Title of the thesis

Capacity Analysis and Interference Mitigation Techniques for Diffusion-Based Molecular Communication Systems

Abstract

Nanotechnology is a revolutionary paradigm for the future of medical applications. The theory of miniaturization has played a pivotal role in the emergence of nanotechnology and biotechnology. The development of micro and nano scale devices is facilitated by the tools provided by nanotechnology. Nanomachines are the basic functional devices with nanoscale size and little complexity. Therefore, they can accomplish only simple tasks like communicating, computing, sensing, data storage, and actuation. Due to their limited functionality and scarce energy resource, nanomachines need to work cooperatively to achieve a wide range of applications including healthcare, industrial, environmental, etc. Nano-communication enables communication between a group of nanomachines to achieve a specific task. Such nanoscale communication can be implemented using electromagnetic (EM), nanomechanical, acoustic, and molecular communication (MC) techniques. Owing to the non-invasiveness and biocompatibility, MC stands out as the most suitable communication paradigm for nanomachine networks, i.e., nanonetworks.

MC is a gifted technique inspired by nature-based communication where information is passed using molecules from sender to receiver. For instance, the human body is a complex network of communicating nanomachines performing a specific function. Motivated by nature, artificial nanonetworks can be formed using synthetic biology for spurring a wider range of biomedical and industrial applications. MC has gained enormous attention from researchers in the past decade still, the research is in its infancy. The key challenges include, inter alia, efficient information transmission through encoding and decoding strategies, lack of end-to-end realistic MC model, propagation of information molecules in a controlled manner, and the highly stochastic nature of MC channel. Therefore, in this dissertation, we evaluate realistic end-to-end MC system using capacity and bit error rate (BER) analysis alongwith providing performance analysis of MC system models utilizing different modulation schemes.

We first present the end-to-end biochemical MC model with the finite number of receptors on the receiver's boundary. The capacity and performance analysis for the aforementioned system model is carried out using the Markov chain. The probability of binding and unbinding of molecules on the receiver's surface depends on the concentration of molecules in the vicinity of the receiver (Rx). Therefore, the Rx is modeled using a two-state Markov chain, where one state is bind and the other state is unbind.

We next move to the study of multiple-input multiple-output (MIMO) modulation techniques in MC system. In order to achieve a high data rate, MIMO systems prove to be beneficial for MC systems. Unlike single-input single-output (SISO) systems, MIMO systems suffer greatly from inter-link interference (ILI) alongwith inter-symbol interference (ISI). The spatial modulation (SM) schemes have shown enormous benefits in terms of their simplicity, high

spectral efficiency, and low energy consumption in MIMO-MC systems. One benchmark SM scheme in MC literature is molecular space shift keying (MSSK) where information is transmitted using antenna indices of the transmitter (Tx) nanomachine. We extend this study to propose a coded index modulation (IM) strategy named molecular spatio-temporal coded modulation (MSTCM) where information is judiciously transferred using antenna index selection. The antenna index in the present interval is judiciously activated in accordance with the antenna activated in the previous symbol indterval. The proposed scheme is shown to mitigate ISI and ILI problems better than the benchmark MSSK modulation scheme. Moreover, the analytical BER expression is derived which very well corroborates with the simulated one.

We then embed the pulse position modulation (PPM) strategy in the MSTCM modulation scheme to form a position molecular spatio-temporal coded modulation (PMSTCM) scheme. It is proved by simulations and analytical results that PMSTCM better alleviates the problem of ISI and ILI in molecular MIMO systems. Until now, the proposed molecular schemes transmit information using a single antenna index in one symbol interval. For enhancing the system throughput, a fixed number of antennas on the Tx side can be activated for transferring information. This calls for generalized space shift keying modulation schemes for molecular MIMO systems. Motivated by conventional radio-based communication, we illustrated the generalized molecular space shift keying (GMSSK) scheme for two activated antennas on the Tx side and compared it with the benchmark MSSK and other modulation strategies considering the same symbol interval. The study depicts that GMSSK outperforms existing molecular MIMO modulation schemes for a majority of bit durations.