks with molecular communications in nanomedicine. *IEEE Commun. Mag.*, 50(1):28–34, January 2012.

[3] N. Farsad, W. Guo, and A. Eckford. Tabletop molecular communication: Text messages through chemical signals. *PLoS One*, 2013.

[4] N. Farsad, W. Guo, and A. Eckford. Molecular communication link. In *Proc. IEEE Int. Conf. on Comput. Commun. (INFOCOM)*, 2014.

[5] N. Farsad, N.-R. Kim, A. Eckford, and C.-B. Chae. Channel and noise models for nonlinear molecular communication systems. *IEEE J. Sel. Areas Commun.*, 32(12):1–10, Dec. 2014.

[6] N. Farsad, H. B. Yilmaz, A. Eckford, C.-B. Chae, and W. Guo. A comprehensive survey of recent advancements in molecular communication. *arXiv:1410.4258*, Oct. 2014.

[7] N.-R. Kim and C.-B. Chae. Novel modulation techniques using isomers as messenger molecules for nano communication networks via diffusion. *IEEE J. Sel. Areas Commun.*, 31(12):847–856, Dec. 2013.

[8] C. Lee, B. Koo, N.-R. Kim, H. B. Yilmaz, N. Farsad, A. Eckford, and C.-B. Chae. Molecular MIMO communication link. In *Proc. IEEE Int. Conf. on Comput. Commun. (INFOCOM)*, 2015.

[9] I. Llatser, A. Cabellos-Aparicio, and E. Alarcon. Networking challenges and principles in diffusion-based molecular communication. *IEEE Wireless Commun.*, 19(5):36–41, Oct 2012.

[10] T. Nakano, A. W. Eckford, and T. Haraguchi. *Molecular communication*. Cambridge University Press, first edition, 2013.

[11] F. Stajano, N. Hoult, I. Wassell, P. Bennett, C. Middleton, and K. Soga. Smart bridges, smart tunnels: Transforming wireless sensor networks from research prototypes into robust engineering infrastructure. *Elsevier Ad Hoc Netw.*, 8:872–888, Nov. 2010.

[12] H. B. Yilmaz and C.-B. Chae. Simulation study of molecular communication systems with an absorbing receiver. *Elsevier Simul. Model. Pract. Theory*, 49:136–150, Dec. 2014.