Embracing the Complexities of Molecular Communication

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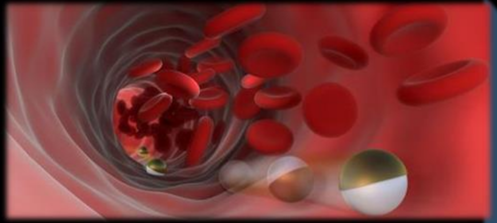
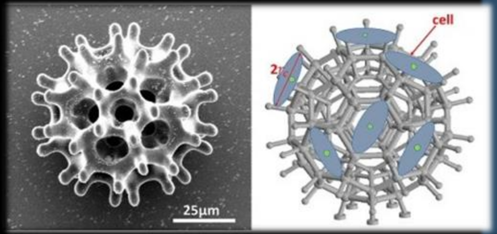
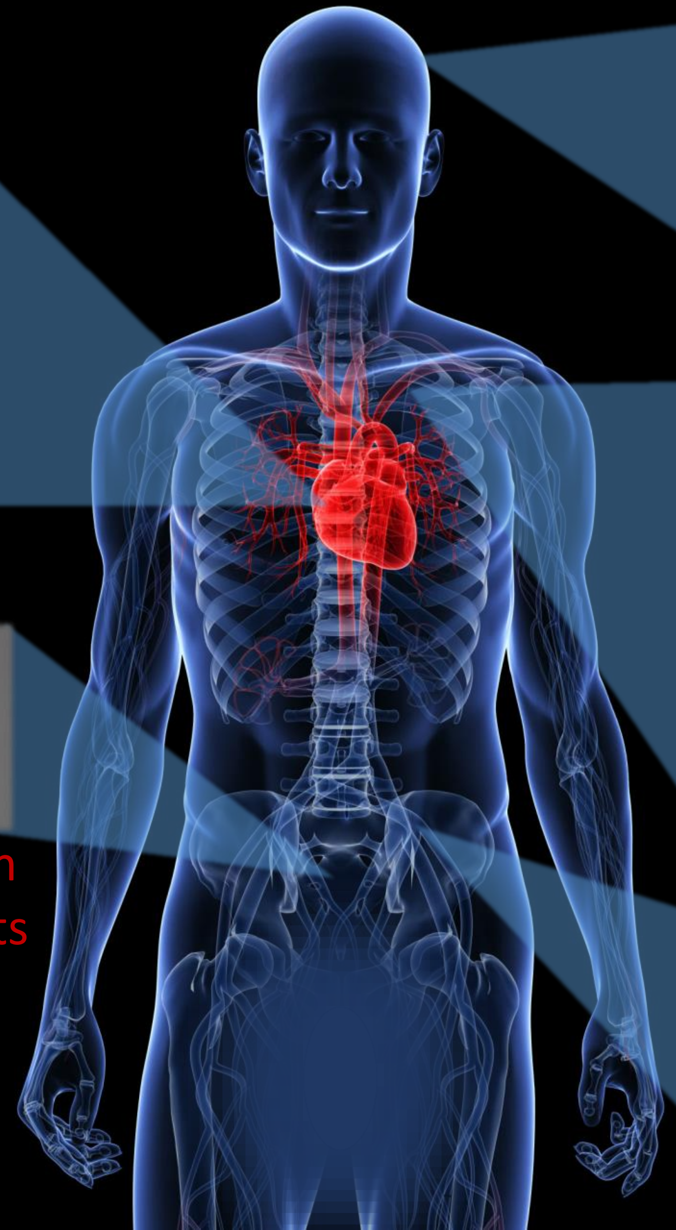
Micro and Nano Bio Implants

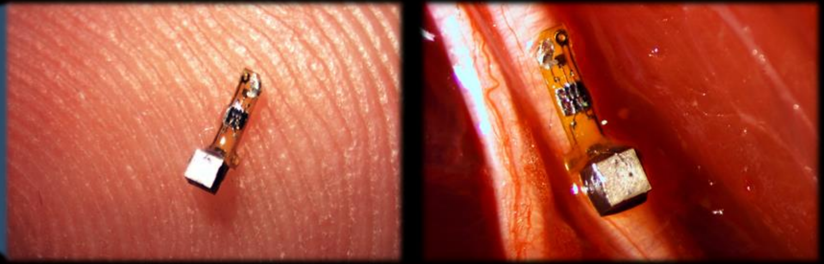
Microrobots for drug delivery

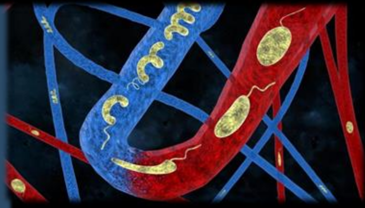




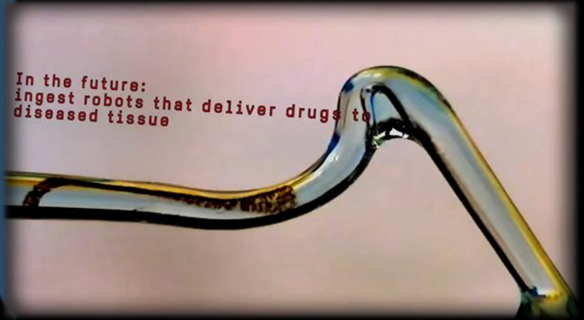


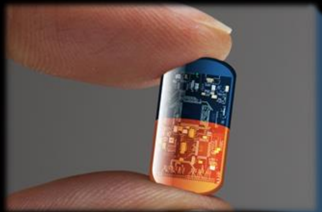
Micro Brain Implants



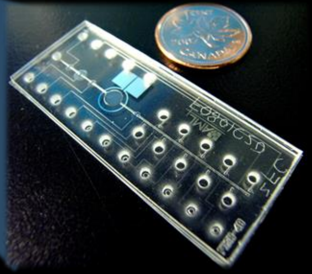


Nano-Implants that can move in the blood vessels





Contraception Micro-Implants



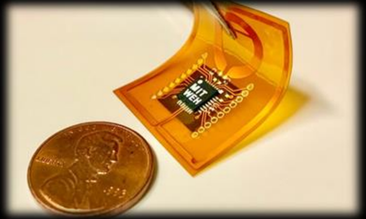
Bio-MEMS Lab-On-Chip for In body Diagnosis

Micro and Nano Bio Implants

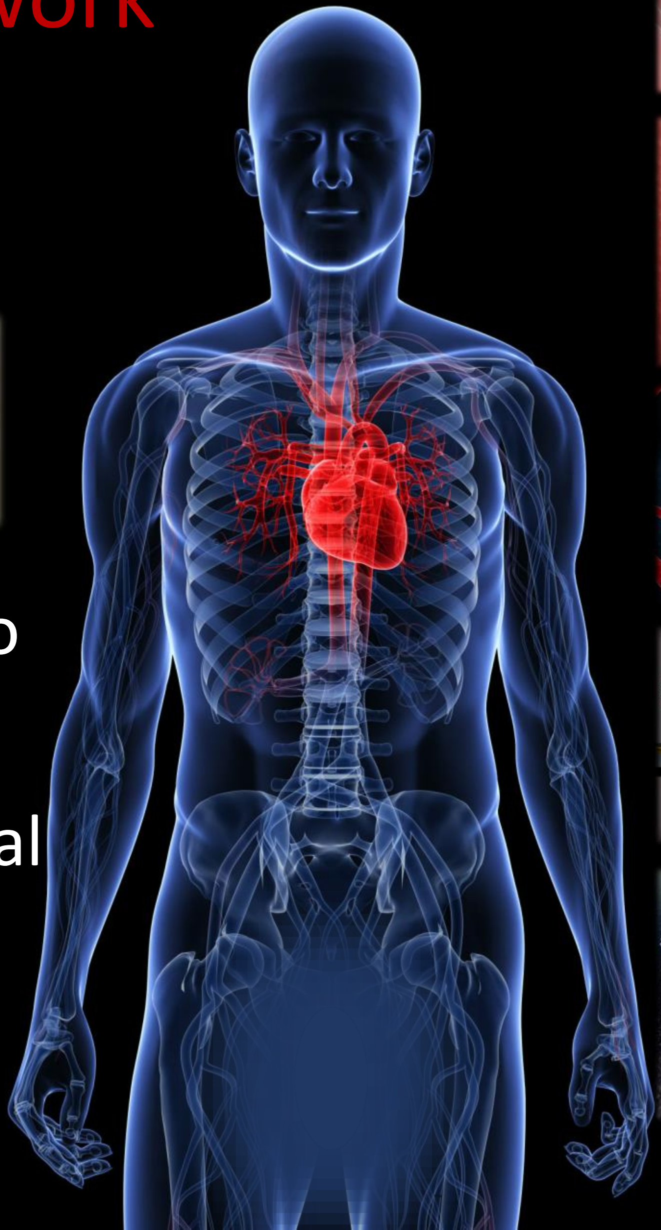
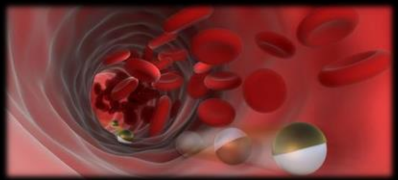
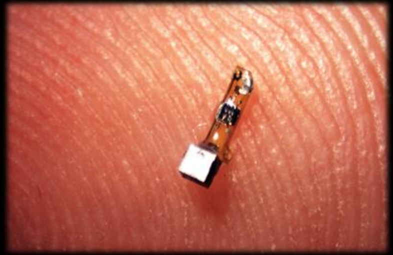
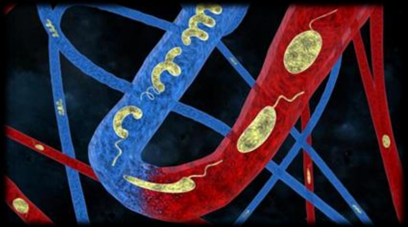
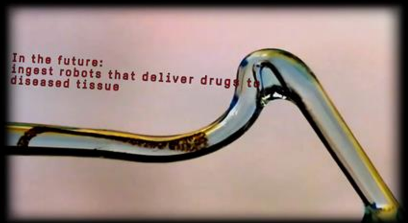
How to communicate with and network Nano & Micro Implants?

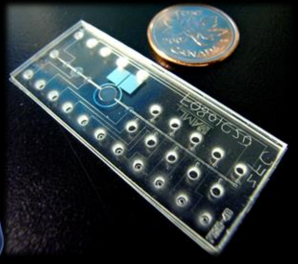
Traditional implants use wireless





- Large form factor for nano and micro implants
- Requires powerful external device
- Cannot network implants inside the body

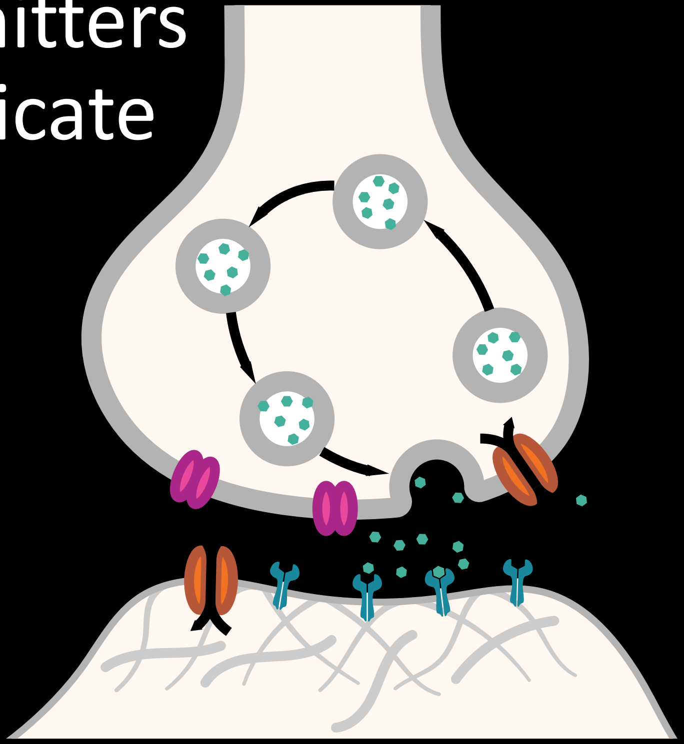








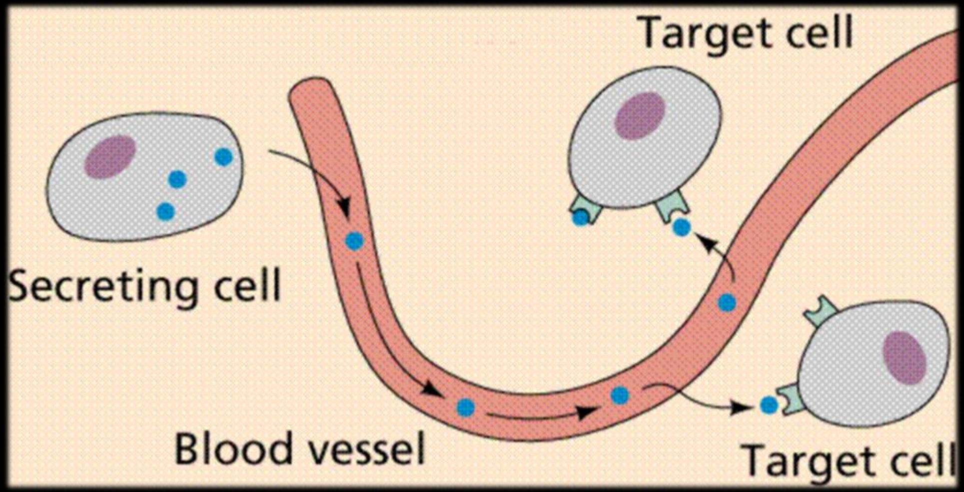
Molecular Communication

Communication paradigm inspired by chemical signaling between cells inside the body.

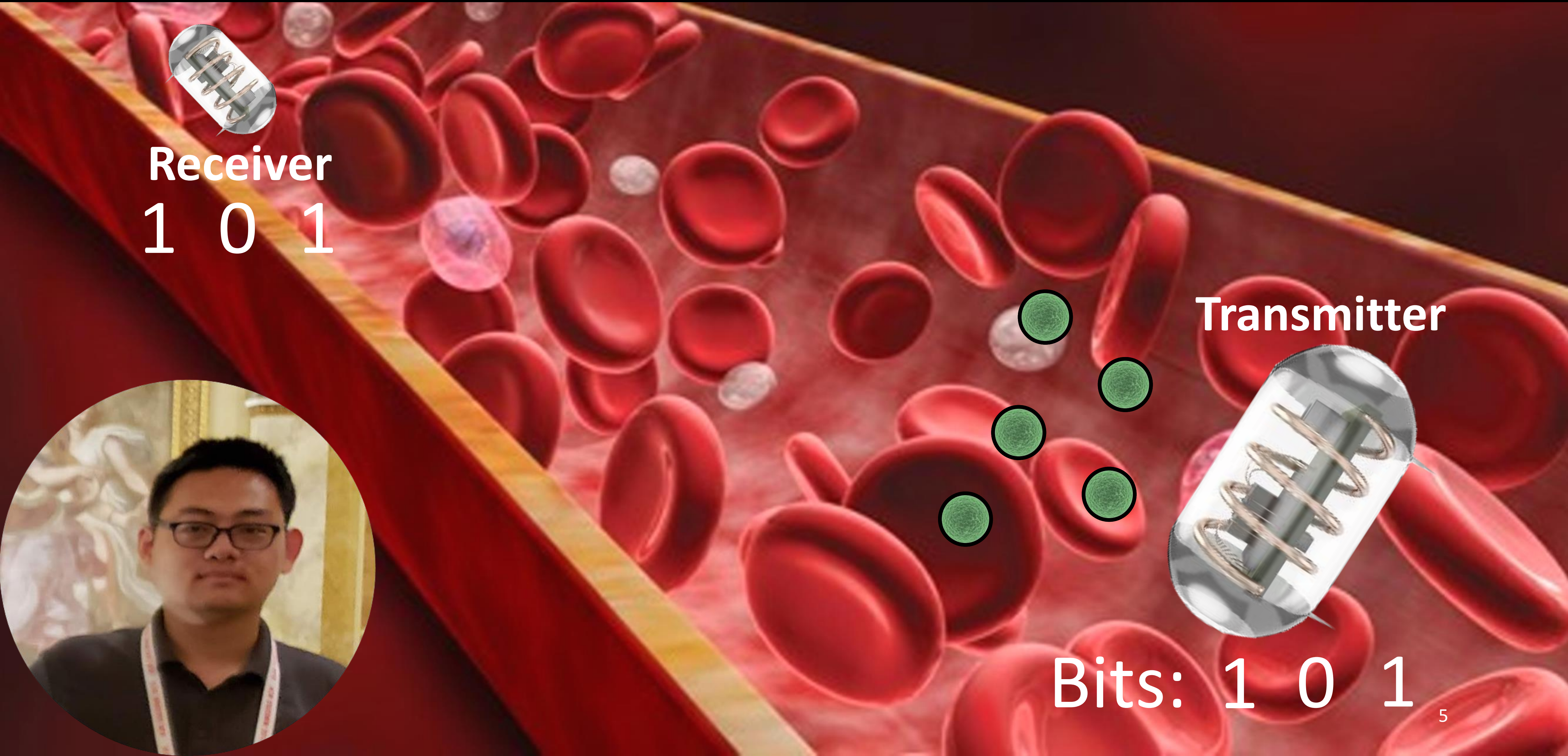
Neurons release neurotransmitters to communicate



Glands release hormones into the blood stream



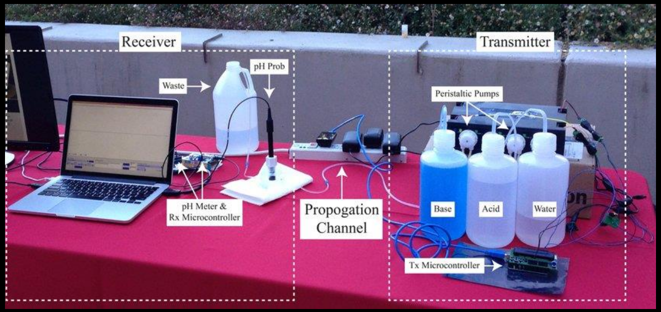
Encode bits by releasing molecules into the blood stream



State of the Art In Molecular Communication

- **Most past work is simulation based:**
  - Models the MC channel
  - Makes overly simplified assumptions

- **Little experimental work:**



Traditional decoders:
0.25 bps with 1 % BER
1 bps with 10% BER

- **Recent Work leverages RNN:**
  - Avoid modeling the MC channel
  - 4 bps with 4% BER

Molecular Communication Channel is Complex

Can we achieve better understanding of the molecular communication channel

&

Improve performance without using Neural Networks?

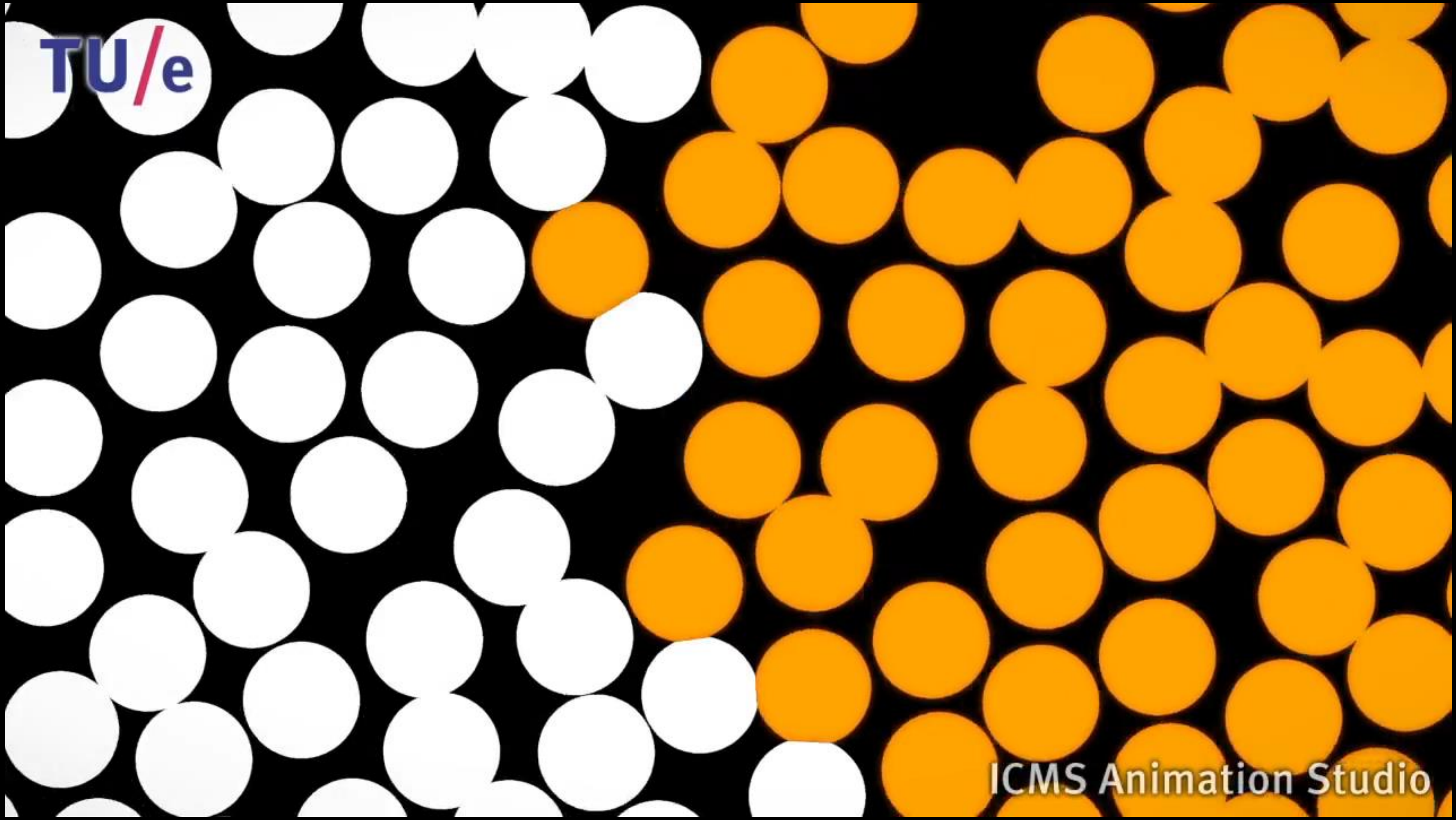
In this paper

1. Highlight two new key characteristics of the MC channel that have been overlooked by past work.

2. Present a system that accounts for these characteristics of the MC channel.

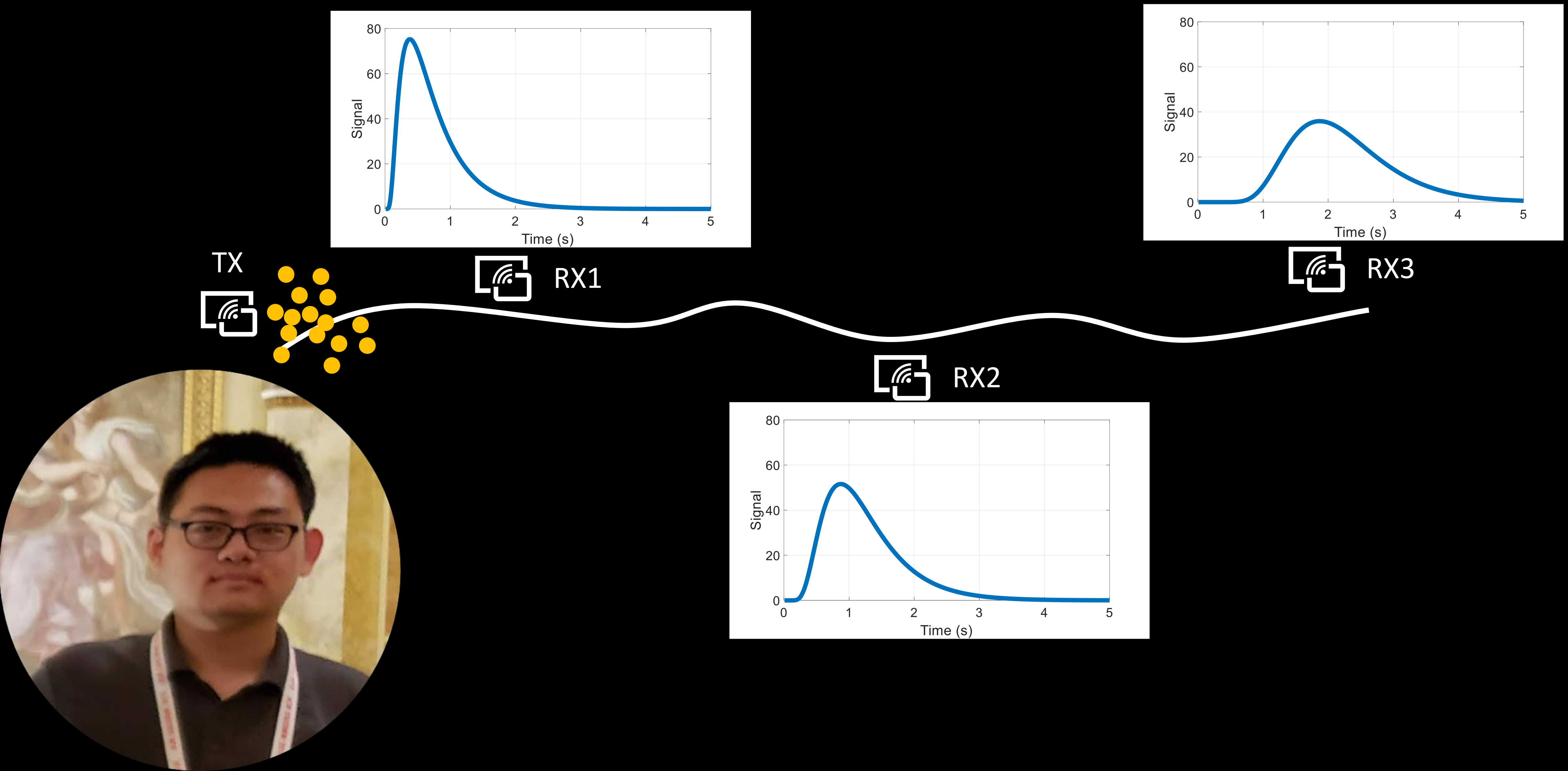
3. Experimentally validate the findings and demonstrate improvement in achievable data rates and BER.

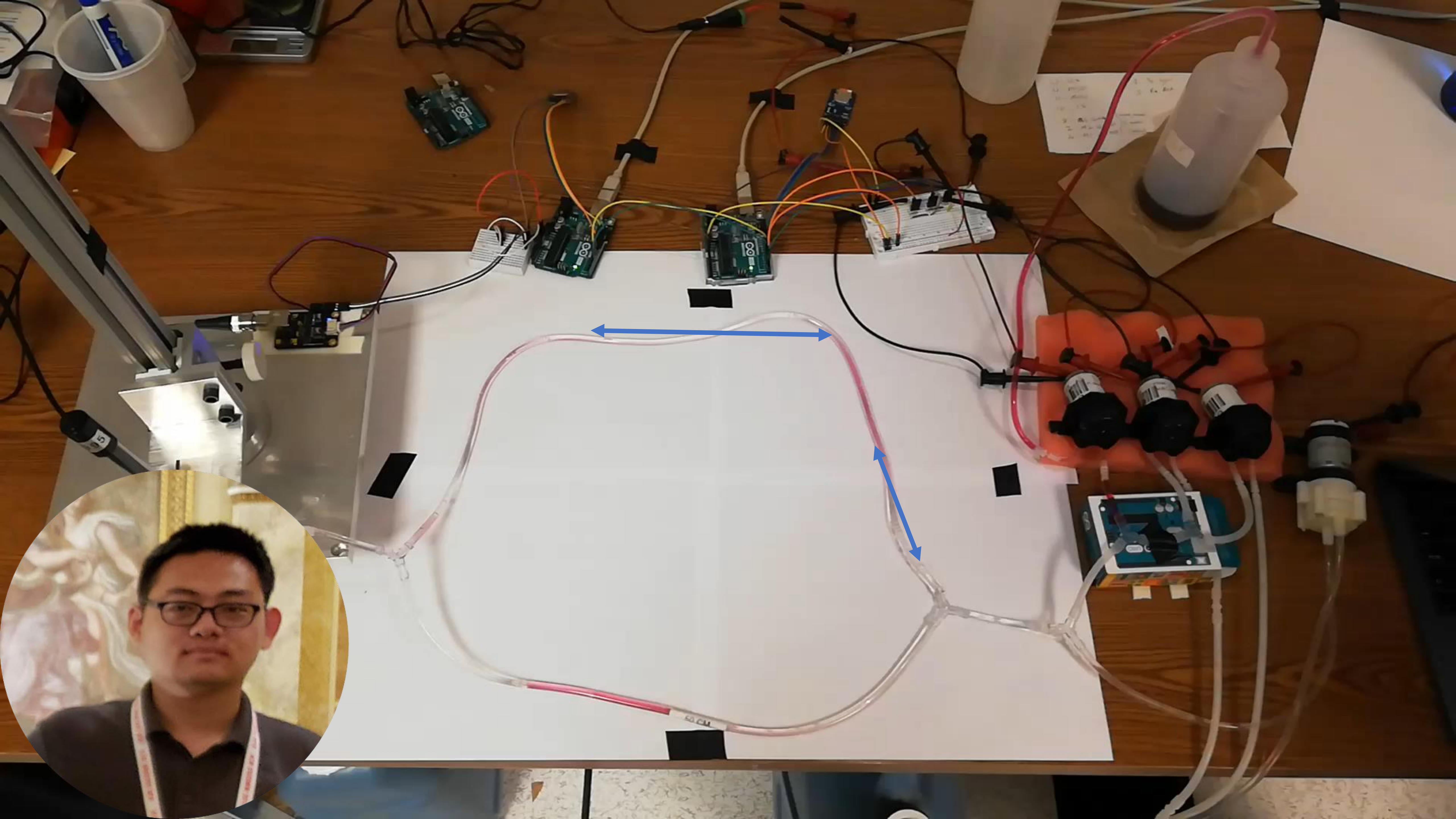
Diffusion



Brownian Motion

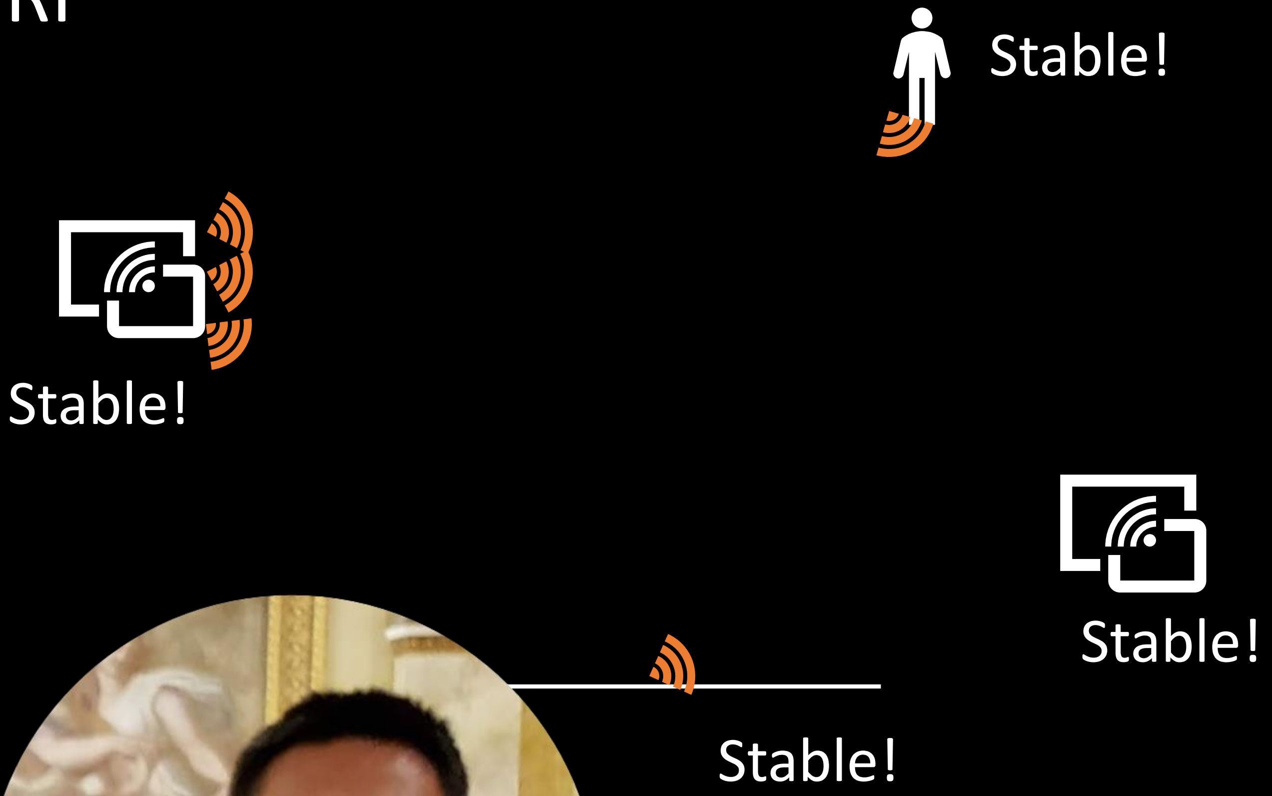
Diffusion

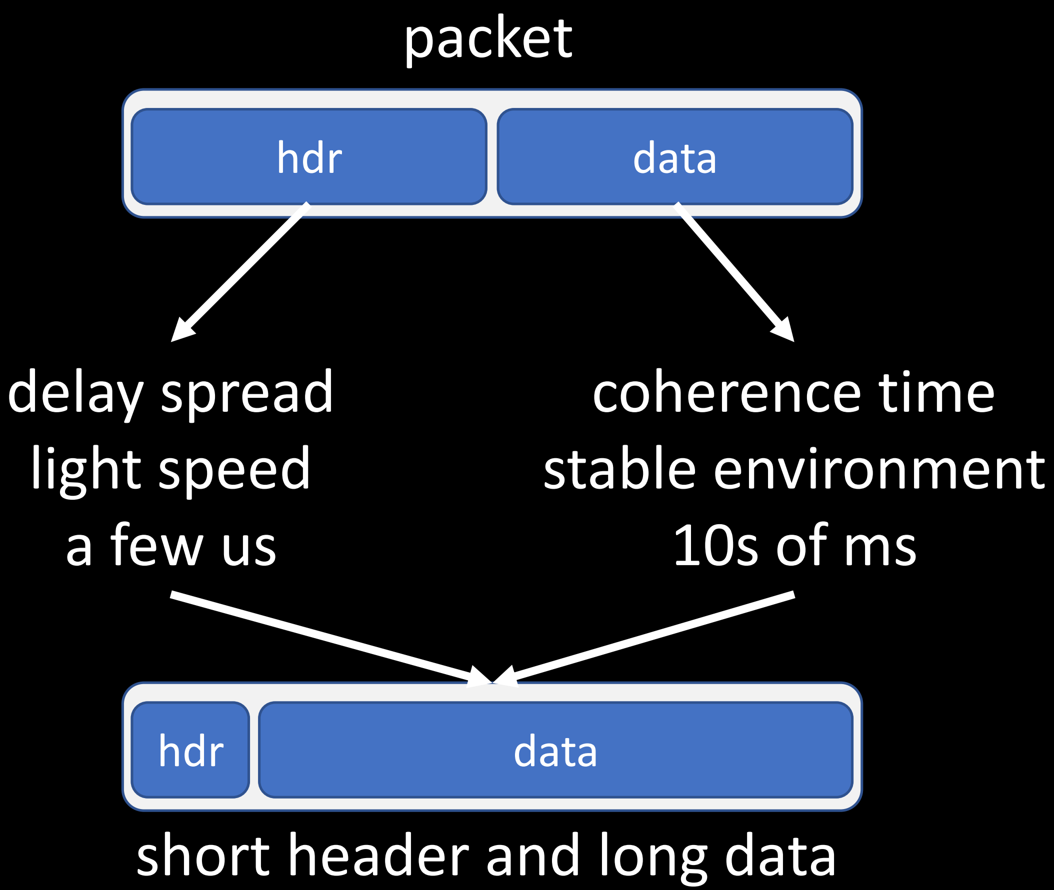




Delay Spread vs. Coherence Time

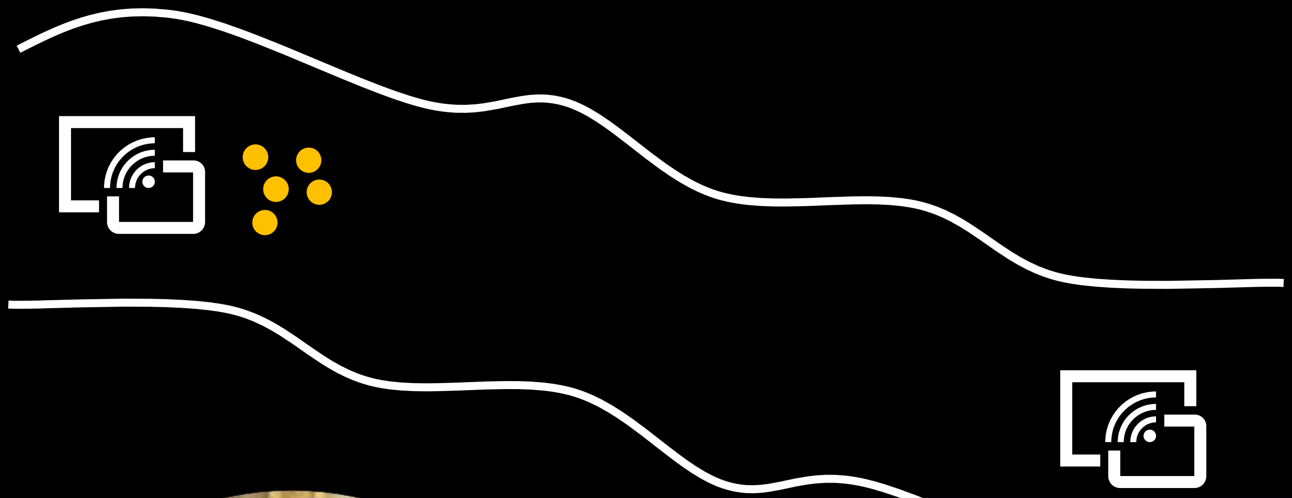
RF





Delay Spread vs. Coherence Time

MC



packet

hdr | data

delay spread
diffusion speed
a few sec

coherence time
stable environment[1]
10s of sec

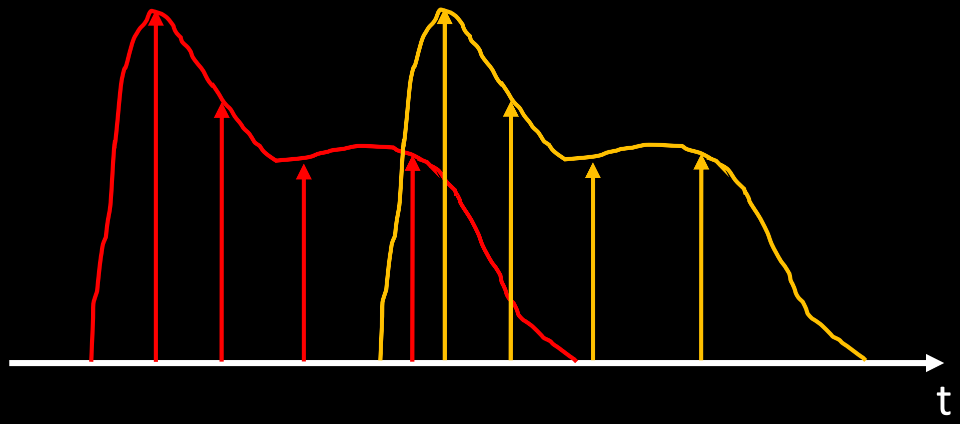
MC requires frequent but smart channel state information estimation

long header and short data

[1]Weisi Guo, Taufiq Asyhari, Nariman Farsad, H. Birkan Yilmaz, Bin Li, Andrew Eckford, and Chan Byoung Chae. 2016. Molecular communications: Channel model and physical layer techniques. IEEE Wireless Communications 23, 4(aug2016), 120–127.

Causality

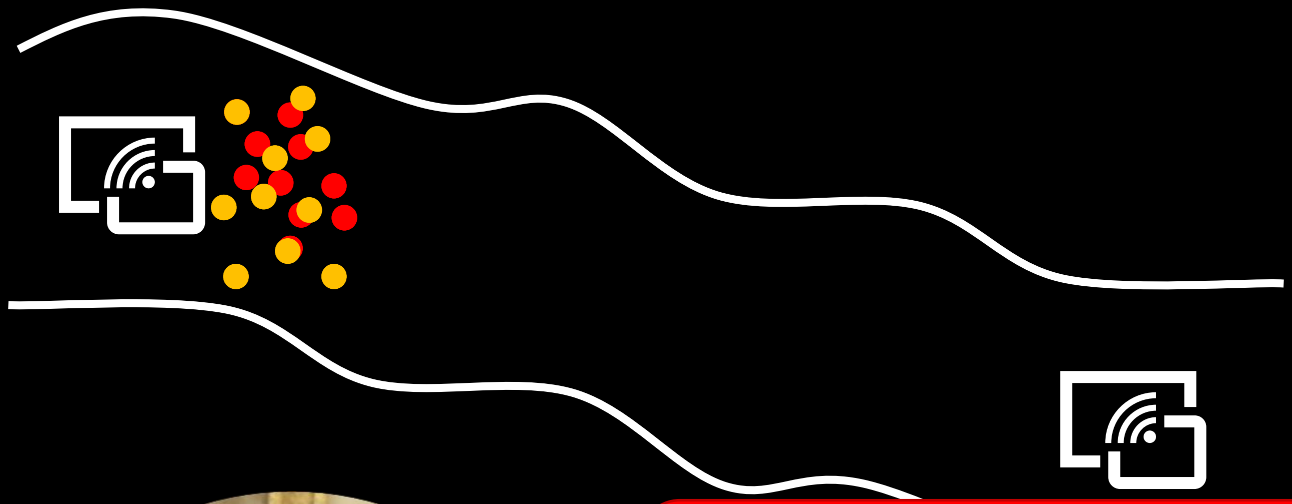
RF

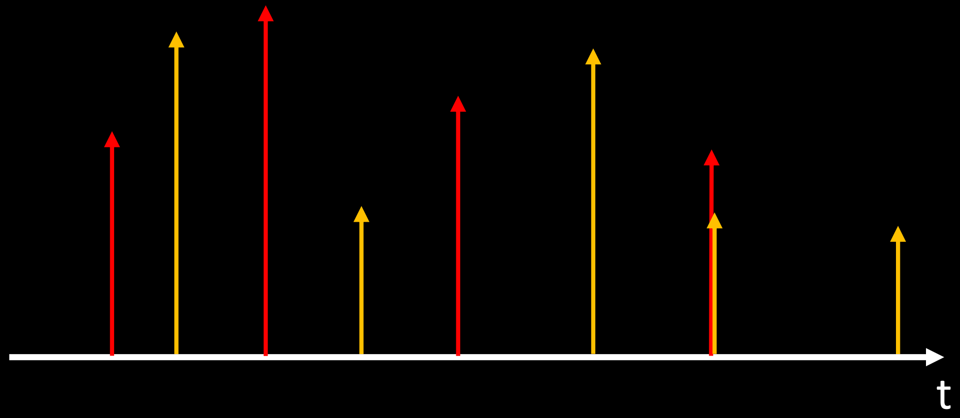


- Light speed in straight line
- First received is first transmitted
- Interference from previous symbols

Causality

MC





- Diffusion is slow and random

MC requires more consideration about inter-symbol interference

- Interference from both previous and following symbols

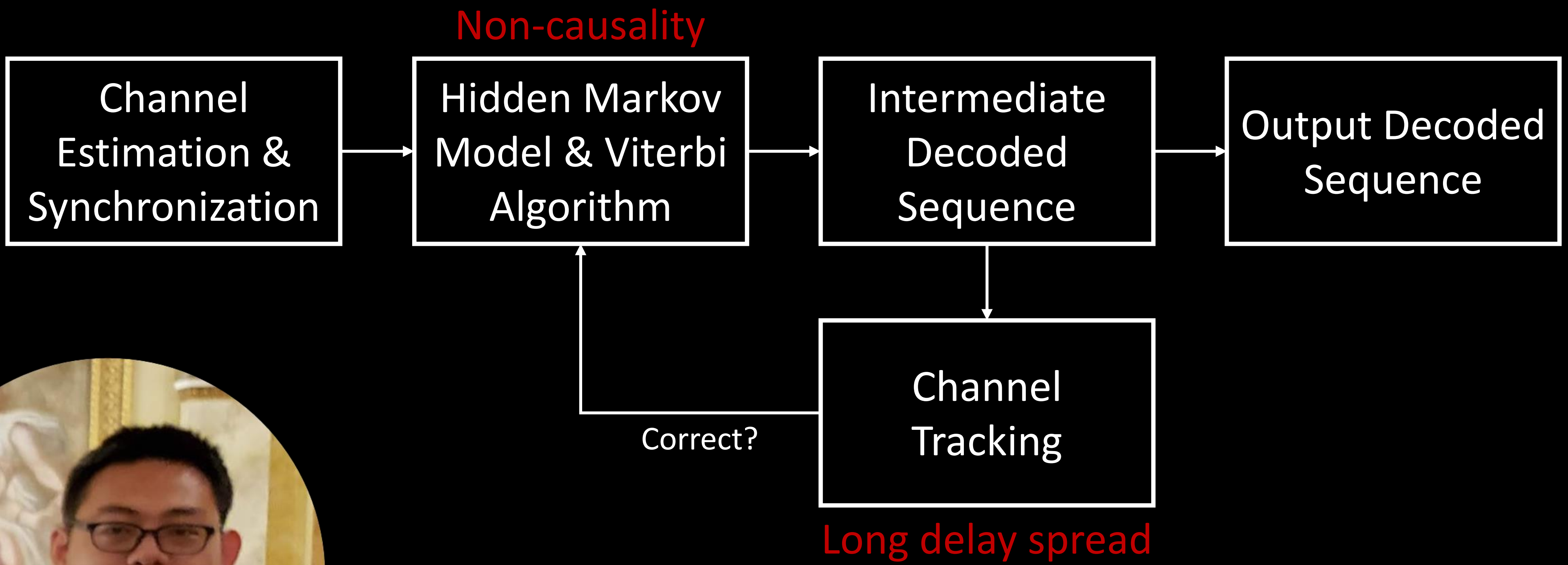
Outline

1. What are the distinct characteristics of MC channel?

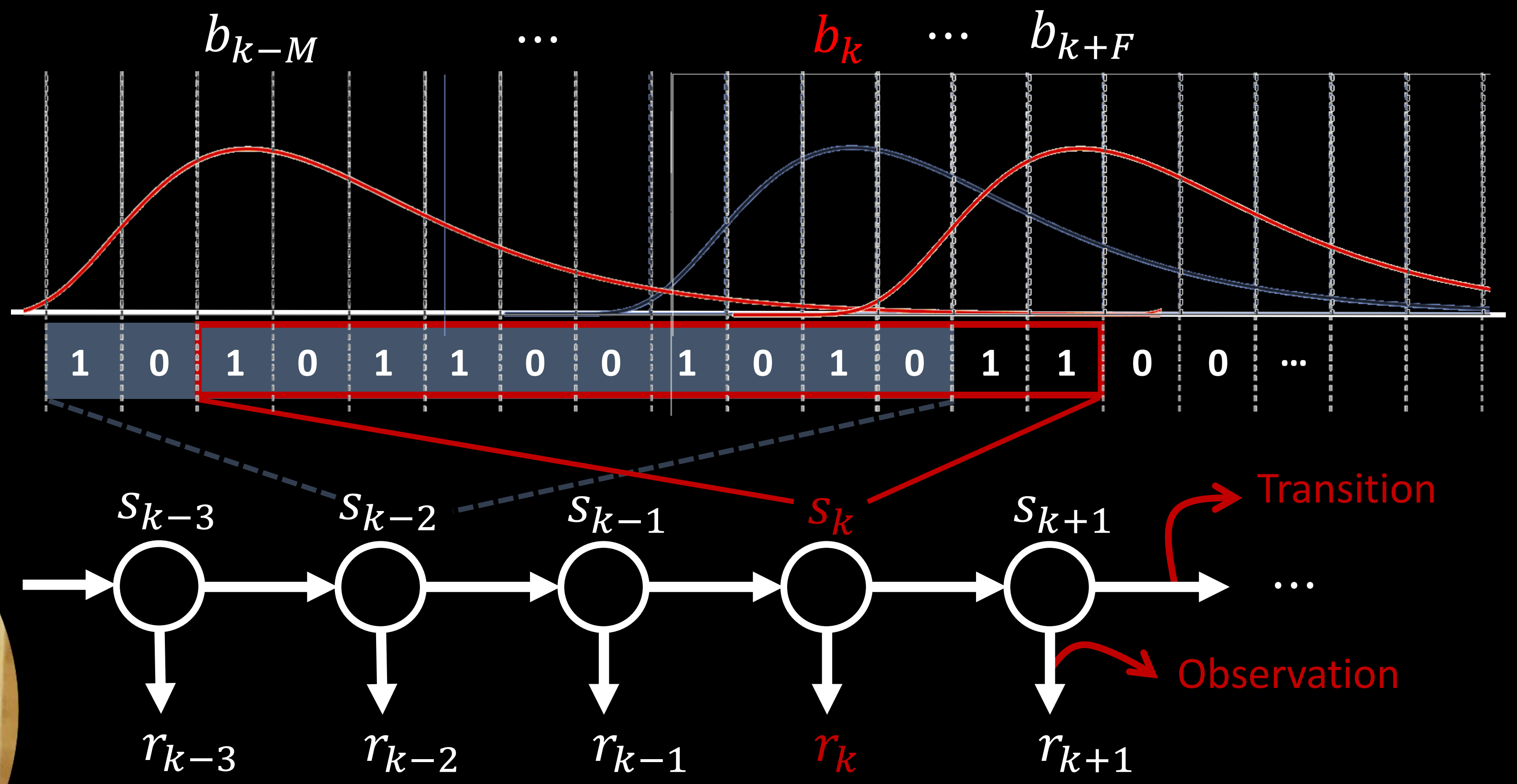
2. How do we handle these characteristics?

3. What is the performance of our solution?

μ-Link

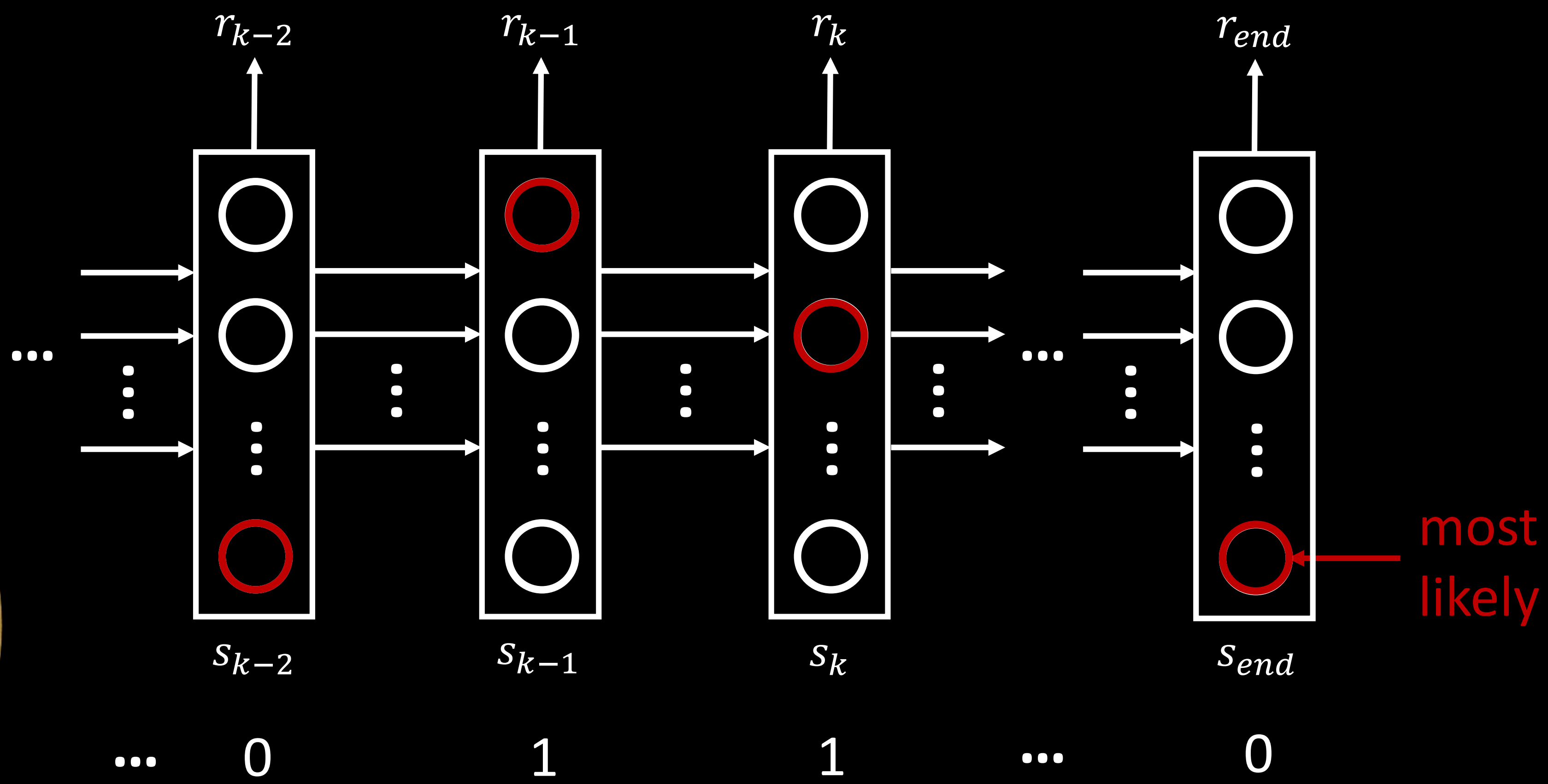

Non-causality
Channel Estimation & Synchronization
Hidden Markov Model & Viterbi Algorithm
Intermediate Decoded Sequence
Output Decoded Sequence
Channel Tracking
Correct?
Long delay spread

μ-Link – Hidden Markov Model



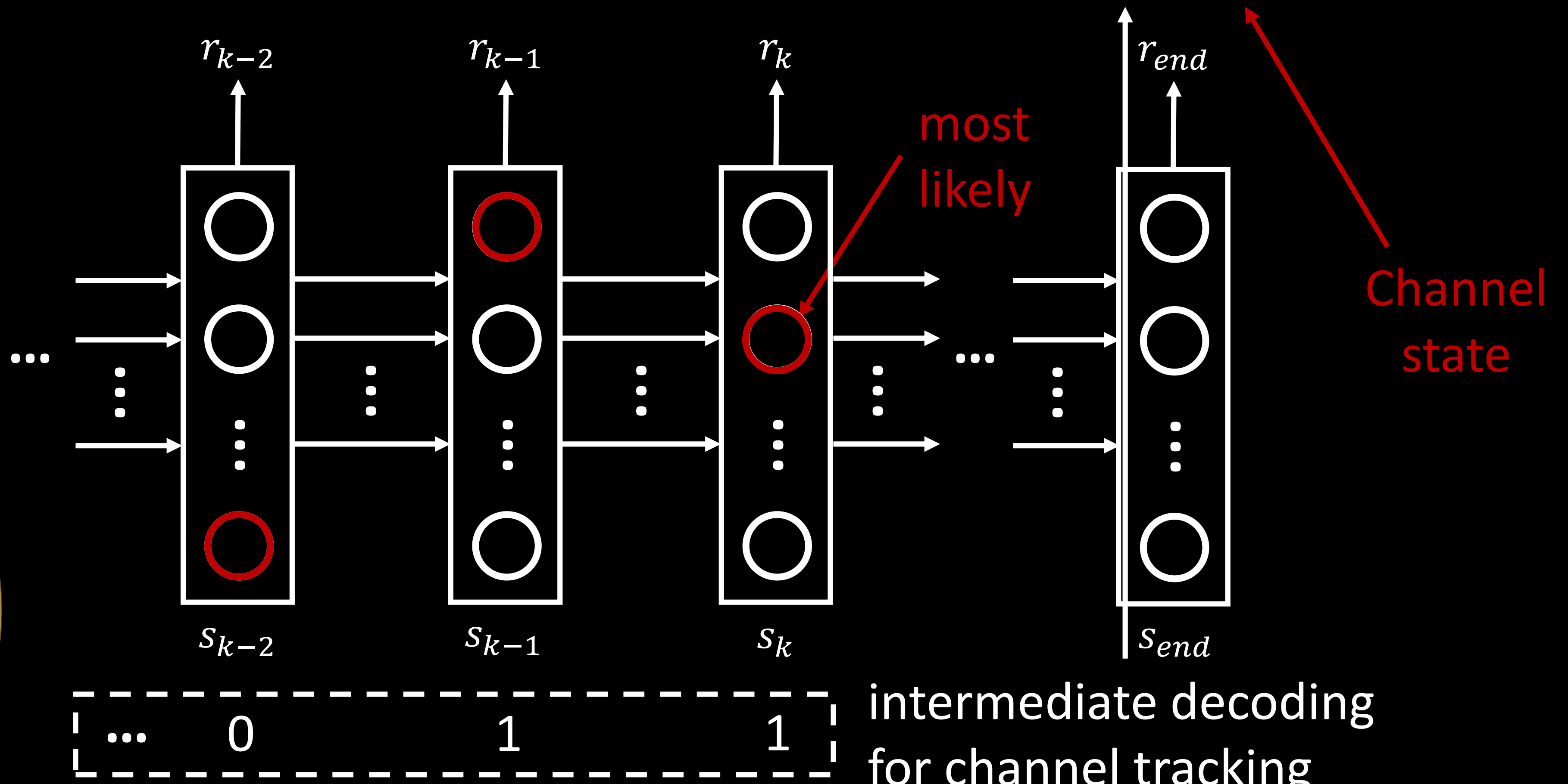
μ-Link – Viterbi Algorithm

$$p(s_1, \ldots, s_{k+1}, r_1, \ldots, r_{k+1})$$
$$= p(s_1, \ldots, s_k, r_1, \ldots, r_k) \cdot p(s_{k+1}|s_k) \cdot p(r_{k+1}|s_{k+1})$$



μ-Link – Channel Tracking

$$p(s_1, \dots, s_{k+1}, r_1, \dots, r_{k+1})$$
$$= p(s_1, \dots, s_k, r_1, \dots, r_k) \cdot p(s_{k+1}|s_k) \cdot p(r_{k+1}|s_{k+1})$$

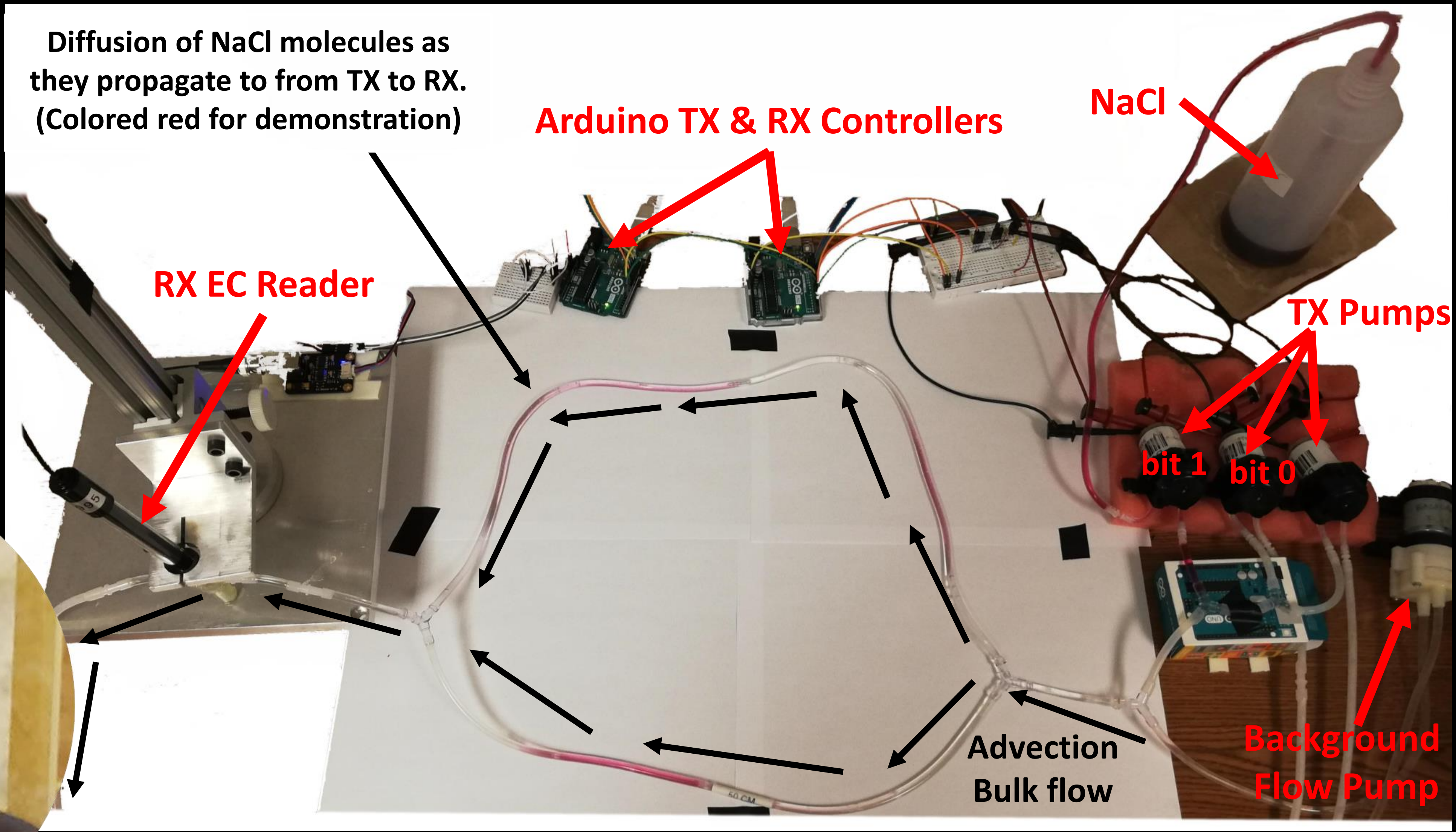


intermediate decoding for channel tracking

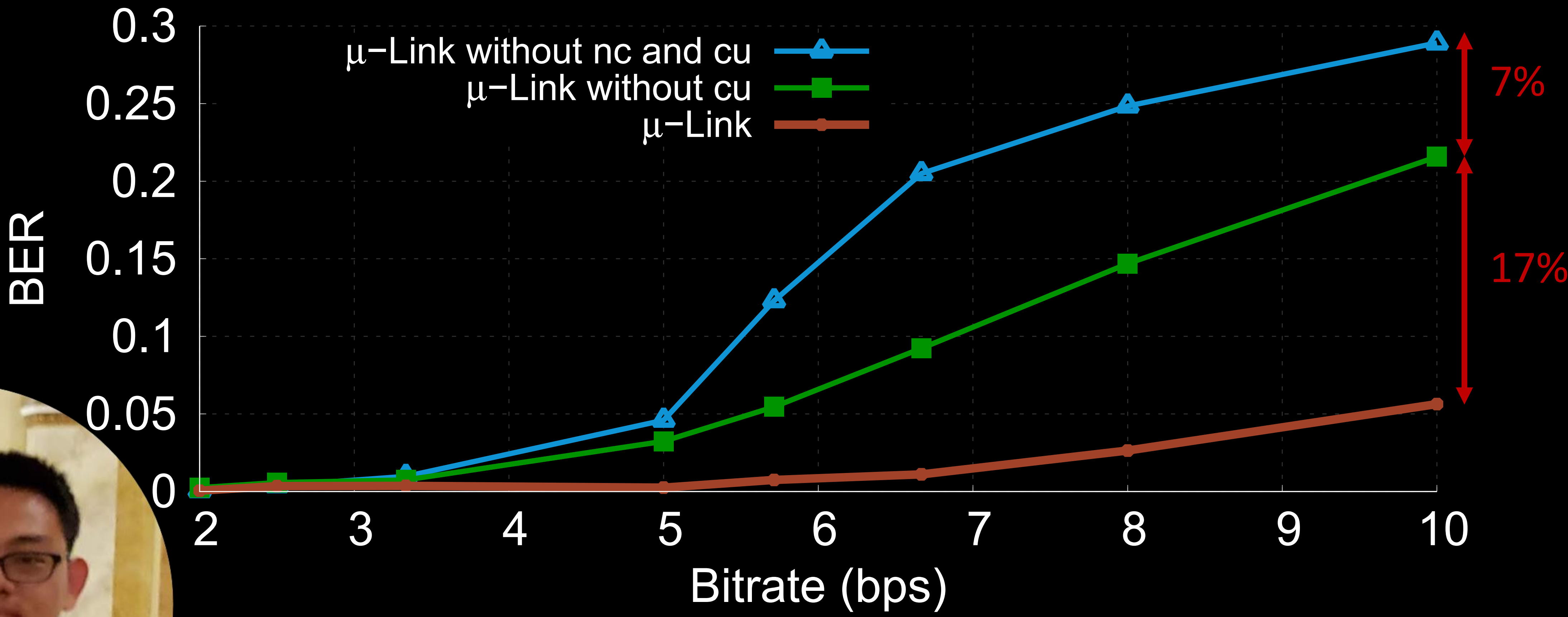
Outline

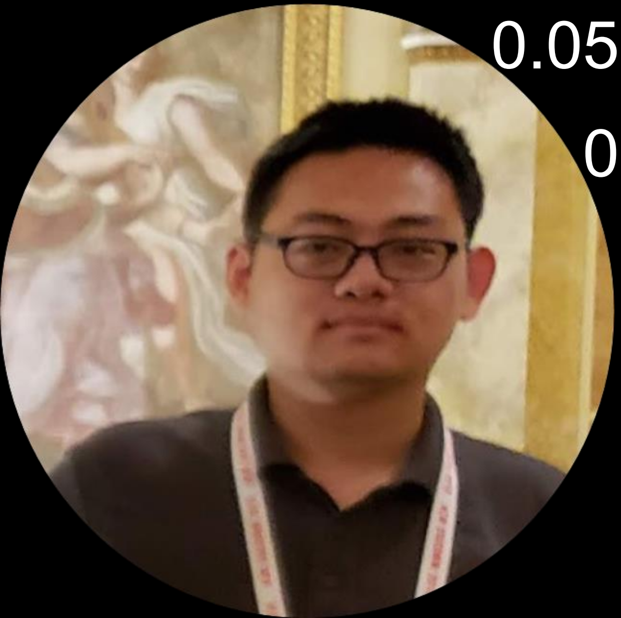
1. What are the distinct characteristics of MC channel?
2. How do we handle these characteristics?
3. What is the performance of our solution?

μ-Link Evaluation



Effectiveness of μ-Link design





[1]CU – Channel update (channel tracking)

[2]NC – Non-causality

Methodology

Compared decoders

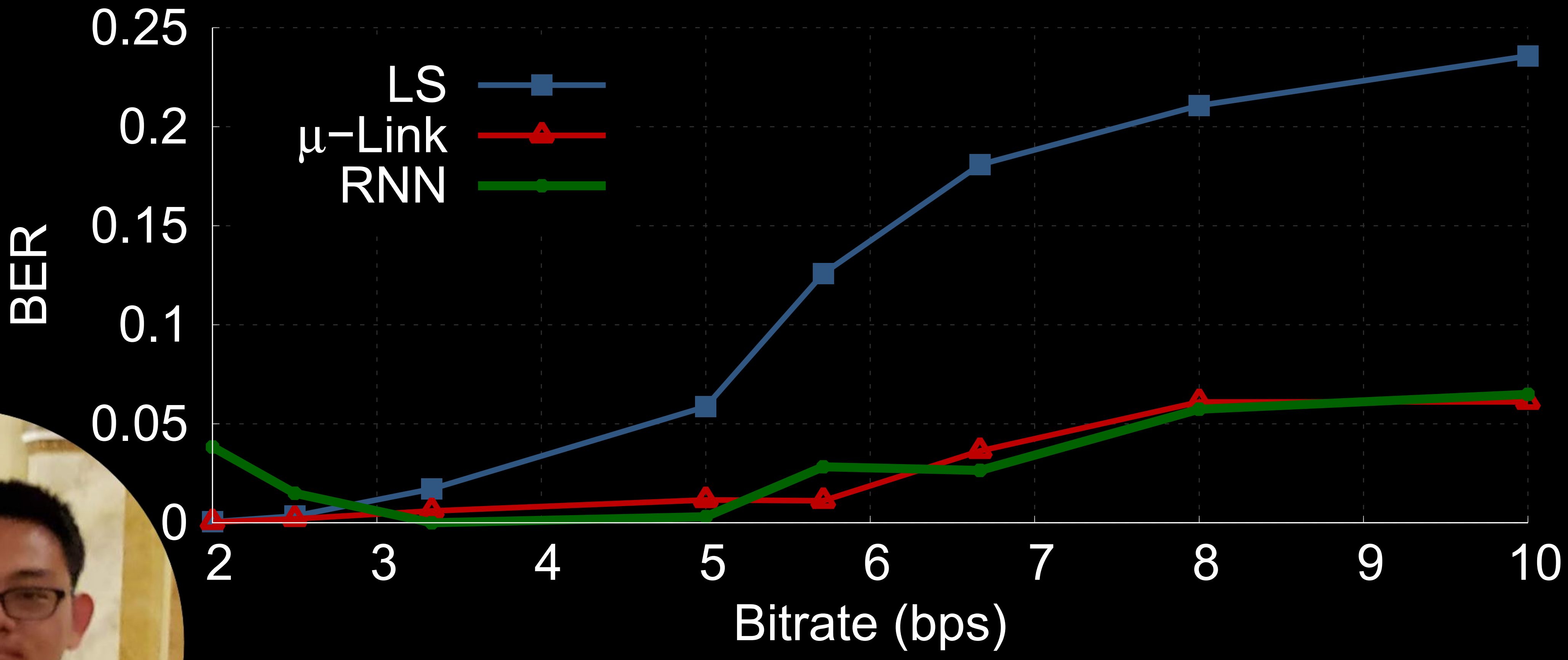
1. Least-Squares decoder
2. RNN decoder (Bi-directional LSTM)[1]

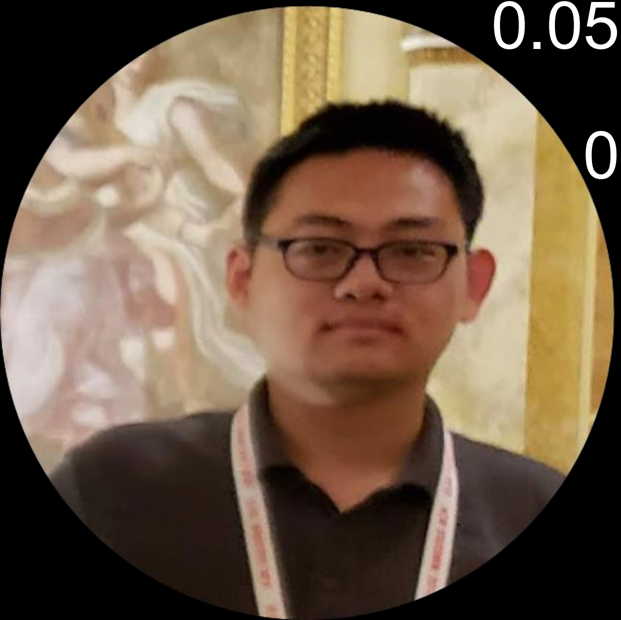
Data set

1. Different data rates
2. Different Tx-Rx distances
3. Different Tx-Rx path (single/double path)

[1]Nariman Farsad and Andrea Goldsmith. 2018. Neural Network Detection of Data Sequences in Communication Systems. (jan 2018).

Overall performance





Conclusion

1. Molecular communication is a potential method to enable networking between micro implants inside human body.

2. This paper highlights distinct channel properties of MC, i.e. non-causality and long delay spread.

3. μ-Link can achieve 0.2% BER at 5 bps and 5% BER at 10 bps, which is comparable to RNN solution.

4. μ-Link takes the first step to investigate these differences and opens discussions about fundamental principles in MC.

Understanding and Embracing the Complexities of the Molecular Communication Channel in Liquids

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ABSTRACT

Molecular communication has recently gained a lot of interest due to its potential to enable micro-implants to communicate by releasing molecules into the bloodstream. In this paper, we aim to explore the molecular communication channel through theoretical and empirical modeling in order to achieve a better understanding of its characteristics, which tend to be more complex in practice than traditional wireless and wired channels. Our study reveals two key new characteristics that have been overlooked by past work. Specifically, the molecular communication channel exhibits non-causal inter-symbol-interference and a long delay spread, that extends beyond the channel coherence time, which limit decoding performance. To address this, we design, μ-Link a molecular communication protocol and decoder that accounts for these new insights. We build a testbed to experimentally validate our findings and show that μ-Link can improve the achievable data rates with significantly lower bit error rates.

CCS CONCEPTS

• **Networks** → **Cyber-physical networks**; *Physical links.*

KEYWORDS

Molecular Communication, Diffusion, Non-Causal Channel, Micro-Implants, Inter-Symbol-Interference, Viterbi.

ACM Reference Format:
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https://doi.org/10.1145/3372224.3419191

1 INTRODUCTION

Molecular communication (MC) has emerged as a promising technology for communication through fluids such as micro-implants communicating through the bloodstream or sensors communicating through industrial pipes [4, 20, 34]. In MC, a device can transmit data by releasing molecules into the fluid which are then transported and detected at a receiver [55]. For example, a device can release molecules to encode a "1" bit and release nothing to encode a "0" bit. The receiver can measure the concentration of molecules to determine whether the transmitted bit was a "1" or a "0".

Molecular communication has the potential to enable micro and nano-implants to communicate with each other inside the human body and coordinate sensing and actuation tasks. Recent advances in biomedical sciences have in fact led to the development of nano-implants that can sense human vitals from inside the body and even travel through the bloodstream to perform targeted drug delivery and treatment [12, 30, 55]. There is significant interest in enhancing the operation of such implants by connecting them using MC [4, 5, 9, 10, 20–23, 34, 53]. MC presents a suitable alternative to other communication technologies such as wireless. In particular, RF signals do not propagate well in fluids and form factor constraints prevent scaling RF radios to micro and nano-dimensions [40, 56, 66]. In contrast, for MC, researchers can design synthetic cells that send and receive molecular signals [17, 52, 57], nano-scale Lab-on-a-Chip that monitor chemical content [30, 54, 61], and bio-implants that collect and process data [41, 43, 51].

While there is still a long way to realize the above vision, this paper takes steps to achieve a better understanding of the characteristics of the MC channel from both theoretical and empirical perspectives. The MC channel tends to be more complex in practice than standard RF, optical, or copper wire channels [28]. Understanding and addressing the differences between these channels and MC allows us to improve the performance of molecular communication.

There has been a significant amount of work on theoretically modeling the MC channel [15, 16, 46, 47, 47, 58, 59, 62, 65, 68]. However, these models tend to be overly simplified with assumptions that do not hold in practice (e.g. no inter-symbol-interference) or overly fitted to a closed form

Much more in the paper…


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