Optimizing Agents Operation in Partially Inaccessible and Disruptive Environment

David Šišlák, Martin Rehák, Michal Pěchouček, Petr Benda
Department of Cybernetics, Czech Technical University
Technická 2, Prague 6, 166 27 Czech Republic
sislakd@feld.cvut.cz, {rehakm1|pechouc|bendap1}@labe.felk.cvut.cz

Abstract

The algorithm we present in this paper aims to optimally distribute and connect the community of loosely coupled middle agents ensuring communication accessibility in a dynamic, inaccessible environment. Complete decentralization, autonomous adaptation to local and global changes in the environment and domain independence are main features of the presented algorithm. The main motivation of this approach is to significantly decrease the number of messages required for communication relaying in inaccessible system operation. We use social dominance models and virtual payments to obtain such behavior.

1. Introduction

Cooperation and coordination in the distributed multi-agent systems is conditioned by the ability of agents to communicate. In our previous contributions in the area, we have defined the concept of **communication inaccessibility** in the multi-agent systems [2] and the formal approach to inaccessibility quantification [4].

We have established the boundaries of usefulness of various inaccessibility solutions, without taking into account the cost (number of middle agents and messages) of the overall solution. Therefore, in our contribution, we address the problem of optimal positioning of middle agents in the distributed dynamic multi-agent system and message flow optimization between these agents to ensure optimum balance between efficiency and redundancy. We don't explicitly restrict the algorithm use to particular type of middle agent, as it can be integrated with stand-in [4] or other [8].

Proposed optimization algorithm tries to: *optimally connect* the multi-agent system, be *local* – operate with the local environment information only, *adapt* to the changing environment both in time and place, be *efficient* in cost and the middle-agent community needs to be *stable*. Our solution is based on virtual payments combined with social dominance [9, 5] model.

2. Middle Agent Architecture

In this section we will address integration of the *swarming controller* (see Section 3) with the generic middle agent architecture (Figure 1). Orthogonally to classical middle-agent architectures [8], whose primary functionality is matchmaking and negotiation, we would like to extend the concept of middle agent by its capability to autonomously migrate in the network, clone and destruct copies.

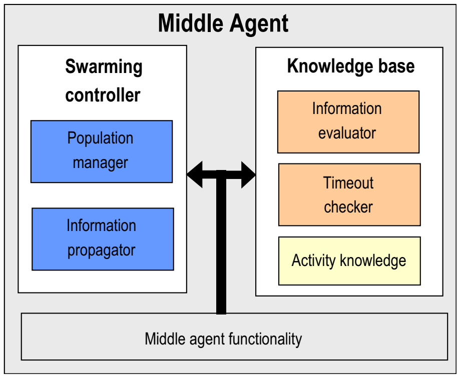

Figure 1. Middle agent architecture.

Swarming controller takes care of middle agent existence (position) in the system and manages information flows through the agent, more specifically the knowledge to transfer or actions to take. The module must balance between two extreme cases of knowledge handling: propagation to all visible targets or no propagation at all. Even if both submodules are domain in-

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dependent, they depend on the domain specific functions included in the knowledge base.

Knowledge base is a domain specific knowledge structure of the middle agent. The *activity knowledge* contains the domain specific knowledge and the middle agent meta-data. The *information evaluator* classifies and indexes the knowledge, so that the index values can be used by swarming controller to manage its activity. The *timeout checker* module implements forgetting of the activity knowledge.

Middle agent functionality – universal interface between modules and agent platform providing fundamental agent functions (cloning, migration, messaging), neighbor monitoring listeners, as well as original middle agent code.

3. Swarming Controller

The distributed middle-agent allocation mechanism can use only locally accessible information about neighborhood – identifying currently visible targets and other middle agents. It does not only minimize the network maintenance communication, but also allows operation in the disruptive or partially inaccessible environment. Scalability in space and density shall also be an important property of the targeted solution.

In principle there are two key approaches to controlling the middle agents allocation: *Forward swarming control* – where the middle agent clones itself only to the locations with higher possibility of future inaccessibility and higher interaction expectancy. It is computationally efficient, as it tries to minimize the number of stand-in agents in the system and prevent the possible swarming explosion. This approach seems to be particularly suitable for domains with high scalability and operational efficiency requirements. *Backward swarming control* – where the middle agents dispatch their clones to every reachable destination and the useless ones are removed in the future depending on their experience. This approach is substantially more domain independent, demands less knowledge about the environment nature and is more robust, as it doesn't *explicitly* use any prediction about the future of the community.

We have opted for the use of the *backward swarming*, as this approach is more robust and domain independent. Abstract criteria of the system quality defined in the introduction were also formulated in a precise manner, with descending priority: (a) provide connection between any two system elements through the minimum number of middle agents, (b) minimize the number of middle agents in the system and (c) minimize the number of messages for system operation and/or knowledge maintenance.

Population manager is driven by a biology inspired algorithm [9, 5]. To ensure the target coverage, middle agents can be reproduced in the system using two main propagation strategies:

◇ *full flood fill* – any middle agent initiates full flood filling reproduction strategy when it identifies a new unserved knowledge target in its reach. The served target set implements *time forgetting*. In practice, the middle agent is cloned to every visible node where it is not already running if the new knowledge target is not reachable from current position of the agent. Created clones further clone themselves to new locations using the same cloning termination condition: target reachability. This simple strategy ensures that the middle agent network will reach the target. Using random walk instead of flood fill is possible, but not advisable, because the random walk does not guarantee finding the target, as known from Pólya's random walk theorem [1],

◇ *bounded flood fill* – is a depth-limited version of the previous reproduction strategy. This reproduction strategy is also triggered by a local accessibility change when the source agent holds relevant, non-expired knowledge. Application of this mechanism can identify shorter paths enabled by the accessibility change or can deliver the knowledge to the isolated cluster by the middle agent on the mobile node.

Both flooding strategies intention are time limited. When this duration expires, the agent no longer reproduces until the new reproduction is started by the agent itself or the others. To keep the number of middle agents close to optimum, the population manager contains also the methods that decrease the number of middle agents in the system:

◇ *random duels* – the attacking middle agent randomly selects an adversary between accessible agents and launches an attack with force proportional to its profit during specific period determined by information propagator. The attack also includes the information about its current active targets. The attacked agent evaluates the attack and decides whether it won or lost. If the attacked agent loses, it removes itself from the system. Attack evaluation compares the current active target sets first and when one is a subset of the other, its owner loses the fight. When the sets are identical, force of the attack decides the fight – stronger agent wins. Agents that are not adapted yet use all directly accessible targets instead of active ones. The youngest agents benefit from the immunity period, during which they can not lose a fight while attacked,

◇ *uselessness detection* – is an individual process.

The middle agent can remove itself while it is isolated from the rest of the community and has no access to relevant knowledge anymore.

Information propagator manages knowledge propagation and use in the system. This component uses virtual payments to reward the other agents for the knowledge, receives payments from the others for the information provided and generates the profit also from acting on behalf of the represented agent. Transmission of the information to other agents is not free of charge for the agent. Each agent optimizes its profit, ensuring the overall information flow efficiency. To make the system more robust, the decision to which nodes we send the information is probabilistic – agents may sometimes send the knowledge to the less rated directions to find better paths in the system.

The domain specific functions that evaluate the usefulness of the knowledge, indexable knowledge characteristics and rewards for actions are provided by the domain-specific knowledge base. We shall keep in mind that the knowledge is not only propagated by messaging in the network of middle agents, but also carried by the agents created during the reproduction process. This is especially important for the communities with low accessibility or clustered agents.

4. Experiments

All experiments described below were executed using $\mathcal{A}$-**globe** platform [6] with inaccessibility support. Agents are running on simulated fixed and mobile nodes (containers). A pair of containers is mutually accessible if each of the two containers is located within the visibility range of the other container. In the experiments, we use testing agents that implement a FIPA CNP in which all requests must involve at least one middle agent, even if a direct link between the sender and the receiver exists, and we didn't use any advanced middle agent capabilities and social knowledge. However, the use social knowledge typically further decreases the number of messages necessary [3].

4.1. Information Propagator Adaptation

In the first experiment, one middle agent resides on each node with deactivated *population manager*. We set full link accessibility in the network – there are many loops and alternative paths. The results (Fig. 2) show the systemwide number of transmitted messages per each testing CNP. We provide the results for two different values of the forgetting parameter. This parameter should be zero in cases of non-changing topologies because all knowledge previously stored in information propagator can be reused and the system rapidly converges to the optimal number of messages. When we increase the value of the forgetting parameter, the number of messages can't converge to the optimum because a certain amount of the knowledge is being lost. The experiment shows that the number of messages is decreasing exponentially until a certain threshold is reached. After reaching the threshold, the number of messages per round remains more or less constant. The experiment also verified that in case of the full accessibility, any routing path contains exactly one middle agent.

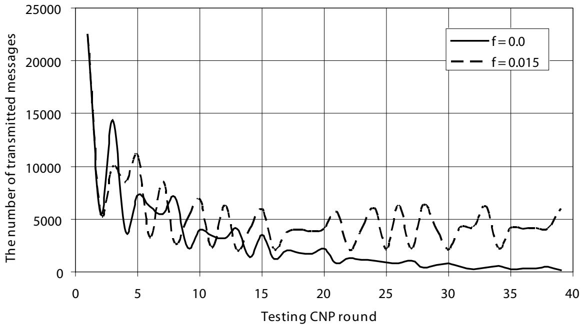

Figure 2. Message reduction using different forget parameter (f) value in fully connected environment with 24 nodes.

4.2. Adaptation to the Changing Environment

In this experiment with active *population manager*, we set minimal link accessibility with complete path accessibility. We measured the evolution of the number of middle agents at two levels of inaccessibility dynamics. To determine the optimal number of stand-in agents in each moment with distance-based accessibility, we have implemented an efficient centralized algorithm.

At first (Fig. 3, top) we were slowly changing visibility ranges on the network with fixed nodes. In the second setup (Fig. 3, bottom), two mobile nodes were moving faster through the community, causing more important disturbances in the network topology. In the experiments, we clearly demonstrate that the agents are able to organize themselves efficiently and to approach the optimal number as determined by the reference algorithm. However, after the steep initial decrease, we can observe the peaks that correspond to agent propagation in response to the topology changes. In the mobile scenario, we have failed to match the reference solution perfectly, as the adaptation time is somewhat higher than the average change period, but the results remain comparable and the robustness and distribution of the algorithm provides enough of the incentive for its application.

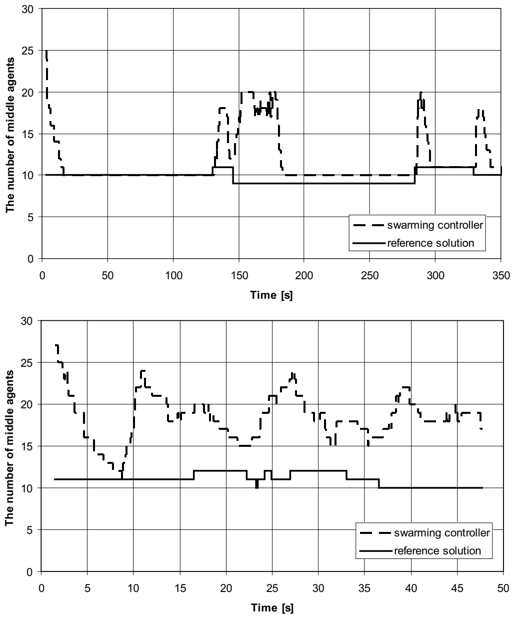

Figure 3. The figure presents adaptation of middle agent network to the changing environment with infrequent changes (top chart) and frequent changes (bottom chart).

5. Conclusions and Future Work

In this contribution, we have presented and evaluated a distributed algorithm for the optimization of the middle agent community in an inaccessible environment. In the experiments, we show that our solution is efficient in communication, is robust with respect to important environment changes and ensures complete system connectivity in the environments with high path accessibility and low link accessibility. In contrast generic routing algorithm, our system can be integrated with any type of middle agent, making it useful even in the partially disconnected environments.

Our future research work will focus on the algorithm tuning and automatic environmental adaptation; many internal parameters are currently set in an arbitrary manner and their learning from the environment can further increase the usability of our solution. To validate the algorithm in the real environment, we will integrate it with the solutions currently used for ad-hoc networking in challenging environment [7].

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