Molecular Communication Across Time

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Resilient Communication Systems

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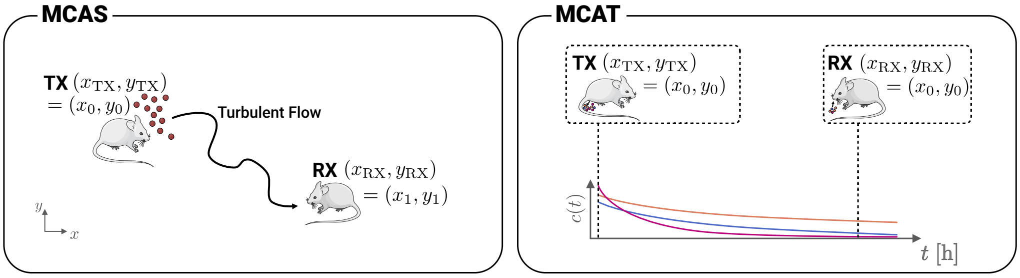
Project Overview

Molecular communications (MC) is an emerging research paradigm where information is encoded into the properties of molecules (e.g., their concentration or type) instead of electro-magnetic waves [1]. In recent years, MC research made tremendous progress in both theory and experiments, improving our understanding about how to encode information into the properties of molecules, how these molecules propagate through fluids and gases, and how a receiver (RX) can recover the transmitted information. In line with *conventional* electro-magnetic (EM)-based communications, MC research focused on **molecular communication across space (MCAS)**, i.e., how to transmit information from point A to point B (see Figure 1, left). Beyond the mere transmission of bit strings, also semantic and goal-oriented communication with applications like source localization or targeted drug delivery has recently gained interest in the community [2].



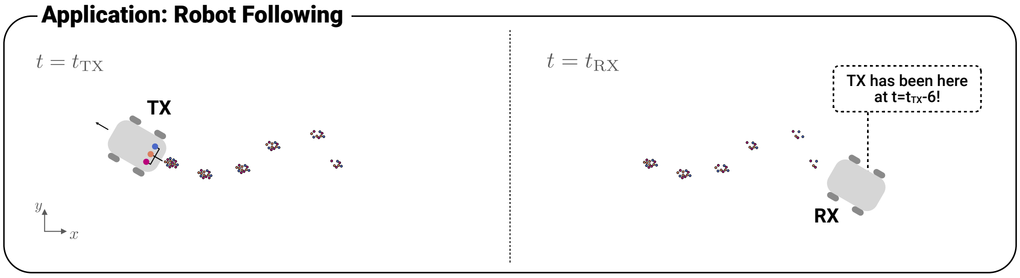
Comparison of molecular communication across space (MCAS) and molecular communication across time (MCAT). In MCAS, the focus is on volatiles that are transmitted through the space and sensed by a RX at another position. In MCAT on the other hand, the transmitter (TX) deposits a molecule marker at a certain position. Later, the RX comes to the same position and senses the molecules markers there.

However, this communication across space aims for *instantaneous* information transmission, i.e., information should be transmitted as fast as possible or a source should be localized as fast as possible. However, this instantaneous MCAS represents only a small part of MC in nature [3]. There, the comparably slow transmission of information across space is no disadvantage, but is intentionally exploited. In fact, a lot of natural MC intends to transmit information across time and not necessarily across space. For example, male mice mark their territory with small urine smears (see Figure 1, right). Female mice then use these urine smears as one way to identify appropriate mates: They determine the relative age of urine smears that are placed upon or next to each other and prefer the male whose urine smear is younger, i.e., they prefer the male who could assert its territory against competing mice [4].

Another example where communication does not necessarily aim for *instantaneous* information transmission is *predator avoidance*: Here, prey (e.g., rats or mice) avoids areas that have been repeatedly marked by predators (e.g., cats) [5]. Here, the prey (i) *eavesdrops* on the intra-species communication of the predator and (ii) exploits that this communication is persistent for some time. This allows the prey to identify areas where predators have not been active historically , which is less risky than relying on the detection of volatile body odors of predators that are in the same area at the moment.

Such **molecular communication across time (MCAT)** is an almost completely untouched dimension of MC where EM-based communication represents no competition, making it extremely attractive to MC researchers.

So far, MCAT has received only little attention in the MC research community. The closest works to MCAT are *molecular barcodes* and robot-following applications. Molecular barcodes, as introduced in [6], are alcohol drops that are released into the environment. Later, a robot can drive over the line on which the drops have been positioned to obtain a binary concentration shift keying (BCSK)-like signal. In robot-following applications, a robot might aim to follow a chemical trail, that could have been released by another robot before [7]. However, until now, no systematic exploration of MCAT has been proposed.



Robot Following as Application of MCAT. Here, a TX robot places molecular markers along its path that degrade over time. Later, a RX robot can not only follow the path of the TX robot but even estimate when the TX has been at which point on the path.

Thus, we take a first towards a systematic exploration of synthetic MCAT by investigating how to estimate when a molecular marker has been released into the environment. Since it has been shown that the volatiles released by urine stains change over time until the stains are not recognized anymore after several days [8, 9], we also employ molecule mixtures. As different molecule types have different evaporation and degradation constants, the ratios of the mixture constituents are expected to facilitate the release time estimation without requiring knowledge about the initial volume of the molecule marker. Furthermore, employing molecule types with vastly different evaporation and degradation constants might permit a multi-scale temporal resolution.

Successful estimation of the release time could have many potential applications, including robot following (see Figure 2), extending existing trail-following approaches such as [7, 10] to not only estimate the TX robot path but also of the temporal history of the path, i.e., to estimate when the TX robot (Figure 2, left) has been where on its path.

Guidelines for the research project:

1. Setup of a MCAT system model including molecule (mixture) evaporation, propagation through the air, and detection.
2. Derivation of an estimator for the release time of drops based on measurements.
3. Identification of a suitable *molecular alphabet* for MCAT, i.e., identification of a combination of substances with evaporation times that permit a good estimate of the release time over a considered time frame.
4. *Optional:* Experimental validation of the developed system model and estimator for our mixture alphabet.

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