From e-Manufacturing to M-Manufacturing

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Abstract: *This paper studies the impact of wireless technologies on enterprises. A multitude of new paradigms and new software technologies have emerged from the web. E-business and e-manufacturing have really transformed concepts and practices in enterprises. Wireless technologies added new possibilities for these technologies, by this work we propose m-manufacturing as a component of e-manufacturing when practiced in mobile environment, then compare e-manufacturing to m-manufacturing. We applied our proposed approach to model m-maintenance of spare parts. Combination of mobile agent technology and fault-tolerant principles has given an appropriate global solution tom m-maintenance issues*

Keywords: *Wireless technologies, mobile enterprise, m-manufacturing, m-maintenance, mobile agents, fault-tolerance*

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1. Introduction

By this work, we present m-manufacturing as the discipline gathering with remote manufacturing practices if done through wireless technologies. First we present briefly the evolution of enterprise networking, the impact of internet on enterprise practices, then we introduce wireless technologies and mobile enterprise and define m-manufacturing. Next sections present a fault-tolerant model of m-manufacturing based on mobile agents and checkpointing techniques. Finally, a mathematical formulation is given with an evaluation of a chosen scenario.

2. Evolution of Enterprise Networking

Modern enterprises have now complex information system typically built on Local Area Networks (LANs) with many subsystems like Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), Knowledge Management (KM), Manufacturing Execution System (MES), and Business Process Management (BPM). Fieldbuses are particular types of LANs dedicated to industrial usage in shop floors. Traditionally, the shop floor was isolated from the rest of the supply chain and within the organization. A traditional fieldbus network consists of several nodes like sensors and actuators physically connected through a wired bus. Fieldbuses are now doted with TCP/IP interfaces with organisation LAN and with Internet [21], as consequence enterprise's network became a complex infrastructure formed by a number of sub-networks interconnected through gateway interfaces typically Ethernet. Links can be wired or wireless (without need of any cable or other physical media).

We call this complex structure a *multi-net* and define it as a complex infrastructure formed by interconnecting a number of heterogeneous LANs like ethernet LANs, fieldbuses, and industrial ethernet and so on with wired or wireless links. In Figure 1, a typical multi-net is presented. This infrastructure provides naturally more possibilities to achieve what is called Enterprise Integration (EI) [11], or Virtual Enterprises (VEs) [22].

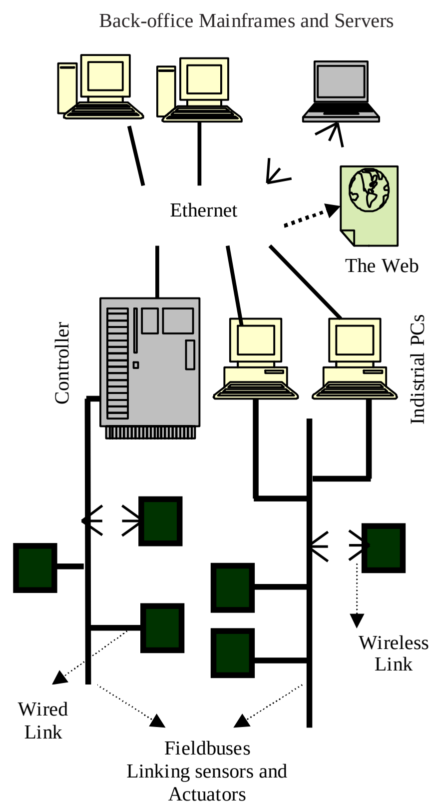

Figure 1. Example of a multi-net.

For the past decade, web-based technologies added new promising possibilities to achieve intra- and inter-organizational integration of the enterprise. Today e-business and in particular e-commerce have emerged as a powerful technology to facilitate business transactions around the world [12]; but internet technology is not just e-business, it is also e-production. E-manufacturing [7] has emerged as a new industrial discipline offering to manufacturing processes what e-business do to business ones. In some fields, using internet technologies to control production lines or mechanical systems is possible. For example with e-maintenance it is now possible to make remote diagnostics, to solve and repair problems, to prepare maintenance phases etc. [9]. With e-expertise, it will become possible for experts to operate from their office a machine located somewhere in the world, just using classic web technologies

3. Mobile Enterprise

The obvious and most important consequence of wireless technology in enterprises is mobility. Today mobility has transformed enterprise by incorporating mobile devices, mobile networking and mobile internet technologies to enable new possibilities and perspectives in communication, information access and business transaction from anywhere and anytime. Enterprise networking has evolved from traditional LANs to Wireless Local Area Networks (WLANs). WLAN are implemented as an extension to wired LANs within a building and can provide the final few meters of connectivity between a wired network and the mobile user [17].

Existing business solutions can be extended easily into m-business with best flexibility and less cost [16]. Mobile computing technology can also be used to support fieldwork and increase collaboration among field workers by providing on-line access to information and interactive communication facilities.

In the MOST project [5], engineers working within the power distribution industry in the field were traditionally coordinated by a single control centre, in order to help field engineers work more efficiently, they were given possibilities to work in a mobile environment. Mobile computers were used to obtain maps indicating the current state of the power distribution system in the area in which they were working. The engineers were also able to communicate with each other and with their control center to coordinate activities and safely resolve switching requirements.

Another good example of mobile work is given by construction project [3]. The global nature of many construction projects means that project teams are increasingly geographically dispersed working across time zones, numerous organisational boundaries and a variety of cultures. These teams are often quickly brought together to deliver a construction project within limited time and resources. At the same time, the construction processes have increased in complexity in the recent years and have become more information-intensive.

Enterprises embracing mobile technologies are often said "mobile enterprises"; mobility in enterprises delivers new concepts related with new forms of business services and work. Next definitions are adopted from [2, 10].

3.1. Mobile Business Solution

Mobile business solution "refers to a set of business-oriented applications that are operated using mobile terminals, such as mobile phones, PDAs or laptops" [2].

3.2. Mobile Work

Mobile work is a "combination of technology, workplace organization, work facilities and support systems allowing people to work mobile and in multiple locations at different times" [2]. Classification of mobile workers has been introduced in [10] in Star-project [18]. In this model, the main factors for classifying mobile workers are frequency of changing location and the number of locations where a worker carries out tasks. There are five categories in this classification: *On-site movers*, *Pendulums*, *Yo-Yos*, *Nomads* and *Carriers*. *On-site-movers* move continuously inside a geographically limited area when working like a plant. *Pendulum* workers change location quite often. They have generally two possible working places. The office and home for example, *Yo-Yo's* are workers that have many working locations inside a geographically limited area. *Nomads* are those persons that work continuously wherever they are. A nomad is highly mobile and the area of mobility is not limited to a certain geographical area. The definition of the *Carrier* type of mobile work refers to personal or commodity transportation involving continuously moving from one place to another.

4. Towards M-Manufacturing

Wireless networking provides the enterprises new prospects in choices for technology to be used not only in management of business information system but also to carry out solutions of remote manufacturing processes in industrial networks. On the basis of these remarks and considering the objectives of our future work, we distinguish between e-manufacturing which is based on wired remote control and m-manufacturing which is based on wireless remote one. The *m-manufacturing* is the discipline gathering of the activities of control or of supervision in a manufacturing system via a wireless network; we associate the concepts of m-maintenance, m-control, and m-supervision to it. This differentiation allows the company to make a judicious choice for the solution to be adopted between the possibilities offered by e-manufacturing, also m-manufacturing through wireless internet, or a pure m-manufacturing through a disconnected WLAN. Combining internet to wireless technologies gathers the advantages of two technologies, but weaknesses of both also concerning the real time and the quality of services.

Table 1. M-manufacturing vs. e-manufacturing.

M-manufacturing (in Limited Area Around the Enterprise)	e-manufacturing (via Traditional Internet)
Low bandwidth	Large bandwidth
General resource poverty (storage capacity, computing power and battery life)	No problem with resources
Real time Relatively controllable (local network)	No real time
Limited QOS	Limited QOS
Reduced Installation cost (no wiring)	High installation cost
Reduced maintenance	High maintenance (wires)
Local network: best security	Extended network: security causes problems
Greater flexibility and reconfigurability	No flexibility and very difficult reconfigurability
Well adapted in geographically limited area (WLAN)	Well adapted in extended area when QOS and real time are not priorities (Internet)

Table 1 compares main characteristic of WLAN m-manufacturing and e-manufacturing, and Figure 2 shows the desirable borders for applications m-manufacturing and of e-manufacturing, the limits in dotted line indicate open borders. The e-manufacturing can be applied through traditional internet without any geographical restrictions when Quality Of Service (QOS) and real time are not priorities; typically, the m-manufacturing is better when applied in a WLAN.

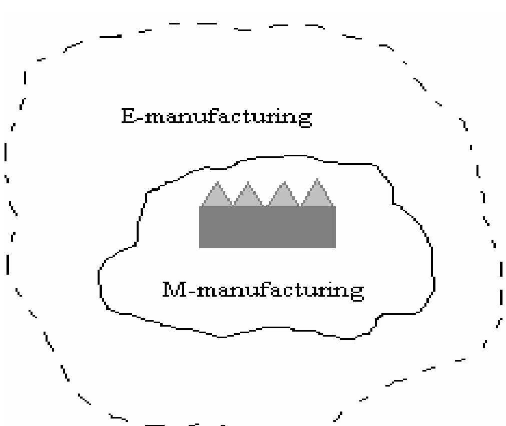

Figure 2. M-manufacturing and e-manufacturing boundaries.

5. Case Study: M-maintenance of Spare Parts

In [4] an agent-based approach was proposed to support the management of spare parts using e-environment. An extended enterprise is described using an organization model, an interaction model is defined to manage the shared resources of the different sites, and each site has an internal architecture based on Multi-Agent System (MAS). The model baptized AGIRAT considers following types of static agents.

- *Supervisor Agent*: it is the main agent of the system associated to a site; its role is the management and the control of the working of the system. The supervisor describes the set of the objectives of the system and observes its state. It communicates the incoming and retiring quantities of articles. He also throws the requests of acquirement and offer of the spare part. The supervisor ensures the communication with other sites.
- *Prevention Agent*: the prevention agent is an intelligent agent, provided with the capacity to decide according to its Knowledge Base (KB), to foresee and then to indicate to the supervisor agent, the cases of under-stock or on-stock of spare parts quantities. This agent studies the operations of prevention using algorithms that calculate the previous consumptions and the time of stock rupture. These algorithms may include other criteria's as mean time between failures, failure rate or mean time to repair (for more details see [4]).
- *The Coordinator Agent of a Group*: an agent representing a group of sites is called Coordinator of the Agents of the Group and is baptized CAG. It receives all requests emanating from supervisors of the group; it is a shape of real estate agency regrouping all information on the offers and the demands of the agents of the group. In case, where the request finds a favourable answer at this CAG, this last puts in contact the concerned agents, in order to enter in direct negotiation. The CAG detains all information concerning the surpluses and the deficits of the different articles used by the members of the group and send periodically to their supervisor, informations about surplus and deficits. The role of a CAG associated to a group of sites (S_1, S_2, …, S_p, ...) is the coordination and the receipt of the needs, in quantity of articles, of the different sites of the group, surpluses and deficit for every article. It classifies these needs; optimises the costs for every article and answers to the claimants.
- *The Inter-Group Coordinator Agent*: an Inter-group Coordinator agent called CIG ensures the communication between the different groups. Its role is the contribution to the establishment of the balance of the loads, once this balance reached; it

has to supervise it, which means to avoid the unbalance.

6. Adapting the Model to Mobility

We think about a scenario where maintenance is under control of mobile workers, typical applications can be in environments similar to those presented in [5] and [3]. Static agents communicate generally through Xml protocols, but it seems that Xml protocols are too “heavy” for mobile devices [1]. Mobile agent’s technology seems to be a good candidate to resolve the problem. A mobile agent can autonomously migrate from one agent platform to an other to interact with other agents and to do specific tasks it can for example, perform local processing, or retrieve information and bring back the results [15]. A mobile agent can suspend its execution at an arbitrary point, transfer itself to another machine, and then resume its execution from the point at which it left off. Mobile agents are advantageous in particular in user mobility where there is intermittent connectivity, low bandwidth and limited local storage. Furthermore, according to Lange and Oshima [8], there are seven good reasons to use mobile agents:

- They reduce the network load.
- They overcome network latency.
- They encapsulate protocols.
- They execute asynchronously and autonomously.
- They adapt dynamically.
- They are naturally heterogeneous.
- They are robust and fault-tolerant.

We extend the model presented in [4] in a manner to make it more appropriate to mobility as explained above, the solution we propose is to use a set of mobile agents called Mobile Collectors Agents (MCAs) to handle interactions between main agents: in one hand between the CIG and the CAGs and in the other hand between the CAG and supervisors of its group. These “scouts” agents are sent to collect useful information or to do specific tasks locally before bringing back with the result.

The interaction model is performed by agents of the system according to this script:

1. *The CAG periodically sends an MCA to the sites of its group to retrieve all information from them: levels of stock ($P_{K, J, surplus}$) to offer and ($P_{K, J, deficit}$) to require.*
2. *The MCA then produces a report to the CAG.*
3. *The CAG evaluates all propositions and establishes the best costs for every article k.*
4. *The site S_i wants to acquire a $P_{k,i}$ quantity or to offer a $P_{k,i}$ quantity, emits its desire to its CAG.*
5. *The CAG already knows the site S_j that proposes the optimal cost, and then sends him a message of proposition. In case of unavailability of article within the group, the CAG associated with the group must call upon other sites of other groups via the Inter Group Coordinator agent (CIG) (by sending an MCA to it).*
6. *Negotiation between the sites S_j and S_i on the cost of the quantity of article k until signature of the contract.*
7. *In any case, the CAG must be informed of the exit of the negotiations and in case of disagreement; he proposes the offer to another site by re-applying the practicum’s (1 to 6) again.*

This operation occurs again until signature and realization of a contract.

7. Fault-Tolerance Model

The three-step interaction model (the MCA sent, the MCA collects information’s or do some task, the MCA come back) ensure better fault-tolerance to the system. For example, in the case of disconnections, the operation can resume without problems after establishing the connection. Figures 3 and 4 represent a scenario when a CIG interacts with its groups in centralized manner AGIRAT and with an MCA.

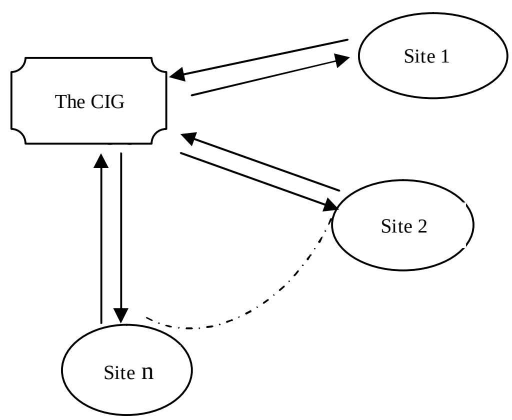

Figure 3. The CIG collecting informations in AGIRAT.

As depicted by Figure 3, the centralized architecture suffers from a bottleneck, mobile agent-based architectures represent a resolution to the bottleneck issue, but this solution must be fault-tolerant, with no fault-tolerance, if an MCA resides at site *n* and site *n* fails, all execution results that occurred between sites 1 and *n* are lost with the MCA and the execution must be performed again. Checkpointing models for fault-tolerance have been proposed to ensure these characteristics [13], in our model, prior to each agent migration, an archival copy of the agent is stored at the site from which it is migrating. One way the sender (CAG, CIG …) can recognize the failure is based on expiration of the duration for the MCA to complete the sequence (i.e., a timeout occurs). When this occurs, the sender can recover the last known copy of the MCA through a search across the sequence path. The agent can then be restarted and sent to complete the rest of the sequence.

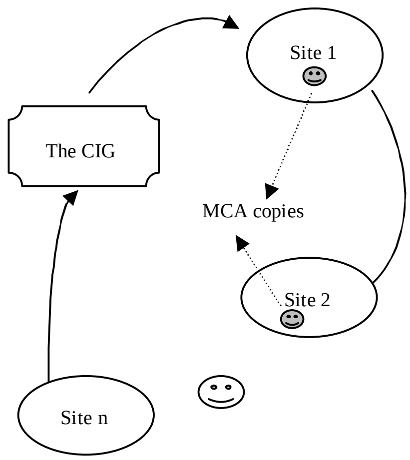

Figure 4. The CIG collecting information with MCA.

8. Model Formulation

This section intends to give a mathematical formulation to the model; this analysis is based on some works namely [14, 19, 20, 6].

We try to evaluate and compare time execution in both AGIRAT model (static agents) and MCA based model (mobile agents). In the next sections we consider each location (site) in a different server.

8.1. Case of AGIRAT Model

In this context when an agent *A* needs some service from a remote Agent *B*, interaction is traditionally done through RPC [19], a (classical) RPC includes binding to the server (destination site), marshalling, transfer, unmarshalling (of the request parameters), execution of the request, and marshalling, transfer and unmarshalling of the reply (marshalling and unmarshalling are transformation of data in a transport format and back). The execution time T_{static} for a simple remote procedure call from location S_1 to location S_2 consists of the time for marshalling and unmarshalling of request and reply (μ) plus the time for the transfer of the data on a network with throughput τ (S_1, S_2) and delay δ (S_1, S_2) plus the time of execution of the request *(q)*

$$T_{static}\left(S_1, S_2, Re_{q_s}, Re_{p_s}\right) = 2d(S_1, S_2) + \left(\frac{1}{t(S_1, S_2)} + 2m\right)\left(Re_{q_s} + Re_{p_s}\right) + q \quad (1)$$

In the case of AGIRAT model, as shown in Figure 4 if the CIG (or the CAG) has to perform n interactions with n sites, total time can be given by following equations

$$TT_{static} = \sum_{i=1}^{n} T_{static}\left(S_0, S_i, Re_{q_s}, Re_{p_s}\right) \quad (2)$$

8.2. Case of MCA Based Model

A (classical) migration includes marshalling, transport and unmarshalling of code, data and execution state of the agent to the server. The agent has also in most cases to perform a local or remote procedure call and eventually to do some specific task; we assume that these activities are with a cost in time (r). Marshalling increases linearly with the size of data with factor (μ)., the corresponding execution time is described by:

$$T_{mobile}\left(S_1, S_2, Re_{q_s}, Re_{p_s}\right) = 2d(S_1, S_2) + \left(\frac{1}{t(S_1, S_2)} + 2m\right)\left(S_1, S_2, Re_{q_s}, Re_{p_s}\right) + r \quad (3)$$

With parameters delay *(d)*, throughput (τ) and marshalling (μ).

In a scenario such as described in Figure 4 the mobile agent MCA has to collect data items from all sites in its itinerary. Let $S = (S_1, \ldots, S_n)$ be a sequence of sites to be visited, when S_0 represent the site of the sender (source site). The size A_s of an agent *A* is initially comprised of $Code_s$, $States$ and Re_{qs}.

Because the MCA collects one reply from each site and must carry all results, at each succeeding site a new data items of cost $(1\text{-}\sigma)$ Re_{ps} must be added and the total data before migration to site S_i equals $(i\text{-}1)$ $(1\text{-}s)$ Re_{ps}. Last stage when the MCA comes back, only $state_s$ and the replies are brought to S_0.

With assumptions above, the execution time for the agent itinerary, without checkpointing is formulated by the following equation:

$$\begin{aligned} TT_{mobile} = & \sum_{i=1}^{n}\left(\begin{array}{l} d(S_{i-1}, S_i) + r \\ + \dfrac{code_s + State_s + Re_{q_s} + (i-1)(1-s)Re_{p_s}}{t(S_{i-1}, S_i)} \end{array}\right) \\ & + d(S_n, S_0) + \frac{State_s + n(1-s)Re_{p_s}}{t(S_n, S_0)} \\ & + m\left((n+1)\left(code_s + Re_{q_s} + 2state_s\right) + 2n(1-s)Re_{p_s}\right) \end{aligned} \quad (4)$$

where $code_s$ is the size in kilo-bytes of code, $state_s$ is the size of execution state of the agent, and Re_{qs} is the size of the request. The size of reply is represented by Re_{ps}; Re_{ps} is reduced (filtering and compressing) to $(1\text{-}s)$ $Reps$ by the agent, with $(0 \leq s \leq 1)$ where s models the selectivity of the agent.

In the fault-tolerant model, the total network execution time for the agent itinerary must be calculated taking into account checkpointing costs; for this purpose, we assume that a copy of the MCA is stored at each visited site, if a certain timeout occurs the sender performs a search among all sites of the itinerary, to recover the last available agent checkpoint copy of the MCA. If this last is found at site *k* it sends a message of size Re_{ks} to site *k* so that a new MCA is restored from the copy and reactivated to resume the itinerary. We suppose that a binary search is performed and require at each step an informational message of size I_s to be sent by the sender and a response of size R_s to be received.

Furthermore, to model the average checkpointing-recovery-rollback costs, we have to evaluate execution time of the checkpoint, time to detect failure and time to recover state after a failure, so we need these additional variables:

- D_i is the speed of local disk write in site S_i measured in kilo- bytes per second.
- F is the probability of sequence path failure.
- L is the factor of acceptable timeout as percentage of expected execution time.

Additional load necessary to perform the recovery-rollback procedure is comprised of all the informational messages and responses respectively sent and received and the message Re_{ks}.

Since a binary search among n nodes implies at average log_{2}^{n} steps, and taking into account the message sent to reactivate the copy of the MCA, we conclude that additional load is given by this equation:

$$A_L = \left(log_{2}^{n} * \left(I_s + R_s \right) \right) + Re_{k_s} \tag{5}$$

As assumed above a checkpoint consists of a local disk write of a copy of the agent MCA, total checkpointing time can be calculated as follow:

$$T_{check} = \sum_{i=1}^{i=n} \frac{code_s + state_s + Req_s + (i-1)(1-s)Rep_s}{D_i} \tag{6}$$

While recovery rollback time is calculated as following:

$$RR = \left(log_2(n) * \left(\frac{I_s + R_s}{t} \right) \right) + \frac{Re\ k_s}{t} \tag{7}$$

where t is the average throughput in the network. The formulation for expected additional execution time for this fault-tolerance model can be given by this equation:

$$A_T = T_{check} + F\left(RR + L * TT_{mobile} \right) \tag{8}$$

This expected execution time is comprised of the total time it takes to perform checkpointing activities, and the expected cost of failure, detection and recovery. Finally expected total execution time for the agent itinerary is given by this equation:

$$TT_{mobile-check} = TT_{mobile} + A_T \tag{9}$$

9. Analytical Validation with a Typical Scenario

In this section we try to compare execution time of both MCA based model and AGIRAT model when practiced in mobile environment. Because the AGIRAT model is not fault-tolerant, at a first step we neglect fault-tolerance then estimate later additional time induced by fault-tolerance mechanisms. For this scenario we suppose in some construction project the equipment maintenance is under a mobile worker, he has the usage of a mobile device (such as PDA or laptop) where the main application is implemented (location S_0).

This device has obviously only wireless low bandwidth access to the internet. The sites proposing spare parts (S_1, ... S_n) are situated on traditional intranets. For sake of simplicity and without lost of significance, we assume disk write speed, throughputs and delays identical for the sites (S_1, ... S_n) and we ignore the execution times r and q which are close to zero. Table 2 presents the presumed characteristics of this typical scenario, these values are proposed with regard to some experimental studies given in works cited above.

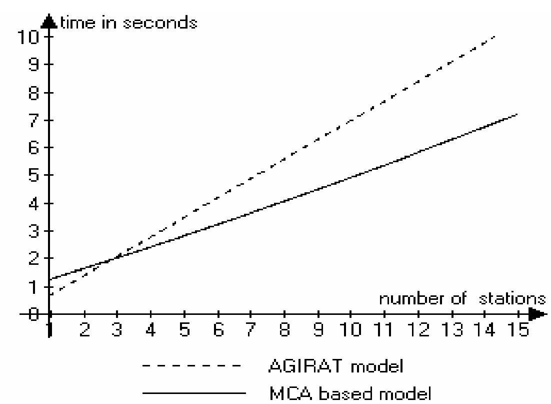

Figure 5. Execution time of AGIRAT model and MCA based model in mobile environment.

Figure 5 shows that for a few number of stations (e.g., less than three), execution time in AGIRAT model are better than execution time in MCA based model; but when the number of stations increases, it is the MCA based model which outperforms the AGIRAT model in time consuming. The reason is that in AGIRAT model we have n low-bandwidth interactions against two low bandwidth and n-1 high bandwidth interactions in the MCA based model. At a first step the MCA migrates from the PDA (S_0) to the first site of its itinerary (S_1) through a mobile connection, then performs its itinerary from S_1 to S_n through high bandwidth connections and finally returns back from the last site (S_n) to its original location through a mobile connection again.

Although the MCA based model produces more load than AGIRAT model; for a number of stations greater than three, the number of low bandwidth links increases in AGIRAT model so that it is not possible any more to produce good performance in time. Furthermore, Figure 6 shows that additional time induced by fault-tolerance mechanism is negligible despite the additional load.

Table 2. Parameters retained for the case study.

Parameter	Value
$Code_s$	25 Kb
$State_s$	5 Kb
Req_s	4Kb
Rep_s	6 Kb
I_s	2 Kb
R_s	3 kb
Rek_s	3 Kb
D_i $i = 1 \ldots n$	2000 Kb/s
μ	5 ms /Kb
s	0.40
F	0.1
L	0.01
$t(S_0,S_1)$	50 kb/s
$d(S_0,S_1)$	200 ms
$t(S_i,S_{i+1})$ i = 1 … n	500 Kb/s
$d(S_i,S_{i+1})$ i = 1 … n	50 ms

M-manufacturing provides powerful solutions to flexible and reconfigurable manufacturing practices in mobile environment. Wireless technologies present some problems at hard level (bandwidth, power, disconnection) that may cause bad consequences at soft level. By this work and future ones, we are exploring possibilities provided by mobile agents technology as a good response for many mobility issues, so we propose an approach for m-manufacturing applications that combines mobile agent technology and a fault-tolerance model based on checkpointing techniques.

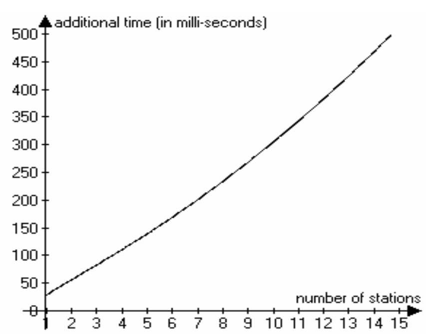

Figure 6. Additional time induced by fault-tolerance mechanism.

10. Conclusion

As a case study, we modelled a platform of m-maintenance of spare parts; finally we presented a mathematical model of our solution. Performance evaluation for a typical scenario had shown that for m-maintenance, mobile agents technology can be better than static agent technology. Currently we are trying to implement a prototype of our model on Java platform using aglets technology with ASDK toolkit.

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