# PLASMA :
# a multi-medium Protocol
# for the link layer

Bernard COUSIN
Pascal ESTRAILLIER

laboratoire MASI - CNRS U.A 818
Tour 65-66 , bureau 201
Université Pierre et Marie CURIE
4, place JUSSIEU - PARIS - 75252
FRANCE

**SUMMARY**

We propose an original protocol (called PLASMA) which will make local area networks both more trustworthy and more operational, while at the same time adapting them to the context of real time for distributed control of a flexible manufacturing system.

This protocol in the link layer, fits between the LLC and MAC layers specified by the standards. To this end we have created the notion of virtual layer, which enables it to remain completely compatible with all the OSI protocols and concepts.

This protocol uses the redundancy of communications devices (two token rings), to correct, through the switching over of major faults, and by the retransmission of transitory faults.

We have validated our protocol by using the regular Petri Nets and the appropriate tools developed in our laboratory.

## 1.- Introduction

The real-time environment of flexible manufacturing needs to take into account a new problem for communications using a local area network: the **reliability** of the transfer delay.

There are many studies which analyse message transfer throughput or delay of existing protocols [MAP 86], [Meyster 85], [Attal 83], or which 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. Our intention in this 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.

It is not realistic to think that the medium and the devices, enabling communications between stations to be made, are safe from all kinds of failures. Likewise, it would be surprising in a flexible manufacturing system if the local area network was not flexible, thus preventing reconfiguration.
These failures can occur at any time, their lengths are not always known, and what is more, they can be final. The only effective solution is to increase the number of the devices which performed the transmission, and, in case of failure, to use **redundancy** in order to maintain the service.

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, synchronisation, loading balance, quality preservation of the service (sequencing, unicity). The PLASMA protocol enables these problems to be resolved.

This protocol meets the following requirements :

1) The integration of the protocol in a new sublayer compatible with the concept from the Open System Interconnection standard [ISO 7498].
2) The transparency of the protocol towards the upper layers and their classes, to support any applications.
3) Maximum simplicity of the protocol so as not to slow down the transmission, and to make the specification and the validation easier.

These requirements may seem conflicting : How can we keep the O.S.I. structures and create a new sublayer ? Is switching (routing) not a Network layer function ? Our choice of structuring has been guided by performance requirements. To switch at the layer where the failures are detected is more efficient than at a higher layer.

Our new layer is virtual, and fits between a layer N and its upper layer N+1, and has the same interface primitives as layer N. So the virtual layer can improve the efficiency of layer N, while the upper layer is unaware that it communicates with the virtual layer.

We have chosen token ring protocol as the medium protocol because its access method and its priority management is especialy suitable for our requirements. True to the standards on local area network, the PLASMA sublayer fits between LLC sublayer [ISO 8802/2] and the MAC sublayer [ISO 8802/5]. In the current version, the protocol is designed to manage a single redundancy, that is, a doubling up of all the devices needed for communication. Each Plasma entity assures the Service required by the LLC entities, using two MAC entities (Figure 1.1).

## 2.- Presentation of PLASMA

### 2.1- The PLASMA environment

According to the standards of interconnection, the different neighbouring layers or sublayers communicate with the help of service primitives. In standard three types of primitives have been defined:

- . Request: A layer transmits a request to the underlying layer.
- . Confirmation : A layer informs the layer immediately above it that the service requested has been performed. This primitive acts as a kind of acknowledgment (positive or negative) of the request, but it is simply restricted to its layer.
- . Indication: A layer informs the layer immediately above it that an operation should be executed.

In accordance with our transparency requirement and notion of virtual layer, the interface primitives between LLC/PLASMA and PLASMA/MAC are those defined by the standard for LLC/MAC (Figure 2.1), the quality of service alone is improved :

| PLASMA-LLC Interface | | PLASMA-MAC Interface |
|---|---|---|
| **PL-DATA.Req** | : Request for transmission of a message | : **MA_DATA.Req** |
| **PL-DATA.Conf** | : Request confirmed | : **MA_DATA.Conf** |
| **PL-DATA.Ind** | : Indication of message reception | : **MA_DATA.Ind** |

The standards of local area networks specify a third interface with an entity called "Network Manager". This entity 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 PLASMA protocol.

**BISON** directs the transfer of messages on the different supports in relation to the amount of traffic and any faults 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.

PLASMA-BISON Interface

**Switch** : **BISON** requests the switching over to **PLASMA**

## 2.2- The functions of PLASMA

Our protocol PLASMA should, in order to maintain (increase) quality of service, face two types of failures :

- **Transitory failures** occur on a short and irregular basis and in only a few frames (called MAC-pdu), and caused by momentary events, or by the self-correction of devices;
- **Major failures** cause incoherence on the overall flow of information, mainly owing to device failures and detected globally by the Network Manager.

For these two types of failures, the protocol has two correction mechanisms :

- For major failures, the **"switching"** is designed to switch all the transfers of a virtual link (linking two PLASMA-sap) from a physical support onto another;
- For transitory failures, the immediate **retransmission** of the faulty frame onto the other support proves to be an efficient technique which has already been shown elsewhere.

Unfortunately, these two mechanisms bring about two perverse effects :

- The retransmission of a frame correctly transmitted, but where the confirmation is positive but lost, bringing about the **duplication** of this frame;
- The difference in speed of transfer obtainable between the two mediums (which are non-synchronised) and the possible loss of frames, can cause the **misordering** of these frames.

These two disadvantages can be 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 frame received** is compared with **the number of the frame expected** If the frame received 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 intend to prove that it is sufficiently effective for solving our problems.

# 3.- Modelling and Analysis

To specify PLASMA, we have selected Regular coloured Petri nets [Haddad 87]. Regular coulored Petri nets are coloured Petri nets [Jensen], which manage classes of colours. For each class, the number of colours is a parameter.

This choice is justified because of succinctness of models obtained and by the use of our analysis tool **ARP** [Haddad 86]. This software is included in the package **AMI** [Bernard 87] produced in the MASI laboratory.

The package is based on a expert system which manages many modelling and validation tools. A coloured base of invariants and a coverability graph are automatically computed and shown with graphics interfaces.

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

**Colours of the models**

In our models, we use the following colours :

. <r> : Identity of Ring ∈ {a, b}

. <s> : Identity of Sender

. <d> : Identity of Receiver

. <x> : Information frame ∈ ℕ

**3.1.-Model of services of the MAC sublayer** (figure 3.1)

**3.11.- Model description**

The model is divided into five parts :

. MAC-PLASMA Interface (sender side) : We model the standardized interface as follows :
  . MA_DATA_Request : **MA_Req** transition
  . MA_DATA_Confirmation :
    . **MA_Conf(+)** transition for a positive confirmation
    . **MA_Conf(-)** transition for a négative confirmation

. MAC - Sender Process : The sender 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 (**MA_Req** transition), the sender process transmits it to the transfer process which sends back a confirmation which is either positive (**MA_Conf(+)** transition) or negative (**MA_Conf(-)** transition);

. MAC - Transfer process : The transfer process manages the ring <r>. As soon as the token is available, the frame is transmited to the receiver process belonging to the addressee <d>. If the transmission is successful , a positive confirmation is sent, otherwise a negative confirmation is sent. **Pert_mess** and **Pert_transf** transitions modelize the failures of frames or network.

. MAC - Receiver process : The receiver process <r,d> is associated with the entity <d> belonging to the ring <r>. The receiver entity of PLASMA is informed about a frame reception (**MA_Ind** transition).

. MAC -PLASMA Interface (receiver side) :
MA_DATA_Indication : **MA_ind** transition

**Initial state :**

$M_0$ **(Repos)** = $\Sigma_{dr,ds}$ <r,s>

$M_0$ **(Jeton)** = $\Sigma_{dr}$ <r>

$M_0$ **(Attente)** = $\Sigma_{dr,dd}$ <r,d>

dr,ds et dd are respectively the domains of <r>,<s> and <d>

### 3.12.- Model properties

With help of AMI, we prove that the model has a home state which is the initial state. Thus, we prove also the quasi-liveness of the model, that induces its liveness.

The model defines four properties which characterize the service provided by the MAC sublayer.

**Pm1:** A transfer request (**MA_Req**) is always followed by a negative (**MA_Conf(-)**) or a positive (**MA_Conf(+)**) confirmation.
**Pm2 :** The MAC sublayer does not produce misordering of frames.
**Pm3 :** A positive confirmation assures that the frame has been delivered to the addressee.
**Pm4 :** A négative confirmation indicates a transmission failure. (but not systematically the absence of delivrance of the frame).

### 3.2.-Model of sending treatment of a frame performed by PLASMA (figure 3.2)

### 3.21.- Model Description

In order to clearly show the **switching** and **retransmitting** operations, we do not fold up the model in the extreme.

The model is structured as follows :

. BISON switching : According to the state of the network, BISON determinates the sending ring for each link (characterized by <s,d>). **Switching** operation and sending treatment are independently processed.

. PLASMA-LLC Interface :
  . PL_DATA.Request : **PL-Req** transition
  . PL_DATA_Confirmation : **PL_Conf(+)** or **PL_Conf(-)** transitions

. Numbering management : In order to simplify the model expression and avoid the increase of the tuple size, we assimilate the frame information to an integer which corresponds to the frame numeration managed by PLASMA.
Thus, on each link, the frames are numered in increasing order (with infinite upper bound).
We associate to each link <s,d> the current value <x> (in **SX** place) of the counter. This value increases when a new frame is received on the link.

. Ring choice : After the numeration operation, the sender process sends the frame to the ring <a> or the ring <b> according to the BISON choice. Thus token colours are <a,s,d,x> or <b,s,d,x>.

. PLASMA-MAC Interface (first sending attempt) : Because of the similarity of treatment on both rings, this paragraph only describes the one performed on the ring <a>.

After the frame has been transmitted to the MAC sublayer (**MA-Req/a** transition), the PLASMA process waits for a confirmation. If it is positive (**MA-Conf(+)/a** transition), it is transmitted, after a preparatory treatment (**E7** place), towards the LLC entity (**PL-Conf(+)** transition). If the confirmation is negative (**MA-Conf(-)/a** transition), a retransmitting treatment on the other ring is tried (**E5u** place).

. PLASMA-MAC Interface (retransmitting attempt) : According to the retransmitting attempt status, a positive or a negative confirmation (**E7** or **E8** place) is prepared for the LLC entity.

**Initial state:**

$M_0$ **(Aa)**+$M_0$ **(Ab)** = $\Sigma_{ds,dd}$ <s,d>

$M_0$ **(Sx)** = $\Sigma_{ds,dd}$ <s,d,0>

$M_0$ **(E1)** = $\Sigma_{ds}$<s>

**3.22.- Model properties**

For this model too, the package AMI, has allowed to demonstrate the model liveness .

The analysis of the model induces the following properties :

**Pe1** : A transfer request (**PL_Req**) is always followed by a negative (**PL_Conf(-)**) or a positive (**PL_Conf(+)**) confirmation.

**Pe2** : On a link, the sending process does not produce misordering of frames.

**Pe3** : On a link, two different frames have different numeration

**Pe4** : The sending process always transmit to the LLC sublayer the confirmation coming from the MAC sublayer.

**3.3.-Model of receiving treatment of a frame performed by PLASMA** (figure 3.3)

**3.31.- Model Description**

Receiving treatment basically consists in verifying of the frame numeration. On each link <s,d>, a reception range is managed like a window with fixed size. This mechanism allows the treatments of **duplication** frames and **misordering** .

The model describing this behaviour is divided into four parts :

. PLASMA-MAC Interface : MA_DATA.Indication : **MA-Ind** transition

. PLASMA-LLC Interface : PL_DATA.Indication : **PL-Ind** transition

. Management of the range reception : For each link, we define a range of N consecutive numbers. Each number corresponds to a frame which must be received. The lower bound (**RX** place) corresponds to the next frame which is expected. We call this bound "current".

In our model, the place **Illegal** contains the references of all numbers which are not included in the reception range.

The range management uses two subsets :

- The subset of the expected frames (**Expected** place)
- The subset of the received frames which are not still delivered to the LLC sublayer (**Received** place).

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

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

- Analysis of the numbering of the received frames : A PLASMA process, associated with the receiving entity <d>, analyses the numeration of the received frame (**MA-Ind** transition). We observe three cases :
  - The frame was expected (**OK** transition)
  - The frame has already been received (**Duplication** transition). The frame is rejected.
  - The frame does not correspond to the receiving range (**Out-of-range** transition). This transition prevents the misordering of frames.

**Initial state:**

$$M_0\,(\mathbf{Rx}) = \Sigma_{ds,dd} <s,d,0>$$

$$M_0\,(\mathbf{R1}) = \Sigma_{dd} <d>$$

$$M_0\,(\mathbf{Illegal}) = \Sigma_{ds,dd\,,d1x} <s,d,x> \quad \text{where } d1x = [N,\infty]$$

$$M_0\,(\mathbf{Expected}) = \Sigma_{ds,dd\,,d2x} <s,d,x> \quad \text{where } d2x = [o,N]$$

### 3.32.- Model properties

We easily demonstrate the liveness of this model. Moreover, its analysis determines the following properties :

- **Pr1** :Each received frame is delivered to LLC or ignored because of its misordering.
- **Pr2** :Receiving process manages the ordering : frames are always delivered in increasing order.
- **Pr3** :Receiving process manages the duplication : two frames with the same number are never delivered to the LLC sublayer.

### 3.4.- Conclusion of the analyses

The overall behaviour of PLASMA can be assessed by the properties issued from the studies of the previous models. The basically properties are :

- **P1** : Transparency : The properties **Pe1** and **Pr1** assure that PLASMA transmits to the LLC Layer the interface primitives expected by the specification of the MAC service.
- **P2** : Misordering : PLASMA does not produce misordering by the sending process and the range management assures the sequencing of the reception process.
- **P3** : Duplication : PLASMA identifies the frames in a unique way (**Pe3**) and corrects the duplication induced by the other levels (**Pr3**).

## 4.- Conclusion

The models described here define a new protocol which uses a double token ring as medium : PLASMA. 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 for the protocol.

A quantitative study, based on Stochastic Colored Petri Net [Zénié 87], is under way, and this will confirm the contribution of our protocol.

Multi-medium management is ready to be applied generally in the number and in the kind of medium, and can easily be implemented because of its simple and well-known mechanisms, and because it agrees with concepts of O.S.I. standard.

**REFERENCES**

[Attal 83] J.L.Attal, G.Florin, S.Natkin, A.Woog, "Quantitative validation of an Ethernet industrial local area network, 3rd IFIP workshop on protocols validation, p.251-256, Zurich 1983.

[Bernard 87] J.M.Bernard, J.L.Mounier, N.Beldiceanu, S.Haddad, " AMI : un atelier de modélisation intégré", publication MASI n°210, 1988.

[Cousin 87] B.Cousin, J.M.Couvreur, "Le Service du niveau MAC", contrat industriel MASI/87.AL4, 1987.

[[David 87] J.P.David, M.Legendre, S.Natkin, "Un protocole de diffusion fiable pour les réseaux locaux industriels", TSI vol6 n°2, p187-190, mars-avril 1987.

[Estraillier 87] P.Estraillier, "le protocole PLASMA", contrat industriel MASI/87.AL3, 1987.

[Haddad 86] S.Haddad, J.M.Bernard, " Les reseaux réguliers: spécification et validation par le logiciel ARP", 3ème colloque de génir logiciel AFCET, Versailles, 1986.

[Haddad 87] S.Haddad, "Une catégorie régulière de réseau de Petri de haut niveau : définition, propriétés et réductions. Application à la validation de systèmes distribués ", Thèse de l'université de PARIS VI, 1987.

[ISO 7498] "ISO : Information processing systems . Open Systems Interconnection , Basic reference model", ISO/DIS 7498,1984.

[ISO 8802/2] "Information processing systems - Local area networks - Part 2 : Logical Link Control" , ANSI/IEEE Std 802.2, ISO/DIS 8802/2-1985.

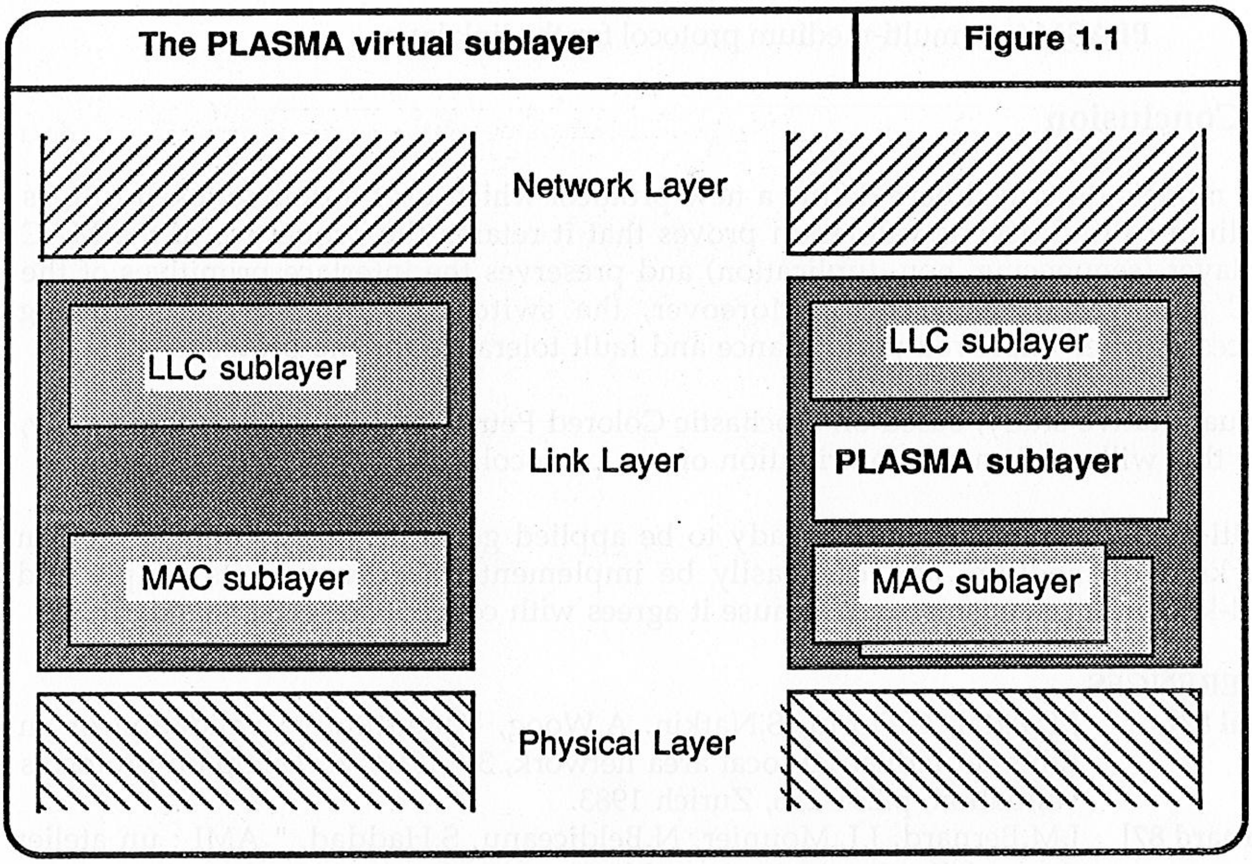
[ISO 8802/5] "Token ring access methode and Physical layer Specification", ANSI/IEEE Std 805.5, ISO/DP 8802/5-1985.

[Jensen 81] K.Jensen, "Coloured Petri Nets and the invariant method", Theorical computer science, n°14, p317, 1981.

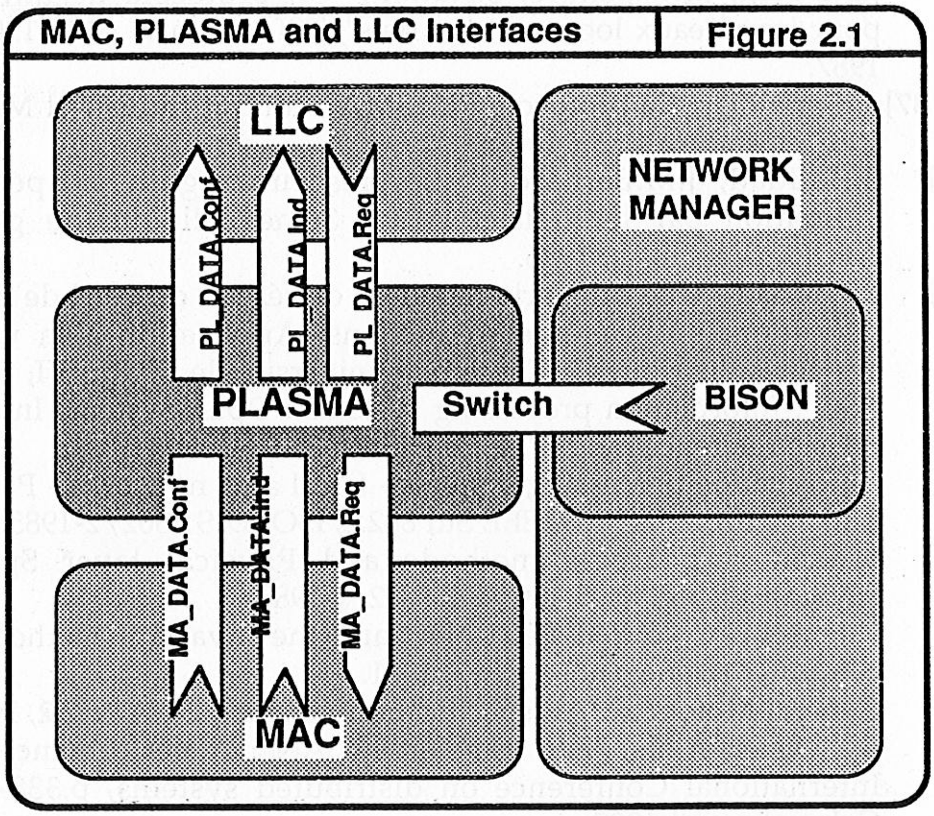
[MAP 86] General Motors : MAP specification versions 2.1.A & 2.2, August 1986.

[Meyster 85] B.Meyster et als, "File transfer in LAN : A performance study", 5th International Conférence on distributed systems, p.338-349, Denver Colorado, mai 1985.

[Zénié 87] A.Zénié, "Les réseaux de Pétri Stochastiques colorés : application à l'analyse des systèmes répartis ", Thèse de l'université de PARIS VI, 1987.



The PLASMA virtual sublayer — Figure 1.1



MAC, PLASMA and LLC Interfaces — Figure 2.1

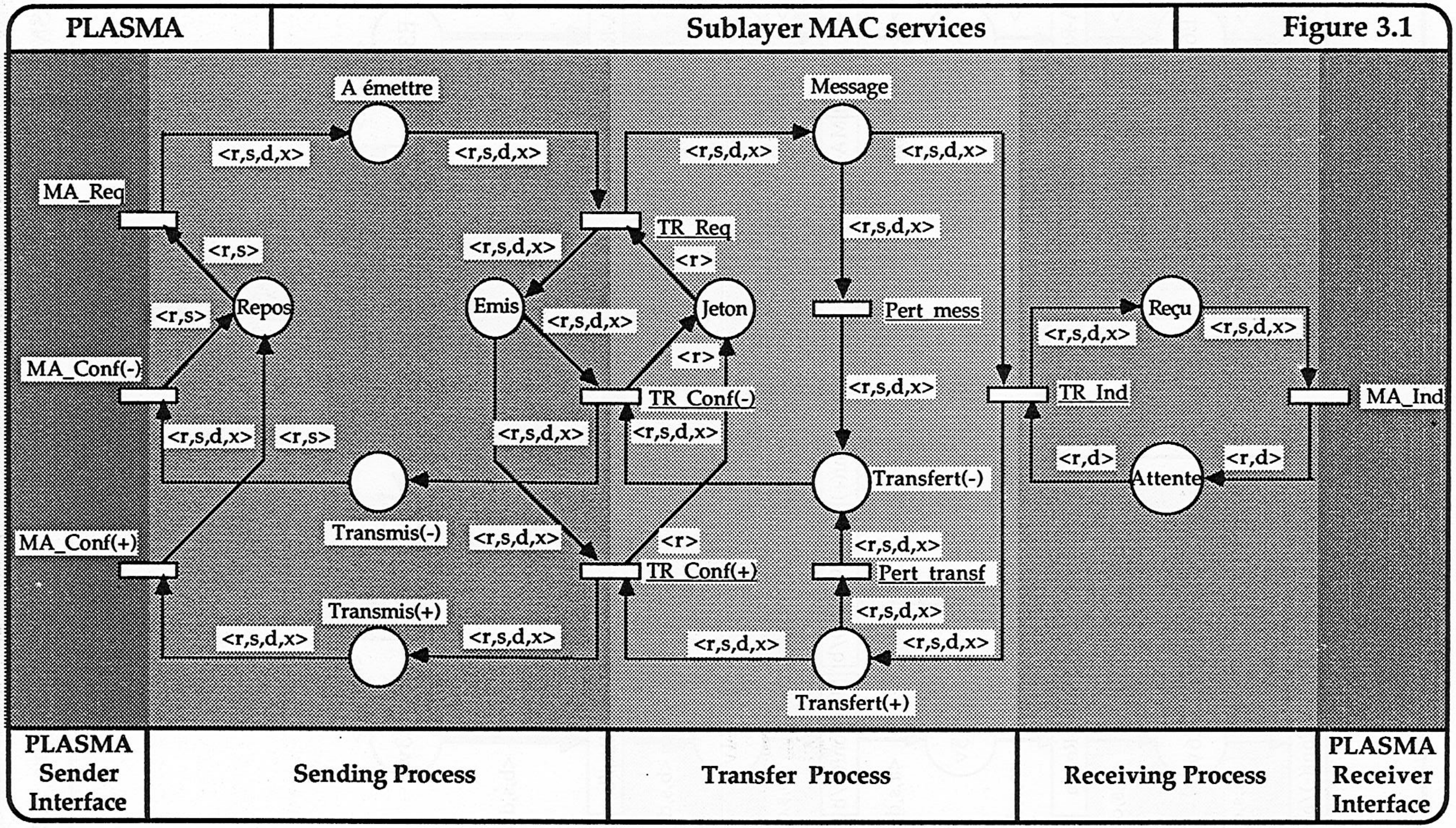
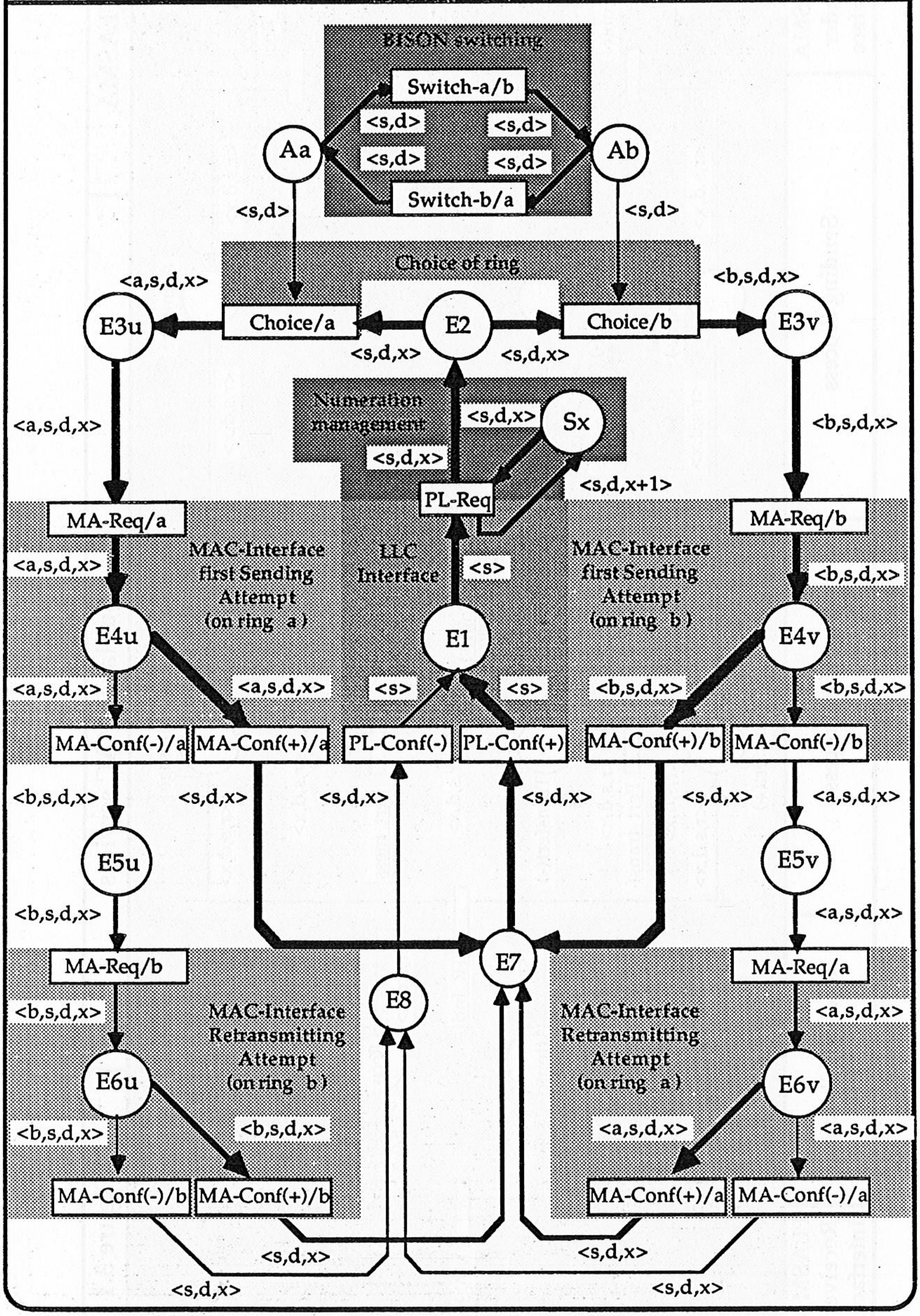
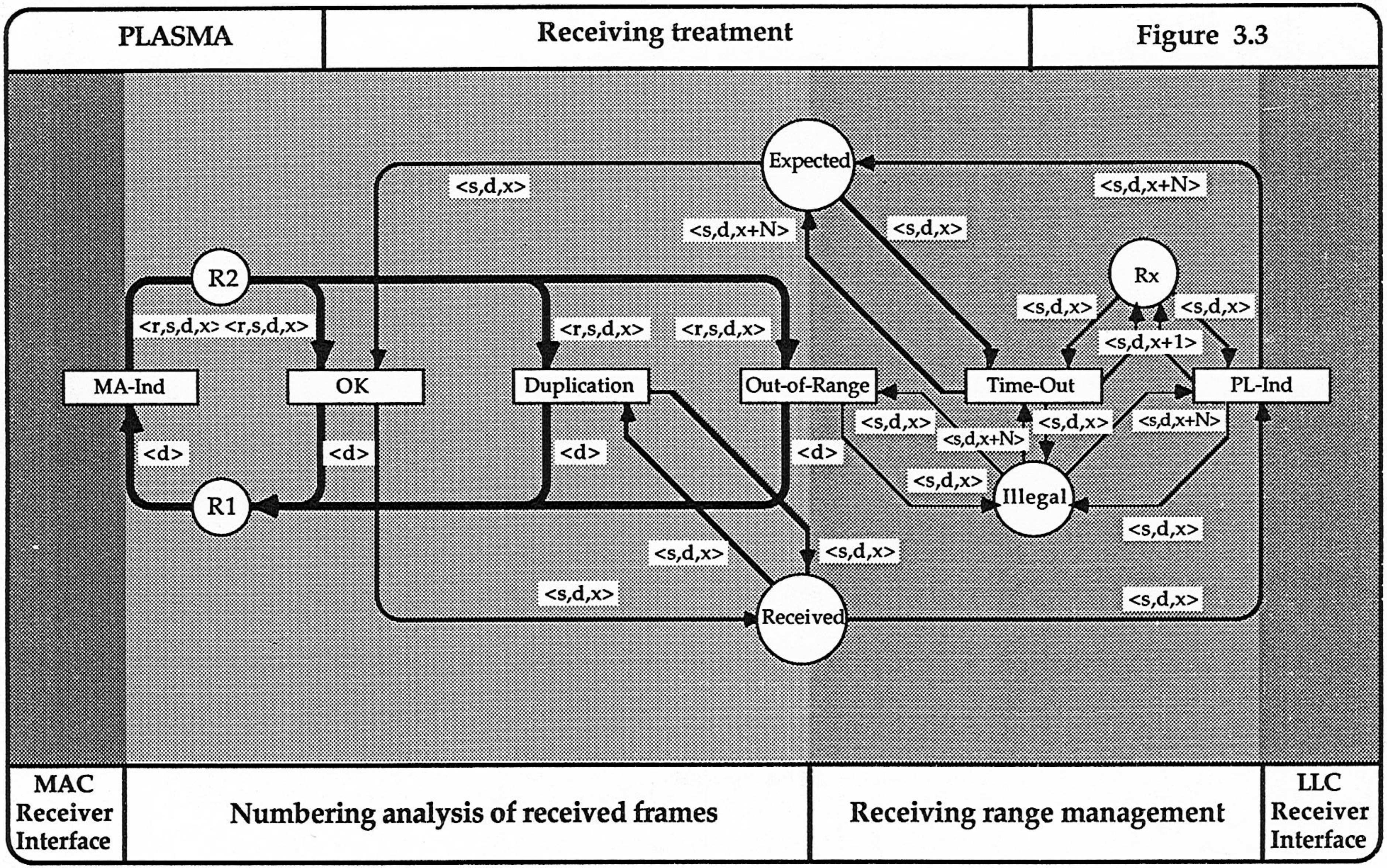

PLASMA
Sublayer MAC services
A émettre
Message
MA_Req
TR_Req
Pert_mess
Repos
Emis
Jeton
Reçu
MA_Conf(-)
TR_Conf(-)
TR_Ind
MA_Ind
Transmis(-)
Transfert(-)
Attente
MA_Conf(+)
TR_Conf(+)
Pert_transf
Transmis(+)
Transfert(+)
<r,s,d,x>
<r,s>
<r>
<r,d>
PLASMA Sender Interface
Sending Process
Transfer Process
Receiving Process
PLASMA Receiver Interface

Figure 3.1

| PLASMA | Sending treatment | Figure 3.2 |
|---|---|---|




PLASMA
Receiving treatment
Figure 3.3
Expected
<s,d,x>
<s,d,x+N>
<s,d,x+N>
<s,d,x>
R2
Rx
<r,s,d,x> <r,s,d,x>
<r,s,d,x>
<r,s,d,x>
<s,d,x>
<s,d,x>
<s,d,x+1>
MA-Ind
OK
Duplication
Out-of-Range
Time-Out
PL-Ind
<d>
<d>
<d>
<d>
<s,d,x>
<s,d,x+N>
<s,d,x>
<s,d,x+N>
<s,d,x>
R1
Illegal
<s,d,x>
<s,d,x>
<s,d,x>
<s,d,x>
Received
<s,d,x>
MAC Receiver Interface
Numbering analysis of received frames
Receiving range management
LLC Receiver Interface