Work-in-Progress: Towards a First Biological Realization of Thermomolecular Communications

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Abstract

This work-in-progress paper introduces a novel concept for the practical realization of a first biological thermomolecular communications testbed using eukaryotic yeast cells as receiver. In particular, we sketch the idea of the testbed and present the theoretical basics.

Keywords

Gateway, Thermomolecular Communications, IoBNT, Molecular Communications, Yeast, Testbed

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1 Introduction

The Internet of Bio-Nano Things (IoBNT) is an emerging paradigm which involves interconnected nano-devices forming nanonetworks. Within this realm, those are envisioned to be connected to external units using a network interface between the internal and external human environment. This technology is set to provide a breakthrough when it comes to the health sector, through services such as health monitoring, disease detection, and targeted drug delivery [1]. Towards bringing IoBNT closer to its realization, Molecular Communications (MC) has been shown to establish information transfer between nano-machines. Particularly important to this aim, is the development of microscale MC testbeds that incorporate biological MC transmitters (TXs) and receivers (RXs), creating the basis for MC applications related to human health. However, conventional MC comes with some drawbacks when it comes to communication performance, which are mainly attributed to the slow nature of particle dynamics. Recently, a promising approach for the information exchange through the human skin was proposed using thermomolecular communications [2]. In particular, heat was used as the information carrier aiming to achieve faster signal propagation. For the thermal RX a chemical RX exploiting the Arrhenius effect was proposed in [2]. However, most artificial components and biological species are temperature sensitive, and thus can respond to temperature changes, which renders them also as possible thermal MC RXs. Hence, in this work-in-progress paper we introduce a novel concept of an end-to-end thermomolecular communications testbed, using yeast cells as biological thermal RX. This novel system is expected to achieve faster and more reliable communication compared to conventional MC, thus forming the basis for different future applications.

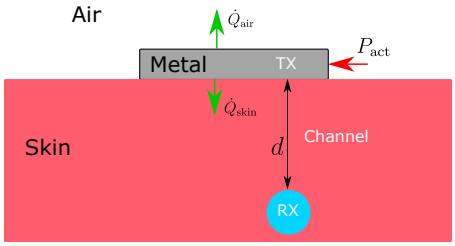

Figure 1: Schematic of thermomolecular communications [2].

2 Theoretical Basics

The idea behind a thermomolecular communication system is depicted in Figure 1. It consists of a TX (e.g., metallic plate or Peltier element), a channel (e.g., human skin) and a (thermomolecular) RX, which converts thermal input signals to readable output.

2.1 Transmitter and Channel

The TX is a temperature controlled thermally well conducting device (e.g., metallic plate), that is in close contact with the communication channel (e.g., the human skin) [2]. The transmitted message is encoded into the TX temperature. As this temperature changes, the TX exchanges heat with the channel altering the temperature inside it. The channel differential equation reads as

$$\frac{\partial^2 T(x,t)}{\partial x^2} - \frac{1}{\kappa}\frac{\partial T(x,t)}{\partial t} = 0, \tag{1}$$

with κ the thermal diffusivity, $T(x,t)$ the temperature at position x and time t. As this equation is structurally the same as the diffusion equation utilized in diffusive MC, findings from this field of study apply to the thermal channel as well. However, it was shown in [2], that thermal information transmission tends to be much faster than diffusive MC. Additionally, the temperature control of the TX can be achieved electrically, eliminating the necessity of a molecular injection into the skin.

2.2 Thermomolecular Receiver - Yeast Cells

The thermomolecular RX is formed by engineered yeast cells, that are cultivated in a yeast growth chamber, at a distance d from

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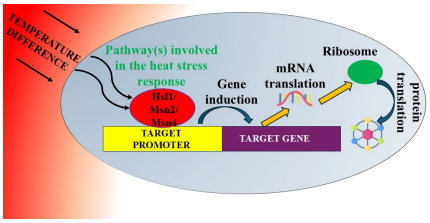

Figure 2: Heat-stress response in the RX yeast cell.

the TX (cf. Figure1). Yeast, due to its genetic amenability and the wealth of knowledge on its operation, constitutes an ideal eukaryotic model organism for MC. The RX under consideration is based on the inherent heat shock response of yeast [3]. The budding yeast *S.cerevisiae* exists in two main types: MATα and MATa, which are involved in the well studied yeast mating system. The utility of yeast as a MC RX is already documented in [4].

Here, we propose either MATα or MATa yeast cells as thermal RXs, which, when exposed to rapid changes in temperature, respond by altering the expression of various genes. The heat shock response of yeast is mediated by Transcription Factors (TF) such as Hsf1 and Msn2/Msn4, which invoke gene expression changes in a large number of genes [3]. Alterations of such kind include the upregulation of as many as 67 genes that encode proteins that belong to the 'Protein Folding' Genome Ontology and encode heat shock proteins that enhances the protein folding of other newly formed proteins, and thus contribute to normal cellular function under heat-stress. A second response mechanism is related to changes in mRNA transcription rate and degradation, leading to stabilization or destabilization of mRNA molecules of various genes within the cell. In this work, we consider the heat-stress gene upregulation notion as the main output of the envisioned communication system. The basic schematic outlining the yeast cell response to temperature difference that result in heat shock protein generation is shown in Figure 2.

To render the proposed RX suitable for the communication system described here, our future steps will be inclined towards finding the right gene candidate for the system output, taking into consideration the speed and robustness of the upregulation dynamics. Moreover, we will thoroughly identify the major steps comprising the heat-stress response pathway, starting from thermal stress sensing up to TF binding and gene expression mechanisms. The yeast cell will be properly engineered to express a Green Fluorescent Protein (GFP), and fluorometric measurements will be conducted using fluorometric equipment similar to [4].

3 Proposed Testbed

In this section, we describe a potential practical realization of the previously proposed thermomolecular communication system with RX yeast cells. A schematic of the testbed is depicted in Figure 3, which can be divided into the three components, TX, channel and RX.

The TX consists of a Peltier element (PE) mounted between a heat sink and the PDMS-chamber containing the yeast cells. With the current I the Peltier element can control the heat flow between the heat sink and the PDMS-chamber and, in further consequence, the

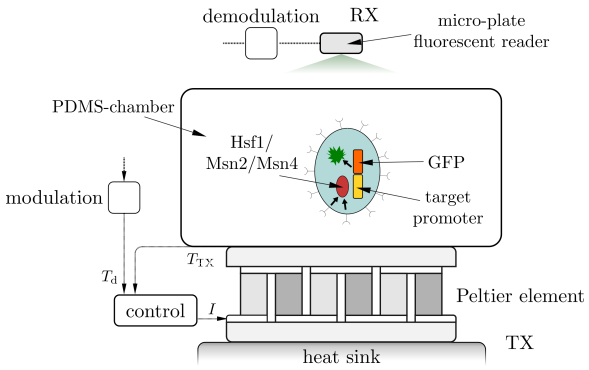

Figure 3: Schematic of the proposed testbed.

contact temperature T_{TX} (see Figure 3). The key benefit of a PE is the possibility of both, heating and cooling, which can be done by an external controller. The information to be sent is modulated onto the desired Temperature T_d according $0 \rightarrow T_{down}$ and $1 \rightarrow T_{up}$. The temperature imposed by the TX propagates through the channel, i.e, the PDMS-chip. Upon reaching the yeast cultivation medium, the heat flow leads to an increase in temperature of the yeast inside it. This increase in temperature results in the upregulation of a number of heat-stress related genes which encode for the heat shock proteins (HSPs). The RX yeast cells, will be engineered to express a reporter GFP, operating under the promoter of the target heat-stress gene. For measurement purposes, the yeast cells will be infused in a well plate. Fluorometric measurements will be conducted using the well micro-plate reader, where green emission will be quantified, as a result of temperature difference induced by the PE. Those readings will serve as the electronic output allowing us to examine both dynamics and robustness of the proposed thermomolecular RX and the entire thermomolecular communication system.

4 Conclusions and Future Work

In this paper, we introduced the concept for the first practical realization of a thermomolecular communication system, using yeast cells as RX. The actual practical realization and characterization will be carried out in future works.

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