SFB 637 Autonomous Logistics

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Analysis of Mobile Agents considering the Fan Out – Mobile Agents for Autonomous Logistics

Markus Becker, Gulshanara Sayyed, Bernd-Ludwig Wenning, Carmelita Görg

***Abstract*— The current trends and recent changes in logistics lead to new, complex and partially conflicting requirements for logistic planning and control systems. Due to the distributed nature of logistics the usage of agent technology is promising. Due to the mobile nature of logistics the usage of mobile agent technology is promising as well. Scenarios of usage of mobile agents in logistics are presented, a notation for those scenarios is defined and it is shown analytically in which cases the usage of mobile agent is superior to conventional communication. The main variable under study is the fan out, which is the number of partners a mobile agent needs to communicate with.**

***Index Terms*— Autonomous Logistics, Fan Out, Mobile Agents, Scenario Notation.**

I. Introduction

Technically, logistics planning and monitoring poses a challenging problem. The types of planning activities are varied including packing, scheduling, route planning with several constraints. The problem is highly distributed, yet interconnected (as the organizations are autonomous). Dynamism also enters the system e.g. in the form of changed logistics requests. The simplest plans involve interaction between the components that are distributed in the logistical networks.

A. Agent Technology

A multi-agent system is a loose aggregation or society of agents each with clearly defined roles, responsibilities and functionality. Thus agent technology is described as a promising field to fit in the distributed nature of the logistical network, due to the widely distributed heterogeneous open nature of agent platforms [1]. It has the potential to play a key role in building and supporting virtual enterprises, enriching higher level of communication and enabling more intelligent services provision. The agent oriented paradigm also includes components related to design, development, deployment and subsequently to handle the management of agents. They need to negotiate and to co-operate in open environments.

A recent development in multi-agent systems research is their application in the logistics of the transportation sector, see [2], [3].

B. Mobile Agents

In some cases agents need to migrate in order to accomplish their assigned tasks, as it would otherwise be impossible to transmit all the data needed for that task due to the limitations imposed by the underlying network. Hence mobile agents are gaining more attention and are proposed to be used in mobile wireless environments.

A mobile agent programmer can move the code to the data, rather than moving the data to the code. In many situations, moving the code may be faster, for example if the agents state is smaller than the data. In some applications a single mobile agent migrates sequentially from host to host, in others, an agent spawns one or more child agents that migrate independently.

C. Mobile Agents in Wireless Networks

The ability to move makes mobile agent technology especially appealing in wireless networks, which tend to have low bandwidth and low reliability. A user of a mobile computing device can launch a mobile agent, which moves across the wireless connection into the wired Internet. Once there, it can safely roam among remote sites in the network utilizing the required resources without having to handle network disconnectivity, thereby accomplishing the assigned tasks. Lastly it can return to (or send a message) to its user, using the wireless network.

Portable computers and hand-held devices with wireless technology, e.g. GSM modems, UMTS cards, WLAN cards etc., offer facilities to employ network services while on the move. Wired links have different characteristics when compared to the wireless links. Wireless links typically have low and variable throughput, high latency, highly variable delays and in some cases long connection establishment times. Thus, an agent-platform supporting agents, that takes the different characteristics of wired and wireless environments into account, is required.

D. Mobile Agents for Logistics

Mobile agents can be representatives of vehicles, distribution centers, packages and other components of autonomous logistic processes [4]. They can then interact with other logistical objects respectively their agents by means of the underlying *multi-agent system* (MAS).

E. Evaluation of Mobile Agents

For economic reasons mobile agents' usage of the scarce network resources shall be advantageous over conventional communication without migration. This implies the need for an analytical analysis of mobile agents in wireless logistic environments.

All authors are with AG Communication Networks, Otto-Hahn-Allee – NW1, University Bremen, 28359 Bremen, Germany. Their email addresses are {mab|guls|wenn|cg}@comnets.uni-bremen.de . This research was supported by the German Research Foundation (DFG) as part of the Collaborative Research Centre 637 "Autonomous Cooperating Logistic Processes".

The remainder of the paper is structured as follows:

Section II gives an overview of research in the area of analytical modelling of mobile agents. For our purpose of studying mobile agents in logistic environments regarding the fan out, we introduce four scenarios in Section III and a specific notation for the scenarios in Section IV. In Section V and VI the analysis and the results obtained are presented. The conclusion obtained from the results is contained in Section VII and an outlook on future research is given in Section VIII.

II. State of the Art

Straßer and Schwehm introduced a performance model for mobile agent systems in [5]. They compared the performance of *Remote Procedure Calls* (RPC) and agent migration analytically and validated their model experimentally.

Helin et al. extended this performance model to wireless networks and studied three different code block transfer scenarios [6].

Yang et al. formalized the description of migration sequences, optimized the communication means of mobile agents and experimentally used the presented optimizations in [7].

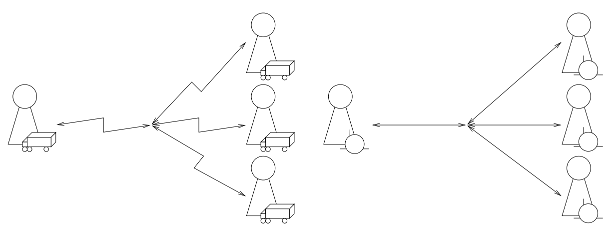
Farjami took TCP and IP for mobile agents into account with respect to the data amount to be transmitted and the execution time [8].

III. Scenarios

The evaluated logistic scenarios can be classified into four different types. Depending on the logistical object represented by the mobile agent, four different combinations of wireless and fixed links are considered.

The topology of a mobile agent, that is representing the intelligence of a vehicle and would like to communicate to other mobile agents of vehicles, is as depicted in Fig. 1(a). This mobile agent requires a wireless connection on the access side as well as on the links to the other vehicles.

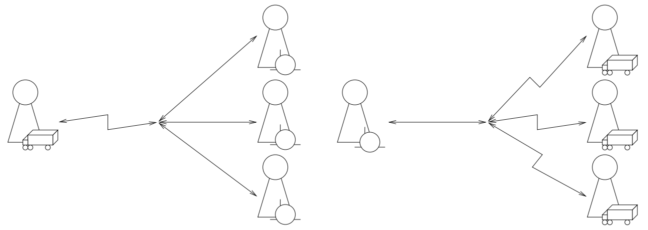
Contrary a mobile agent being a representative of a distribution center that would like to interact with other representatives of distribution centers, has all fixed connections as shown in Fig. 1(b).



(a) Wireless/Wireless (b) Fixed/Fixed

Fig. 1. Common Scenarios

Similarly a vehicle mobile agent communicating with a distribution center agent has a mixed wireless and fixed connection and vice versa for a distribution center agent interacting with a vehicle agent, see Fig. 2(a) and Fig. 2(b).



(a) Wireless/Fixed (b) Fixed/Wireless

Fig. 2. Mixed Scenarios

The middle point where the connections are forked is assumed to be host of a mobile agent system. Furthermore an infrastructure network is assumed, so that there is no direct peer-to-peer ad-hoc communication possible. In this mobile agent system, the translation between migration and communication and vice versa is done. When there is communication on the first link and migration on the later links, it is assumed that the mobile agent is already available at the interfacing host.

IV. Scenario Notation

The scenarios depicted in Fig. 1 and 2 can be referred in general with the notation A/nB-a/b-S, where

- A is the type of access (F-Fixed/Wired, W-Wireless),
- n is the fan out (integer value),
- B is the connection in the network (F-Fixed/Wired, W-Wireless),
- a is the access operation (first link) (C-Communication, M-Migration),
- b is the network operation (later links) (C-Communication, M-Migration),
- S is the strategy employed (Sequential, Parallel, Branch).

As an example the scenario depicted in Fig. 2(b) is thus described using this notation as F/3W-M/C-Sequential, when doing migration on the fixed link and communication on the three wireless links. The communication on the wireless link is done according to the sequential strategy, so that communicating with each partner agent is done after the other. In the parallel strategy the communication or the migration of the links is not waiting for the previous links communication or migration to be finished. In the branch strategy the link that needs to be chosen to fulfil the assigned task is known and therefore there is only one path used on the right hand side of the network.

V. Analytics

The mobile agent technology sets the platform in which the agents can either migrate to other hosts or just communicate with other agents in the network to accomplish the assigned tasks. In some cases the agents tend to be more efficient with migration rather than just communicating. In this analysis part, it is assumed that the agent migrates from the source host to the destination host to accomplish the assigned tasks. An agent is defined as a set of code blocks (B_{code}). If the code is not available on the remote server, the code needs to be requested. B_{cr} is the size of this request. An agent has its own execution state (B_{state}) and arbitrary private data B_{data}. Thus, an agent is described as a four tuple given by

$$B_{Agent} = (B_{code}, B_{cr}, B_{state}, B_{data}). \tag{1}$$

This section describes the effect of agent migration and communication on the network load and execution time. The network load C_{Load} and the execution time C_{Exec} for Communication-operation is given as

$$\begin{aligned} C_{Load} &= B_{req} + B_{rep}, && (2) \\ C_{Exec} &= 2\delta(H_i, H_{i+1}) + (1/\tau)C_{Load}, && (3) \end{aligned}$$

where B_{req} is the size of therequest send by the host H_i to the host H_{i+1} and B_{rep} is the size of the reply received. The parameter $\delta(H_i, H_{i+1})$ and τ are the delay and throughput of the underlying network.

The network load M_{Load} and execution time M_{Exec} of agent migration is given by

$$\begin{aligned} M_{Load} = &\; P(B_{cr} + B_{code}) + B_{data} + B_{state} + M_{selec}, && (4) \\ M_{Exec} = &\; (2 + 2P)\delta(H_i, H_{i+1}) + (1/\tau)(M_{Load}), && (5) \end{aligned}$$

where $M_{selec} = \theta \cdot B_{rep}$. θ represents the selectivity of the agent, which depicts as how much of the reply data (B_{rep}) is reduced by remote processing. If $\theta = 1$, then no reduction of the reply data is done by the mobile agent. P denotes the probability that one of the code blocks is unavailable at the destination host. The delay δ is half a *Round Trip Time* (RTT). The 2δ in Eq. (5) is contributed by $B_{data+state}$ of the agent (that is summed into a single delay) plus the delay for B_{rep} and the factor $2P\delta$ is contributed by a request for certain code blocks B_{cr} plus the code blocks B_{code} which are unavailable at the destination.

The total cost for the network load and execution time for the scenarios depicted in Section III is given by

$$\text{Cost}_{Load} = \text{Cost}_{a}^{Load} + \text{Cost}_{n,b,s}^{Load} \tag{6}$$

and

$$\text{Cost}_{Exec} = \text{Cost}_{A,a}^{Exec} + \text{Cost}_{n,B,b,s}^{Exec}. \tag{7}$$

Thus the Cost_{Load} and the Cost_{Exec} are the summation of the Cost of the left hand side of the network and the right hand side of the network. The left hand part of Cost_{Load} is only depending on whether Migration or Communication is done, the right hand part is additionally dependent on the fan out and the strategy. Cost_{Load} is not dependent on the network characteristics, i.e. whether the network is wireless or fixed. Cost_{Exec} is additionally dependent on the network characteristics, which can be seen by the parameters A and B.

The left hand part of Cost_{Load} can be calculated by

$$\text{Cost}_{a}^{Load} = \begin{cases} M_{Load} & \text{if a=M,} \\ C_{Load} & \text{if a=C,} \end{cases} \tag{8}$$

where M_{Load} refers to Eq. (4) and C_{Load} refers to Eq. (2).

The right hand part of Cost_{Load} is described by

$$\text{Cost}_{n,b,s}^{Load} = \begin{cases} n * M_{Load} & \text{if b=M, s=Sequential/Parallel,} \\ n * C_{Load} & \text{if b=C, s=Sequential/Parallel,} \\ M_{Load} & \text{if b=M, s=Branch,} \\ C_{Load} & \text{if b=C, s=Branch.} \end{cases} \tag{9}$$

This means that the network load depends on the strategy chosen. Strategies Sequential and Parallel impose a network load that increases with the fan out, while strategy Branch does not, due to the selection of only one link.

The time it takes to execute migration or communication is given by the two components

$$\text{Cost}_{A,a}^{Exec} = \begin{cases} M_{Exec}(\delta = \delta_A, \tau = \tau_A) & \text{if a=M,} \\ C_{Exec}(\delta = \delta_A, \tau = \tau_A) & \text{if a=C,} \end{cases} \tag{10}$$

and

$$\text{Cost}_{n,b,B,s}^{Exec} = \begin{cases} n * M_{Exec}(\delta = \delta_B, \tau = \tau_B) \\ \quad \text{if b=M, s=Sequential,} \\ n * C_{Exec}(\delta = \delta_B, \tau = \tau_B) \\ \quad \text{if b=C, s=Sequential,} \\ M_{Exec}(\delta = \delta_B, \tau = \tau_B) \\ \quad \text{if b=M, s=Parallel/Branch,} \\ C_{Exec}(\delta = \delta_B, \tau = \tau_B) \\ \quad \text{if b=C, s=Parallel/Branch.} \end{cases} \tag{11}$$

For example, if the transmission technology in the left hand part of the scenario is wireless technology (A=W), then δ_W and τ_W are used for the calculation of the execution time. The same holds for the right hand part of the network.

The execution time also depends on the strategy chosen. Strategy Sequential imposes an execution time that increases with the fan out, while the strategies Parallel and Branch do not, due to the selection of only one link or the parallel execution.

The values used in the analysis, whose results are laid out in Sec. VI, are listed in Tab. I for the agent characteristics and in Tab. II for the network characteristics. The parameters used for the agent characteristics and network characteristics are according to [6] and [7]. The parameters B_{code}, B_{data}, B_{state} denote the byte size of code, data and execution state respectively. Here the migration of the agent is assumed to be "weak form" and hence the value of B_{state} is considered to be zero [7]. It is also assumed that no code is available at the destination host ($P = 1$).

Agent Characteristics:	Values (kB)
Code blocks (B_{code})	9.5
Data (B_{data})	300
Execution (B_{state})	0
Code for request (B_{req})	0.5
Code block request (B_{cr})	0.5
Code block reply (B_{rep})	512

TABLE I
AGENT CHARACTERISTICS

Network Characteristics:	Values
Throughput (Fixed) (τ_F)	560 kBps
Throughput (Wireless) (τ_W)	9600 bps
Delay (Fixed)(δ_F)	8 ms
Delay (Wireless)(δ_W)	400 ms

TABLE II
NETWORK CHARACTERISTICS

VI. Fan Out Results

The variation of network load and execution time with the increase in fan out n (the number of destinations) along with the varying selectivity for the scenarios presented in the Sec. III is analysed in this section.

The network load is independent of whether the connections are fixed or wireless (W/W, W/F, F/W or F/F) as it is independent of the factors throughput and delay, cf. Eq. (2) and Eq. (4). Fig. 3(a) depicts the network load with varying fan out n and selectivity θ. The M/M case has highest curve for $\theta = 1$ and is more dominant with increasing n, as more code needs to be migrated. For $\theta = 0$ the C/C surface is comparatively higher than the surface of M/M case. This is due to the factor $B_{rep} = 512$kB that is dominating in the communication mode whereas, the factors $(B_{cr}, B_{code}, B_{data})$ in migration process have smaller values comparatively. The C/C case remains constant with respect to selectivity as there is no dependency on θ in Eq. (2), but increases with increasing fan out.

In Fig. 3(b) for the mixed case, migration (M/C) on the first link dominates (higher value) in comparison to C/M. At the lower values of n both C/M and M/C overlap each other as for $n = 1$, both have one communication and one migration and vice versa.

In total it can be seen, that M/M has the better performance for good selectivity, i.e. $\theta < 40\%$. Further it can be seen, that C/M behaves almost the same as M/M, as the fan out n puts the dominance on the second part of the network.

Fig. 4 depicts the execution time with varying fan out and selectivity for F/nW case. Since the later links associated with n being wireless it dominates the results in overall. The wireless connection on the later links amounts up to larger execution time compared to the W/nF case depicted in Fig. 5. For the cases C/M and M/C again the second part of the network (the wireless part) dominates the overall behaviour, thus C/M behaves almost the same as M/M and M/C the same as C/C.

In case of Wireless-Fixed (W/nF) case as in Fig. 5, the wireless connection has more dominance in the first link. In the case of M/M and C/C as depicted in Fig. 5(a) for $n = 1$ shows the same result as Fig. 4(a) for $n = 1$.

In the Fig. 5(b) M/C shows much dominance compared to C/M for increasing value of θ due to combination of migration with wireless connection in the first link.

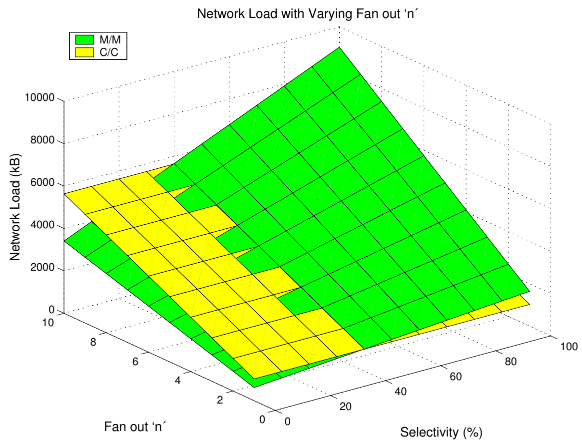
VII. Conclusion

This paper shows the applicability of mobile agents in logistical networks. Different scenarios of mobile agent usage are presented and combined in a unified notation. The analytical evaluation of mobile agents in logistical environments is presented with a strong focus on the fan out. It is shown that the influence of the fan out is either relatively lowering the network load and execution time of migration over traditional communication, when the selectivity is good. Or it is lowering the network load and execution time of traditional communication further over migration, if the selectivity of the mobile agent is not high enough.

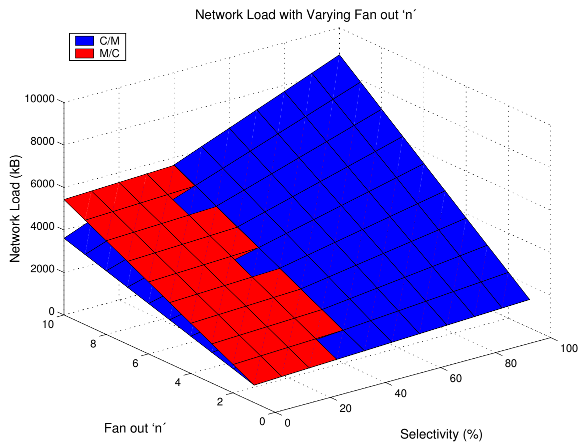
Improved caching as done for the MAS JADE by [9] should be increasing the advantage of migration also for worse selectivity, if the agents' code is already present at the execution location and does not need to be (completely) transmitted.

VIII. Outlook

Future work shall include experimental validation of the analytical modelling. TCP/IP overhead as introduced in [8] should also be integrated into the analytical evaluation of heterogeneous networks regarding the fan out. Finally other wireless networks' parameters shall also be used, as the execution time of the currently evaluated 9600 kbps channel is very high.



(a) M/M and C/C



(b) C/M and M/C

Fig. 3. Network load with varying fan out and selectivity

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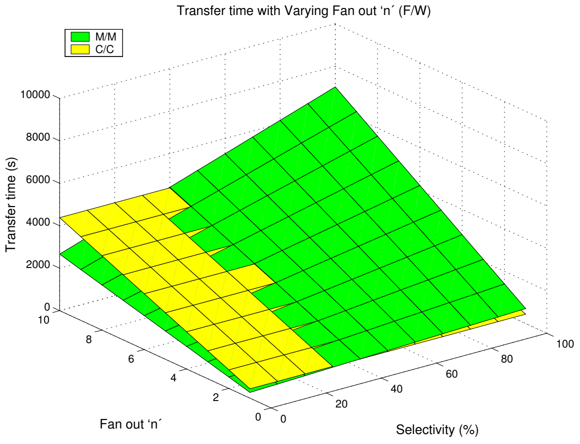
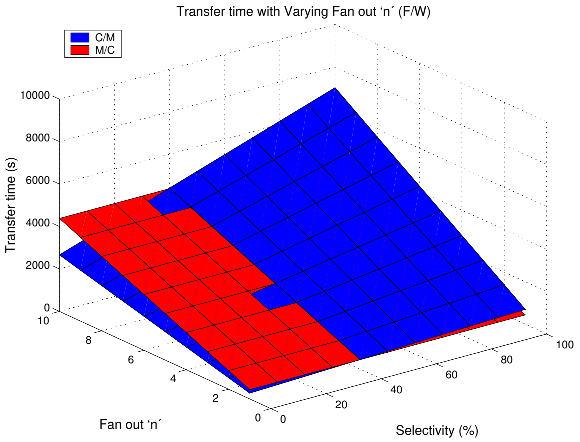
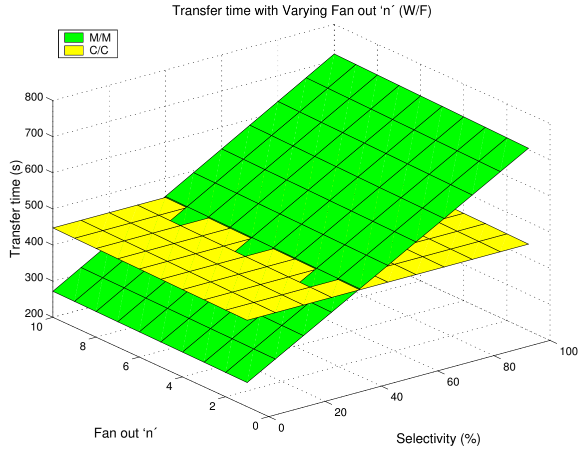


(a) M/M and C/C

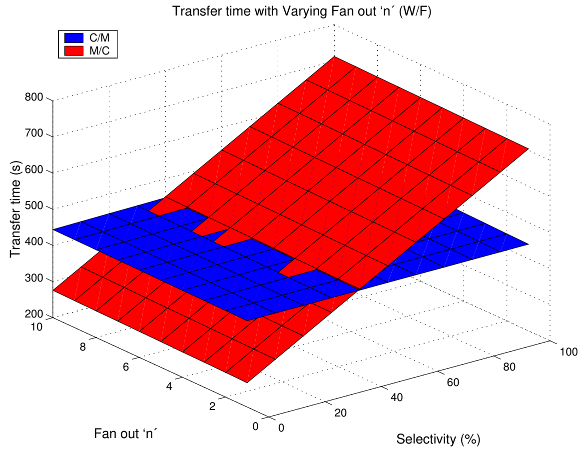


(b) C/M and M/C

Fig. 4. Execution time with varying fan out and selectivity `F/nW-Sequential`



(a) M/M and C/C



(b) C/M and M/C

Fig. 5. Execution time with varying fan out and selectivity `W/nF-Sequential`

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