Towards Practical and Scalable Molecular Networks

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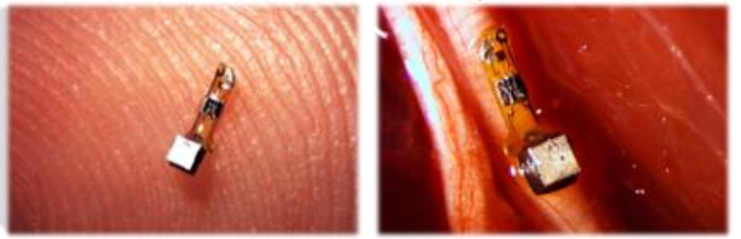
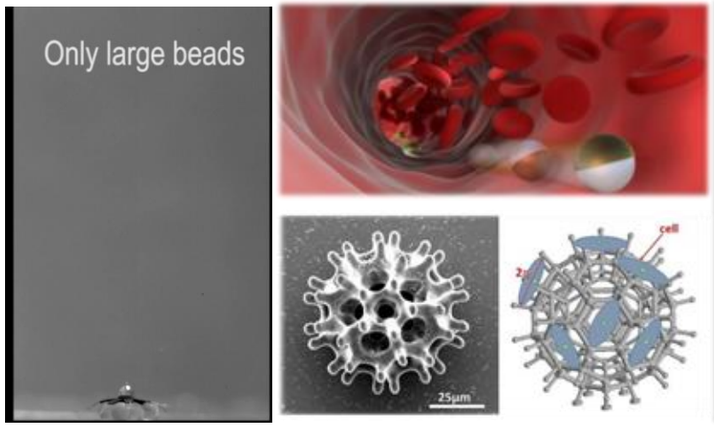
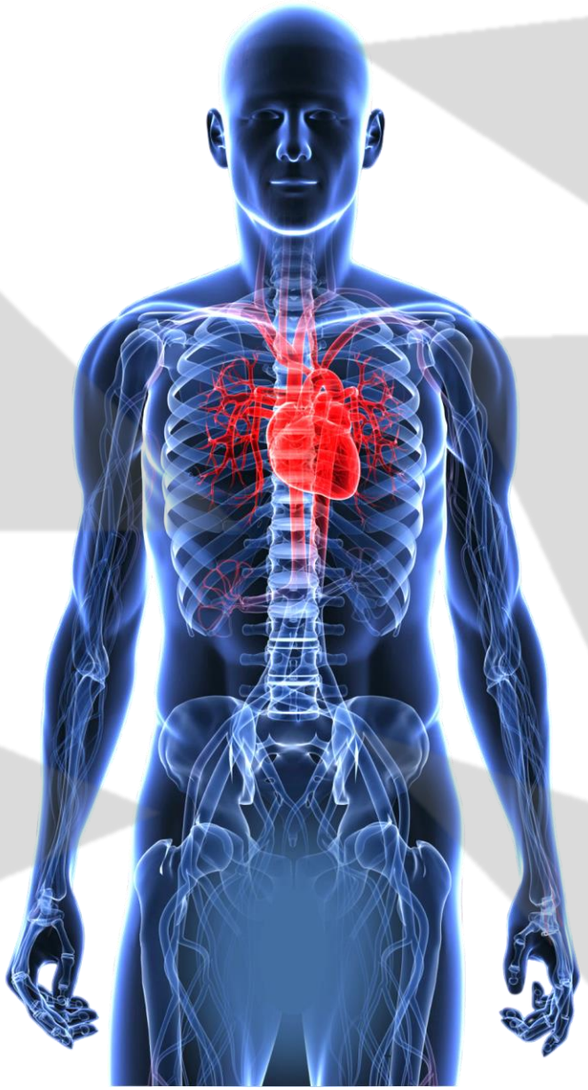
Micro and Nano Bio Implants

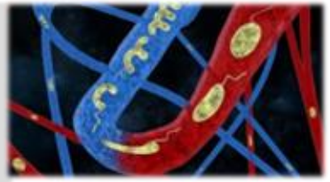
Micro Brain Implants



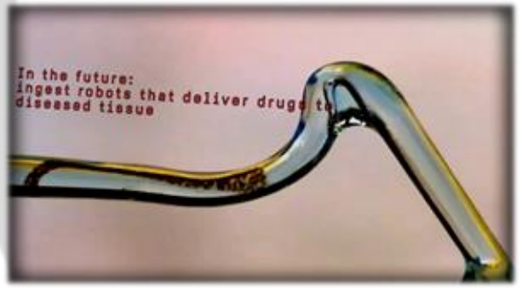
Microrobots for drug delivery







Nano-Implants
that can move in
the blood vessels



Contraception
Micro-Implants

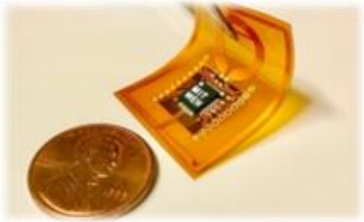
Bio-MEMS
Lab-On-Chip for
In body Diagnosis

Micro and Nano Bio Implants

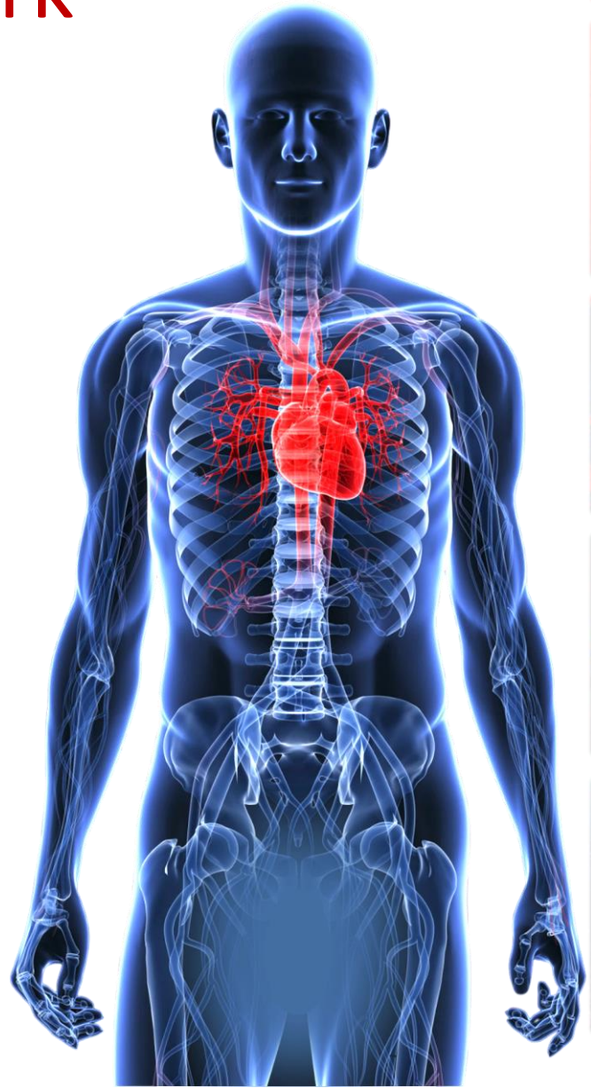
How to communicate with and network micro and nano implants?

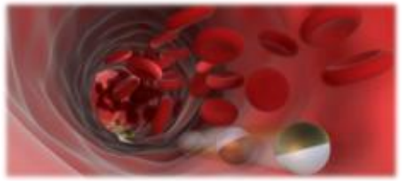
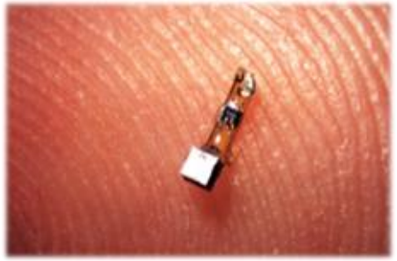
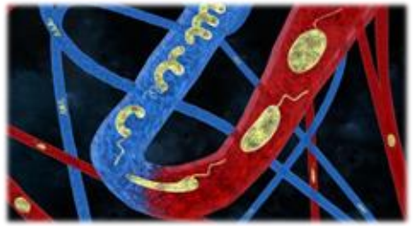
Traditional implants use wireless

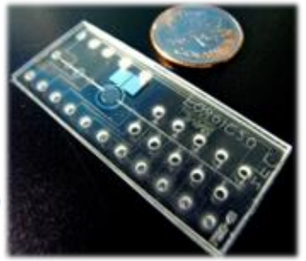




- Large form factor
- Powerful external device
- High propagation loss



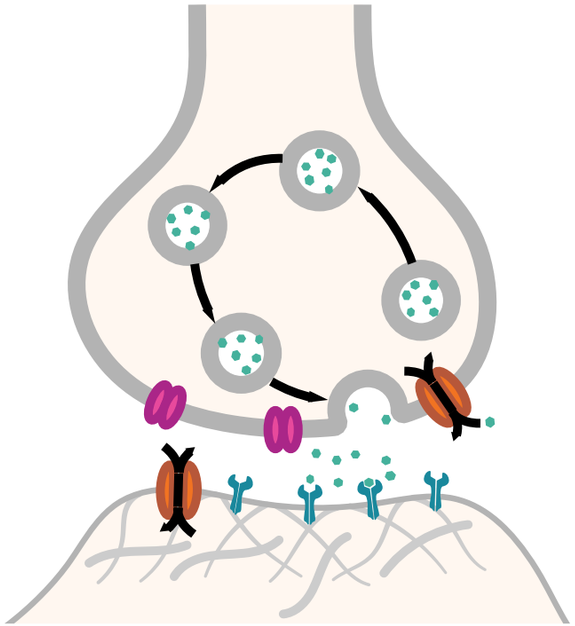




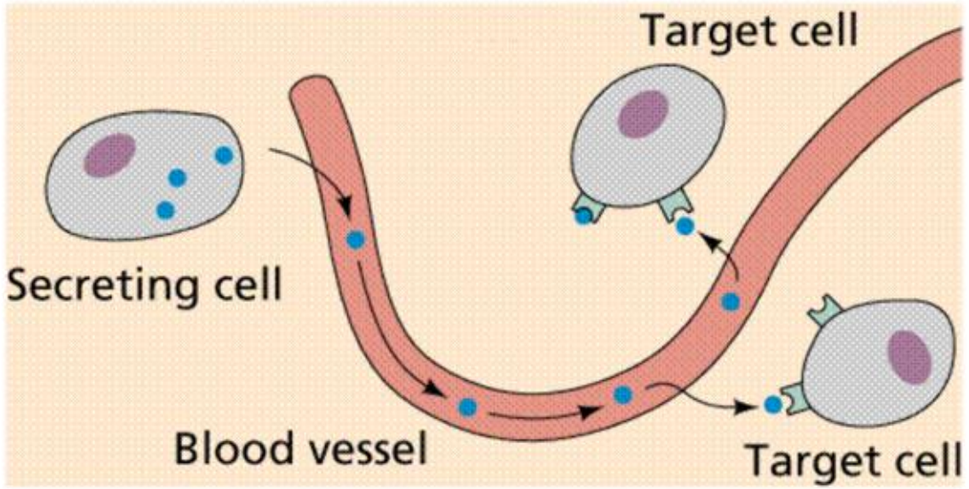
Molecular Communication

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

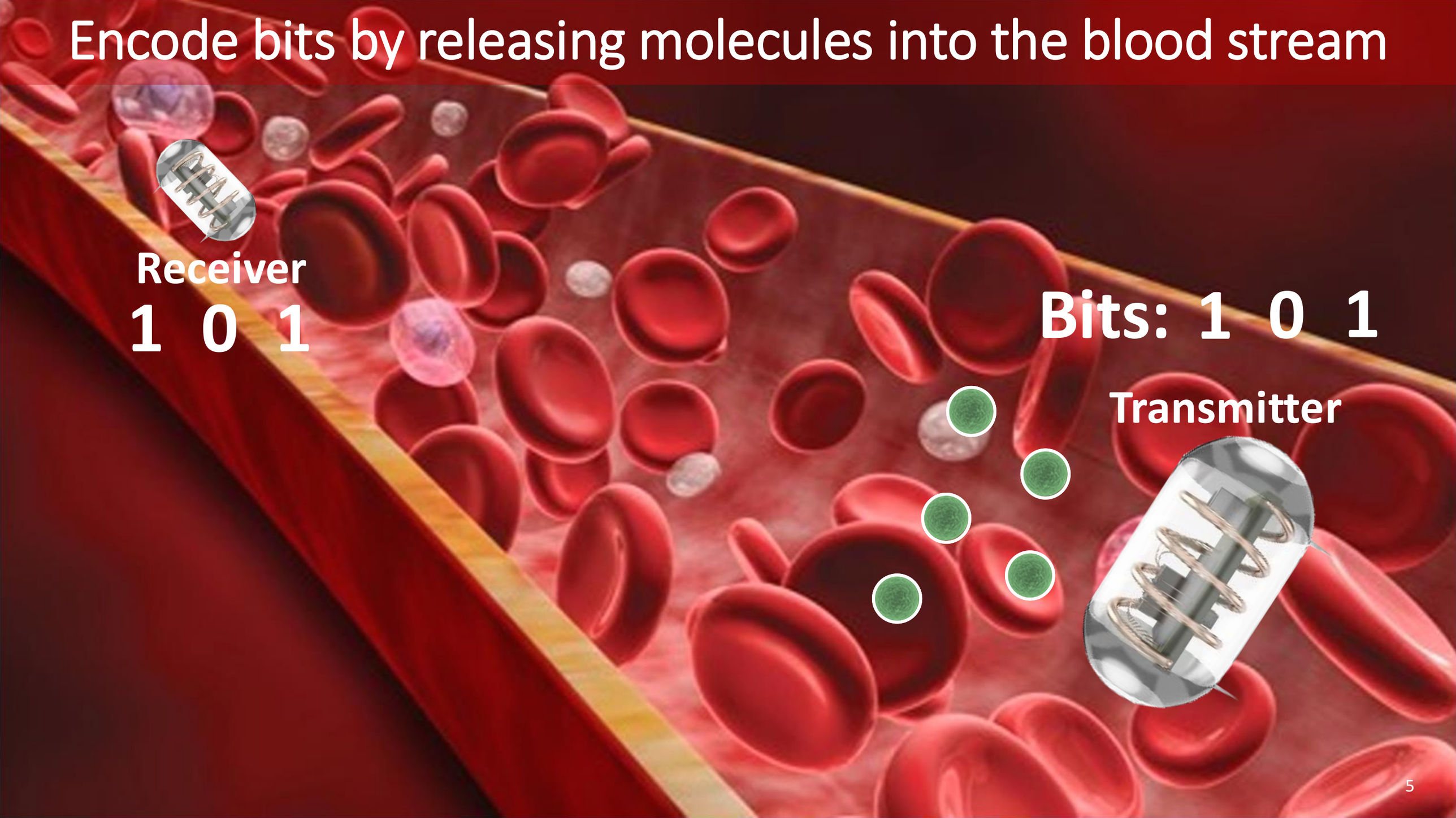
Neurons release neurotransmitters



Glands release hormones into the blood stream



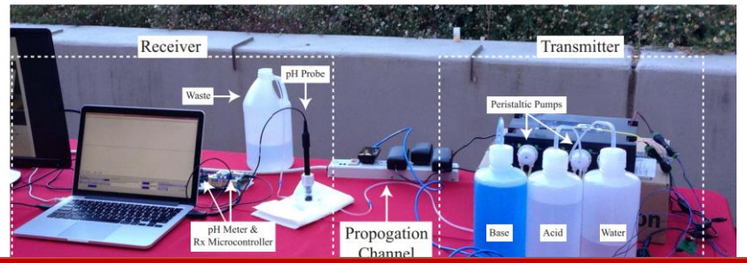
Encode bits by releasing molecules into the blood stream



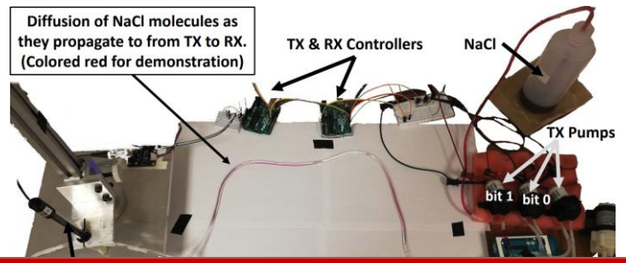
Little Experiment and System Work on This Topic

Emulated Testbeds

[1] Acid/Base Molecules

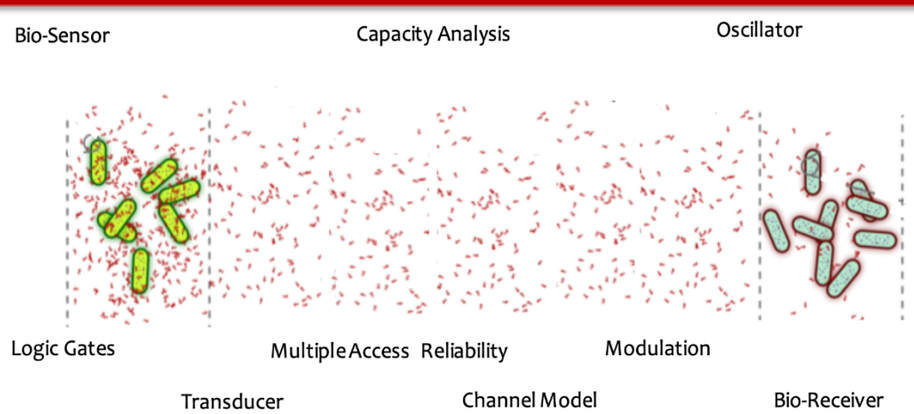


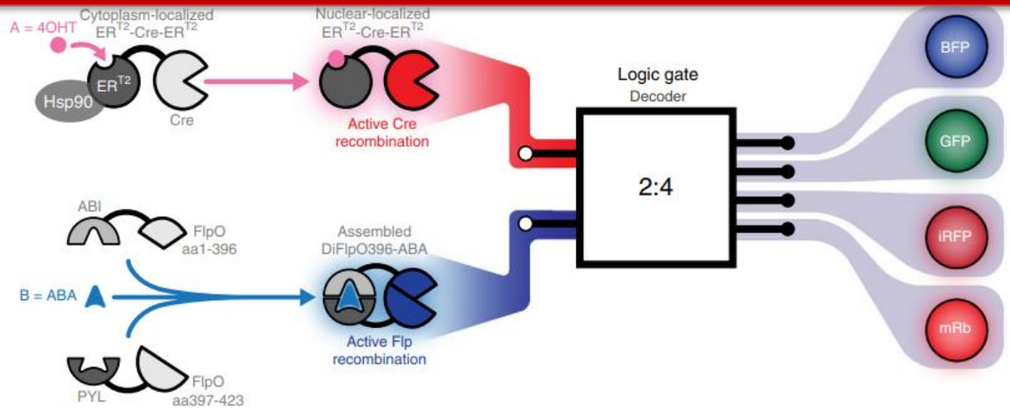
[2] Salt



[3] Magnetic Particles

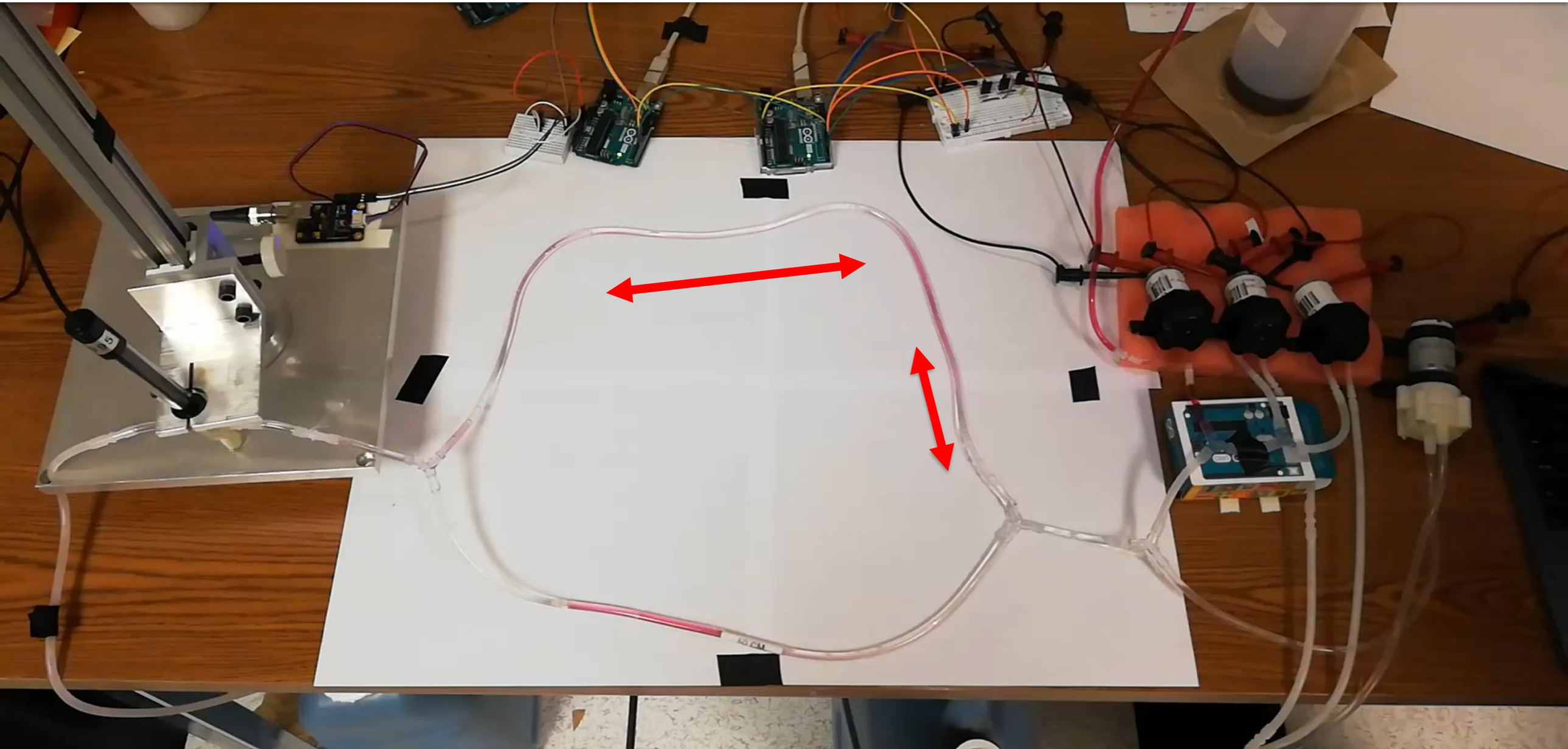
Need more experimental work to understand how to build practical Molecular Networks



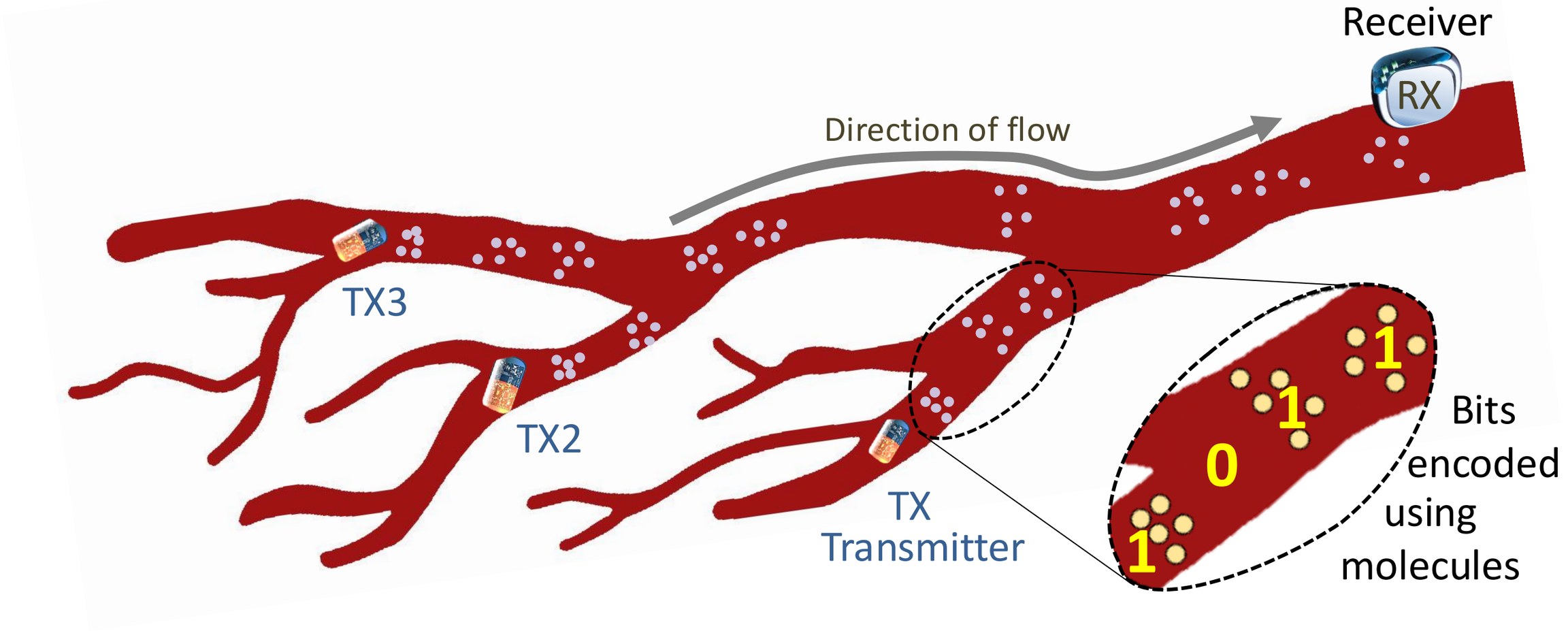


[1] "A novel experimental platform for in-vessel multi-chemical molecular communications." GLOBECOM 2017
[2] "Understanding and embracing the complexities of the molecular communication channel in liquids." MobiCom 2020
[3] "Experimental molecular communication testbed based on magnetic nanoparticles in duct flow." IEEE Workshop SPAWC 2018.
[4] “Algorithms for molecular communication” Bhuvana Krishnaswamy, Ph.D. Thesis, 2018
[5] "A modular cell-based biosensor using engineered genetic logic circuits to detect and integrate multiple environmental signals." Biosensors and Bioelectronics

Prior Work [MobiCom'20]: By accounting for the complexities of the molecular communication channel → Improve decoding bit error rate and throughput

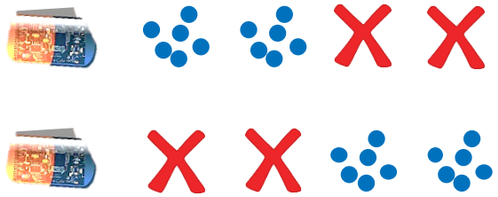


How do we scale molecular networks from a single transmitter to multiple transmitters?



Medium Access Control in Molecular Networks

TDMA



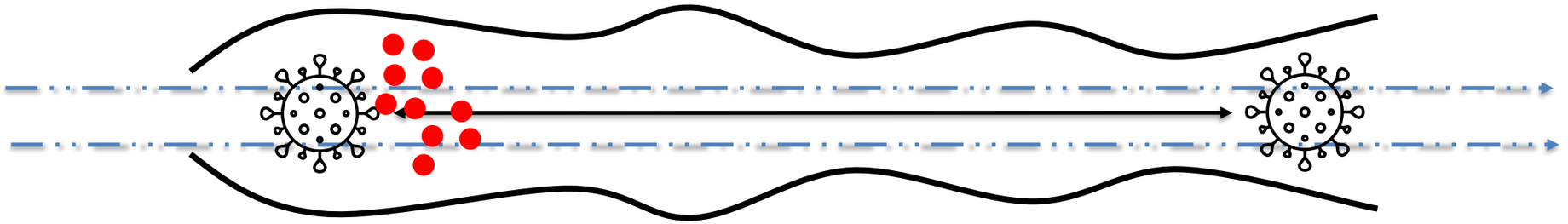
No interference

Synchronization

Challenge: Lack of Synchronization

- Long propagation delay

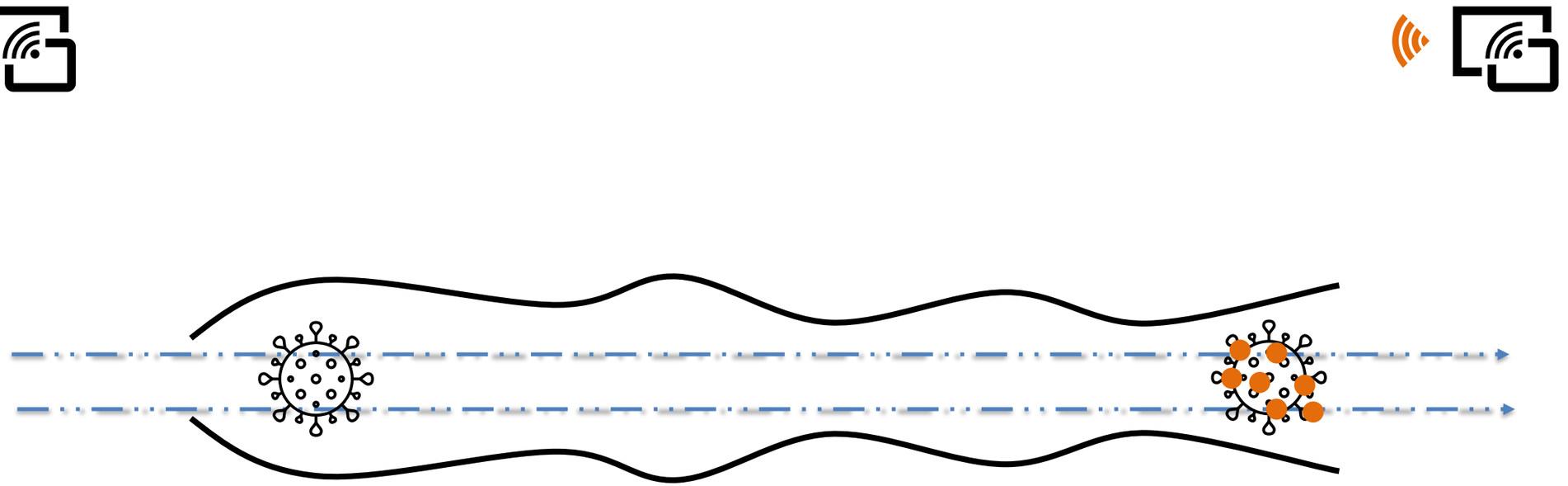
$$30\ \text{m} \quad = \quad 3 \times 10^8\ \text{m/s} \quad \times \quad 100\ \text{ns}$$



$$1\ \text{m} \quad = \quad 1\ \text{m/s} \quad \times \quad 1\ \text{s}$$

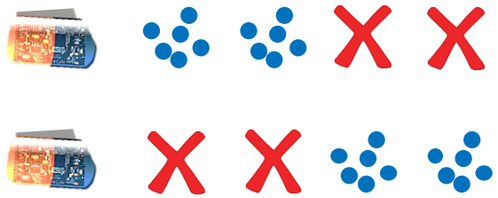
Challenge: Lack of Synchronization

- Asymmetric channel



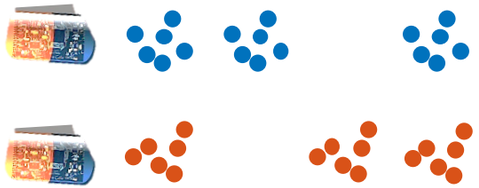
Medium Access Control in Molecular Networks

TDMA



- ⊕ No interference
- ⊖ Synchronization

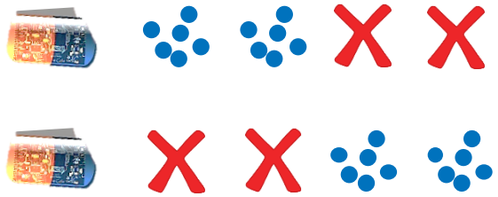
MDMA



- ⊕ No interference
- ⊖ Not scalable: max 2 to 3 molecules

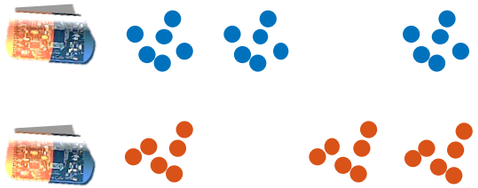
Medium Access Control in Molecular Networks

TDMA



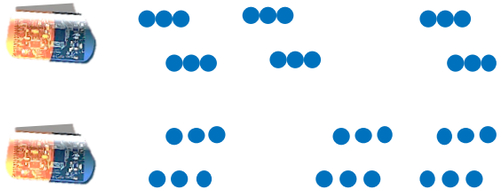
- ⊕ No interference
- ⊖ Synchronization

MDMA



- ⊕ No interference
- ⊖ Not scalable: max 2 to 3 molecules

CDMA



- ⊕ No synchronization
- ⊕ Scalable
- ⊖ Non-negative signal
- ⊖ Very high ISI

How do we design an efficient medium access protocol for molecular networks?

MoMA (Molecular Multiple Access)

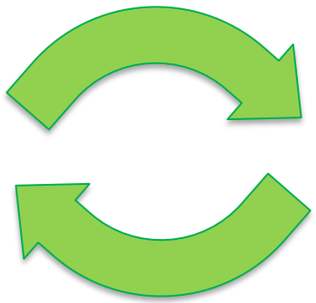
a practical and scalable protocol

to enable molecular networking

with multiple transmitters

MoMA Key Design Ideas

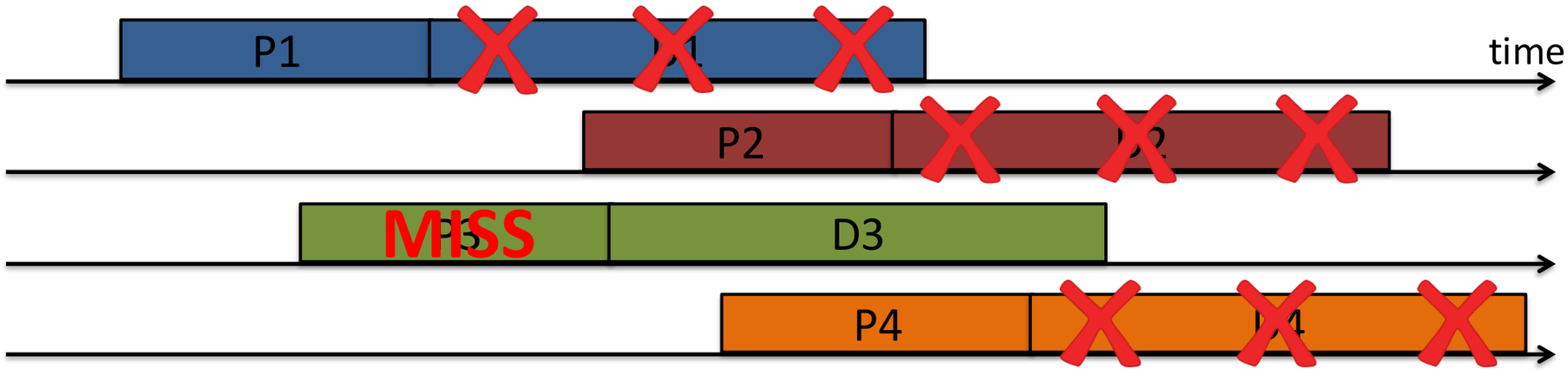
- Account for properties of molecular channel in protocol design
- Use customized CDMA codes to separate molecules from different transmitters
- Keep transmitters simple: transmit anytime they have data
- Push complexity to receiver:
  - Packet Detection (***prioritized***)
  - Channel Estimation



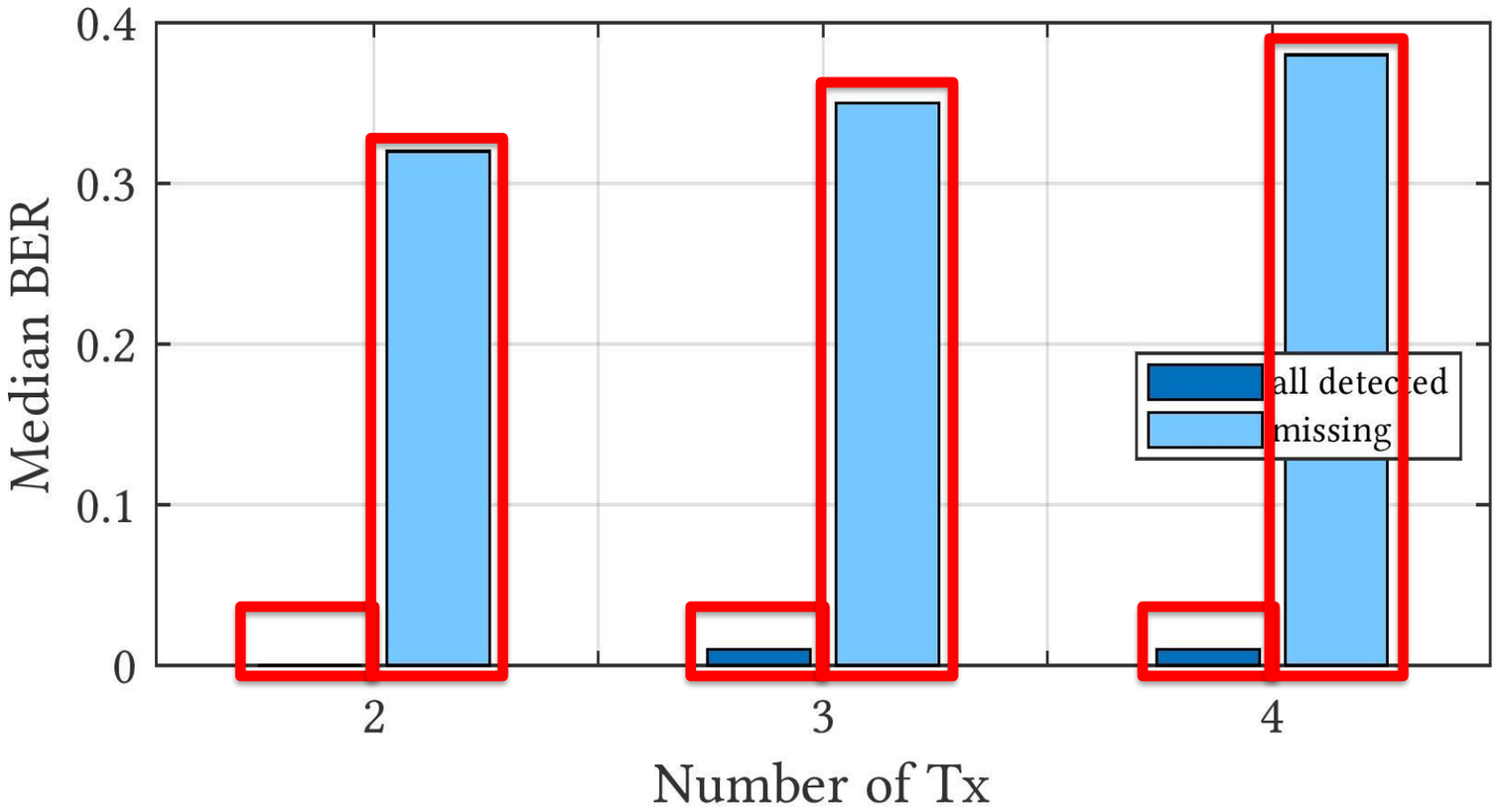
  - Decoding
- Use 2 molecules per transmitter to improve decoding performance.

Prioritize packet detection

- Why should we do so?



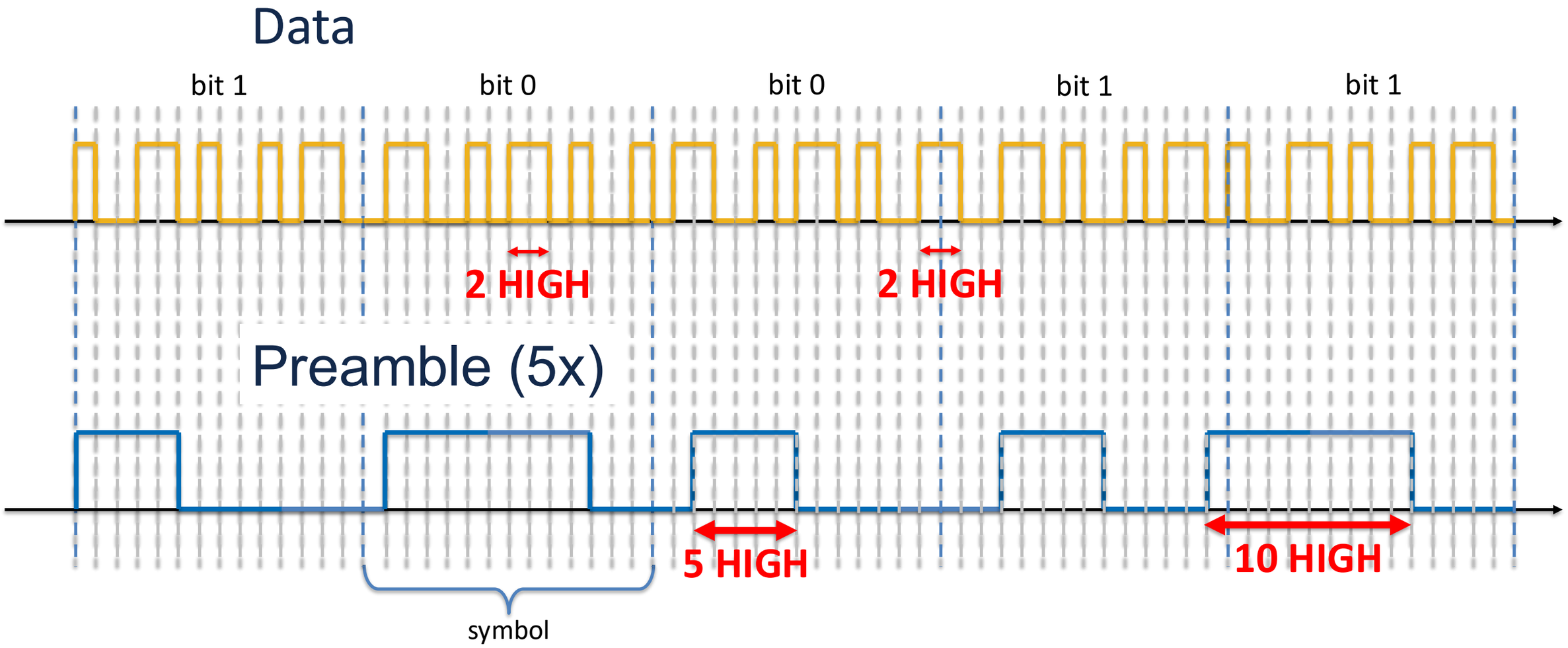
Prioritize packet detection



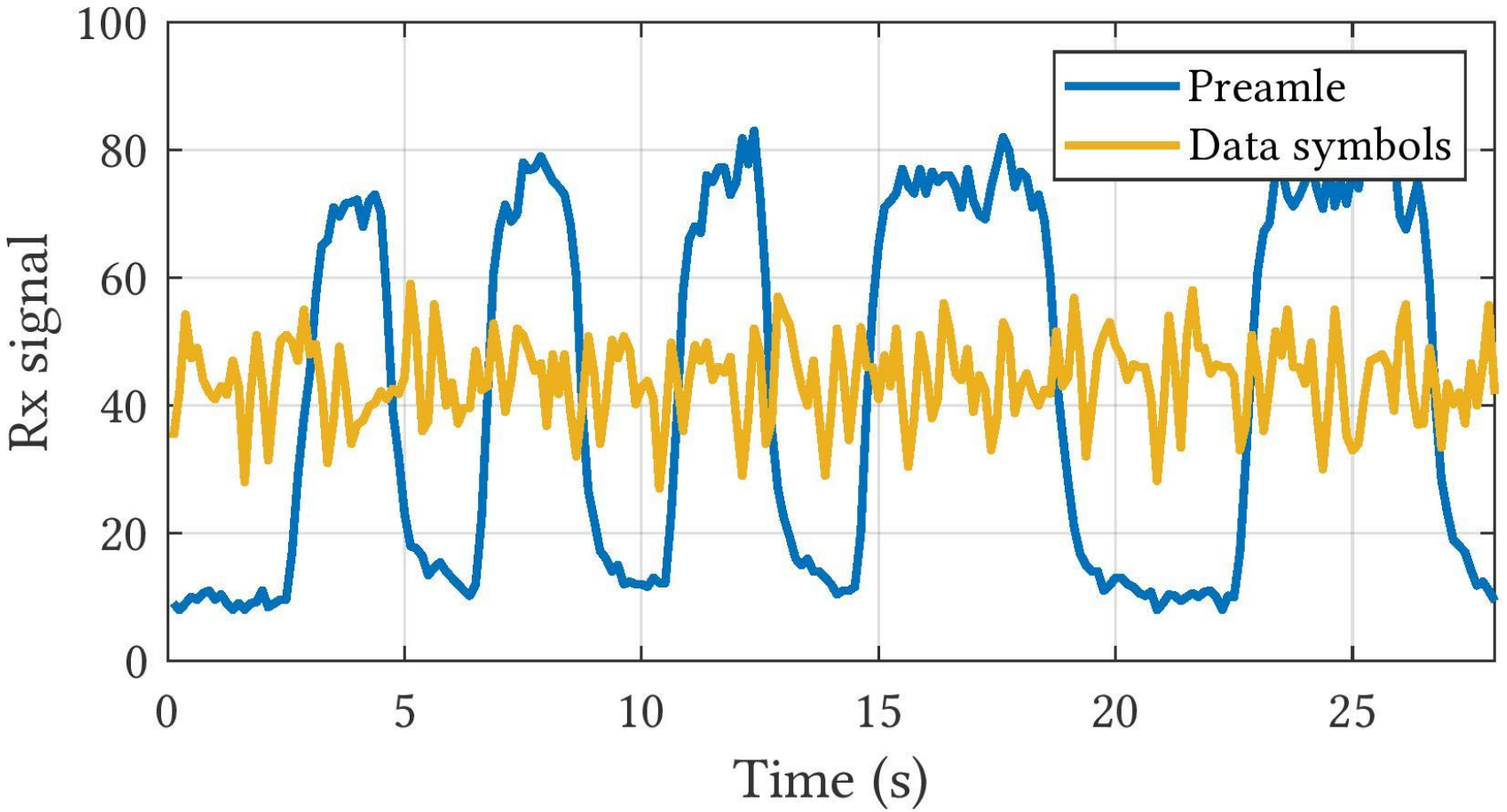
Prioritize packet detection

- Existing MC CDMA

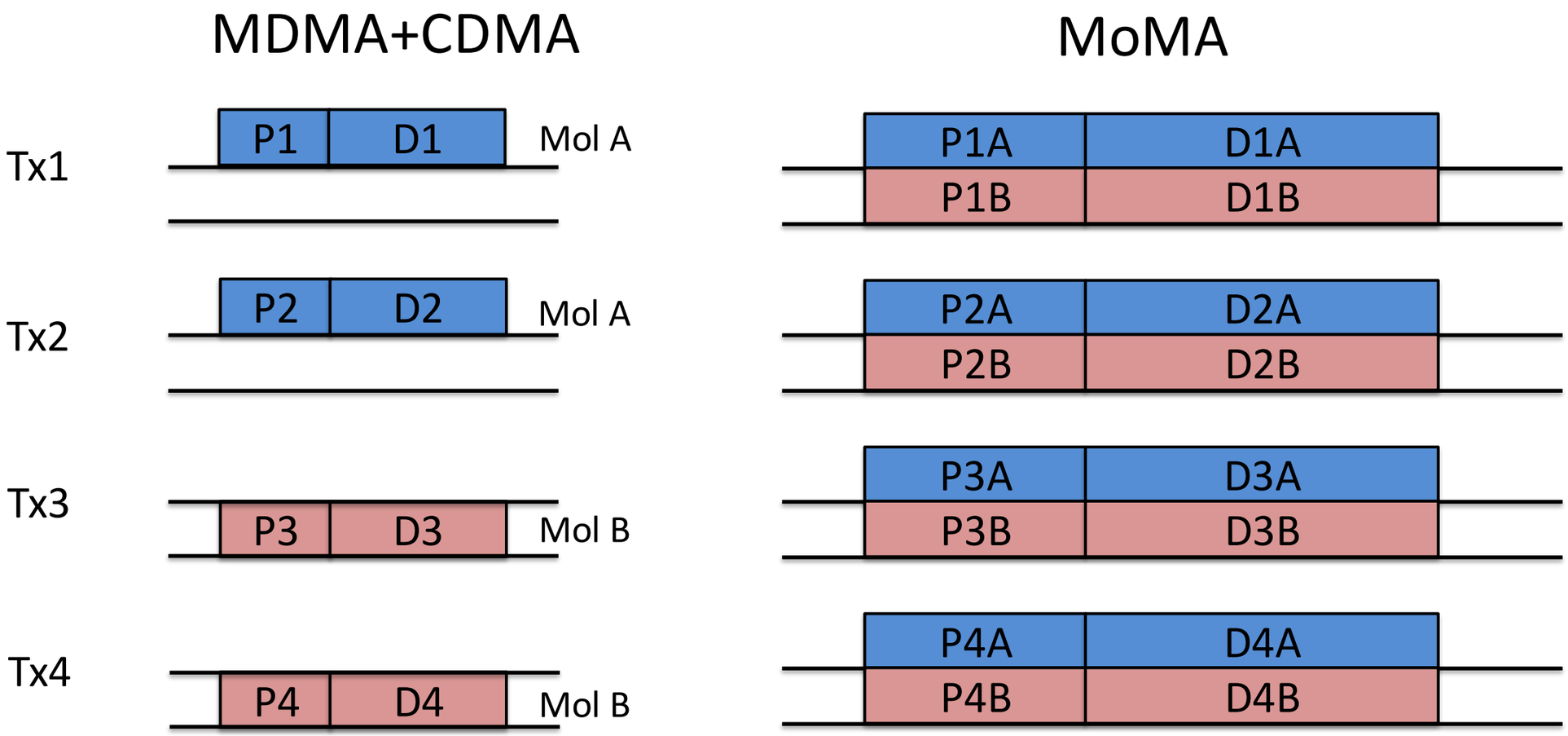
Prioritize packet detection



Prioritize packet detection



How to make the best use of 2 molecules?



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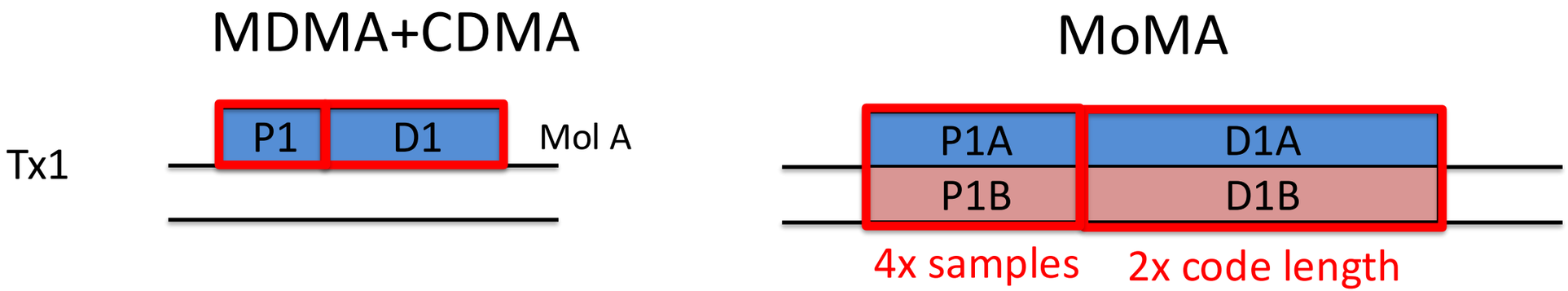
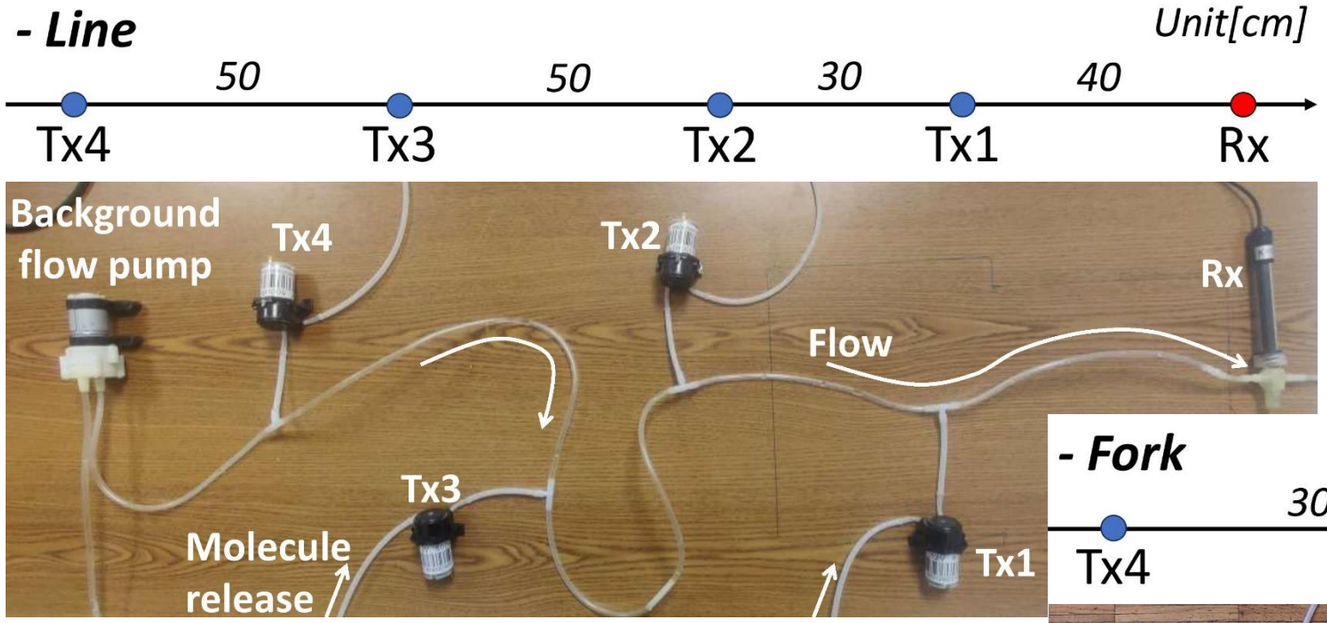
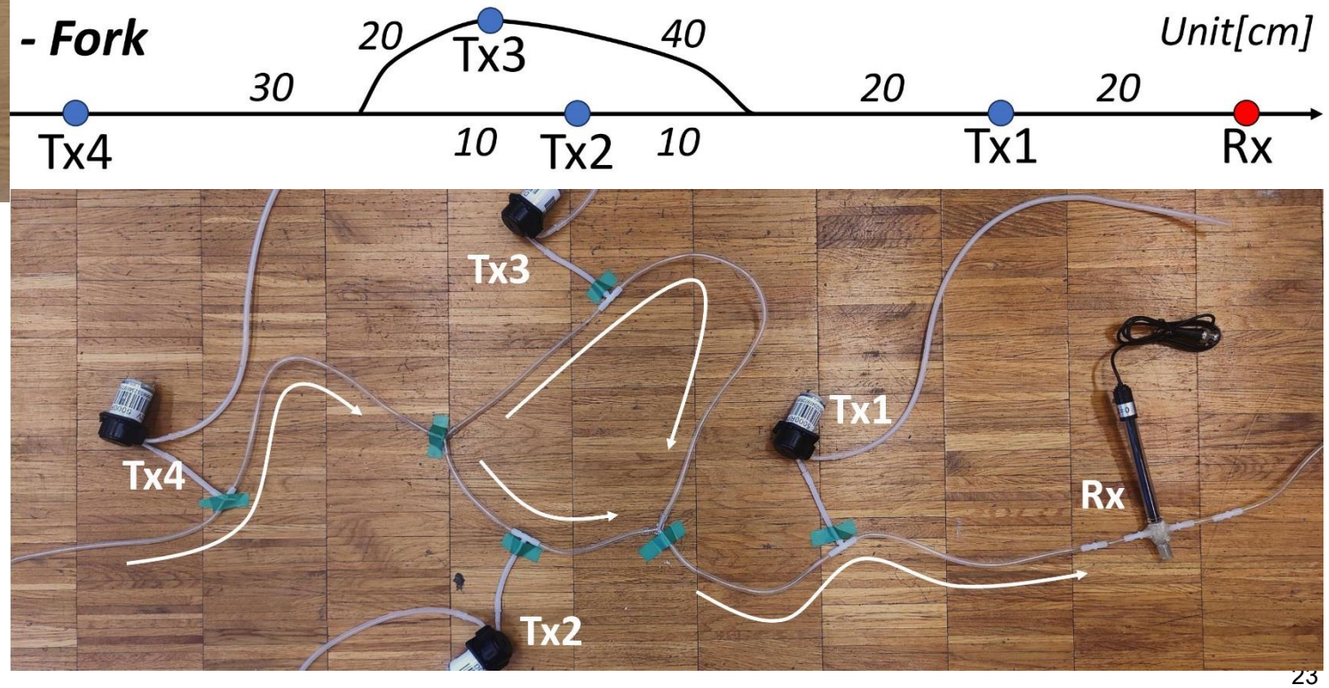


- Same datarate and scalability
  - Independent data streams
  - Longer code
- Better packet detection and channel estimation
  - More preamble samples

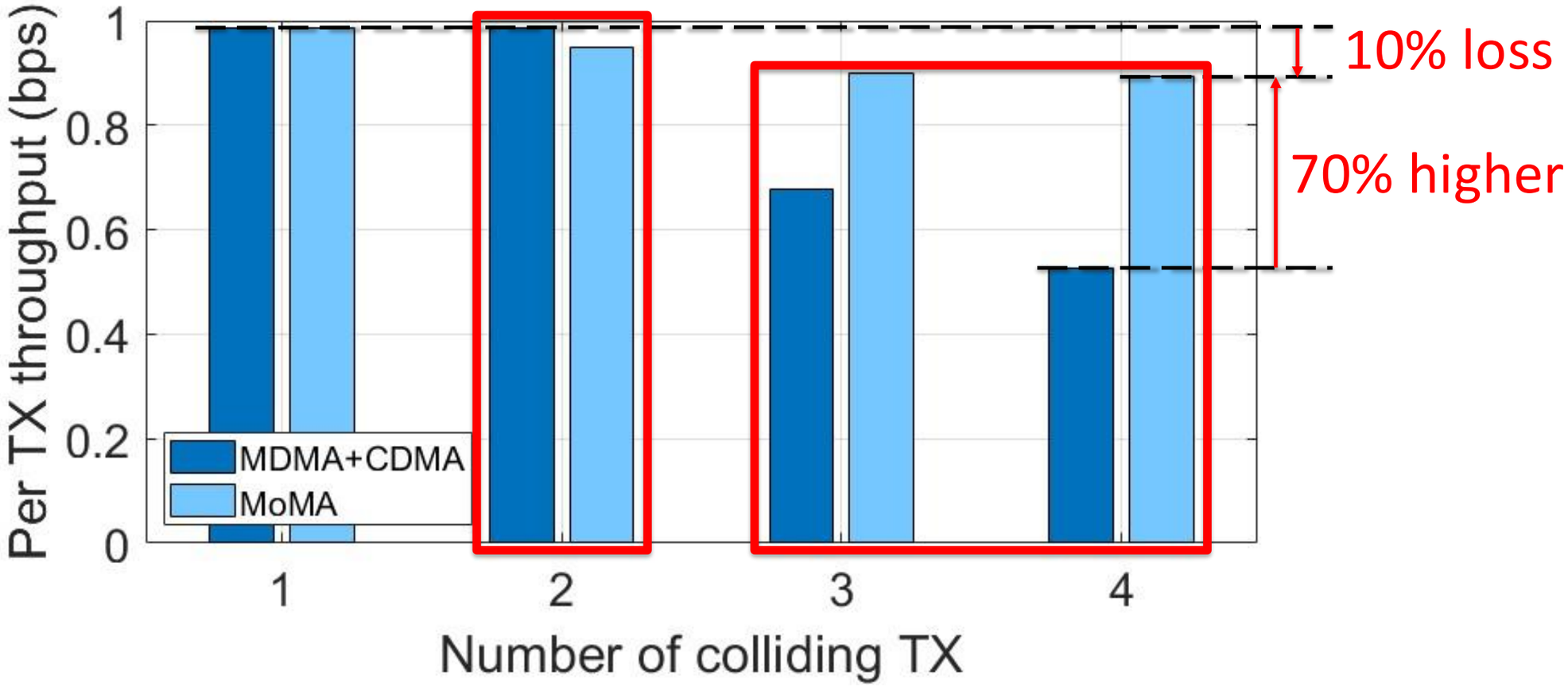
Testbed



- Table salt ($NaCl$)
- Baking soda ($NaHCO_3$)



Result: Overall Throughput



Conclusion

- Molecular Networks are essential for communicating with micro and nano-implants.
- MoMA is a molecular multiple access protocol that can scale to multiple molecules while keeping molecular transmitters as simple as possible.
  - MoMA is only uplink and assume powerful receiver.
  - We need to rethink and redesign our networking protocols while working closely with biologists and bio roboticists.

https://github.com/JMWinding/MoMA