On Mobile Agents for Autonomous Logistics: An Analysis of Mobile Agents considering the Fan Out and sundry Strategies

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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.

Keywords: Autonomous Logistics, Fan Out, Mobile Agents, Scenario Notation.

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1 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).

To achieve a significant increase in the efficiency of a logistic system, it's required to exploit technology and change the paradigm of the current logistic system. Interaction is the key factor for successful operation which may require communication between various entities of the logistic system. Within a project on "autonomous cooperating logistics processes" interaction of autonomous representatives in the logistic supply chain is researched. The focus lies on a paradigm shift from central coordination to a more distributed coordination.

1.1 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 autonomous cooperating logistics processes, due to the widely distributed heterogeneous open nature of agent platforms, e.g. by Klügl et al. (2005). 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.

A recent development in multi-agent systems research is their application in the logistics of the transportation sector, see Dorer and Calisti (2004, 2005); Martin Lorenz and Timm. Agent technology is assumed to be one of the promising fields that are foreseen to provide quality information flow for effective operation within the functional bodies of logistic networks, as their model of individualism is also very present in the logistics industry.

1.2 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 a spcific task due to the limitations imposed by the underlying communication network. Hence mobile agents are gaining more attention and are proposed to be used in mobile wireless environments by Straßer and Schwehm (1997); Helin (1999) among others.

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.

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1.3 Mobile Agents in Wireless Networks

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. Wireless networks tend to 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.

The ability to move the code, among other good reasons (see Mitsuru (1998)), makes mobile agent technology especially appealing in wireless networks. 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.

1.4 Mobile Agents for Logistics

Mobile agents can be representatives of vehicles, distribution centers, packages and other components of autonomous cooperating logistics processes (which are described in Scholz-Reiter et al. (2004)). They can then interact with other logistical objects respectively their agents by means of the underlying *multi-agent system* (MAS).

1.5 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.

The remainder of the paper is structured as follows:

Section 2 gives an overview of research in the area of analytical modelling of mobile agents. For our purpose of studying mobile agents in logistic environments, we introduce four scenarios in Section 3 and a specific notation for the scenarios in Section 4. In Section 5, 6 and 7 the analysis and the results obtained are presented. The conclusion obtained from the results is contained in Section 8 and an outlook on future research is given in Section 9.

2 State of the Art

Straßer and Schwehm (1997) introduced a performance model for mobile agent systems. They compared the performance of *Remote Procedure Calls* (RPC) and agent migration analytically and validated their model experimentally.

Helin (1999) extended this performance model to wireless networks and studied three different code block transfer scenarios.

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

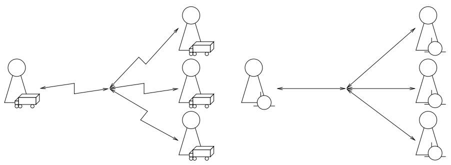
Transport Control Protocol (TCP) and *Internet Protocol* (IP) for mobile agents were taken into account with respect to the data amount to be transmitted and the execution time by Farjami (2004).

3 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.

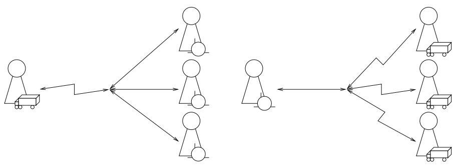
Contrary a mobile agent being a representative of a distribution center that would like to interact with other representatives of distribution centers, has all fixed connections as shown in Fig. 1(b).



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

Figure 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

Figure 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.

4 Scenario Notation

The scenarios depicted in Fig. 1 and 2 can be referred to 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.

5 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. 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

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

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

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

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

$$M_{Load} = P(B_{cr} + B_{code}) + B_{data} + B_{state} + M_{selec}, \quad (4)$$

$$M_{Exec} = (2 + 2P)\delta(H_i, H_{i+1}) + (1/\tau)(M_{Load}), \quad (5)$$

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 3 is given by

$$\mathrm{Cost}_{Load} = \mathrm{Cost}_a^{Load} + \mathrm{Cost}_{n,b,s}^{Load} \quad (6)$$

and

$$\mathrm{Cost}_{Exec} = \mathrm{Cost}_{A,a}^{Exec} + \mathrm{Cost}_{n,B,b,s}^{Exec}. \quad (7)$$

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

$$\mathrm{Cost}_a^{Load} = \begin{cases} M_{Load} & \text{if a=M,} \\ C_{Load} & \text{if a=C,} \end{cases} \quad (8)$$

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

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

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

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

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

and

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

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. In the analytics we implicitly assume that the decision in the branch strategy and the merging of the replies in the sequential and parallel strategy takes no time.

The values used in the analysis, whose results are laid out in Sec. 6, are listed in Tab. 1 and 2 for the agent characteristics and in Tab. 3 for the network characteristics. The parameters used for the agent characteristics and network characteristics are according to Helin (1999) and Yang. 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 as by Yang. It is also assumed that no code is available at the destination host ($P = 1$).

Agent Characteristics (Fan Out):	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 1 Agent Characteristics

Agent Characteristics (Strategy):	Values
Code for request 1 ($Breq_1$)	0.5
Code for request 2 ($Breq_2$)	5.0
Code for request 3 ($Breq_3$)	0.5
Code for request 4 ($Breq_4$)	5.0
Code block reply 1 ($Brep_1$)	640
Code block reply 2 ($Brep_2$)	10240
Code block reply 3 ($Brep_3$)	5120
Code block reply 4 ($Brep_4$)	10240

Table 2 Network Characteristics used for the Strategy results

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 3 Network Characteristics used for the Fan Out results

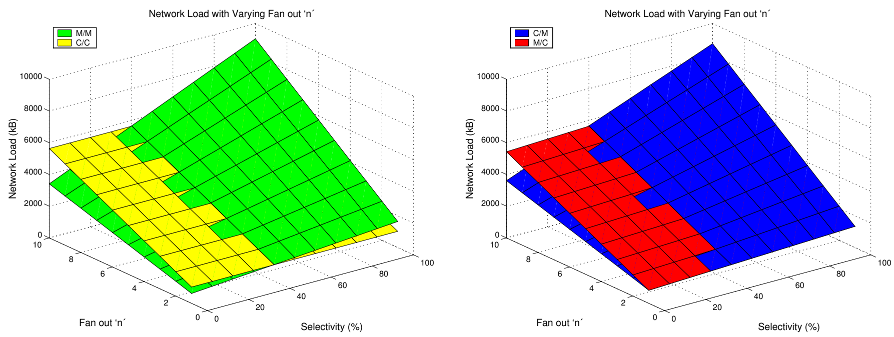
6 Fan Out Results

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. 3 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.

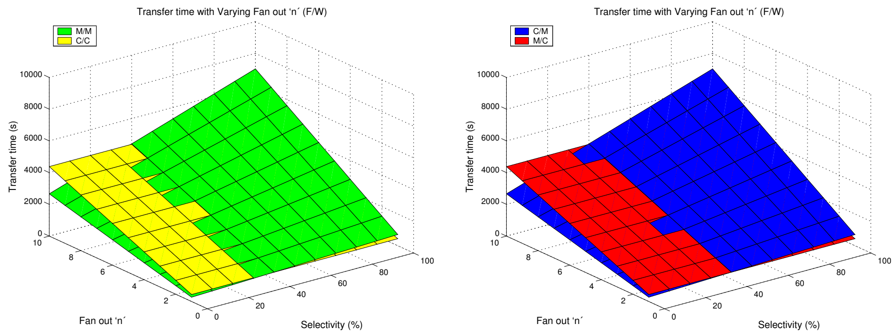
In total it can be seen, that M/M has the better performance for good selectivity, i.e. $\theta < 40\%$. Further it can be seen, that C/M behaves almost the same as M/M, as the fan out n puts the dominance on the second part of the network.



(a) M/M and C/C (b) C/M and M/C

Figure 3 Network load with varying fan out and selectivity

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.

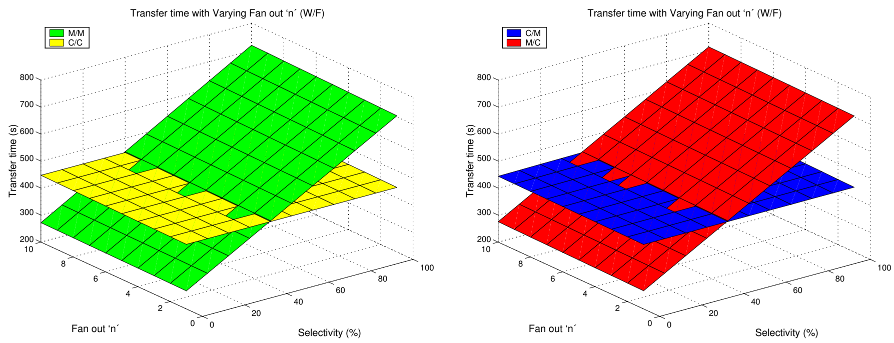


(a) M/M and C/C (b) C/M and M/C

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

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.



(a) M/M and C/C (b) C/M and M/C

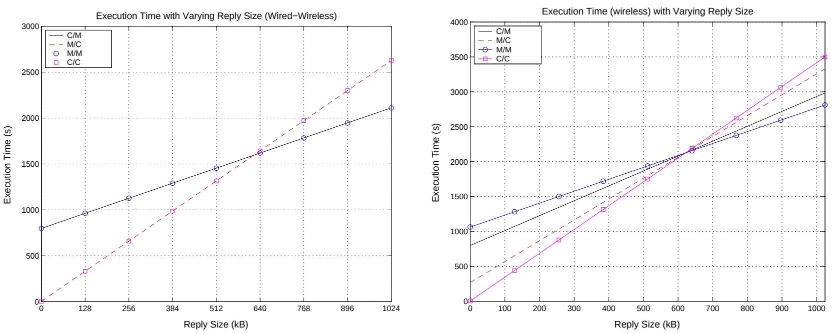
Figure 5 Execution time with varying fan out and selectivity `W/nF-Sequential`

7 Strategy Results

This section presents results and analysis drawn from the scenarios presented in the Sec. 3. Sequential, parallel and branch strategies are implemented for these scenarios and their effect on execution time is studied with respect to the parameter reply size.

For the results depicted below, it is assumed that the number of distributed links (fan out) n to be constant and equal to 3 as shown in Fig. 1 and 2.

In Fig. 6(a) and Fig. 6(b), sequential mode of functioning is depicted wherein the communication or migration takes place over the links in a sequential pattern i.e., one after the other. In Fig. 6(a) it is assumed that the wireless distributed links are exploiting wireless network and the first link to the gateway is within



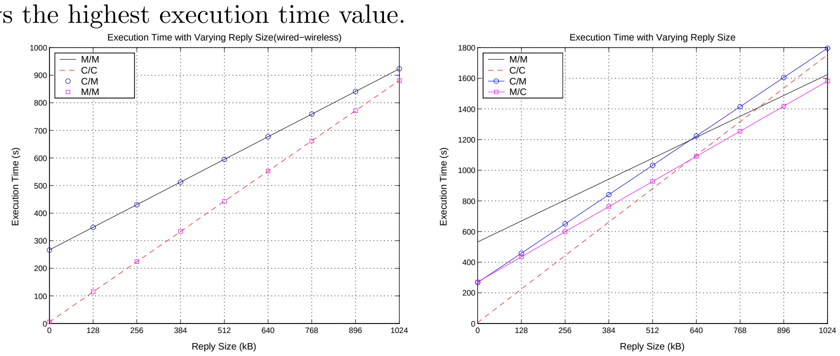
(a) F/3W (b) W/3W

Figure 6 Sequential

a fixed network. Since, wireless networks suffer from low bandwidth and higher delay, they have a dominant effect on the execution time and hence its seen that the combinations which have common scheme over the distributed wireless links overlap each other (C/C and M/C; C/M and M/M).

The time is multiplied by the fan-out n of the right hand side network and variation introduced by the fixed first link is negligible. It can be noticed that at 0 reply size the required execution time due to communication is almost 0 whereas for migration there is an offset. But, as the reply size increases the execution time increases more steeply for communication rather than migration resulting in an intersection of the two curves.

In Fig. 6(b), the results for the scenario where all links are wireless are depicted. As depicted earlier, communication does not have an offset at low reply sizes but it increases more rapidly with increase in reply size when compared to migration. Therefore, C/C curve start has the lowest value for 0 reply size whereas M/M has the highest value of execution time. But at reply size of 1024kB, the curve for C/C shows the highest execution time value.

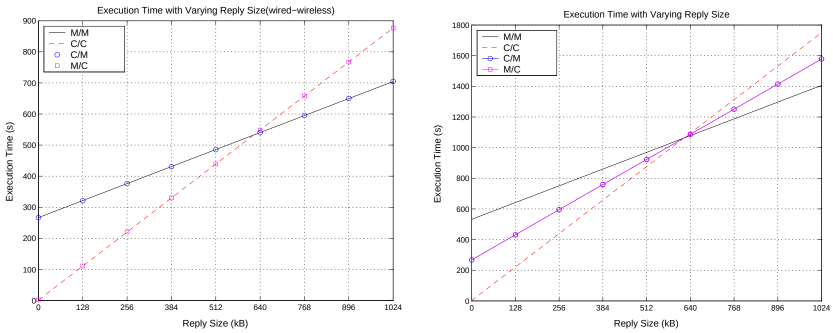


(a) F/3W (b) W/3W

Figure 7 Parallel

In Fig. 7(a) and Fig. 7(b), parallel implementation of migration/communication is depicted. As the name suggests migration/communication can take place over the distributed links in a parallel mode and need not wait for the other links to finish their operation. As expected the execution time is much reduced in this case when compared to the sequential implementation.

In Fig. 7(a) overlapping of C/M with M/M and M/C with C/C is observed due to the afore-mentioned reasons. In Fig. 7(b), it is observed that the M/M curve has the largest offset and C/C has the lowest. Whereas M/C and C/M has the same offset at start (reply size=0), but due to the larger selectivity in latter links (refer Table 2) migration (C/M) is more affected with increasing reply size which results in higher slope compared to the mixed case (M/C).



(a) F/3W (b) W/3W

Figure 8 Branch

In Fig. 8(a) and 8(b), another strategy is depicted that might be encountered in the world of logistics, termed as branch implementation. In this strategy, the network has to pick only one link out of the whole network. And unlike in parallel where the slowest link was the deciding factor for the execution time, here it will be the fastest link that will be selected. The fastest link is assumed to have the required information.

Similar to Fig. 6(a) and Fig. 7(a), in Fig. 8(a) too C/C and M/C curves overlap as do the curves of M/M and C/M. Here too it can be concluded that the curves intersection are solely due to the chosen parameter values in the Tables 1, 2 & 3. In Fig. 8(b) curves of M/C and C/M overlap as in branch we have the link with minimum load selected from the right hand side of the network and the chosen parameter values happen to be same for both sides of the network.

8 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 regard to the fan out and the strategies employed.

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.

Furthermore agent communication and migration has been evaluated with respect to three different execution strategies: Sequential, Parallel and Branch. With the more complex implementation of the parallel and branch strategies an improvement can be reached compared to the simple sequential strategy.

Improved caching as done for the MAS JADE by Braun (2005) 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.

9 Outlook

Future work shall include experimental validation of the analytical modelling. TCP/IP overhead as introduced by Farjami (2004) 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. For a further decrease of the amount of data to be transferred and the time needed, intelligent adaptation methods in agents that can change between communication and migration at runtime according to their knowledge on expected reply sizes and execution times shall be investigated.

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