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Autonomous anomaly detection and molecular signaling framework for synthetic nanodevices

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ABSTRACT

The usage of biological nanodevices, i.e. bacteria cell, is problematic because of the unpredictability and possible dangers Akgül and Canberk (2014). There is not any complete deterministic model of these devices and there exist many unobservable parameters in bacteria action determination. So most of the experiments with biological nanodevices are not repeatable. Additionally, the usage of bacteria cells can be dangerous as they can become dangerous after they encountered with other bacteria cells Akgül and Canberk (2014). The idea of synthetic nanodevices is proposed as a solution to the uncertainty and safety problems of biological nanodevices. However, the most basic attribute of this concept is still a mystery. The data-gathering process in synthetic nanodevices is also essential for biological nanodevices. In the existing studies, usually the user directly presents the data to the nanodevice. However, as most of the nanonetwork applications are intra-body applications, the idea of collecting data from the environment is crucial for nanodevices. To the best of our knowledge any data-gathering process from the environment is not covered yet. Collecting the data from the surroundings is essential to determine the state of the environment and to determine the action of the nanodevice. In this study, we are presenting a knowledge harvesting framework that is designed for synthetic nanodevice model presented in Akgül and Canberk (2014). As the model is applied for mobile synthetic devices, the transmission of the harvested data becomes a challenge. A molecular flooding algorithm is also proposed to help the spread of the detected anomalies. In particular, we focus on the blood sugar anomaly, which leads us the performance metric of capability of regulation. The effects of interference and sampling time are investigated in the performance evaluation part.

1. Introduction

Nanonetwork, which attracts attention of many researches from different disciplines, is one of the hottest research topics. Being such a new concept, there exist many challenges in each design step from the nanodevice layout to the implementation of the communication between nanodevices. As the wireless communication in nanodevices is not applicable, molecular communication is proposed to maintain the communication between different nanodevices. The application of biological nanodevice (e.g. bacteria cells) becomes a norm in nanonetwork applications due to the technological constraints. However, as argued in [1], the determination process of the bacteria cell output (i.e. molecular signal) is challenging. The molecular output is a function of lots of unobservable parameters, (e.g. light, heat etc.). However, there is not any deterministic model that covers all of these parameters and presents a complete nanodevice model. Due to this, most of the nanonetwork experiments are unrepeatable. The practicability of bacteria cells is open to question due to its

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unreliable nature and possible danger to human health. Due to this reason, in [1], we proposed a synthetic nanodevice model that exist of five main blocks, as presented in Fig. 1. In addition to this model, we also proposed a filter architecture that enables simultaneous communication by preventing the device-to-device interference. The previous studies do not cover the data concept and accept that the nanodevices are trying to transmit certain molecular packets that contain a specific data about their environment observations. However, the concepts of data and data extraction are still uncertain for nanonetworks.

Data concept varies with the application area. In an observation of blood sugar, the data can be defined as the high or low diffusion of sugar in blood; whereas for a cancer cell observation, the data can be defined as the existence of such a cell structure. In this study, we consider an intra-body nanonetwork that observes the anomalies of blood sugar and has the capability to apply specific drugs to stabilize the blood sugar. In this case, the accepted data definition is the changes in blood sugar. There exist two kinds of nanodevices, *sensor nanodevices* and *drug centers*. The duties of sensor nanodevices are observing the blood sugar, detecting possible anomalies and transmit a molecular signal to the drug centers in case of anomalies. The drug centers are responsible for the emission of related drugs. However, this observation and detection processes in sensor nanodevices bring out some challenges. First of all, as the data source (Blood Sugar) is distributed over the body, the process of data gathering is problematic. More specifically, a possible anomaly, e.g. high or low sugar diffusion in blood, can be detected at any part of the body. The mobile nature of the sensor nanodevices is capable of moving over body, but the drug centers are immobile, as they would need to be renewed in time. Due to this immobile nature of drug centers, sensor nanodevices have to transmit their anomaly messages to them. The detection of an anomaly and transmission of this anomaly message to the drug center are still challenging open issues. However, this lack of definition of the most basic attributes for nanonetworks causes an uncertainty in modeling and design of frameworks for nanodevices. Even though there exist some studies about the transmission of the data and the capacity of a nanonetwork [2,3], to the best of our knowledge, there is no applicable theory on how to measure the specific attributes that could create the data.

In order to maintain a completely defined base for our work, we first researched the channel models. There exist three main channel structures in the literature, flow-based, walk-away based and diffusion-based channels [4]. The diffusion-based channels are the simplest channel form in which the molecules are not guided and move freely in 3D space according to the diffusion movement. The flow-based channels are directed and the molecular movement is stable through a certain direction. Finally in walk-away based channels, the molecule movement is performed using some kind of special molecule motors, carriers [4]. Among these channel structures, flow based channel is used in this work not only because it is more applicable than the walk away based structure but also it is more immune to noise than diffusion based channel. Even though

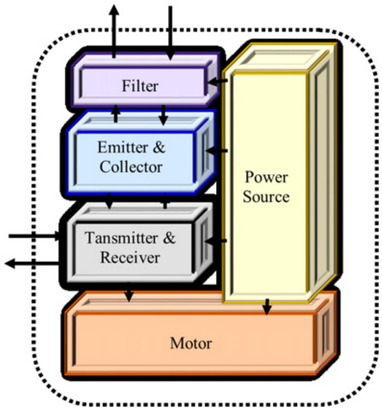

Fig. 1. Synthetic nanodevice structure proposed in [1].

there exist some walk-away based structures in the literature [5,6], the previously mentioned unreliable and dangerous nature of the biological nanomachines is also valid for carriers. The-walkaway-based channel needs a different molecule motor (carrier) for each nanodevice type as each molecule carrier type only transmits to a specific receiver nanodevice [7]. Based on this necessity of large molecule carriers, for most of the intra body applications, the application of walkaway-based channels is impractical. Addition to the channel type, the modulation framework of the molecular signal is also important in molecular communication and nanodevice model. In [8], two different types of modulation frameworks are presented, Molecular Shift Keying (MoSK) and Concentration Shift Keying (CSK). In MoSK modulation scheme, the molecular signal is encoded using two different types of molecules. However, CSK modulation framework offers the usage of a single molecule during the communication. The 1s and 0s are encoded changing the molecular concentration. As different molecule types are applied to modulate the chemical signal, the interference between two different symbols is decreased in MoSK type modulation. Even though MoSK modulation framework is more immune to the noise, most of the studies are using the CSK type modulation because of the impracticality of carrying many different molecules in an intra-body application. More specifically, usage of different types of molecules for each device type harms the homeostatic balance of the human body. In this study, CSK type communication is applied.

In all previous studies within the literature, the most critical concern is the transfer of molecular data. This is mostly because of the usually applied biological nanodevices inadequacy for the intending observations. More specifically, as the bacteria cells are alive, the observation samples can affect the cell structure and change it. However, with the proposal of a synthetic structure, the nanodevices that are dedicated to specific purposes can be designed. Such an application is especially important in drug delivery and illness detection, which are two of the most important application areas of intra-body nanonetworks. On the other hand, with the implementation of mobile synthetic nanodevices, the communication also becomes more challenging. As the nanodevices are capable