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# Multi-agent Systems as a Middleware to Automate Mobile Business Processes: State of the Art

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*Abstract:* - The dynamic working environment of mobile workforces attracts the use of multi-agent systems in supporting mobile business processes. An agent's autonomy, sociality and intelligence are highly prized features when it comes to supporting those mobile workers who are geographically isolated from the main knowledge source (i.e. the corporate Intranet) and are frequently moving from one location to another. This paper proposes desirable metrics for any multi-agent systems platform intended for enterprise mobilisation use, and evaluates currently available multi-agent platforms for mobile devices based on the identified metrics. This paper also identifies some improvement points of currently available multi-agent platforms as an enterprise mobilisation platform.

*Key-Words:* - Multi-agent systems, mobile business processes, evaluation metrics, Mobility, Mobile devices.

## 1 Introduction

Despite its importance, the information system (IS) support provided for the management of a mobile workforce is frequently inferior to that provided for in-office workers. This is mainly due to the fact that the IS support requirements for a mobile workforce are different in many ways from those for in-office workers, as the latter work within a reliable computing environment [6]. Furthermore, the behavioural differences between mobile and in-office workforces also make it difficult for mobile workers to directly re-use an IS developed for in-office workers. This proposition has already been proved by some studies in the Task/Technology Fit research area [9].

Multi-agent systems (MAS) are considered as one of the main technologies to support mobile workers as the intelligence, autonomy, and sociality of software agents can easily be used to benefit them [1][10]. However, despite this potential usage, most existing MAS platforms have been primarily designed for in-office end users.

This paper aims to identify features that should be incorporated in a MAS platform in order to support an enterprise's mobile workforces. From this, we derive a set of metrics that are used to evaluate several MAS platforms in order to establish the goodness of fit of each with the needs of the mobile computing environment.

This paper is organized as follows. The next section reviews related work and Section 3 explains how the metrics for the evaluation of MAS platforms have been derived. Section 4 briefly describes the MAS platforms selected with our designed criteria for evaluation and then details the evaluation results. Finally, Section 5 discusses the issues found during the evaluation and concludes this paper.

## 2 Literature Review

The comparison of MAS platforms is considered difficult due to the lack of an agreed set of specific metrics, a consequence of the fact that many MAS platforms have been developed using different design philosophies, and targeted on different domains. As a result, existing evaluations or comparisons of MAS platforms are based on either generic or high level metrics. Mangina [11] reviewed thirty-six MAS platforms mostly focusing on their components and features. At the end of the review, he differentiated the platforms by their licensing policy and origins (academia or commercial). Giang and Tung [7] have also performed a similar study. They however used metrics such as the type of Java virtual machine (JVM) used, message type (KQML or FIPA ACL for example), security features, support for agent mobility, etc, for their evaluation. Ricordel and Demazeau [13] surveyed and compared four MAS platforms from a developer's point of view. Their comparison is focused on evaluating the level of support provided for each stage of a development

methodology (analysis, design, development, and deployment). Dikaiakos et al. [5] compared the performance of three mobile agent platforms. For this, they proposed a hierarchical performance evaluation framework, which consisted of four layers of metrics.

Carabelea and Boissier's work [2] has a similar motivation to this paper in that they focused on MAS platforms designed for mobile devices. However, they used basic metrics for the comparison, such as the target device, communication protocols supported, FIPA compliance, target JVM, etc. This paper is distinguished from their study by the metrics used for the evaluation and comparison of platforms. In this paper, we identify metrics specific to mobile computing for our comparison of MAS platforms.

# 3 Evaluation Methodology and Results

This section details the results from the evaluation of currently available MAS platforms, which target mobile devices. Section 3.1 briefly describes how the evaluation metrics are selected, and section 3.2 describes how MAS platforms were selected. Finally, the methodology used for their evaluation is described in Section 3.3.

**Table 1** Required features of a MAS platform for enterprise mobilisation

| Domain | Features |
|---|---|
| Usability | Platform replication<br>Agency recovery<br>Agency re-connection<br>Ghost agent management<br>Agent mobility<br>Multi-modal human agent interaction<br>Reasoning support |
| Device adaptability | Supported configurations |
| | Modularity support<br>Ease of configuration<br>User interface independence |
| Communication | Data compression support<br>Message buffering support<br>Firewall penetration by GPRS |
| Lightness | Static RAM footprint<br>Dynamic RAM footprint<br>Boot-up time |

## 3.1 Selection of Evaluation Metrics

The unique features that an IS must provide in order to support nomadic workers are derived from the constraints imposed by the mobile computing environment. Based on the literature review in the mobile computing area [2] and the experience gained from two field trials where a MAS platform was used to support mobile teams in the UK and Germany [1], we have identified a set of metrics can be used to evaluate the suitability of a MAS platform to support a mobile workforce. Table 1 summarises the identified evaluation metrics.

## 3.2 Selection of MAS platforms for evaluation

Anecdotal evidence suggests that there are a large number of MAS platforms in circulation. Therefore to reduce the number to be evaluated against the metrics identified in Section 3, we used three screening criteria: i) publicity, ii) explicitness, and iii) availability. Publicity was measured by checking if the MAS could be found on the Internet using a search engine or was described within published papers. Explicitness was fulfilled if the MAS platform explicitly stated that it was targeting mobile devices. Availability was satisfied if the MAS platform is available for use, either in an unrestricted or restricted (evaluation) mode. Based on these three criteria, five platforms were selected for evaluation, as shown in Table 2.

A detailed description of each MAS platform can be found via the references provided in this paper.

**Table 2** Selected MAS platforms

| Platform | Developer | License |
|---|---|---|
| JADE-LEAP [8] | LEAP Consortium | LGPL |
| DIET Agents [4] | BT Group | GPL |
| Micro FIPA OS [12] | University of Helsinki | Emorphia Public License |
| Cougaar [3] | BBN Technologies | Cougaar Open Source License |
| KSACI [9] | Uni. of São Paulo / Uni. of Federal de Pernambuco | Open Source |

**Comment:** Is this correct? I thought that Motorola were also a part of this?

## 3.3 Evaluation methodology

The evaluation of the selected MAS platforms was completed by checking both the user/developer guides and source code provided within the platform distribution. Furthermore, where an analytical approach was not feasible, live experiments were conducted using a PDA device and a GPRS network.

Fig. 1 shows the environment in which the live experiments were conducted. The environment consisted of two devices: i) a wireless PDA (D1, RAM 64M, Processor ARM SA1110), and a laptop (D2). Both devices ran the MAS platform under

investigation at the time and a single agent. Device (D1) communicated over a GPRS network, while device (D2) was connected to a wireline network. Communication between the devices was achieved via a virtual private network (VPN).

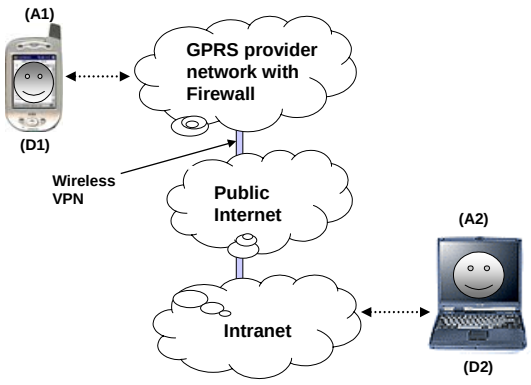


**Fig. 1** Platform evaluation environment

The metrics evaluated through live experiments were: i) agency re-connection support, ii) ghost agent management support, iii) message buffering support, iv) firewall penetration by GPRS, v) run time RAM footprint, and vi) boot up time. We now discuss how the first four of these were evaluated.

Agency re-connection was evaluated by terminating the network connection on device (D1), and after two minutes re-establishing the network connection, and checking to see if agent (A1) could reconnect to its previous community by sending a message. If the message was received by agent (A2) the platform passed. Ghost agent management was evaluated by terminating agent (A1) abnormally by stopping the JVM. Then after two minutes agent (A2) sent a message to agent (A1). If the platform indicated a failure has occurred with the message delivery, then it passed. Message buffering was evaluated by terminating the network connection for two minutes on device (D1), during this time agent (A2) sent a message to agent (A1). After two minutes the network connection was re-established for device (D1), and if the message was received, then the platform passed. Firewall penetration by GPRS was evaluated by sending a message from agent (A2) to agent (A1). If agent (A2) received the message, then the platform passed.

## 4 Evaluation Results

Table 3 summarizes the evaluation result of the platforms.

Note that each platform was evaluated 'as is' with no optimisations (such as those described in [15]) applied.

Firstly, Cougaar was the only platform that failed to run within the environment described in section 4.2. This is because it uses a Virtual Machine (KVM) which is no longer supported and is not available.

The majority of the platforms failed many of the usability metrics. In particular, no platform passed metrics such as agency recovery, multi-modal interface, and provision of an inference engine. On the other hand, agent mobility is the most supported metric (by four of the five platforms).

With regard to device adaptability, two platforms provided two different configurations for two types of mobile devices. As a result only these two platforms passed the ease of configuration metric. Support for the development of a user interface for different types of mobile devices is only partially supported by one platform, the rest do not provide any support. This seems to indicate that the platforms consider the development of a user interface as an application-specific task.

**Table 3** Evaluation results for selected MAS platforms: (1) kSaci, (2) DIET Agents, (3) JADE-LEAP, (4) FIPA-OS, and (5) Cougaar.

| **Metric** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** |
|---|---|---|---|---|---|
| *Usability* | | | | | |
| Platform replication | No | No | Yes | No | No |
| Agency recovery | No | No | No | No | No |
| Agency reconnection | Yes | Yes | Yes | Yes | N/A |
| Managing ghost agent | No | No | Yes | NO | N/A |
| Agent mobility | Yes | Yes | Yes | NO | Yes |
| Multi-modal interface | No | No | No | NO | No |
| Reasoning support | No | No | No | NO | No |
| *Comms Efficiency* | | | | | |
| Data compression | No | No | Yes | No | No |
| Message buffering | No | Yes | Yes | No | N/A |
| Firewall penetration by GPRS | No | No | Yes | No | N/A |
| *Device Adaptability* | | | | | |

| **Metric** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** |
|---|---|---|---|---|---|
| Supported configuration | J2ME CLDC | J2ME CDC | J2ME CDC/ CLDC | J2ME CDC | KVM TINI |
| Modularity support | Low | Low | Low | Low | Low |
| Ease of configuration | N/A | N/A | High | N/A | Med |
| UI configuration support | Low | Low | Med | Low | Low |
| *Lightness* | | | | | |
| Static RAM footprint | 64.8 kb | 315 kb | 1,034 kb | 1,298 kb | N/A |
| Dynamic RAM footprint | 99 kb | 95 kb | 111 kb | 340 kb | N/A |
| Boot-up time | 2606 ms | 164 ms | 10107 ms | 4180 ms | N/A |

Only one platform passed all the metrics for communication efficiency while the other platforms didn't consider this functionality in their design. Particularly, it is notable that most of the platforms except JADE-LEAP failed to penetrate the GPRS network provider's firewall, which prevents the use of these platforms in a GPRS environment.

The size of the static RAM footprint seems proportional to the functionality provided by the platform. The platform that passed most of the metrics had the biggest static RAM footprint while the platform that failed most of the metrics had the smallest one.

Summarizing, most of the platforms evaluated failed most of the metrics. In particular, we consider agency recovery, multi-modal interface, inference engine and UI configuration support as important areas which need to be addressed by developers of MAS platforms. JADE-LEAP is an exception, which failed very few of the metrics.

## 5 Discussion and Conclusions

Due to both time constraints and page limitations, certain metrics have been excluded from this paper. For example, message latency, dynamic RAM usage, and platform stability (the length of time a MAS platform can provide its services) have been excluded although they are seen as important metrics within a mobile computing environment. And, it should be noted that the metrics presented within this paper originated from the analysis of requirements for mobile business processes. Therefore the metrics may differ from those for say a MAS for mobile commerce or an entertainment environment. Finally, it must be mentioned that every effort has been made to ensure an extensive search was conducted to locate suitable MAS platforms that could satisfied the initial screening criteria. However, we acknowledge that there may be a number of MAS platforms that satisfy all our metrics, but were not located, despite our best effort.

In summary, the contributions of this paper are twofold. Firstly we identify functionality that is considered useful if supported by a MAS platform for enterprise mobilization, and secondly we evaluate a handful of publicly available MAS platforms to give an overview of the state of the art. Despite the limitations mentioned above, this paper proposes some areas for improvement for MAS platforms to enable them to better support enterprise mobilization.

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