A potpourri of results on molecular communication with active transport

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Molecular Communication

- Molecular communication (MC) is a model of information transmission where the signal is transmitted by information-carrying molecules through their physical transport from a transmitter to a receiver through a communication channel.
- We investigate how active transport influences the efficacy of molecular communication, quantified by the mutual information between transmitted and received signals. We consider two specific scenarios: (a) active transport through relays and (b) active transport through a mixture of active and diffusing particles. In each case, we discuss the efficacy of the communication channel and discuss their potential pitfalls.

Model and Methods

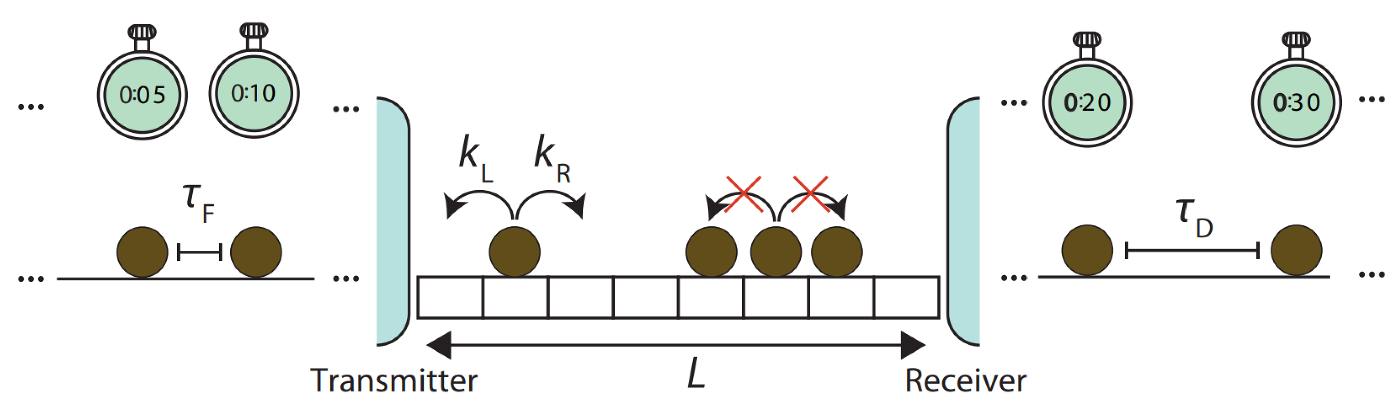

Figure 1. Schematic diagram of the model.

$$I(\tau_F, \tau_D) = \sum_{\tau_F} \sum_{\tau_D} P(\tau_F; \tau_D) \ln \frac{P(\tau_F; \tau_D)}{P(\tau_F)P(\tau_D)} \quad (1)$$

$$= \sum_{\tau_F} \sum_{\tau_D} P(\tau_F)P(\tau_D|\tau_F) \ln \frac{P(\tau_D|\tau_F)}{P(\tau_D)} \quad (2)$$

$$I = \frac{I(\tau_F; \tau_D)}{H(\tau_F)} \quad ; \quad H(\tau_F) = -\sum_{\tau_F} P(\tau_F) \ln P(\tau_F) \quad (3)$$

Results: Channels with One Relay

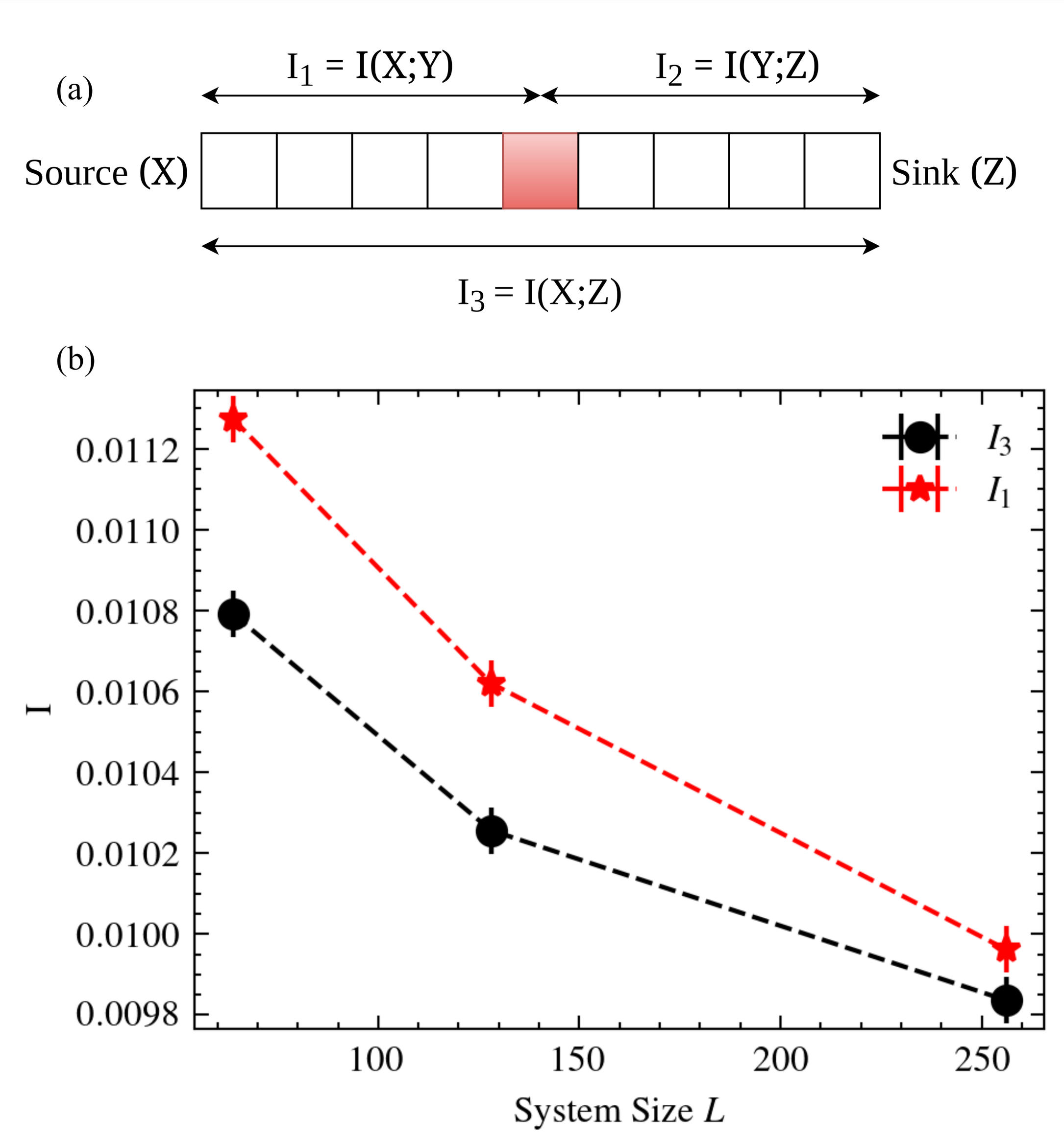

Figure 2. (a) Schematic of the one relay lattice. The red site is the relay. (b) I_1 and I_3 vs. system size for channels with *one* relay. The relay is kept at the midpoint of the 1D channel.

For a Markov chain $X \to Y \to Z$, the *data processing inequality* holds, which states that: $I(X;Y) \geq I(X;Z)$. Here, $I(X;Y)$ is the mutual information between the random variables X and Y, and $I(X;Z)$ is the mutual information between X and Z. Channels with one relay follow the *data processing inequality*.

Results: Channels with Many Relays

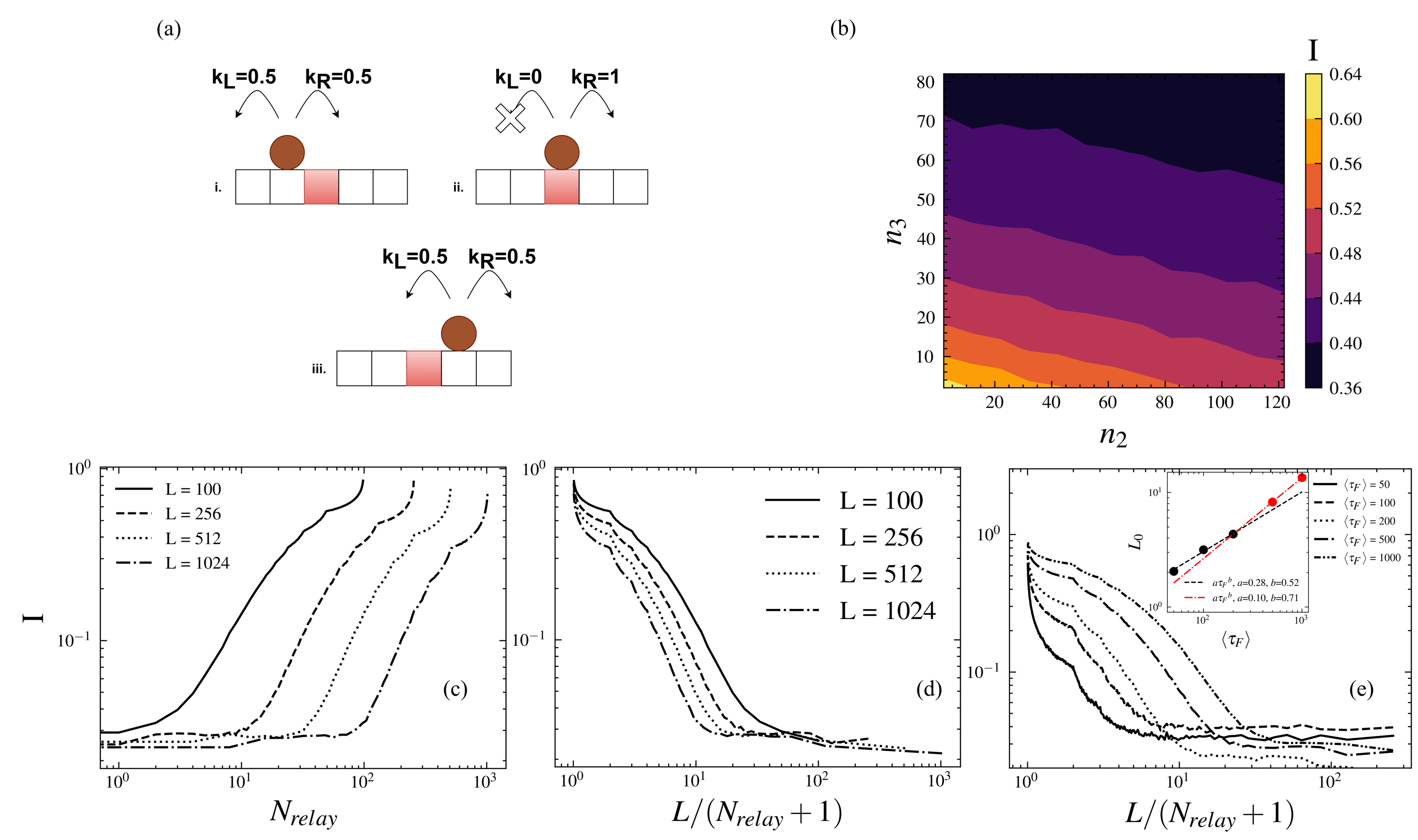

Figure 3. How MI changes with the number of relays in the channel.

Information loss in small diffusive channels follows a stretched exponential law:

$$I(n_l) = e^{-\left(\frac{n_l}{\alpha}\right)^{\mu}} \quad (4)$$

where,

n_l = number of diffusive channels of length l

μ = stretching exponent

$\alpha = (\ln(1/I(1)))^{-\frac{1}{\mu}}$

Results: Channels with Active Particles

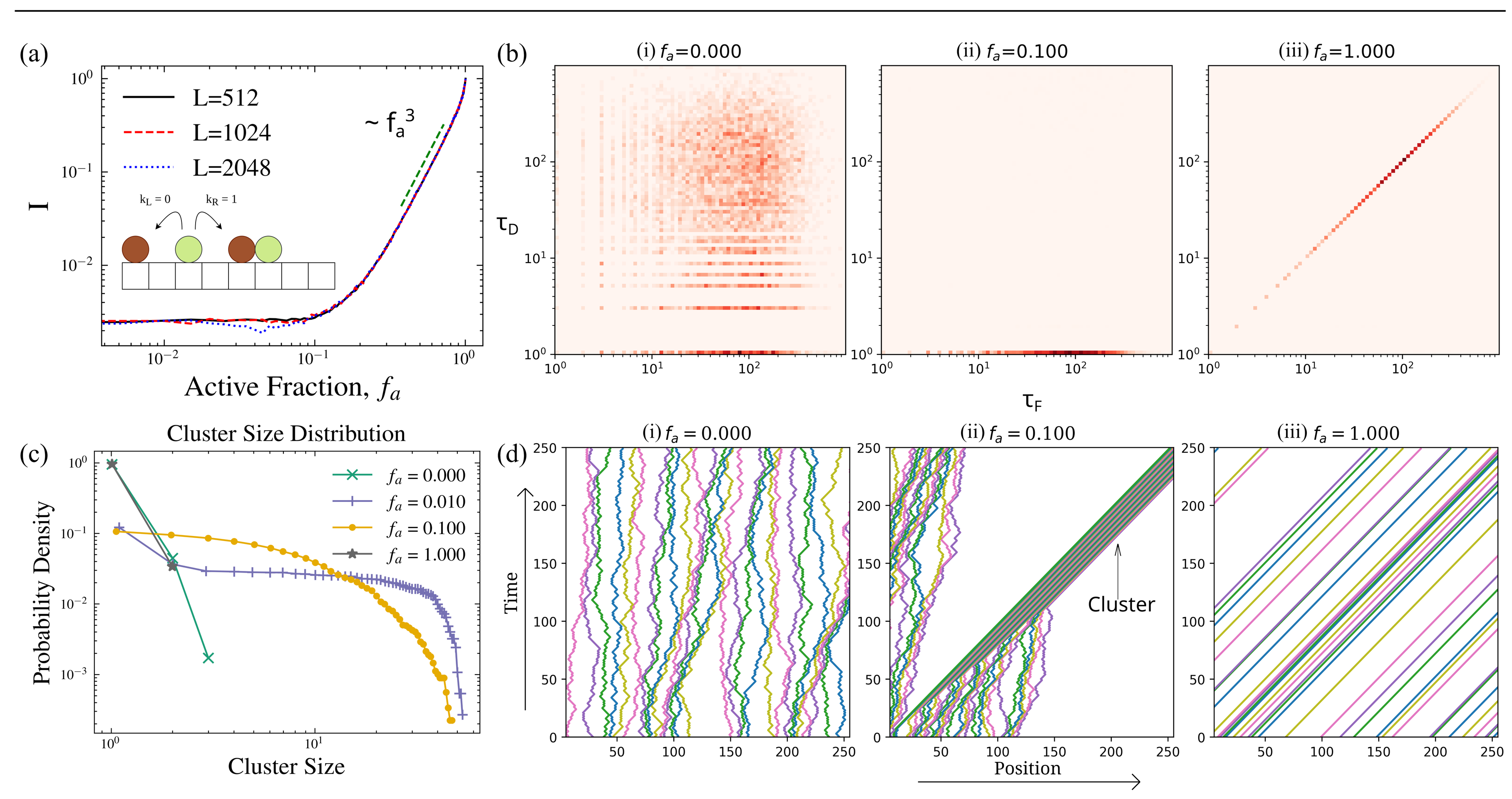

Figure 4. How MI changes with active particles in the channel.

The variation of MI above a threshold is well-defined and follows a power law:

$$I(f_a) = \begin{cases} {f_a}^0 & f_a \leq 0.1 \\ {f_a}^3 & f_a > 0.1 \end{cases} \quad (5)$$

References

[1] P. Dewan and S. Sarkar, "A potpourri of results on molecular communication with active transport," *arXiv preprint arXiv:2410.19411*, 2024.

[2] S. Sarkar, M. Z. Ali, and S. Choubey, "Efficacy of information transmission in cellular communication," *Physical Review Research*, vol. 5, no. 1, p. 013 092, 2023.