Institute for Digital Communications

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Bachelor/Master Thesis or Research Project

MC-Signals for the Neutralization of Insect Populations in Confined Environments (MC-SNIPE)

for

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While conventional communication systems rely on electromagnetic waves, in Molecular Communication (MC), information is encoded into the properties of small particles. This allows communication between nodes with sizes on the order of nano- and micrometers, and in fluidic and biological environments, where classical communication concepts are not applicable. Thus, engineered MC systems are expected to enable communication between nanomachines and facilitate interaction with biological systems. This will pave the way for several medical, agricultural, and industrial applications including targeted drug delivery, environmental monitoring, nanoscale quality control, and communication in oil and gas pipelines [1,2].

Beyond mere environmental monitoring, MC offers innovative solutions for agricultural pest management. Molecular sensors in fields can detect insect-specific signaling molecules, enabling early detection of pests and the implementation of more effective management strategies [3]. This technology also provides entomologists with tools to study insects. For example, molecular signals emitted by the insects can be used to track their movement and migration patterns, offering valuable insights into their behavior and ecological roles [4]. As part of an active control component, signaling molecules can be deployed to specifically disrupt the mating or foraging behaviors of pests. Thereby, farmers can reduce reliance on broad-spectrum pesticides and minimize environmental impact. Furthermore, synthetic molecular signals can be used in devices to lure and trap agricultural pests or disease-carrying insects in targeted areas, enhancing control measures.

Figure 1: Left: Synthetic MC system involving living insects. Transmitter: Evaporation of toxic signaling molecules (fumigants); Channel: Sealed chamber; Receiver: Swarm of insects. Right: Schematic illustration of the signaling molecule uptake by the insects. Signaling molecules are either accumulated, leading to death of the insect, or meabolized to biomass.

A further application of MC is the management and control of insect colonies in controlled environments. In this context, it is important to understand how insects react to the exposure to specific signaling molecules. The left hand side of Fig. 1 shows a simple MC system for the analysis of the behavior of an insect population in the presence of toxic signaling molecules. The transmitter is evaporating toxic signaling molecules into the channel, a sealed chamber. In the channel, a population of insects act as receivers. The right hand side of Fig. 1 shows the interaction of an individual insect with the toxic signaling molecules. Upon the uptake of the signaling molecules, they are either accumulating and poisoning the insect, or metabolized into biomass.

The goal of this project is to investigate the MC system shown in Fig. 1. In particular, the release, propagation, and reception of signaling molecules by the insect shall be described mathematically and suitable communication-theoretical models shall be derived. Then, the models shall be compared to the results from experiments and applied to investigate different scenarios of practical relevance.

The main objectives can be summarized as follows:

- Development of a suitable model for the evaporation of signaling molecules in confined environments. Based on the considered system, suitable simplifications (e.g., well-mixed, reduction of spatial dimensions) shall be investigated.
- Development of a simulation model for the signaling molecule reception process of insects as shown on the right hand side of Fig. 1. The starting point for the model is an existing kinetic model for the uptake and processing of signaling molecules by insects.
- Development of an end-to-end model for the MC system, including models for evaporation, propagation, and uptake of signaling molecules.
- Extensive analysis of the model parameters and their influence on the overall system.
- *Optional:* Comparison of the developed models to experimental results and refinement of the models.

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Start date: –
End date: –

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