Simulation Framework for Communication Protocols of Molecular Communication Systems

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ABSTRACT

In this paper, we describe a protocol stack to enable communication between biological nano scale (*bio-nano*) devices. We identify key design considerations and protocol components and suggest suitable molecular computing mechanisms to create these components. Finally, we introduce a modeling and simulation framework for bio-nano communication networks.

Keywords

Molecular Communication, Molecular Computing, Communication Protocols.

1. INTRODUCTION

Molecular Communication seeks to develop communication mechanisms that use encoded biomolecules as information carriers. Recent experimental results in this area have demonstrated experimentally the creation of a Molecular Communication System [1] and the use of molecular signals for communication between distant bio-nano devices. These advances demonstrate the potential to create biological based communication networks of devices. However, controlled communication on the nano scale is a key challenge in realizing practical applications of bio-nano devices. Just as conventional data networks require communication protocols to function, bio-nano will require the development of similar protocols, implemented using biological based computing techniques. Furthermore, bio-nano devices will require access to the computational capability to implement and control molecular communication mechanisms. We anticipate the bionano devices will be synthetically engineered cells that are functionalized with the required sensors and computing mechanisms to support communication. Alternatively, the bionano device may interface with engineered biological cells, offloading the necessary logic computation required by the communication protocol.

2. Defining Protocols for Molecular Communication

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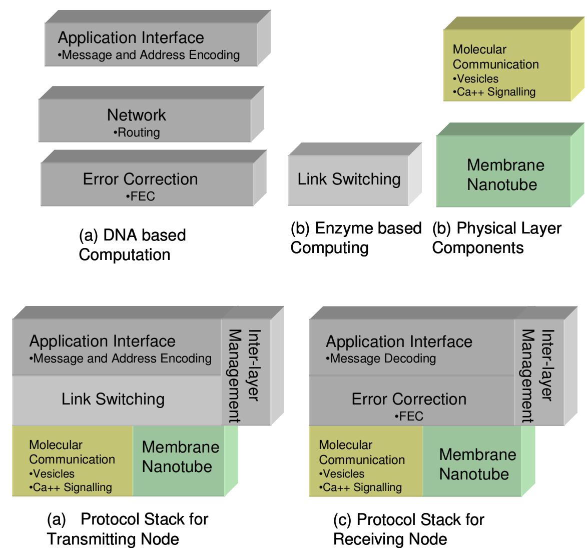

Figure 1. Components of Molecular Communication Protocol Stack.

Inspired by existing communication protocols, we propose a communication protocol stack to enable communication between bio-nano devices. In adopting this approach, the intrinsic characteristics of Molecular Communication relative to standard data communication networks must be considered. For example, Molecular Communication transport is slow, more often via low speed diffusion. Also, bio-nano devices are deployed in harsh biological environments where properties such as pH, temperature and chemical noise are highly variable. These characteristics indicate that high speed transmission and switching found in existing data networks are not achievable. Similarly, connection orientated protocols such as TCP are not suitable due to their associated overhead. Communication is also affected by the potential applications of bio-nano devices which also influences the protocol design where some devices will perform simple sensory functions while others may route data or actuate received commands. Thus we envision two types of data; sensory data (low priority) and command data (high priority). Based on these considerations, we propose a communication protocol stack where components composing the stack depend on device type. This loose association prevents unnecessary complexity for resource limited devices. Fig. 1 illustrates protocol components and suggested compositions for transmitting (sensor) and receiving (actuator) bio-nano devices. Bio-nano devices that only receive command messages do not require components associated with message encoding and transmission whereas devices that receive command data require error correction capabilities.

Each protocol component is mapped to a suitable biomolecular computing technique depending on its requirements. We consider two molecular computing techniques for this purpose; DNA computing and Enzyme computing. DNA computing is generally considered superior for faster, complex operations and can now be accurately and cheaply engineered to a high degree. Enzyme based computing takes advantage of the bi-stable nature of biochemical enzymatic reactions to create logic operations and is more suitable for simpler computations that require interactions with cytosolic and cell surface components. Fig 1 (a) illustrates the computing techniques selected for each protocol component. Communication protocols can usually be represented as a Finite State Machine which is mapped to either DNA or enzyme computing solution based on location and complexity of the operation. DNA computing techniques are adopted for application interfaces and message encoding while enzyme computing is used for link switching due to its ability to interact with cell surface components. For message encoding, an autonomous DNA encoding automaton based on [3] could be engineered to include the ability to release an encoded biopolymer such as a DNA strand. This automaton process is controlled by a set of DNA "rule" molecules that can be selectively activated by the bio-nano device.

3. Design and Simulation Framework

Bio-nano device research requires the assimilation of technologies and concepts from several research domains. To assist this complex process, we propose a simulation framework to allow researchers investigate, analyze, and design molecular communication systems. Based on our proposed protocol stack, we will develop a set of software and computational components using and combining computational models from systems biology. This approach seeks to extend existing efforts to investigate mechanisms that underpin biological system to create a library of molecular components that can be used to engineer bio-nano systems. We seek to re-use and extend existing design and simulation tools and techniques already emerging in systems biology to enable users of the framework to evaluate cell based communication platforms for molecular communication. Thus the simulation framework can be used by researchers to evaluate designs before progressing to costly and time consuming experimental stage. The high level architecture of the framework is illustrated in Fig 2. The design stage allows the user to design and configure the biological system using a molecular communication toolkit. Components available would relate to environment, bio-nano device, interface mechanisms, and connection type (e.g. gap junction/calcium signaling). The designer stage produces an independent representation of the system that can be simulated using a suitable simulation package.

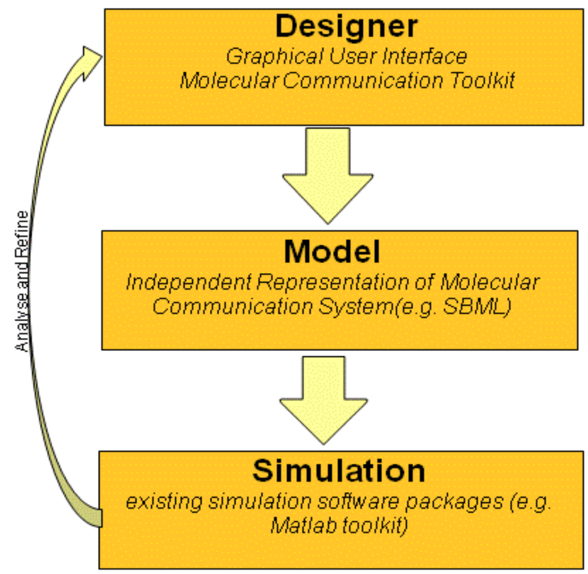

Figure 2: Molecular Communication Simulation Framework

A similar process is adopted in Systems biology research and this research will seek to extend emerging tools and standards such as E-Cell[4] and Systems Biology Markup Language(SBML)[5].

4. Conclusions and Future Work

We are currently investigating protocols for reliable molecular based communication between bio-nano devices based on the reuse of current data communication protocols. Furthermore, we have highlighted the need for modeling simulation tools to support ongoing experimental research in this area. Our future work will include the investigation and evaluation of existing tools and standards to develop a simulation framework for communication between bio-nano devices.

5. REFERENCES

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