Validation of a protocol managing a multi-token ring architechture

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SUMMARY

We propose an original protocol (called **PLASMA**), which uses the redundancy of communication devices (several **token rings**), to correct major faults by a **switching** of the medium, and transitory faults by **retransmitting**.

This protocol is located in the **LINK layer** and fits between the LLC and MAC sublayers specified by the international standards for local area networks. In a context of distributed system, it increases the reliability and the performance of the data transfer.

To modelize our protocol and to analyse the model, we propose an invariant theory in a subclass of coloured net : the **Ordered Regular Petri Nets**. We develop a method of resolution which find all the invariants generated by the **diffusion** and the **successor** functions independently of the class cardinalities.

The model and the invariants are parameterized, so our protocol is validated for any number of token rings and any width of the receiving window.

1.- Introduction

In distributed systems, the **redundancy** of the devices which perform the transmission increases the **reliablility** in a significant way.
Many studies on message transfer throughput or delay of existing protocols [Meyster 85], [Attal 83] have been made. Other ones propose new protocols for this particular problem [David 87]. But all these studies are generally confined to the analysis of the data transfer phase without loss and without failure.
The aim of our paper is to propose a more precise and realistic study, where the service has to be assured whatever the states of the communication devices may be.

To use the multi-medium rationally, a dynamic loading balance is carried out by an external entity. In normal phase, the load is distributed among all the devices, and this assures a fast service. In failure phase, the load is distributed among the remaining devices (in our terminology "**the switching**"), which must be able to maintain the service.
Obviously, the use of multi-medium introduces many problems : redundancy management, synchronization, loading balance, preservation of the service quality (sequencing, unicity).

We propose a protocol which enables these problems to be resolved while it improves the service quality (availability, transfer delay) of the link layer, or to be more precise, of the MAC sublayer (Medium Access Control) of the **token ring** protocol [ISO 8802/5].
The PLASMA sublayer fits between LLC sublayer (Logical Link Control)[ISO 8802/2] and the MAC sublayer.

The protocol is designed to manage redundancy. Each Plasma entity assures the Service required by the LLC entities, using the MAC entities (Figure 1).
Moreover, we underline the **transparency** of the protocol towards the upper layer because it keeps a complete compatibility with the service definition of the Link layer and with the protocol specification of the LLC sublayer. It provides the same Service as its MAC sublayer [Cousin 88].

Complete studies of MAC and PLASMA sublayers are proposed in [Cousin 87] and [Estraillier 87].

To design the model and analyse it, we propose an invariant theory in a subclass of coloured Petri net : the **Ordered Regular Petri Nets**. We develop a method of

resolution which find all the invariants generated by the **diffusion** and **successor** functions independently of the class cardinalities.
We use the formal calculus system [Macaulay 86] and the package **AMI** [Bernard 88] which allows to automatically compute a coloured base of invariants, and a symbolic and coloured coverability graph.

The paper is organized as follows : the second chapter introduces the principles of our PLASMA protocol. The third chapter presents the **Ordered Regular Petri nets.** The fourth describes the model, and we analyze it in the fifth chapter.

2.- Presentation of PLASMA

2.1- Standardized interfaces

According to the standard O.S.I (Open System Interconnection), the different neighbouring layers or sublayers communicate with the help of service primitives. In the Local Area Network standards three types of primitives have been used:

. <u>Request</u>:	A layer transmits a request to the lower layer.
. <u>Confirmation</u> :	A layer informs the upper layer that the service requested has been performed. This primitive acts as a kind of acknowledgment (positive or negative) of the request, but it is only restricted to its layer.
. <u>Indication</u>:	A layer informs the upper layer that an operation should be executed.

In accordance with our transparency requirement, the interface primitives between LLC/PLASMA and PLASMA/MAC are those defined by the standards for LLC/MAC, only the quality of service is improved :

<u>PLASMA-LLC Interface</u>		<u>PLASMA-MAC Interface</u>
PL_DATA.Req	: Request for transmission of a frame	: **MA_DATA.Req**
PL_DATA.Conf	: Request confirmed	: **MA_DATA.Conf**
PL_DATA.Ind	: Indication of frame reception	: **MA_DATA.Ind**

2.2- The functions of PLASMA

The medium and the devices, enabling communications between stations, are subject to all kinds of failures. These ones can occur at any time, their lenghts are not known, and moreover they can be final.

In order to maintain and to improve the quality of the Link layer service, our protocol PLASMA should face two types of failures by using appropriate correction mechanisms :

Transitory failures occur on a short and irregular basis and in only a few frames, and are caused by momentary events, or by the self-correction of devices (frame corruption, congestion, disconnection, token loss, etc...);
The immediate **retransmitting** of the faulty frame onto an other medium proves to be an efficient technique.
In our protocol, a **retransmitting policy process** defines the retransmitting strategy. When a transmission failure occurs, it decides either to retransmit the frame or to send back the negative confirmation to the LLC sublayer.

Major failures cause incoherence on the flow of information, mainly owing to device failures.
The **"switching"** mechanism is designed to switch a Plasma link from a token ring onto another;
The standards on local area networks specify an entity called "Network Manager" which is responsible for the overall management of the network : indication of faults, reconfiguration, statistics, etc... We find it natural to include in it supplementary functions needed by the protocol PLASMA.
BISON thus directs the transfer of messages on the different media in relation to the amount of traffic and any fault it detects. Specifically, BISON is informed through the Network Manager of all changes in the state of communication devices, and oversees the operations of switching links from ring to ring.

In our study, both **BISON** and the **retransmitting policy process** manage the strategies of the rings use in an non-deterministic way. So we validate our protocol for all possible behaviours.

Unfortunately, these two mechanisms bring about two perverse effects :

Duplication :
After a correct frame transmission, the receiver entity sends back a positive confirmation to the sender. Unfortunately, this confirmation can be lost and a negative confirmation (**MA_DATA.Conf(-)**) is received by the sender. The retransmitting process can decide to retransmit the same frame, which leads to the

duplication of the frame.

Misordering :

The difference in the speed of transfer between the two mediums (which are non-synchronized), and the retransmitting treatment after the loss of frames, can cause the **misordering** of these frames.

These two drawbacks can be easily corrected by the following procedures:

- At the sending phase, **the frames are numbered** in order to identify them.
- At the reception phase, **the number of the received frame** is compared with **the number of the expected frame.** If the received frame is late or has been duplicated, it is rejected; if it is early it can be buffered for a short while; if it is the expected number, of course, it is transmitted to the upper layer.

These procedures are deliberately simple and are well known, and we prove in the next paragraph that they are sufficiently effective for solving our problems.

3.- Ordered Regular Petri Nets

To model our protocol we need to use a **successor function** to describe several mechanisms :

. frame numbering in the PLASMA sending process,

. window management in the PLASMA receiving process,

. possible strategies in BISON and retransmitting policy processes.

So, we propose a subclass of the coloured Petri net [Jensen 81] : the **Ordered Regular Petri Net** which generalizes the theory of the **Regular Petri net** [Haddad 87]. This theory manages classes of colours, such as the cardinal of each class is a parameter. Our work extends this theory to the generalized **successor function** : "$X \oplus p$" [Couvreur 88].

The **Ordered Regular Petri Net** theory requires the following definitions :

Classes of colours

Let $\Omega = \{C_1, \ldots, C_q\}$ be a set of classes of objects.

The objects belonging to a class C_i are numbered from 0 to N_i-1. So, $CARD(C_i) = N_i$.

The colour domains of places and transitions are built by the product $C_1 x C_2 x \ldots x C_q$.

Identity function : X_i

For each class C_i, we define the associated **Identity** function X_i :

$\forall x \in C_i$, $X_i.<x> = <x>$

Successor function: $X_i \oplus 1$

We define an order relation in each class C_i, which is defined by:

Let x_i be an element of C_i; We denote $x_i \oplus 1$, the **successor** of the element x_i constructed by : $x_i \oplus 1 = (x_i+1)$ modulo N_i.

We construct the successor function, denoted by $X_i \oplus 1$, and defined by :

$\forall x \in C_i$, $X_i \oplus 1 .<x> = <x \oplus 1 >$.

Generalized Successor function : $X_i \oplus k_i$

k_i compositions of the successor function $X_i \oplus 1$ give the k_i th successor , denoted by:

$(X_i \oplus 1)^{k_i} = X_i \oplus k_i$

The following functions are expressed as a linear combination of successor functions. We construct the diffusion (**S**) and restricted diffusion (**SR**) functions.

Diffusion function : S

The function S_i represents all the elements of a class C_i:

$S_i = \sum_{k \in [0, N_i[} X_i \oplus k$

Restricted diffusion function : SR

The function **SR** is a function associated to $x \oplus RL$ (in which RL is a parameter of the model representing a restriction limit).

$SR_i = \sum_{k \in [0, RL[} X_i \oplus k$, with $RL \in [0, N_i[$

We extend the previous functions to the domain built on the cartesian product of the classes.

Successor product function

The elementary function $X_i \oplus 1$ associated with the class C_i transforms the i^{th} component of a token $<x_1, . . ., x_i, . . ., x_q>$ into its successor : $<x_1, . . ., x_i \oplus 1, . . ., x_q>$.

This transformation defines the function :

$<X_1, \ldots, X_i \oplus 1, \ldots, X_q> . <x_1, \ldots, x_i , \ldots, x_q> = <x_1, \ldots, x_i \oplus 1, \ldots, x_q>$

composition :

By composition of the elementary functions, we obtain monomial functions :

$<X_1 \oplus k_1, \ldots , X_q \oplus k_q > . <x_1, \ldots, x_i , \ldots, x_q > = <x_1 \oplus k_1, \ldots , x_q \oplus k_q >$

Colour functions

The complete structure of colour functions is an algebra of polynomial functions of successor product function. We describe such functions using the notation below with linear combinations of monomial functions :

The colour functions L are linear combination of generalized successor functions.

$$L(X_1, \ldots, X_q) = \sum_{k_1, \ldots, k_q \in \Delta} K(k_1, \ldots, k_q) <X_1 \oplus k_1, \ldots, X_q \oplus k_q>$$

where $K(k_1, \ldots, k_q) \in \mathbb{N}$ (the set of positive integers), and $\Delta = C_1 \times \ldots \times C_q$.

4.- Modelling

This chapter introduces the model of PLASMA and MAC sublayers (figure 4.1 for the model, figure 4.2 for the key, figure 4.3 for the initial marking).

Classes of colours

In our models, we use the following objects :

- <r> : Identity of the Ring $\in [0, N_r[$
- <s> : Identity of the Sender $\in [0, N_s[$
- <d> : Identity of the Receiver $\in [0, N_d[$
- <x> : Frame number $\in \mathbb{N}$

4.1.-Model of the service provided by the MAC sublayer

To model the service provided by the MAC sublayer, we consider three submodels :

- The model of the sending treatment,
- The model of the transfer treatment,
- The model of the receiving treatment.

MAC - Sending submodel : The sending process <r,s> is associated with the entity belonging to the ring <r>. This process performs the sending of the frames coming from <s>.

When a sending request is taken into account (transition **MA_Req**), the sending process transmits it to the transfer process (transition **TR_Req**) which sends back a confirmation. This one may be either positive (transition **TR_C(+)**) or negative (transition **TR_C(-)**). According to this confirmation, the MAC-Sending process sends to the PLASMA sublayer a positive (transition **MA_C(+)**) or negative (transition **MA_C(-)**) confirmation.

MAC - Transfer submodel : The transfer process manages the ring <r>. As soon as the token is available (transition **TR_Req**), the frame is transmitted (transition **TR_Ind**) to the receiver process belonging to the addressee <d>. When the transmission is unsuccessful, a negative confirmation (transition **TR_C(-)**) is sent back (transition **TR-Sa** (resp.**TR-Sb)** represents the loss of the frame before (resp. after) its reception by the addressee).

MAC - Receiving submodel : The receiving process <r,d> is associated with the entity <d> belonging to the ring <r>. It receives the frame (transition **TR_Ind**) and sends it back to the receiver of PLASMA (transition **MA_Ind**).

4.2.- Model of BISON Service

BISON manages the overall view of the distributed system. In particular, according to the state of the network, BISON determinates (transition **BI-Sa**) the sending ring <r> for each link (characterized by <s,d>).
BISON and PLASMA sending process share information in the place **BI-PL**. The coloured token contained identifies the ring which must be used for the sending treatment.

This kind of model allows to describe any strategy of management by BISON. For the analysis, we have chosen to switch the transfer on the next ring at any time.

4.3- Model of the PLASMA Sublayer

We model separately the sending, the retransmitting policy and the receiving treatments.

4.31.- Model of the service provided by the retransmitting policy process

The retransmitting policy process is informed when a transmission failure occurs (transition **MA-C(-)**). It indicates its choice to the PLASMA sending process by sharing information in the following places :

- place **RP-SP1** indicates (to the PLASMA sending process) to send back a negative confirmation to the LLC sublayer. Thus, the retransmitting treatment is aborted.
- place **RP-SP2** identifies the ring which must be used for the retransmitting treatment.

In this model too, we do not judge what the retransmitting strategy might be. So we model all the possible behaviours. For the analysis, we have chosen either to retransmit the frame on the next ring, or to send back a negative confirmation to the LLC entity.

4.32.- Model of the sending treatment of a frame performed by PLASMA

In order to simplify the model expression and avoid the increase of the colour size, we assimilate the frame information to an integer which corresponds to the frame numbering managed by PLASMA.
Thus, on each link, the frames are numbered in increasing order (with infinite upper bound).

We associate to each link <s,d> the current value <x> (in place **PL-SX**) of the counter. This value increases each time a new frame is transmitted (transition **PL-Sa**).
After the numbering operation, the sender process sends (transition **MA_Req**) the frame to the ring <r> according to the choice of BISON. Thus, the token colour of a frame is <r,s,d,x>.

Once the frame has been transmitted to the MAC sublayer, the PLASMA sending process waits for a confirmation.

- If the confirmation is positive (transition **MA_C(+)**), it is transmitted towards the LLC sublayer (transition **PL_C(+)**).
- If the confirmation is negative (transition **MA_C(-)**), according to the retransmitting policy decision, a retransmitting treatment is tried (**PL-Sb** and **MA_Req** transitions) or a negative confirmation is transmitted towards the LLC sublayer (**PL-Sc** and **PL_C(-)** transitions).

4.33.-Model of the receiving treatment of a frame performed by PLASMA

Receiving treatment basically consists in verifying the frame number. For each link <s,d>, a receiving window is managed. This mechanism allows the treatments of **duplicated** frames and **misordering** .

For each link, we define a range of N consecutive numbers. N is called the width of the receiving window. Each number corresponds to a frame which must be received. The lower bound (place **PL-RX**) corresponds to the next frame which is expected. We call this bound "current".
In our model, the place **PL-RI** contains the references of all numbers which are not

included in the receiving window.

The window management uses two subsets :

- The subset of the expected frames (place **PL-RE**).
- The subset of the received frames which are not yet delivered to the LLC sublayer (place **PL-RR**).

The window is modified by increasing the lower bound (and consequently the upper one) in two cases :

- When the "current" frame is delivered to LLC (transition **PL_Ind**).
- When the time-out associated with the "current" frame occurs (transition **PL-Rd**).

A PLASMA process, associated with the receiving entity <d>, analyses the number of the received frame (transition **MA_Ind**).
We observe three cases :

- The frame was expected (transition **PL-Ra**).
- The frame has already been received (transition **PL-Rb**). It is a duplicated frame. So, the frame is rejected.
- The frame does not correspond to the receiving window (transition **PL-Rc**).

5- Analysis

To analyse the model, we develop a method of resolution which find all the invariants generated by the **Ordered Regular Petri Nets** model and its **diffusion** and **successor** functions, independently of the class cardinalities.

Such a study requires in fact to proceed with polynomial matrix algebra, whereas in classical RdP the study requires only to proceed with integer matrix algebra. The complexity of polynomial algebra does not allow to compute a generative family of flows with the parameterization in the general case.

5.1.- Method

As we have seen before, each colour function is a linear combination of generalized successor functions, and a generalized successor function can be written as a power of a successor function. As a consequence, each colour function can be written as a polynomial of succesor functions. However, when an element belongs to an infinite class, we obtain colour functions which are infinite series of elementary functions, thus imposing restrictions to get parameterized flows that we can process. The flows are restricted to those generated by a linear combination of the previously defined colour functions (X,S and $\oplus$). It is the set of functions involved in the model.

The diffusion function S allows to solve the polynomial equations produced by the validation. This result is obtained from the following non-trivial relations :
$X_i \oplus N_i = (X_i \oplus 1)^{N_i} = Id$; The N_ith successor of an element of a class C_i is the element itself.
Considering the polynomial equation : $a^N - 1 = (a-1)(1 + a + a^2 + \ldots + a^{N-1})$, we have the implication :
$(X_i \oplus 1) . S_i = S_i$; The set of the successors of all the elements of a class is the class itself.

The method organizes the analysis of the model into 3 steps :

- The **homogenization** of the domain of colours for places and transitions consists in building the product $C_1 \times C_2 \times \ldots \times C_q$, where $\{C_1, \ldots, C_q\}$ is a set of object classes. The non-significant components of the tuple are replaced by the **diffusion functions**.

- The **expression** of standard parameterized functions in a polynomial form allows to base the analysis on the polynomial algebra.

- The **resolution** requires the transformation of the incidence matrix into a polynomial matrix. Using the equations $(X_i \oplus 1) . S_i = S_i$, we can build an ideal [Couvreur 88]. The invariants of the model are obtained from the resolution of the linear equations derived from the matrix on the set of polynomials quotiented by the ideal.

5.2. Results

Like the model, the flows are parameterized, so they are true for :
- Any number of PLASMA sending process <s>,
- Any number of PLASMA receiving process <d>,
- Any width of the window management "N", and above all,
- Any number of token ring medium <r>.

We exhibit the thirteen flows found by the analysis. The first twelve are usual and linear. But the thirteenth is very interesting and original. It describes concisely the properties of the receiving window (Figures 5.1 et 5.2).

Plasma sending process

A1: $PL\_S1\ (s) + \Sigma_d\ PL\_\ S2\ (s,d) + \Sigma_{r,d,x}\ PL\_\ S3\ (r,s,d,x) + \Sigma_{r,d,x}\ PL\_\ S4\ (r,s,d,x) + \Sigma_d\ PL\_\ S5\ (s,d) + \Sigma_{d,x}\ PL\_\ S6\ (s,d,x) + \Sigma_d\ PL\_\ S7\ (s,d) = 1$

This flow gives the different states of each Plasma sending process <s>.

A2: $\Sigma_x\ PL\_\ SX\ (s,d,x) = 1$

For each link <s,d>, the token gives the current value <x> of the frame counter.

A3: $\Sigma_x\ PL\_\ S6\ (s,d,x) = \Sigma_r\ RP\_\ P1\ (r,s,d) + \Sigma_r\ RP\_\ SP1\ (r,s,d) + RP\_\ SP2\ (s,d)$

For each link <s,d>, if the Plasma sender process <s> is in the state PL_S6, the retransmitter determines if the frame must be retransmited or not.

Bison process

A4: $\Sigma_r\ BI\_\ PL\ (r,s,d) = 1$

For each link <s,d>, there is only one ring <r> which must be used to send the frame.

Mac sending process

A5: $MA\_S1\ (r,s) + \Sigma_{d,x}\ PL\_\ S4\ (r,s,d,x) = 1$

This flow describes the exchanges between the Mac and the Plasma sender.

A6: $PL\_S4(r,s,d,x) = MA\_S2\ (r,s,d,x) + MA\_S3\ (r,s,d,x) + MA\_S4\ (r,s,d,x) + MA\_S5\ (r,s,d,x)$

This flow shows that the Mac sending process is activated by the Plasma sender.

With combination of the two previous flows, we get the only five states of the Mac sending process:

C1: $MA\_S1(r,s)+\Sigma_{d,x}MA\_S2(r,s,d,x)+ \Sigma_{d,x}MA\_S3(r,s,d,x)+\Sigma_{d,x}MA\_S4(r,s,d,x)+\Sigma_{d,x}MA\_S5(r,s,d,x)=1$

Mac transfer process

A7: $TR\_S1\ (r) + \Sigma_{s,d,x}\ MA\_\ S3\ (r,s,d,x) = 1$

This flow says : either the ring <r> either broadcasts a frame <s,d,x>, or is idle.

A8: $MA\_S3\ (r,s,d,x) = TR\_S2\ (r,s,d,x) + TR\_S3\ (r,s,d,x) + TR\_S4\ (r,s,d,x)$

This invariant shows the three active states of Mac transfer process <r> .

The combination of the two previous flows gives the four states of the ring :

C2: $TR\_S1\ (r) + \Sigma_{s,d,x}\ TR\_S2\ (r,s,d,x) + \Sigma_{s,d,x}\ TR\_S3\ (r,s,d,x) + \Sigma_{s,d,x}\ TR\_S4\ (r,s,d,x) = 1$

Mac receiving process

A9: $MA\_R1\ (r,d) + \Sigma_{d,x}\ MA\_R2\ (r,s,d,x) = 1$

This flow shows the only two states of the Mac receiving process(active or idle).

Plasma receiving process

A10: $\Sigma_{s,x}\ PL\_R2\ (s,d,x) + PL\_R1\ (d) = 1$

Each receiving process <d>: either is idle (PL_R1), or is processing a frame.

A11: $PL\_RI\ (s,d,x) + PL\_RE\ (s,d,x) + PL\_RR\ (s,d,x) = 1$

This flow gives information about the management of the receiving window. For each link <s,d> each number <x> can be : either illegal (PL_RI), either expected (PL_RE), either received (PL_RR).

A12: $\Sigma_{x}\ PL\_RX\ (s,d,x) = 1$

For each link <s,d>, the place PL_RX contains the current value <x> of the lower bound of the receiving window.

A13: $PL\_RI\ (s,d,x) + \Sigma_{k \in [0,N[}\ PL\_RX\ (s,d,x-k) = 1$

This flow is produced by the successor functions. It can be interpreted with the help of the previous flow (Figure 5.1) : For each link <s,d>,

With the A12 flow, we know that there is only one current bound xo:

$\forall <s,d>, \exists!\ xo\ PL\_RX(s,d,xo)=1.$

and for $\forall x \neq xo\ PL\_RX\ (s,d,x) = 0$,

So, for $x < xo$,or $xo+N \leq x$: $\Sigma_{k \in [0,N[}\ PL\_RX\ (s,d,x-k) = 0$

for $xo \leq x < xo+N$: $\Sigma_{k \in [0,N[}\ PL\_RX\ (s,d,x-k) = 1$

And on the opposite place, we have:

for $x < xo$,or $xo+N \leq x$: $PL\_RI\ (s,d,x) = 1$

for $xo \leq x < xo+N$: $PL\_RI\ (s,d,x) = 0$

It means that all the numbers out of range ($x \leq xo$ or $xo < x+N$) are illegal (PL_RI).

In the Plasma sending process, the frame numbering is strictly incremental, and likewise, in the Plasma receiving process, the frame delivery is done on the strict observance of this incremental numbering. This assures the following properties :

Misordering : PLASMA does not produce misordering by the retransmitting process, and the window management assures the control of the frame reception.

Duplication : PLASMA identifies the frames in a unique way and rejects the duplicated frame induced by the redundancy.

The next property can be validated on the symbolic coverability graph :

Transparency : PLASMA transmits to the LLC Layer the interface primitives expected by the specification of the MAC service.

5.- Conclusion

The model described in this paper defines a new protocol : PLASMA, which uses redundant token rings as medium. Its validation proves that it retains the properties of the MAC sublayer (sequencing, non-duplication) and preserves the interface primitives of the LLC sublayer (transparency). Moreover, the switching and the retransmitting processes offer improved performance and fault tolerance of the protocol.

Our theory of **Ordered Regular Petri nets** and the automatic method of resolution enable these parameterized results to be obtained. A quantitative study, based on Coloured Stochastic Petri Nets, is under way, which will require to specify the BISON and retransmitting policies. This will confirm the contribution of our protocol.

Multi-medium management is ready to be applied to all link layer protocols, which have not satisfactory rate of availability or transfer delay for the envisaged applications. The protocol can take into account any number and any kind of medium. We can easily implement it because of its simple and well-known sliding window mechanisms, and because it agrees with the concepts of O.S.I. standard.

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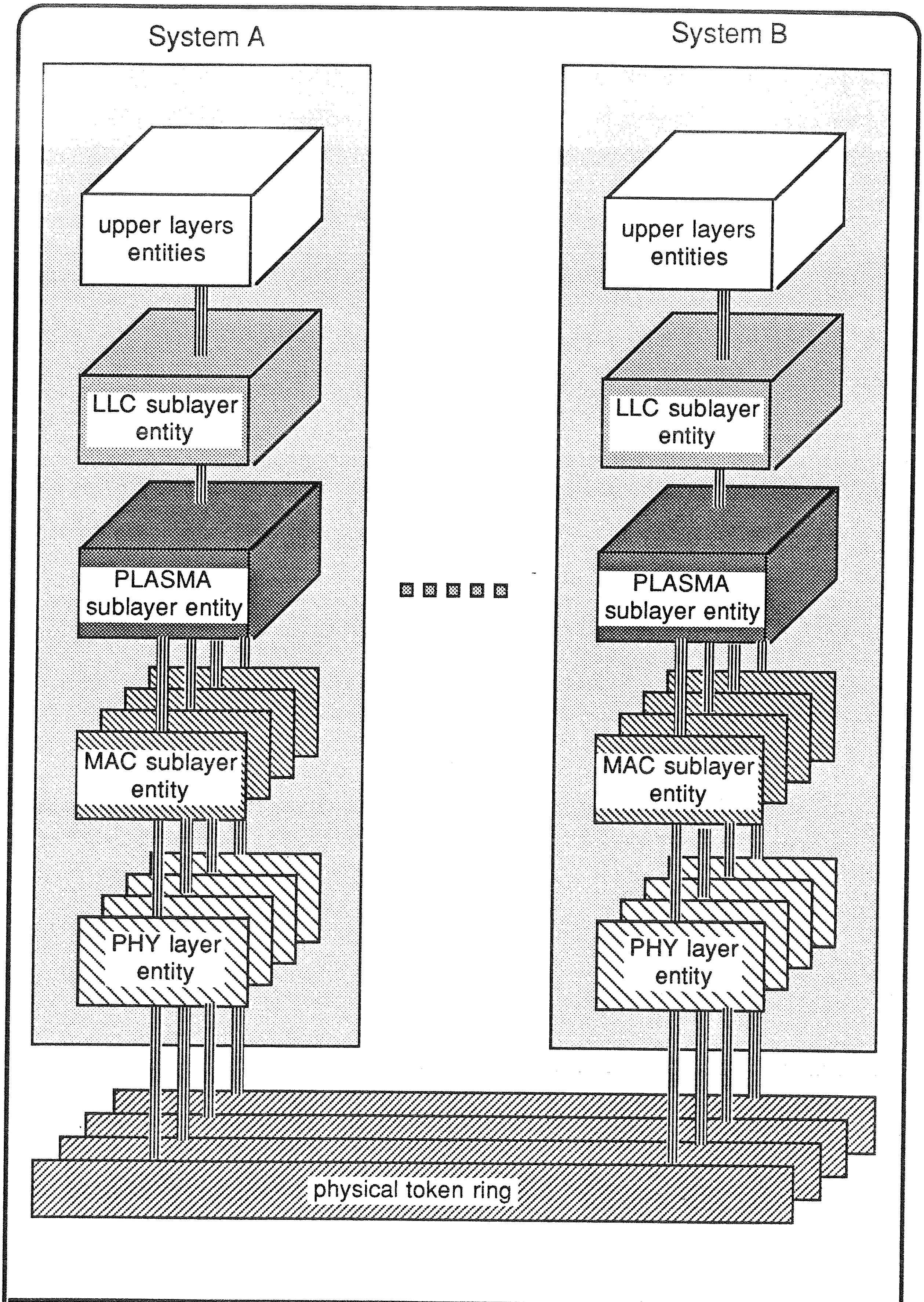

Figure 1 PLASMA redundancy layered architecture

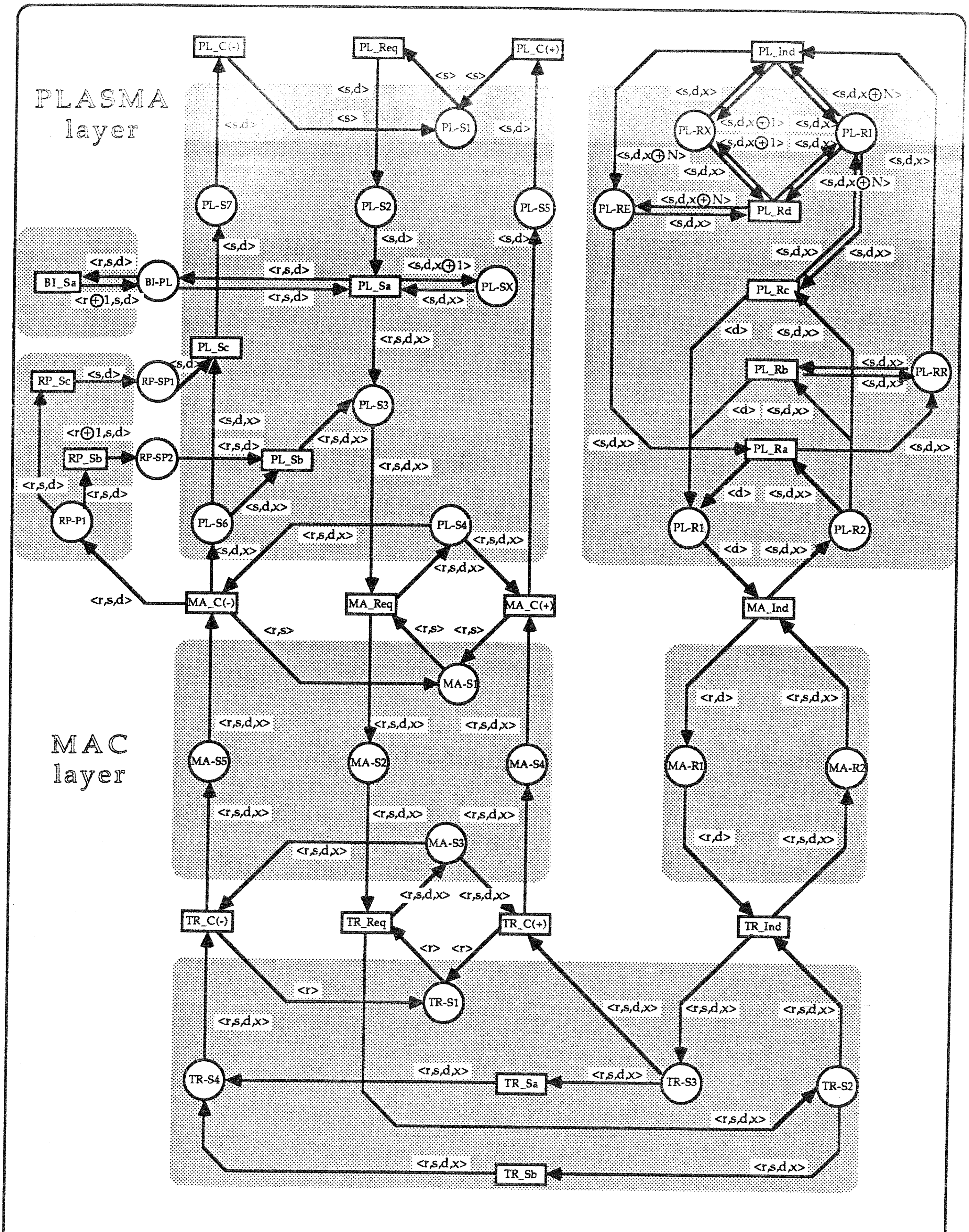

Figure 4.1	Model of PLASMA and MAC sublayers

Bison

Transition
BI-Sa : Ring switching

Retransmitting policy

Place
RP-P1: Failure indication

Transition
RP-Sb : Retransmitting decision
RP-Sc : Negative confirmation sending back decision

Sending process

Places
PL-S1 : waiting for request
PL-S2 : request received
PL-S3 : preparation of sending
PL-S4 : waiting for confirmation
PL-S5 : C(+) received
PL-S6 : C(-) received
PL-S7 : C(-) sending back
PL-SX : Value of frame

Transitions
PL-Sa : numbering and routing
PL-Sb : retransmitting preparation
PL-Sc : C(-) sending back prep.

Receiving process

Places
PL-R1 : waiting for frame
PL-R2 : frame received
PL-RE :subset of expected frames
PL-RR :subset of received frames
PL-RX :lower receiving bound
PL-RI : illegal references

Transitions
PL-Ra : expected frame receiving
PL-Rb : duplication treatment
PL-Rc : out-of-range treatment
PL-Rd : time-out treatment

PLASMA

LLC - PLASMA interface
PL_Req : PL_DATA_ Request
PL_C(+) : Positive Confirmation
PL_C(-) : Negative Confirmation
PL_Ind: PL_DATA_Indication

BISON - PLASMA interface
BI-PL : Ring identity for the sending

Internal PLASMA interface
RP-SP1 : Abort sending indication
RP-SP2 : identity of ring for the retransmitting

PLASMA - MAC interface
MA_Req : MA_DATA Request
MA_C(+) : Positive Confirmation
MA_C(-) : Negative Confirmation
MA_Ind: MA_DATA_Indication

Internal MAC interface
TR_Req : TR_DATA Request
TR_C(+) : Positive Confirmation
TR_C(-) : Negative Confirmation
TR_Ind: TR_DATA_Indication

Sending process

Places
MA-S1 : waiting for request
MA-S2 : request received
MA-S3 : waiting for confirmation
MA-S4 : C(+) received
MA-S5 : C(-) received

Receiving process

Places
MA-R1 : waiting for indication
MA-R2 : indication received

Transfer process

Places
TR-S1 : waiting for request
TR-S2 : request received
TR-S3 : Indication transmitted
TR-S4 : Failure during the transfer

Transitions
TR-Sa : loss of frame or failure before the delivery
TR-Sb : loss of frame or failure after the delivery

MAC

Figure 4.2 key of the model

Initial marking :

MAC layer			BISON	PLASMA layer	
Sending process	Transfer process	Receiving process	Switching process	Sending process	Receiving process
MA-S1=Σdr,ds <r,s>	TR-S1=Σdr <r>	MA-R1=Σdr,dd <r,d>	BI-PL=Σds,dd <r,s,d>	PL-Sx=Σds,dd <s,d,0> PL-S1=Σds<s>	PL-Rx=Σds,dd <s,d,0> PL-R1=Σdd <d> PL-RI=Σds,dd ,d1x <s,d,x> PL-RE=Σds,dd ,d2x <s,d,x>

dr | is the domains of | <r>
ds | | <s>
dd | | <d>

d1x = [N,∞[
d2x = [o,N[

Figure 4.3 Initial marking

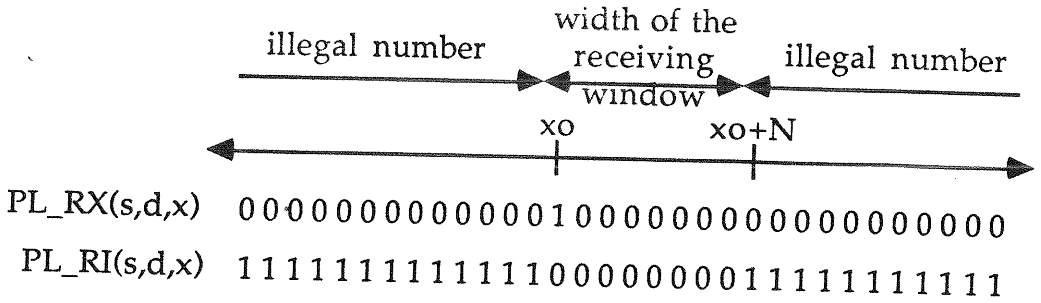

Figure 5.1 Receiving window management

Analysis results

MAC layer			BISON	PLASMA layer	
Sending process	Transfer process	Receiving process	Switching process	Sending process	Receiving process
A5 + A6	A7 + A8	A9	A4	A1 + A2 + A3	A10+A11+A12+A13

A1: $\mathrm{PL\_S1}\ (s) + \Sigma d\ \mathrm{PL\_\ S2}\ (s,d) + \Sigma r,d,x\ \mathrm{PL\_\ S3}\ (r,s,d,x) + \Sigma r,d,x\ \mathrm{PL\_\ S4}\ (r,s,d,x) + \Sigma d\ \mathrm{PL\_\ S5}\ (s,d) + \Sigma d,x\ \mathrm{PL\_\ S6}\ (s,d,x) + \Sigma d\ \mathrm{PL\_\ S7}\ (s,d) = 1$

A2: $\Sigma x\ \mathrm{PL\_\ SX}\ (s,d,x) = 1$

A3: $\Sigma x\ \mathrm{PL\_\ S6}\ (s,d,x) = \Sigma r\ \mathrm{RP\_\ P1}\ (r,s,d) + \Sigma r\ \mathrm{RP\_\ SP1}\ (r,s,d) + \mathrm{RP\_\ SP2}\ (s,d)$

A4: $\Sigma r\ \mathrm{BI\_\ PL}\ (r,s,d) = 1$

A5: $\mathrm{MA\_S1}\ (r,s) + \Sigma d,x\ \mathrm{PL\_\ S4}\ (r,s,d,x) = 1$

A6: $\mathrm{PL\_S4}(r,s,d,x) = \mathrm{MA\_S2}\ (r,s,d,x) + \mathrm{MA\_S3}\ (r,s,d,x) + \mathrm{MA\_S4}\ (r,s,d,x) + \mathrm{MA\_S5}\ (r,s,d,x)$

A7: $\mathrm{TR\_S1}\ (r) + \Sigma s,d,x\ \mathrm{MA\_\ S3}\ (r,s,d,x) = 1$

A8: $\mathrm{MA\_S3}\ (r,s,d,x) = \mathrm{TR\_S2}\ (r,s,d,x) + \mathrm{TR\_S3}\ (r,s,d,x) + \mathrm{TR\_S4}\ (r,s,d,x)$

A9: $\mathrm{MA\_R1}\ (r,d) + \Sigma d,x\ \mathrm{MA\_\ R2}\ (r,s,d,x) = 1$

A10: $\Sigma s,x\ \mathrm{PL\_\ R2}\ (s,d,x) + \mathrm{PL\_R1}\ (d) = 1$

A11: $\mathrm{PL\_RI}\ (s,d,x) + \mathrm{PL\_\ RE}\ (s,d,x) + \mathrm{PL\_\ RR}\ (s,d,x) = 1$

A12: $\Sigma x\ \mathrm{PL\_\ RX}\ (s,d,x) = 1$

A13: $\mathrm{PL\_\ RI}\ (s,d,x) + \Sigma\ k \in [0,N[\ \mathrm{PL\_\ RX}\ (s,d,x-k) = 1$

Figure 5.2 Analysis results