Self-Cleaning Transmitters in Diffusion-based Molecular Communcation

Ethan Fox
Undergraduate Student
University of Nebraska-Lincoln
Lincoln, NE USA
efox6@huskers.unl.edu

Jackson Herman
Undergraduate Student
University of Nebraska-Lincoln
Lincoln, NE USA
jherman5@huskers.unl.edu

***Abstract*—Molecular Communication Systems are a revolutionary new field of research that promises to open pathways in many different areas, such as in the military or the medical field. The use of biological processes to emulate traditional communication systems can help supplant the need for implanting machines within the body to perform tasks such as medical injections or early warning systems for diseases. The major benefit of these systems is that they are extremely biocompatible, as they are made out of cells and molecules already present within the human body. This increased biocompatibility makes these systems far safer and less likely to be rejected than traditional machines. This paper looks to explore the nature of using a molecular communication system to emulate simple logic gates by simulating an experiment using populations of bacteria. This experiment explores the different aspects of the system and attempts to correct several common problems found in a diffusion-based system through use of a novel cooperative channel clearing system where the transmitter populations release special molecules to neutralize any lingering transmission molecules and remove clutter from the transmission channel. Afterwards, the results of the experiment are discussed, and conclusions about the effectiveness of this novel design are made.**

***Index Terms*—molecule, bacteria, communication network, molecular communication, diffusion, diffusion-based, channel, transmitter, transmission molecules, clearing molecules**

I. Introduction

The concept of using molecules and biological processes to emulate traditional computer communication networks is a relatively new field of research, and as such there are plenty of areas within it where new advancements and discoveries can be made. For example, in a diffusion-based communication system one of the most prevalent problems is the channel being clogged by transmitted molecules, leading to inaccurate data as the receiver detects molecules, even when it shouldn't be.

Efforts have been made to find ways to clear the channel, one such method is the concept of releasing an additional molecule into the channel whose sole purpose is to break down any remaining transmitted molecule to prevent the receiver incorrectly reading a transmitted bit when there isn't supposed to be one. However, this method suffers a similar problem to not clearing the channel at all, except now instead of the transmitted molecules it is the clearing ones that remain, meaning any molecules sent to transmit a new bit could be broken down before they can reach the receiver, leading to a false negative as opposed to the false positives that not clearing can cause. These problems, caused by the channel being clogged by leftover molecules, is what the experiment detailed in this report endeavors to solve.

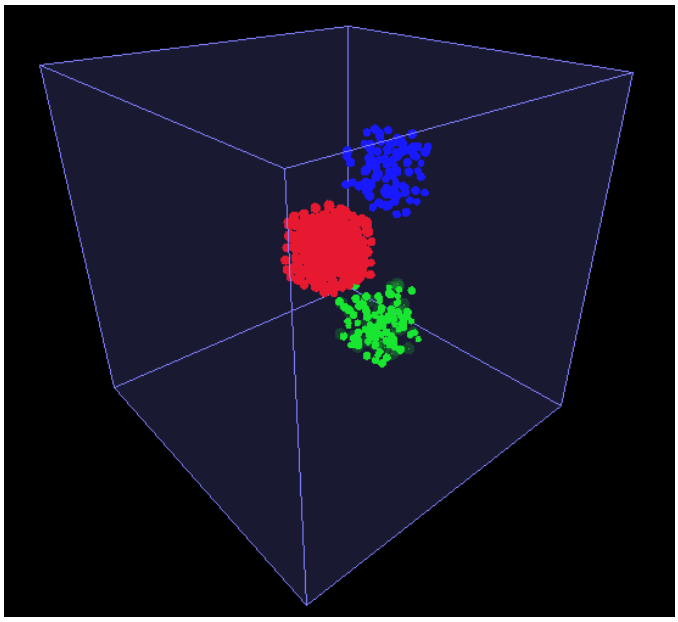

Fig. 1. Fig 1: Receiver represented in red, transmitters represented in blue and green.

II. Design

A. Logic Gate Design

Before delving into solving the problems with channel clearing and saturation, first a communication system is needed to perform tests on. This experiment utilizes a simple system of a single receiver and two transmitters placed at equal distances horizontally from the receiver and at equal and opposite vertical distances.

The experiment was performed utilizing the Simulation tool BSim [1], and was done in a large 3-Dimensional space as to most accurately represent the environment a real form

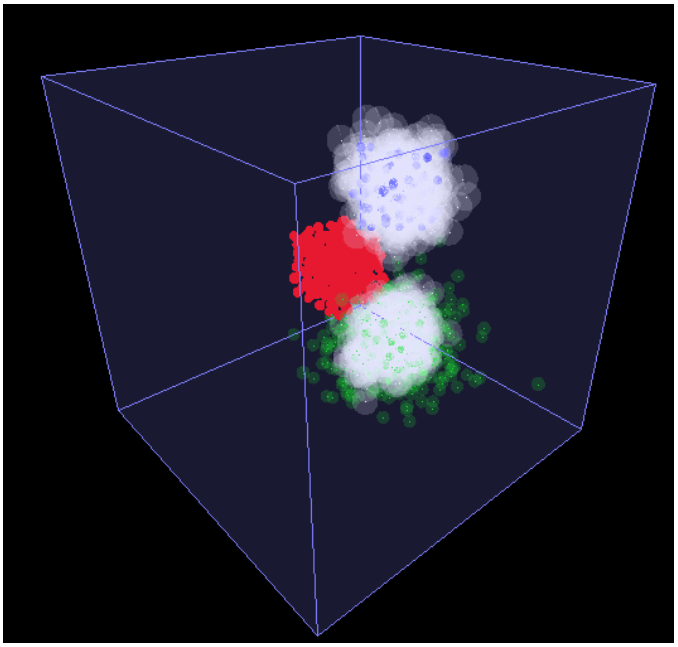

Fig. 2. Fig 2: Populations A and B producing clearing molecules, represented in white.

of the experiment would occur within the human body.

The sizes of all three bacteria populations remained constant throughout the main portion of the experiment, as well as the molecule vesiculation rate and the time the molecules have to propagate towards the receiver before the output is computed, more about these constants will be discussed in the Experiment Design section of this report. The system was built to act as either a simple AND logic gate or a simple OR logic gate, and the output of the receiver changed to reflect its behavior.

B. Clearing Design

After the transmitter molecules have been given enough time to propagate through the channel, the clearing process begins. The two transmitters cooperate together towards the end of every time slot to clear the channel of any extra transmitter molecules. Both populations start to produce clearing molecules that propagate after the transmitter molecules, and upon contact with a transmitter molecule, they neutralize it, preventing it from binding to the receiver.

To achieve this neutralization, a hypothetical molecule is used that will bind with a transmitter molecule, preventing it from binding with anything else, be it the receiver or another clearing molecule. Each clearing molecule will similarly only be able to bind with a single transmitter molecule. Thus, a collision between the two molecules would effectively neutralize them both, preventing the transmitter molecule from causing false positives, and the clearing molecule from causing false positives.

III. Experiment Design

The core premise of this experiment is to find out how the cooperation of the transmitters to clear the channel, as well as the neutralization method of clearing, affect the accuracy and reliability of the system when compared to a system with no clearing.

A. Finding a Control Test

To be able to effectively test the change in accuracy and reliability, a set of control constants needed to be found for the system. The criteria the control test needed to meet was to be able to detect both a 1 bit within a specific time slot both when sent as the first bit of the bitstring, as well as when sent after nothing has been sent for a time slot to represent the bit sequence 01. First, a suitable distance was set for the channel between the transmitters and receivers. These values were not tweaked during the testing of other values when searching for an optimal control test. The center of each transmitter population was set to 20 microns along the x-axis away from the center of the receiver, 20 microns away along the y-axis, and 5 microns away along the z-axis.

The values of the control that were tested were all changed with respect to these distances. Of these values, the one that was tweaked first was the time slot duration. This is how long the receiver will detect collisions from transmitter molecules before determining the output. In each test, the transmitter would only generate molecules for half the time slot, to reduce channel clutter. This buffer period was kept in tests beyond the search for the control. For the duration of these tests, the transmitter population sizes were 100 each, the receivers population size was 250, and the threshold of collisions detected for a 1 to be outputted was set to 100. With these tests, a bit string of size three was sent from each transmitter, 100 from transmitter A, and 010 from transmitter B.

Time Slot	Sent A	Sent B	Received A	Received B
10	100	010	000	000
20	100	010	110	000
30	100	010	110	001

TABLE I
FIG 3: RESULTS FROM CHANGING THE TIME SLOT DURATION.

From these tests, it was believed that 30 seconds was a suitable time slot duration, so long as other values were tweaked accordingly. Thus, the next set of values changed was the threshold. Population sizes were kept the same as the previous tests, and a 30 second time slot duration was used.

Threshold	Sent A	Sent B	Received A	Received B
80	100	010	110	001
60	100	010	110	001
40	100	010	111	011

TABLE II
FIG 4: RESULTS FROM CHANGING THE THRESHOLD.

The first 1 of population B's bit string was read correctly in the test with the threshold of 40, however that threshold was determined to be too low to get accurate results, as the first 1 from population A's bit string was stretching to 3 time slots instead of the 2 it lasted in higher thresholds. Thus, the threshold was returned to 100, and a 40 second time slot was tested. This test resulted in a 110 from A and a 011 from B, which were satisfactory results. With that, the constant had been decided, and the control test accomplished. Now, testing could be done to compare clearing against the control.

B. Comparing No Clearing and Clearing

Now that a control test has been set, it can be used for tests without clearing to be compared against tests with clearing. When introducing the clearing molecules to the channel, a buffer period is present, similar to the control test, however part way through that buffer is when the clearing molecules are generated into the channel.

Each transmitter generates its transmission molecules for 50% of the time slot duration, and then the next 25% is a buffer period to allow it to propagate, and then the last 25% is when the clearing molecules are generated. With these clearing molecules generated, hopefully the channel will be less saturated, and less false positives and negatives are read.

IV. Simulation Results

A. No Clearing

Running the simulation without clearing gave results that were to be expected. The accuracy in this mode was 0.72. Each incorrect bit that was received occurred through a common bit sequence. The leading 0 bits would all be received correctly. However, any 0 bit that followed a 1 bit resulted in a 1 bit being received. After a time slot ended, there would still be enough molecules near the receiver to reach the threshold, and trigger a 1 bit, regardless of the current transmission. The lingering molecules dispersed enough to never register a third 1 bit on their own. The bit sequence 100 would result in 110 being received for example.

B. Clearing

The accuracy with clearing was 0.71, close to the same as without clearing. The clearing molecules did bind with and remove transmission molecules. However, they were almost completely ineffective in the first few bits of a transmission. Despite producing the half number of clearing molecules and transmission molecules per time slot before signal reception, the concentration of clearing molecules was not initially sufficient to prevent the repeated bits that occurred without clearing. As the simulation ran, the concentration of clearing molecules increased to become effective in preventing repeated bits.

However, this also caused some transmitted 1 bits to not be received. This was especially prevalent when both transmitters sent 0 bits. Due to the design, each transmitter emitted clearing molecules in every time slot without knowing if the other transmitter emitted transmission molecules. The environment would be flooded with a surplus of clearing molecules that prevented further transmissions for 1-2 bits. The 1 bits in bit sequences with leading 0 bits, like 001, were not received.

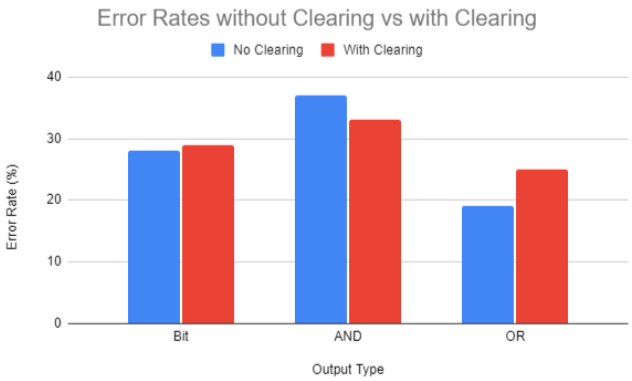

Fig. 3. Fig 5: Error rates with and without clearing.

V. Conclusion

The goal of the clearing system was to increase the accuracy of a diffusion-based system. With the implementation testing, there was no improvement. This design failed to account for repeated 0 bits from each transmitter and still had some of the failures from the system without clearing. The other point of failure was designing the transmitters to emit clearing molecules every time slot. This design assumes that the other transmitter is always emitting 1 bits. A way to resolve this error would be to have the transmitter populations receive transmission molecules like the receiver to monitor the other transmitter. The clearing molecules would only be emitted when the transmitter sends a 1 bit or detects the other transmitter sending a 1 bit. The amount of clearing molecules released would be proportional to the amount of 1 bits transmitted.

Another potential solution would be using multiple channels. Each transmitter would have two types of transmission molecules and clearing molecules, that alternate between time slots. With this system, lingering transmission molecules would no longer cause repeated bits. Combining these two changes would likely result in a much more accurate system. However, designing a biological implementation of this simulated design would be far more complex. Creating biological communication systems is a balance of simplicity and accuracy, and the design discussed is currently far too inaccurate to be useful.

References

[1] Matyjaszkiewicz A, Fiore G, et al. (2017) BSim 2.0: An Advanced Agent-Based Cell Simulator. ACS Synthetic Biology (web)Article ASAP doi:10.1021/acssynbio.7b00121