



HAL
open science

Digital Simulation of Bioluminescent Bacteria Cells Tweeting via Quorum-Sensing Molecules

Nedjma Djezzar, Nouredinne Djedi, Iñaki Fernández Pérez, Yves Duthen

► **To cite this version:**

Nedjma Djezzar, Nouredinne Djedi, Iñaki Fernández Pérez, Yves Duthen. Digital Simulation of Bioluminescent Bacteria Cells Tweeting via Quorum-Sensing Molecules. Conference on Artificial Life (ALIFE 208), Jul 2018, Tokyo, Japan. pp.1-2. hal-02124405

HAL Id: hal-02124405

<https://hal.science/hal-02124405v1>

Submitted on 9 May 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Open Archive Toulouse Archive Ouverte

OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible

This is an author's version published in:

<http://oatao.univ-toulouse.fr/22618>

To cite this version: Djeddar, Nedjma and Djedi, Nouredinne and Fernandez Perez, Inaki and Duthen, Yves *Digital Simulation of Bioluminescent Bacteria Cells Tweeting via Quorum-Sensing Molecules*. (2018) In: Conference on Artificial Life (ALIFE 208), 23 July 2018 - 27 July 2018 (Tokyo, Japan).

Any correspondence concerning this service should be sent to the repository administrator: tech-oatao@listes-diff.inp-toulouse.fr

Digital Simulation of Bioluminescent Bacteria Cells *Tweeting* via Quorum-Sensing Molecules

Nedjma Djezzar^{1,2}, NourEddine Djedi¹, Iñaki Fernández Pérez and Yves Duthen²

¹Biskra University-LESIA/ ²University of Toulouse Capitole-IRIT
n.djezzar@univ-batna2.dz

In this paper, we propose a computational multiagent model of a bacterial light-producing communication system, termed quorum sensing (QS). Specifically, we propose a bottom-up agent-based approach combined with Ordinary Differential Equations, which abstract the intracellular dynamics, such as a proposed bioluminescence model. Results show that bacteria cells have a metabolism allowing them to grow, reproduce, interact, and cooperate at the population level to exhibit near-optimal light producing behaviors. The ultimate goal is to develop a self-regulated network in which the rules governing the formation of the network are linked to the internal dynamics of its units without any centralized control. Such a bacterial-inspired networks, can address issues such as mobility, and energy that are key factors for the development of new self-organized network such as mobile Ad-hoc networks.

Cellular Dynamics Model

To simulate cell-to-cell communication, we use a generic *LuxI/LuxR* QS. All *LuxI/R* systems are mediated by autoinducers, such as acylated homoserine lactone (*AHL*). Explicitly, the *AHL* and the receptor *LuxR* form a dimerized complex (*C*) that regulates the expression of both *LuxI* and *LuxR* genes. The QS model is based on the ODE-models proposed in (Melke et al., 2010). We model bioluminescence or light production as a function of the dimerized complex (*C*) as follows:

$$\frac{d[L]}{dt} = \frac{L_{max}[C]}{K_L + [C]}$$

where *L* is the light production rate, *L_{max}* is the maximum light production rate and *K_L* is the concentration of *C* at which *L* is at half-maximum. Bioluminescence is expressed as the accumulation of the green fluorescent protein *gfp*. The bacterial metabolism (ATP cycle) is implemented as follows:

$$\Delta ATP = (ATP_0 + E \cdot ATP_S + ATP_G + ATP_D + ATP_L + ATP_M)(\Delta t)$$

Where:

- *ATP₀* is the basal energy.
- *ATP_S* represents the energy produced from substrates and is calculated as follows:

$$\frac{d[ATP_S]}{dt} = Y_{ATP/S} \cdot \frac{d[S]}{dt}$$

Where *Y_{ATP/S}* is the energetic substrate yield *i.e.* the amount of *ATP* produced by per a unit of substrate (*S*).

- *E* is the substrate metabolism efficiency.
- *ATP_G* represents consumption of *ATP* due to the cell growth and is calculated as follows:

$$\frac{d[ATP_G]}{dt} = -\frac{1}{Y_{X/ATP}} \cdot \frac{d[X]}{dt}$$

Where *Y_{X/ATP}* is the energetic growth yield coefficient.

- *ATP_D* is the division energy.
- *ATP_L* is the light energy. The consumption of energy due to light production is given by:

$$\frac{d[ATP_L]}{dt} = -\frac{1}{Y_{L/ATP}} \cdot \frac{d[L]}{dt}$$

Where *Y_{L/ATP}* is the energetic light yield coefficient.

- *ATP_M* is the maintenance energy.

Results

The experiments were conducted using "gro" (Jang et al., 2012). The number of bioluminescent cells represents 73% of the population. This corresponds to the empirical rates found in real populations of bacteria (Anetzberger, Pirsch, & Jung, 2009). At the population level, figure 1.d shows a self organized behavior of the microbial population. Figure 2a shows the amount of autoinducer over time. In our simulations the accumulation of *AHL* exceeds the rate achieved in (Melke et al., 2010) (0.6 against 0.1). This shows that the cells in our model provide self-sustainable behaviors that allow them to exploit metabolism (figure 2b) to grow, survive and produce more *AHL* molecules, which in turn triggers communication.

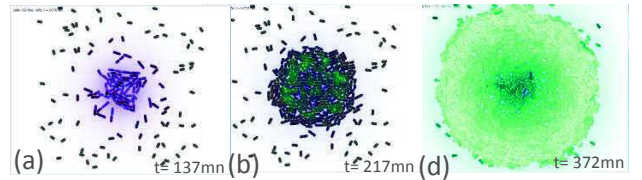


Figure 1: Evolution of bioluminescence. Substrate is shown in purple, *AHL* in blue, black cells are non-fluorescent. (a) cells grow and divide. In (b) the quorum is being reached, fluorescent cells begin to appear. (c): Bioluminescent cells organize themselves around the colony to be located at the edges of it.

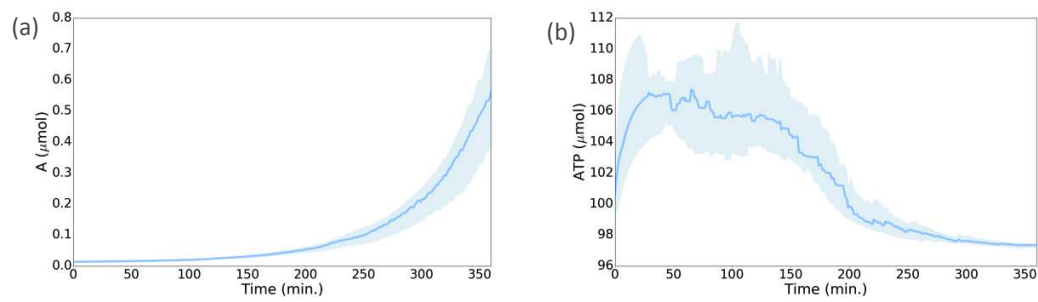


Figure 2: Evolution of the average amount of autoinducer (a) and ATP (b) inside cells over time : median and interquartile range of 20 independent runs of the simulation)

References

- Anetzberger, C., Pirch, T., & Jung, K. (2009). Heterogeneity in quorum sensing-regulated bioluminescence of *Vibrio harveyi*. *Molecular microbiology*, 73(2), 267-277.
- Jang, S. S., Oishi, K. T., Egbert, R. G., & Klavins, E. (2012). Specification and simulation of synthetic multicelled behaviours. *ACS synthetic biology*, 1(8), 365-374.
- Melke, P., Sahlin, P., Levchenko, A., & Jönsson, H. (2010). A cell-based model for quorum sensing in heterogeneous bacterial colonies. *PLoS computational biology*, 6(6): e1000819.