Firefly-Inspired Synchronization in Multi-Agent Systems (Extended Abstract)

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1. INTRODUCTION

People have always tried to understand nature phenomena. In computer science they are mostly used as a source of inspiration for solving various problems. In my Ph.D. research I use fireflies as a role model for synchronization in a heterogeneous Multi-Agent System (MAS). In nature, each firefly flashes at regular intervals when isolated, while as a part of a group it adjusts its flashes upon reception of flashes from other fireflies in order to synchronize with them. This concept can be used in MASs since every agent can run an algorithm similar to the one "ran" by fireflies.

Although many scientists (e.g. Leidenfrost et al. [5] and Tyrrell et al. [11]) gave their contribution to science investigating firefly-inspired synchronization, there are still open issues such as the one I am working on. My research objective is to answer the following question: ***Can different agents in a heterogeneous MAS (such as the Machine-to-Machine (M2M) system) synchronize themselves using a self-organizing principle inspired by fireflies.***

The M2M is a concept that defines rules and relationships among different machines which communicate in heterogeneous networks. This concept also implies a high level of independence among communicating machines. Even though there are hundreds of different species of fireflies, all those fireflies can self-organize themselves and achieve synchronization regardless of which species they belong to. Thus, I conduct research to see whether the same principle can be applied in a heterogeneous MAS, i.e. the M2M system.

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2. RESEARCH CHALLENGES

When using a self-organizing principle inspired by fireflies to synchronize machines (i.e. agents) in M2M systems, one should take into an account network limitations (e.g. delays and limited bandwidth) as well as characteristics of M2M systems (e.g. a large number of connections among machines). My research methodology is as follows. In the first phase I investigate how to reduce network traffic and still maintain a success rate of the synchronization process. The goal of the second phase is to model firefly agent's behavior in such a manner that it would increase *robustness* of the synchronization process without significantly decreasing its scalability. Finally, in the third phase a solution to overcome network heterogeneity in M2M systems is proposed.

2.1 How to reduce network traffic

In their seminal work, Mirollo and Strogatz [9] modeled firefly-inspired synchronization with pulse-coupled oscillators. They proved that synchronization can be achieved in fully-meshed systems in which physical connectivity exists among all components in a system. Lucarelli and Wang [7] proved that synchronization can also be achieved within meshed systems where connections among components are described with a graph in which its edges join only neighboring components. Since then, impacts of different overlay network topologies (e.g. meshed [12] and chain [5]) on the synchronization process were investigated. Overlay network topology describes connectivity among agents in the system.

In our previous work [2, 3], we compared impacts of four topologies (e.g. line, mesh(n)[1], ring and star) on the success rate of the synchronization process. Results showed that mesh(3) achieves best results. In our most recent work [4], we described each agent a_i with $z_i = f(\varphi_i) + \sum_{j=1}^{N} \varepsilon_{ij}\, g_{ij}(t)$, where z_i is a state variable, φ_i denotes the agent a_i's internal phase, $f(\varphi_i)$ describes the *excitation* evolution of the agent a_i's oscillator, N denotes the number of agents in a MAS, ε_{ij} is the coupling constant, while $g_{ij}(t)$ is a coupling function between agents a_i and a_j. The coupling constant ε_{ij} reflects the intensity of the influence that connected agents have on each other and is calculated by using different metrics (i.e. *Euclidean* and *Manhattan*). We concluded that the choice of the overlay network topology has greater impact on the synchronization process than the choice of the metric.

[1] Parameter n denotes the number of agents that each agent is connected with. For example *mesh(3)* denotes overlay network topology in which every agent has 3 neighbors.

2.2 How to increase robustness

Firefly-inspired synchronization is shown to be scalable mostly because agents do not keep information about their neighbors during the synchronization process. The only information that is stored concerns their internal phase. Therefore, the number of connected agents does not have any impact on the synchronization process. Nevertheless, I argue that if additional information was stored in the firefly agent's memory, this would result in higher robustness of the synchronization process without significantly affecting its scalability[2].

I propose the usage of coupling constants as *regulation parameters of robustness* in the synchronization process. In related work equal coupling constant ε_{ij} is mostly assumed for all agents (e.g. [7, 9]) meaning that the influence agents have on each other is equal. However, there are projects where coupling constants are different for different agents (e.g. coupling constants depend on the degree-based weighting [10]). An et al. [1] proved that synchronization can be achieved if coupling constants stayed fixed and were distributed in a close interval during the synchronization process.

When talking about robustness, we can identify two situations which have negative effects on the robustness of the synchronization process. In the first situation an agent can change its behavior by accident (e.g. due to occurrence of malfunction). In the second situation, agents are intentionally designed with faulty behaviors which classify them as attackers. I argue that the usage of coupling constants, which denote agents' *credibility* such that some agents (e.g. attackers) are less trustworthy and thus have small impact on other agents, will provide higher robustness in both situations.

2.3 How to overcome network heterogeneity

Since in M2M systems machines communicate using different types of communication technologies, not only do delays appear within one network, but also between different networks. Although for instance Tyrrell et al. [11] and Werner-Allen et al. [12] investigated how delays affect the synchronization process, they did not take network heterogeneity into consideration. I argue that every agent in heterogeneous MASs will have to keep information about its neighbors with respect to the type of communication technology that connects them.

Saving additional information in agent's memory surely causes an overhead for the synchronization process. However, in other to synchronize agents in large heterogeneous MASs it is a necessity. Moreover, since some agents will serve as *gateways* between different networks, their behaviors will differ from other agents' behaviors. Consequently, heterogeneous MASs will be susceptible to occurrences of single point of failures.

Since it is still not mathematically proven that synchronization can be achieved in systems with delays, let alone in heterogeneous systems, I will use simulations and experiments in a real-world environment to find parameters which will result in the highest success rate of the synchronization process. As a simulation tool I will use a single-process simulator called the Multi-Agent Simulator of Neighborhoods [8], while experiments in a real-world environment will be conducted using Libelium Waspmote sensors [6].

[2]When using meshed overlay network topologies, every agent keeps information only about its neighbors, and not the whole network.

3. CONCLUSIONS

In this extended abstract, I identified some of the research challenges that emerge when using fireflies as role model for synchronization process in heterogeneous Multi-Agent Systems (MASs). In my Ph.D. thesis I will conduct a research that will tackle aforementioned research challenges. Result of my Ph.D. research will be an algorithm in which firefly agents will be able to identify other agents in MAS that have faulty behaviors. Consequently, this will increase robustness of the synchronization process without affecting its scalability.

4. ACKNOWLEDGMENTS

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