Impact of Mobility on Air-Based Macroscopic Molecular Communication – A Simulation Study

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ABSTRACT

Molecular communication (MC) is considered to become a very relevant communication technology for many industrial and health care applications. Here, we study the impact of mobility on the channel impulse response. Building upon previous work on simulation and experimental insights on air-based MC, we investigate a mobility scenario in which the sender moves with respect to the receiver of the signal. Our findings show the impact of the mobility on the amplitude as well as the width of the received signal. We consider our results as a first step towards general mobility-impact mitigating waveform and protocol designs for MC.

CCS CONCEPTS

• **Networks** → **Network simulations**; • **Computing methodologies** → *Model development and analysis.*

KEYWORDS

Molecular communication, mobility, air-based, particle simulation

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1 INTRODUCTION

Molecular communication (MC) and particularly macroscopic MC is considered as one of the pillars for many next generation communication concepts, particularly in industrial and health care applications [3]. So far, the mobility of MC transmitter (Tx) and receiver (Rx) was analyzed theoretically to consider the impact of varying distance and relative velocities on the communication performance [2, 4, 6, 7]. The linear time-variant channel impulse response (CIR) was derived for a free-diffusion medium [6], free diffusion with drift [4], and turbulent channels [7]. Movement patterns of Tx and Rx were typically based on the random walk model [4, 6], but also a more realistic scenario was considered when accounting for flagellated bacteria as in [2].

Due to the diffusion process in the molecular channels, interference is one of the most noticeable undesirable effects [5]. Past emissions affect the current ones due to the spreading effects and the mechanical interactions between the emitted molecules and the medium. The produced inter-symbol interference (ISI) was estimated through the CIR tail component, which becomes a challenging problem considering the dynamics of the mobile molecular channel. The higher the tail component of the CIR, the higher the produced interference in the upcoming symbols, which in turn limits the rate of transmissions due to the produced errors.

A variety of mechanisms were considered to reduce the impact of ISI to increase the allowable transmission rate. Modulation schemes are conceived to mitigate ISI by dynamically adjusting the number of released molecules (concentration shift keying (CSK)), the type of molecules (molecular shift keying (MoSK)), the threshold detection level, or by equalization techniques [5]. In the mobile scenario, the study reported in [2] used adaptive mitigation methods based on the estimated distance between the communicating nodes.

However, these techniques are still generic ones, without accounting for the specifics of the mobility patterns. In this work, we elaborate on the impact of mobility on air-based macroscopic MC. We are primarily interested in the changing CIR due to the Doppler effect. We build upon our previous work in [1], in which we studied air-based MC both in simulation as well as in an experimental lab setup – in a stationary scenario. We now make the Tx move with respect to the Rx to explore the impact on the communication quality. We report first results of this study, which help with better understanding the impact of MC in mobile scenarios and to start developing mitigation strategies.

2 SCENARIO

We consider the following mobility scenario, based on a previously presented and simulated fluorescent spray-based physical testbed [1] and illustrated in Figure 1. In the testbed, a sprayer acting as Tx emits particles into a 2 m long tube. At different distances inside this tube, a camera and ultra-violet light can be positioned to detect the fluorescent particles. In our simulation, initially, Rx and emitter are placed 2.15 m apart. During emission, the sprayer then moves at a constant velocity towards Rx (positive velocity) or

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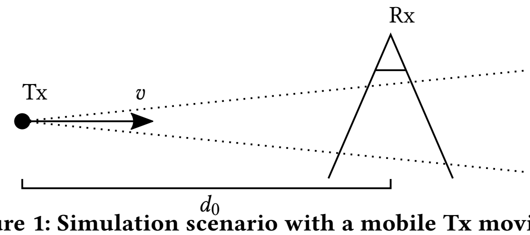

Figure 1: Simulation scenario with a mobile Tx moving towards a stationary camera-based Rx with velocity v. The initial Tx-Rx distance is d_0 = 2.15 m.

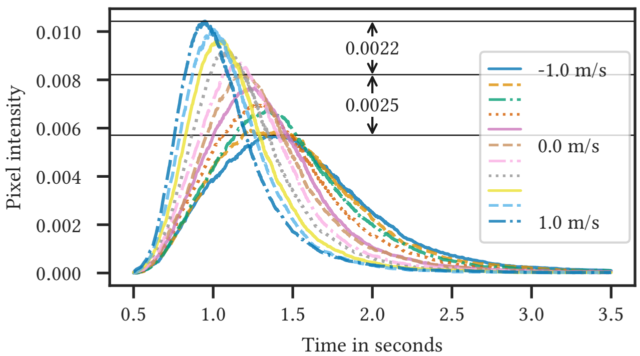

Figure 2: CIR for different Tx velocities.

away from it (negative velocity). We choose velocities in the range from −1 m/s to 1 m/s in 0.2 m/s intervals. Tx sprays 10 particles per time step at a rate of 480 Hz (matching the camera frame rate) for a duration of 0.52 s. This leads to a maximum travel distance of 0.52 m at the highest velocities. The particles themselves are ejected from the simulated sprayer with normally distributed velocities with μ = 1.267 m/s and σ = 0.3 m/s [1].

3 RESULTS

The effect of different relative velocities becomes visible when studying the respective CIR in Figure 2. Compared to the stationary configuration, the peak height shrinks by 30.5 % at −1 m/s and grows by 26.9 % at 1 m/s. At the same time, it appears as though the CIR narrows the faster Tx approaches Rx and widens in positive correlation with the speed at which their distance increases. The full width at half maximum (FWHM) values plotted in Figure 3 for 10 simulation runs per observed velocity confirm this appearance. At −1 m/s, the average FWHM is 0.99 s. When Tx is stationary, the FWHM is 0.71 s, and when it is moving at 1 m/s towards Rx, the FWHM is 0.48 s. The largest 95 % confidence interval is 0.031 s wide for the −1 m/s case. Larger confidence intervals are expected for high negative velocities as the maximum Tx-Rx distance grows and fewer particles are detected. These observations are in line with the Doppler effect commonly encountered in acoustics or electromagnetic radiation; like acoustic waves stretching when a source moves away from a listener, the original positions at which each fluorescent spray particle is emitted grow farther apart the faster Tx moves away. The inverse holds true when Tx moves towards Rx.

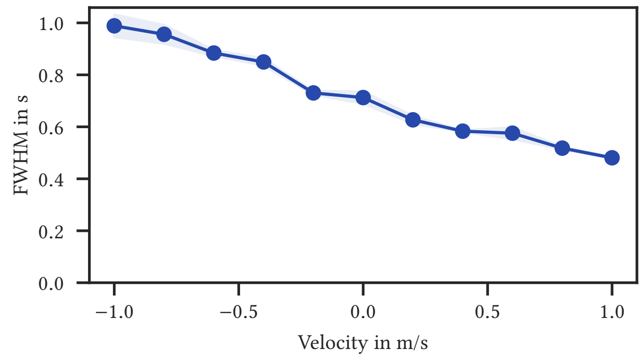

Figure 3: FWHM for different Tx velocities. The shaded area shows the 95 % confidence intervals.

4 CONCLUSION

We studied the impact of mobility on macroscopic MC. In particular, we realized a simulation scenario for mobility in macroscopic spray-based MC and characterised the effect of different relative velocities between Tx and Rx on the CIR. We found that our results match expectations based on the Doppler effect. In future work, our approach can be extended to derive the coherence time of the channel, and to investigate the robustness of different modulation techniques in mobile scenarios. Such information can be valuable to tune modulation parameters based on the current context, especially if Tx and Rx have some localization capability, or to pick an optimal modulation scheme. Furthermore, different mobility patterns like jittering motion, random paths, or fluctuating angles of the sprayer towards the Rx can be implemented.

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