Hierarchical token based mutual exclusion algorithms

Marin Bertier, Luciana Arantes, Pierre Sens

INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Hierarchical token based mutual exclusion algorithms

Marin Bertier — Luciana Arantes, Pierre Sens

N° 5177

Avril 2004

THÈME 1

ISSN 0249-6399 ISRN INRIA/RR--5177--FR+ENG

Hierarchical token based mutual exclusion algorithms

Marin Bertier*† , Luciana Arantes, *† Pierre Sens *†

Thème 1 — Réseaux et systèmes
Projet REGAL

Rapport de recherche n° 5177 — Avril 2004 — 20 pages

Abstract: Mutual exclusion is a basic block of distributed synchronization algorithms. One of the challenge in highly distributed environments (like peer-to-peer or Grid configurations) is to provide scalable synchronizations taking into account the hierarchical network topology. This paper proposes hierarchical mutual exclusion algorithms. These algorithms are extensions of the Naimi-Trehel's token algorithm, reducing the cost of latency and the number of messages exchanges between far hosts. We propose three main extensions : (1) hierarchical proxy-based approach, (2) aggregation of requests, and (3) token preemption by closer hosts.

We compared the performance of these algorithms on an emulated Grid testbed. We study the impact of each of the extensions, showing that the combination of them can greatly improve performances of the original algorithm.

Key-words: experiement, mutual exclusion, token, hierarchical, grid

* Laboratoire d'Informatique de Paris 6, CNRS
† INRIA

Unité de recherche INRIA Rocquencourt
Domaine de Voluceau, Rocquencourt, BP 105, 78153 Le Chesnay Cedex (France)
Téléphone : +33 1 39 63 55 11 — Télécopie : +33 1 39 63 53 30

algorithme hiérarchique d'exclusion mutuelle à jeton

Résumé : L'exclusion mutuelle est un bloc de base de l'algorithmique de synchronisation distribué. Un des défis dans les environnements fortement distribués (comme le pair-à-pair ou les configurations de grille) est de fournir des synchronisations scalable tenant compte de la topologie hiérarchique du réseau. Ce rapport propose des algorithmes d'exclusion mutuelle hiérarchiques. Ces algorithmes sont des extensions de l'algorithme à jeton de Naimi-Trehel, réduisant le coût de la latence et du nombre de messages échangés entre les sites distant. Nous proposons trois extensions principales: (1) approche basée sur des proxys hiérarchique, (2) l'agrégation des demandes, et (3) la préemption par des sites locaux.

Nous avons comparé l'exécution de ces algorithmes sur un banc d'essai émulé de grille. Nous étudions l'impact de chacune des extensions, montrant que leur combinaison améliore considérablement les performances de l'algorithme original.

Mots-clés : expériementation, exclusion mutuelle, jeton, hierarchique, grille

1 Introduction

Basic classical algorithms are commonly used by distributed applications. However, with the emergence of peer-to-peer and Grid computing, these applications spread over a larger number of nodes. Furthermore, in such environments latency gaps between hosts interconnects are very important. Therefore, distributed algorithms should be adapted to take into account those characteristics. A well-known example of such algorithms is mutual exclusion algorithm, which ensures exclusive access to a shared resource.

Many algorithms have been proposed to solve the problem of mutual exclusion in distributed systems. They can basically be divided into two groups: *permission-based* (Lamport [1], Ricart-Agrawala [2], Carvalho-Roucairol [3], Maekawa [4]) and *token-based* (Suzuki-Kazami [5], Raymond [6], Naimi-Trehel [7], Neilsen-Mizuno [8], Chang, Singhal and Liu [9]). The first group of algorithms are based on the principle of consensus between hosts, i.e., a host gets into a critical section only after having received permission from all other hosts. In the secong group of algorithms, a system-wide unique token is shared among hosts and the possession of it gives a host the exclusive right to enter into the critical section. Permission-based algorithms generally suffer from limited scalability. In contrast, token-based algorithms have an average low message cost and usually result in logarithmic message complexity O(log(N)) with regard to the number of hosts.

The majority of O(log(N)) token-based algorithms are tree-based, i.e., a logical tree structure expresses the different token requests and token propagation paths at a given time. Raymond'algorithm [6] organizes the hosts in a static logical tree structure. This tree remains unchanged, but the direction of its edges can change dynamically as the token propagates. Consequently, the directions of the edges always point to the possible token holder. Neilsen and Mizuno [8] extended this algorithm by passing the token directly to the requesting host instead of through intermediate hosts. Naimi-Trehel's algorithm [7] maintains a dynamic logical tree, such that the root of the tree is always the last host that will get the token among the current requesting ones. Chang Singhal and Liu [9] improved this algorithm, aiming at reducing the number of messages to find the last requesting host in the logical tree. Mueller [10] also proposed an extension to Naimi-Trehel's algorithm, introducing the concept of priority in it. A token request is associated with a priority and the algorithm first satisfies the requests with higher priority.

Although all those O(log(N)) token-based algorithms achieve better performance with respect to the average number of messages exchanged per critical section entry when compared to other mutual exclusion algorithms, they do not consider latency differences in hosts interconnects. We propose distributed token-based mutual exclusion algorithms, based on Naimi-Trehel's algorithm, which takes into account network topology, specially the latency gap between local and remote clusters of machines. Our algorithms reduce the numbers of inter-cluster messages and give a higher priority to local mutual exclusion requests. We have chosen to adapt Naimi-Trehel's algorithm because it uses a changeable logical tree structure to control mutual exclusion requests. This dynamic property of the tree is strongly exploited in our solution in order to tolerate higher latencies.

It is worth reminding that some authors [11] [12] have proposed mutual exclusion algorithms where nodes are, for some reason, gathered into groups. They basically propose hybrid approaches where the algorithm for intra-group requests is different from the inter-group one. However, they do not consider difference in network latency between hosts as a factor for grouping hosts. In [13], the authors propose to adapt the mutual exclusion mechanism of a DSM system to the latency hierarchy of an interconnection of clusters. Contrary to our proposal, their solution is based on a centralized token-based mutual exclusion protocol.

In the rest of the paper, we consider a general model where each host has a local memory and can send messages to any other. Communication between hosts is assumed to be perfect. Hosts are divided into clusters.

We distinguish local hosts belonging to the same cluster from remote hosts belonging to remote clusters. Furthermore, the words hosts and nodes are interchangeable.

Section 2 describes Naimi-Trehel's algorithm. In section 3, we present our hierarchical versions of Naimi-Trehel's algorithm, which limit the propagation of requests between clusters. The three extensions to Naimi-Trehel's algorithm that we propose, per cluster proxy, aggregation and token preemption, are also described in this section. Section 4 presents comparative performance evaluation of these algorithms, while the last section concludes our work.

2 Naimi-Trehel's algorithm

Naimi-Trehel's algorithm is a token-based algorithm, which maintains a logical dynamic tree structure such that the root of the tree is always the last node that will get the token among the current requesting nodes.

Each node i stores the following variables:

- The *owner* variable, which represents the probable owner of the token.
- The *next* variable, which represents the node that will receive the token when the critical section is released by i.
- The boolean *token* variable, whose value is true if the process owns the token, or false otherwise.
- The boolean *requesting* variable, whose value is true if the process requests the token, or false otherwise.

The identifier of i is represented by the variable *self*, while *Elected_node* identifies a unique node, among all nodes, that initially holds the token.

Figure 1 summarizes Naimi-Trehel's algorithm.

An example of Naimi-Trehel's algorithm execution with 4 nodes is shown in figure 2. Solid lines represent *owner* links, while dashed ones represent *next* links. The dark node keeps the token. Initially (a), A is the *Elected_Node* which holds the token. The *owner* of

```
Every node i:

Initialization
    resquesting ← false
    next ← ∅
    owner ← Elected_node
    if owner = self then
        token ← true
        owner ← ∅
    else
        token ← false

Request_CS
    requesting ← true
    if owner ≠ ∅ then
      {The process hasn't the token, request for it:}
        Send ⟨Resquest, S_i⟩ to owner
        owner ← ∅
        Wait for receiving message ⟨Token⟩

Release_CS
    requesting ← false
    if next ≠ ∅ then
        Send ⟨Token⟩ to next
        token ← false
        next ← ∅

Receive_Request_CS(S_j)
                          {S_j is the requesting process}
    if owner = ∅ then
                                        {Terminal node}
        if resquesting = true then
                                    {The node asked for CS}
            owner ← S_j
            if next = ∅ then
                next ← Sj
        else
      {First request to the token since the last CS,}
{directly send the token to the requesting process}
            token ← false
            Send ⟨Token⟩ to S_j
    else
        {Non-ternimal node, following the resquest}
        Send ⟨Request, S_j⟩ to owner
        owner ← S_j

Receive_Token
                        {Receive the token from node k}
    token ← true
```

Figure 1: Naimi-Trehel's algorithm

all nodes points to A. In (b), B asks for the token, sending a request to its *owner* (A), and becomes the new root ($owner_B = \emptyset$). Then, A updates its *next* and *owner* to point to B. In (c), C asks A for the token, then the request is forwarded to B which updates its *next* to C. Both A and B update their *owner* to C, since the latter is the last requester of the token (C becomes the root of the tree). When A will release the critical section, the token will be sent to B (*next*).

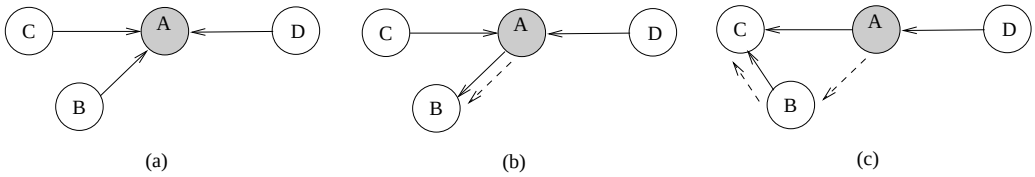


Figure 2: Sample execution of Naimi-Trehel's algorithm

3 Hierarchical algorithms

Since inter-cluster latencies are higher than intra-cluster ones, the three extensions we proposed to Naimi Trehel's algorithm is based on the idea of limiting the propagation of requests between nodes of different clusters. To this end, we apply the following three extensions to Naimi-Trehel's algorithm:

- First, we introduce on each cluster, excepting the one that initially holds the token, a dedicated process, called proxy, which is in charge of storing the last request to remote clusters. Before asking for a token which it believes belong to a node of a remote cluster, a node i first sends a request to its corresponding proxy. If another node j of the same cluster has recently asked for the token and the proxy is aware of it, the proxy redirects the request to j avoiding transmission to the remote cluster. In fact, the proxy operates like a cache of remote requests. This hierarchical algorithm is presented in section 3.1.

- The second extension aims at reducing the number of inter-cluster messages by aggregating remote requests. When a request has to be redirected to a probable owner, belonging to a remote cluster, the request is not sent to it but stored in a queue. This queue accumulates therefore requests for remote clusters. It is stored in the last node which will enter the critical section within the cluster. We name this node the *local_root*. We must remind that queuing of requests has been used by other Naimi-Trehel's-based algorithms as in [10]. However, in our case, it is applied only for remote cluster requests.

- Finally, we perform a local preemption of the token giving a higher priority to requests originating from the local cluster in order to exploit cluster locality. We define a

threshold that defines the degree of locality and avoids starvation. When the number of local request is below this threshold, the requesting path is modified in order to serve local requests first. These last two extensions are presented in section 3.2.

3.1 Proxy-based algorithm

We modify Naimi-Trehel's algorithm presented in section 2 as follows:

The *LocalCluster* variable, added on each node i, identifies the cluster to which node i belongs.

On each cluster Ci, excepting the one that has the *Elected_node*, a node is elected among Ci's nodes to have a specific initialization role. This node is called the $Proxy_i$.

Initially, the *owner* variable of $Proxy_i$ points to the *Elected_Node* as well as the *owner* variable of the nodes that belong to *Elected_node*'s cluster. On the other hand, the *owner* variable of the other nodes points to the $Proxy_i$ of their respective cluster.

Figure 3 summarizes our hierarchical proxy-based version of Naimi-Trehel's algorithm.

Figure 4(a) presents an example of an initial configuration with two clusters, $C0$ and $C1$, where nodes A, B, and C belong to cluster $C0$, and nodes D, E and $P1$ belong to $C1$. $P1$ is the *Proxy* of $C1$. Initially, A has been elected to have the token (the *Elected_Node*). We consider that A is in the critical section (CS).

In 4(b), B asks A for the token. A and B belong to the same cluster. Since A is in the CS, A sets both its *owner* and *next* variable to B.

In 4(c), D, which does not belong to the same cluster of the token holder, asks for the token. It sends then a request to its proxy $P1$, which redirects the request to A. $P1$ sets its *owner* to D. When arriving at A, the request is forwarded to the root (B) which simply updates its *next* and *owner* variables to D. E asks then for the token. The proxy $P1$ locally redirects the request to D which updates its *next* and *owner* variables to E. At the end of each critical section execution, the token will follow the path pointed by *next* variables. This scenario shows the advantage of the algorithm since E request was not forwarded to the remote cluster C_0, as it would be the case in the original Naimi-Trehel's algorithm.

3.2 Aggregation and preemption algorithms

We have modified the proxy-based algorithm of the previous section 3.1 to reduce even more the number of inter-cluster messages. This improvement is based on aggregation of messages and preemption of the token by local nodes.

On each node i, we added the following variables:

- The *R_ Queue* variable, which is a queue of requests issued from remote clusters.
- The *nb_preempt* variable, which represents the number of local requests that have preempted requests issued from remote clusters.

Figures 5 and 6 describe the algorithm.

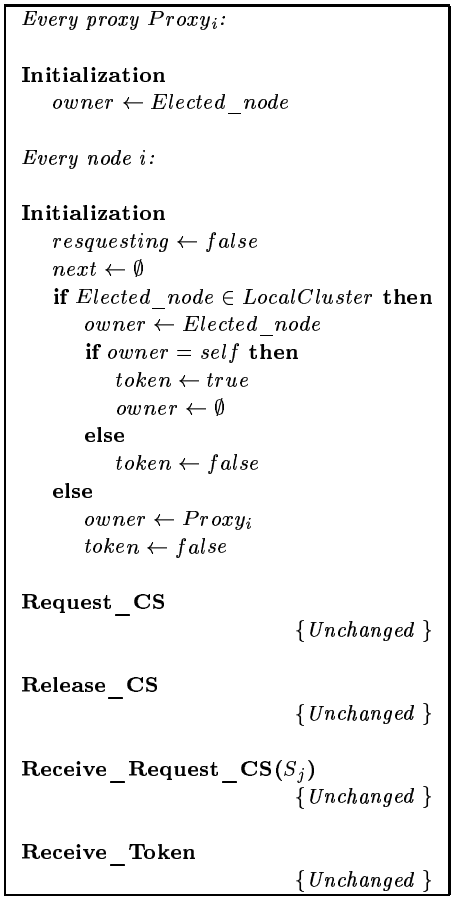
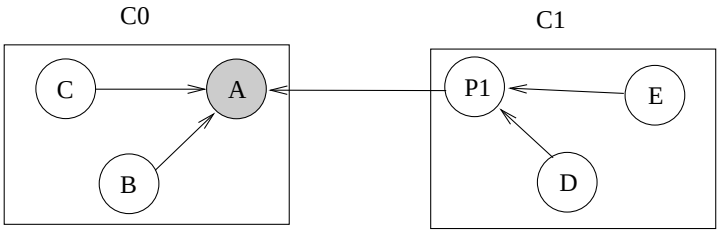
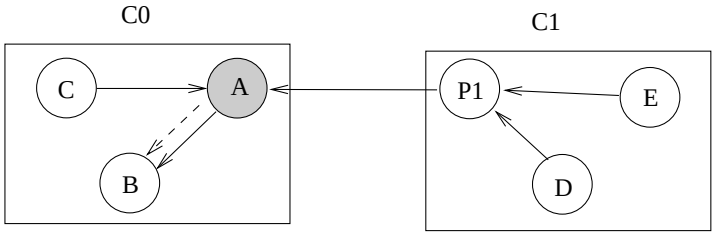


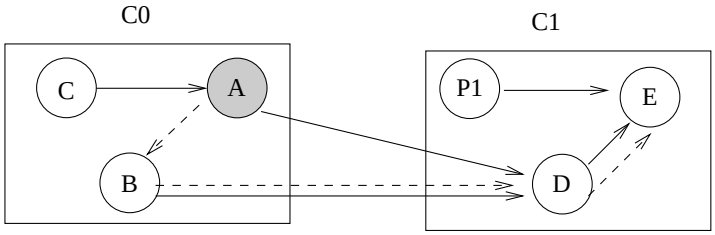
Figure 3: Proxy-based algorithm



(a) Initial configuration A holds the Token



(b) B asks for CS



(c)D and E ask for CS

Figure 4: Hierarchical proxy-based algorithm execution scenarios

```
Every proxy Proxy_i:

Initialization
    owner ← Elected_node

Every node i:

Initialization
    requesting ← false
    next ← ∅
    R_Queue ← ∅
    if Elected_node ∈ LocalCluster then
        owner ← Elected_node
        if owner = self then
            token ← true
            owner ← ∅
        else
            token ← false
    else
        owner ← Proxy_i
        token ← false

Request_CS
    requesting ← true
    if owner ≠ ∅ then
        {The process hasn't the token, request for it:}
        Send ⟨Request, S_i⟩ to owner
        owner ← ∅
        R_Queue ← ∅
        Wait for receiving message ⟨Token⟩

Release_CS
    requesting ← false
    if next ≠ ∅ then
        if next ∉ LocalCluster then
                {The token will be sent to a remote}
            nb_preempt ← 0
            if R_Queue ≠ ∅ then
                owner ← Queue(R_Queue)
            else
                owner ← next
        Send ⟨Token, R_Queue, nb_preempt⟩ to next
        token ← false
        next ← ∅
```

Figure 5: Aggregation and preemption algorithm: request and release critical section

```
Every node i:

Receive_Request_CS(S_j)                                   {S_j is the requesting process}
  if owner = ∅ then                                                    {Terminal node}
    if resquesting = true then                                  {The node asked for CS}
      if next = ∅ then
        next ← S_j
        if S_j ∈ LocalCluster then
          owner ← S_j
      else
        if S_j ∈ LocalCluster and nb_preempt < Threshold then
          nb_preempt ← nb_preempt + 1        {Local preemption of the token by the sender}
          R_Queue ← next + R_Queue
          next ← S_j
          owner ← S_j
          Send ⟨Queue, R_Queue, nb_preempt⟩ to owner
          R_Queue ← ∅
        else                                          {Add the sender to the end of R_Queue}
          R_Queue ← R_Queue + S_j
          owner ← S_j
    else                                                {First request to the token since the last CS,}
      token ← false                                {directly send the token to the requesting process}
      Send ⟨Token, R_Queue, nb_preempt⟩ to S_j
  else                                                 {Non-ternimal node, following the resquest}
    Send ⟨Request, S_j⟩ to owner
    if S_j ∈ LocalCluster then
      owner ← S_j

Receive_Token(R_Queue_k, nb_preempt_k)                          {Receive the token from node k}
  token ← true
  R_Queue ← R_Queue_k + R_Queue
  if k ∈ LocalCluster then
    nb_preempt ← nb_preempt_k
  if next = ∅ then
    next ← Head(Q)
    R_Queue ← R_Queue − Head(Q)
  else
    if next ∈ LocalCluster then
      Send ⟨Queue, R_Queue, nb_preempt⟩ to owner
      R_Queue ← ∅

Receive_Queue(Q, nb)
  nb_preempt ← nb
  if next = ∅ then
    next ← Head(Q)
    R_Queue ← R_Queue − Head(Q)
  else
    if next ∈ LocalCluster then
      Send ⟨Queue, R_Queue, nb_preempt⟩ to owner
      R_Queue ← ∅
```

Figure 6: Aggregation and preemption algorithm: message handlers

Similar to the original Naimi-Trehel's algorithm, a request for entering a critical section (CS) follows the *owner*'s path until it reaches its *local_root* (the node of the same cluster whose *owner* variable is set to $\emptyset$, i.e., the last node of the cluster to have requested the critical section).

When a node receives a request, if it is not a *local_root* node ($owner \neq \emptyset$), it forwards the request and updates its *owner* (only if the request is issued from the local cluster in order to avoid redirection to remote clusters). If the receiver is a *local_root* node ($owner = \emptyset$) which waits for the token ($requesting = true$), we distinguish two cases: (1) The received request is the first one since the node waits for the token (i.e. $next = \emptyset$). Then, the *next* is set to the requester because after the node obtains and releases the critical section, it will have to send the token to the requester. The *owner* is also updated *only if* the request came from the local cluster. (2) The *next* is already set. Since the receiver is a *local_root*, the *next* inevitably points to a remote node. In this case, if the requester is local, and the number of preemptions is below the threshold, we perform a local preemption of the token by setting *next* to the requester and memorizing the old *next* in the beginning of R_Queue. Each time a node becomes the new *local_root*, the R_Queue is sent to it. The R_Queue is also included in the token message.

Figures 7 and 8 show some samples of the algorithm's execution. We consider the same configuration presented in figure 4(b) where B asks A for the token. A third cluster $C2$, with nodes F, G and $P2$ ($Proxi_2$) is included in the figure. $Threshold$ of preemption is equal to 2.

In figure 7(a), the node D asked for the token. It sends a request to its proxy $P1$, which redirects it to A, setting its own *owner* to A. On A the request is propagated to the *local_root* (B), which simply updates its *next* (the *owner* of A and B are not updated since the requester is a remote node). Then, F belonging to cluster C_2 asks A for the token. The request is forwarded to the *local_root* (B). Since B's *next* is already set ($next = D$), the requester (F) is inserted in the R_Queue.

In figure 7 (b), node E of $C1$ asks for the token. The proxy $P1$ *locally* redirects the request to D (the *local root* of C_1) which updates its *next* and *owner* to E. At the same time, C reclaims the token. The request is redirected to B. Since B's *next* points to a node of a remote cluster and the number of local preemption is below the threshold, the *next* and *owner* paths are changed: the *next* and *owner* of B are updated to designated the local node C. The old value of B's *next* (D) is added at the beginning of R_Queue (it is not shown in the figure). C is the new *local_root*, receiving then the R_Queue. When C receives the R_Queue, it removes the head value of it ($= D$) and sets its *next* to this value.

In figure 8(a), A releases the token. It sends it to its *next* node (B). B releases then the CS and sends the token to C. A and B set their *next* to $\emptyset$. In (b), C ends the execution of the CS and sends the token with the R_Queue to the remote node D. It also sets it *owner* to F. At the end of its section, D will send the token to E according to its *next*. In (c), when D ends executing the CS, it sends the token to E and the R_Queue. When receiving the message, E updates its next variable to F.

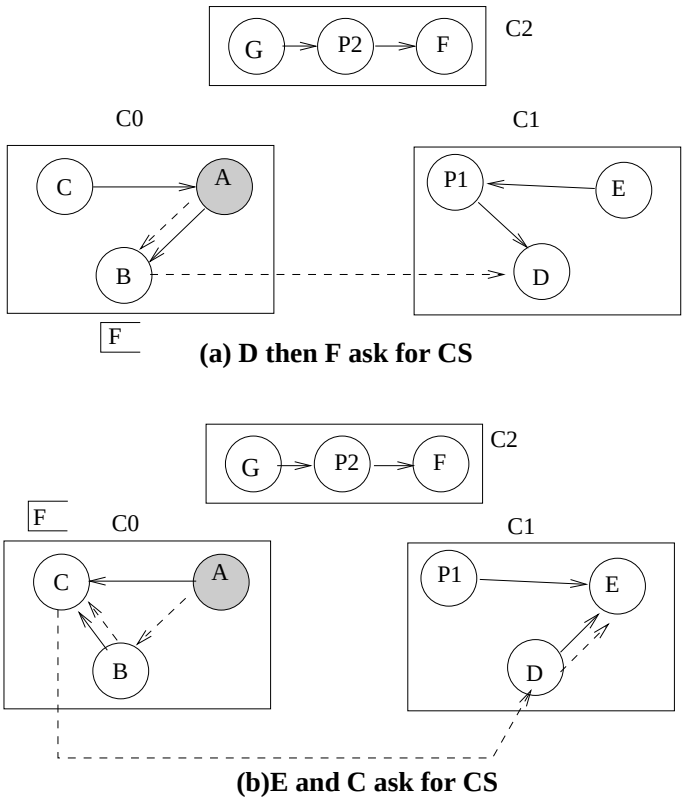
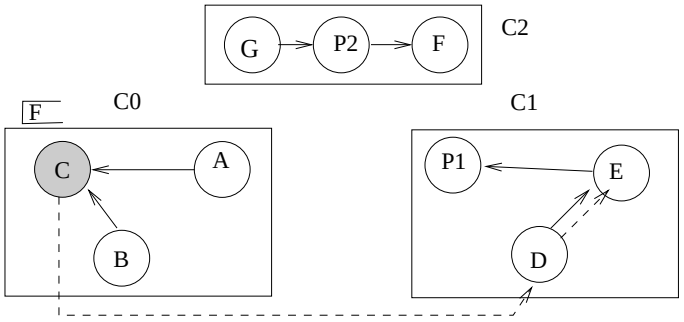
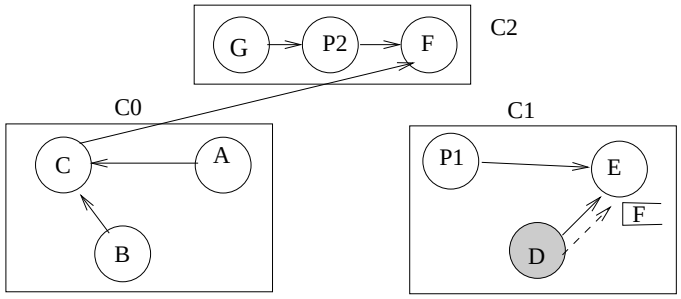


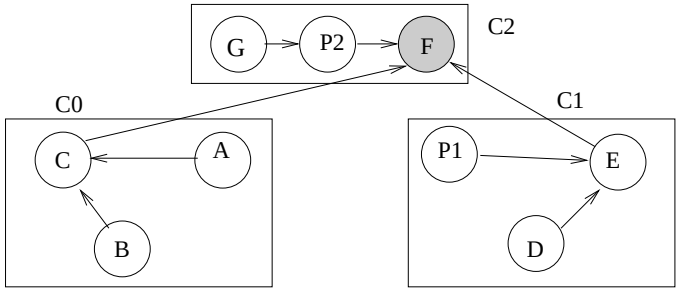
Figure 7: Aggregation and preemption algorithm execution: Inter-clusters requests



(a)A then B end CS



(b) C ends CS



(c) D and E end CS

Figure 8: Aggregation and preemption algorithm execution: Token transmission

4 Performance evaluation

This section presents the performance evaluation of several experiments which compare the efficiency of mutual exclusion algorithms. We compare the six following algorithms:

- *Centralized* token-based algorithm. In this classical algorithm, a unique host, the *lock_manager*, manages all token requests and granting messages. When a host wants to enter into the CS, it sends a request to the *lock_manager*; when a host ends the CS it gives back the token to the *lock_manager*, which forwards it to the next requesting host.
- *Broadcast* algorithm, which implements the permission-based Ricart-Agrawala algorithm [2]. A node wishing to enter into the CS sends a request to every other node and waits for their permission. When a node receives a request, it sends its permission to the requesting node if either it is not requesting itself the token or another node's request precedes its own.
- *NaimiTrehel* algorithm, which implements the Naimi-Trehel's token-based algorithm presented in section 2.
- *Proxy* algorithm, which implements the algorithm presented in section 3.1.
- *PreemptAggregation* algorithm, which implements the algorithm presented in section 3.2, which provides token preemption and message aggregation approaches.
- *Preempt* algorithm, which just disables the aggregation mechanism of *PreemptAggregation* algorithm.

To emulate a Grid environment with multilevel network latencies, we have used a specific distributed test platform, that allows injection of network delays. We establish a virtual router by using DUMMYNET [14] and IPNAT. We use IPNAT, an IP masquering application, to divide our network into virtual LANs. DUMMYNET is a flexible tool originally designed for testing network protocols. It simulates bandwidth limitations, delays, packet losses. In practice, it intercepts packets, selected by address and port of destination and source, and passes them through one or more objects called queues and pipes which simulate the network effects. In our experiment, each message exchanged between two different LANs passes through this specific host.

4.1 Evaluation experiment configuration

The experiment described in this section was performed on a non dedicated cluster of nine PCs. We consider a heterogeneous network composed of two Pentium III 600 MHz and six Pentium IV 2 GHz linked by a 100 Mbits/s Ethernet. The algorithms were implemented in Java (Sun's JDK 1.4) on top of a Linux 2.4 kernel.

PCs are spread in 3 clusters of 3 hosts. The topology is preliminary known by every system member as well as the initial owner of the token.

For these experiments, we introduce a delay of 300 ms for inter-cluster communication. Every involved site produces 20 mutual exclusion requests.

These requests are characterized by :

- α is the time taken by a node to execute the critical section,
- β specifies the mean time between releasing the critical section and requesting it again,
- ϵ is the preemption threshold only for *Preempt* and *PreemptAggregation* algorithms.

The performance measures include :

- the **number of exchanged messages**, divided in two categories : messages exchanged between two hosts in the same cluster (local messages) and messages between two hosts of different clusters (global messages).
- **obtaining time** is the time for an host between the moment when it requests the critical section and the moment when it get into it.

4.2 Results and Discussion

The aim of these experiments is to observe evolution of the behavior of each algorithm when the relation between α and β varies and ϵ increases. Figures 9 and 10 show the obtaining time as a function of α, β and ϵ. Figure 9 compares our *PreemptAggregation* algorithm with classical algorithms : *NaimiTrehel*, *Centralized* and *Broadcast* algorithms. While figure 10 compares the same algorithm *PreemptAggregation* with our other algorithms : *Proxy* and *Preempt*. The figure 11 compares the number of messages exchanged between hosts during an experiment where $\alpha = \beta = 500$ ms and table 1 summarizes the same experiment. To represent in the same figure the number of messages exchanged in the broadcast experiment, this number of messages is represent by a scale four times greater than the scale of the other algorithms.

For all algorithms when the ratio α/β decreases the obtaining time decreases too, simply because statistically when an host requests the token, there are less requesting hosts and they stay less time in the CS. The first remark about these experiments is that for each algorithm which uses the preemption, the obtaining time decreases when the preemption threshold increases. We can easily explain this result by the fact that local communication is cheaper than global communication. As shown in figure 11, the number of local messages increases when the number of preemption increases while the number of global message decreases. This also explains why all the algorithms presented in figure 10 are more efficient than the classical algorithms presented in figure 9.

The *PreemptAggregation* algorithm is the most efficient algorithm presented here. The *Aggregation* mechanism reduces the number of messages exchanged in the *Preempt* algorithm. In the *Proxy* algorithm, the fact that initial inter-Lan requests are intercepted by the local cluster leader allows to decrease the number of global messages.

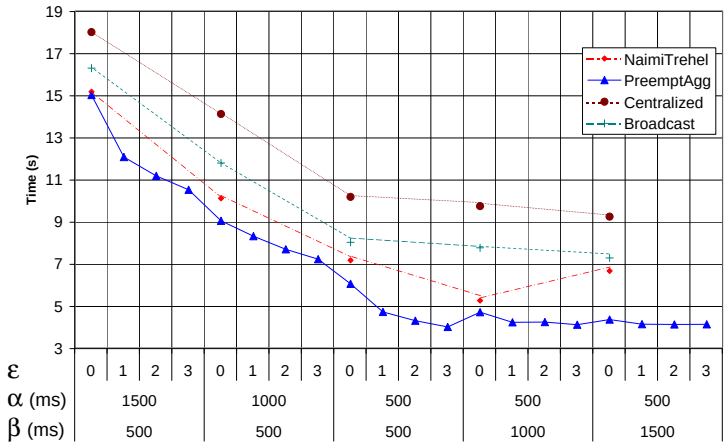


Figure 9: Comparison algorithm : obtaining time

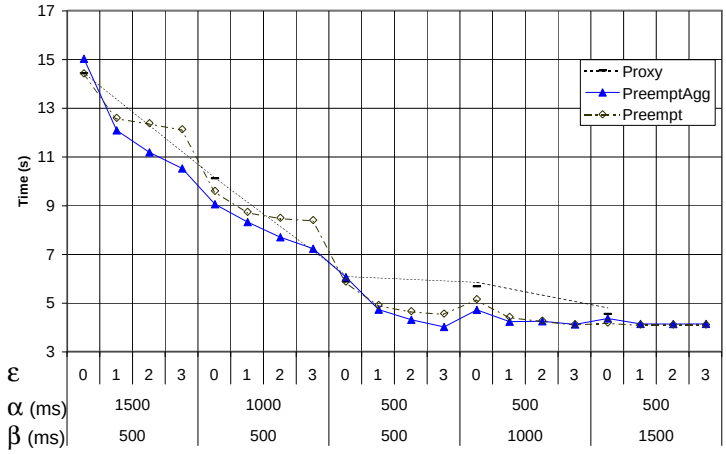


Figure 10: Comparison algorithm : obtaining time

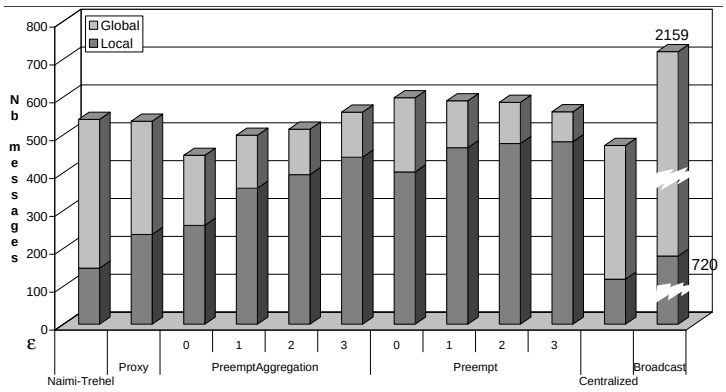


Figure 11: Comparison algorithm : Number of messages exchanged

Type	ϵ	Obtaning time (s)		Average path length	Total path length	Nb of messages		
		average	standard deviation			local	global	%
Naimi-Trehel		7.157	1.351	2.37	419	148	393	0.39
Proxy		5.858	1.016	2.35	414	237	299	0.84
PreemptAgg	0	6.037	1.186	4.14	731	261	185	1.53
	1	4.704	1.757	4.56	806	359	140	2.56
	2	4.287	2.269	4.53	804	395	120	3.34
	3	3.992	2.573	4.68	840	395	120	3.34
Preempt	0	5.858	0.999	2.75	486	402	196	2.11
	1	4.897	2.053	2.69	473	466	124	3.76
	2	4.640	2.517	2.66	470	477	109	4.37
	3	4.540	2.884	2.62	463	482	79	6.12
Centralized		10.161	1.981			119	353	0.34
Broadcast		8.007	1.010			720	2159	0.33

Table 1: Summary of experiement with α and β equals to 500 ms

One avantage of the *PreemptAggregation* algorithm is that global requests are not transmited to the host which has requested the critical section. Therefore, as long as the token has not arrived in a cluster, no hosts in the cluster know that a remote host has requested the token. Consequently, the number of *preemption* is not limited by ϵ but by $n+\epsilon$ where n is the number of hosts in the cluster. The locality mechanism is more exploited but the absence of starvation is preserved.

5 Conclusion

We have presented in this paper a new approach to optimize mutual exclusion algorithms in a GRID environmement. The main idea is to adapt the algorithm according to network topology in order to confine most communications to intra-cluster. This improvement allows to optimize the obtaining time of the token at the expense of fairness.

This behavior is particulary shown with the *PreemptAggregation* algorithm presented in section 3.2. As we have seen in the performance evaluations, this algorithm allows to decrease significally the obtaining time with respect to the other algorithms presented but specially with *NaimiTrehel* or *Centralized* algorithms.

References

[1] L. Lamport, "Time, clocks, and the ordering of events in a distributed system," *Communications of the ACM*, vol. 21, no. 7, pp. 558–564, July 1978.

[2] G. Ricart and A. Agrawala, "An optimal algorithm for mutual exclusion in computer networks," *CACM: Communications of the ACM*, vol. 24, 1981.

[3] O. S. F. Carvalho and G. Roucairol, "On mutual exclusion in computer networks," *Communications of the ACM*, vol. 26, no. 2, pp. 146–147, 1983.

[4] M. Maekawa, "A $\sqrt{N}$ algorithm for mutual exclusion in decentralized systems," *ACM Transactions on Computer Systems*, vol. 3, no. 2, pp. 145–159, May 1985.

[5] I. Suzuki and T. Kasami, "A distributed mutual exclusion algorithm," *ACM Transactions on Computer Systems (TOCS)*, vol. 3, no. 4, pp. 344–349, 1985.

[6] K. Raymond, "A tree-based algorithm for distributed mutual exclusion," *ACM Transactions on Computer Systems (TOCS)*, vol. 7, no. 1, pp. 61–77, 1989.

[7] M. Naimi, M. Trehel, and A. Arnold, "A log (N) distributed mutual exclusion algorithm based on path reversal," *Journal of Parallel and Distributed Computing*, vol. 34, no. 1, pp. 1–13, 10 Apr. 1996.

[8] M. L. Neilsen and M. Mizuno, "A dag-based algorithm for distributed mutual exclusion," in *Proceedings of the 11th International Conference on Distributed Computing Systems (ICDCS)*, Washington, DC, 1991, pp. 354–360, IEEE Computer Society.

[9] I. Chang, M. Singhal, and M. T. Liu, "An improved log (N) mutual exclusion algorithm for distributed systems," in *Proceedings of the 1990 International Conference on Parallel Processing*, Aug. 1990, pp. 295–302.

[10] F. Mueller, "Prioritized token-based mutual exclusion for distributed systems," in *Proceedings of 12th Intern. Parallel Proc. Symposium & 9th Symp. on Parallel and Distr. Processing*, Mar. 1998, pp. 791–795.

[11] I. Chang, M. Singhal, and M. T. Liu, "A hybrid approach to mutual exclusion for distributed system," in *Proceedings of the 14th IEEE Annual International Computer Software and Applications Conference*, 1990, pp. 289–294.

[12] A. Housni and M. Trehel, "Distributed mutual exclusion by groups based on token and permission," in *Proceedings of the ACS/IEEE International Conference on Computer Systems and Applications*, June 2001, pp. 26–29.

[13] L. Bouge G. Antoniu and S. Lacour, "Making a DSM consistency protocol hierarchy-aware: an efficient synchronization scheme," in *Proceedings of the Workshop on Distributed Shared Memory on Clusters*, 2003, pp. 516–521.

[14] L. Rizzo, "Dummynet: a simple approach to the evaluation of network protocols," *ACM Computer Communication Review*, vol. 27, no. 1, pp. 31–41, 1997.

Contents

Unité de recherche INRIA Rocquencourt
Domaine de Voluceau - Rocquencourt - BP 105 - 78153 Le Chesnay Cedex (France)

Unité de recherche INRIA Futurs : Parc Club Orsay Université - ZAC des Vignes
4, rue Jacques Monod - 91893 ORSAY Cedex (France)
Unité de recherche INRIA Lorraine : LORIA, Technopôle de Nancy-Brabois - Campus scientifique
615, rue du Jardin Botanique - BP 101 - 54602 Villers-lès-Nancy Cedex (France)
Unité de recherche INRIA Rennes : IRISA, Campus universitaire de Beaulieu - 35042 Rennes Cedex (France)
Unité de recherche INRIA Rhône-Alpes : 655, avenue de l'Europe - 38334 Montbonnot Saint-Ismier (France)
Unité de recherche INRIA Sophia Antipolis : 2004, route des Lucioles - BP 93 - 06902 Sophia Antipolis Cedex (France)

Éditeur
INRIA - Domaine de Voluceau - Rocquencourt, BP 105 - 78153 Le Chesnay Cedex (France)
http://www.inria.fr
ISSN 0249-6399