Verification Results for the ISO ROSE Protocol Specified in Estelle

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Existing methods of verifying Estelle specifications involve translating the specifications into another form, such as finite state machines or Petri nets. Their limitations are that they have to be based on a variant of Estelle, impose some restrictions on the specifications to be verified and do not handle the dynamic behaviours of an Estelle specification. We have developed a technique of translating a standard Estelle specification, including its dynamic behaviours, into a Numerical Petri Net specification, which can then be verified by a proven automated verification tool, PROTEAN. This paper describes the verification results for the ISO ROSE (Remote Operation Service Element) protocol specified in Estelle using this approach.

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1. INTRODUCTION

Verification of Estelle [1, 2] specifications is still the subject of much research. Several techniques have been devised, however, these techniques have so far been based on the translation of Estelle specifications into another form, such as finite state machines, Petri nets or temporal logic formulas, for which tools of verification have already been implemented. All of the Estelle verification tools impose some restrictions on the specifications to be verified: they use a subset of Estelle or restrict the complexity of the specifications that can be verified; or the specifications need to be in a variant of Estelle, rather than standard Estelle; dynamic behaviours and exported variables of an Estelle specification are not handled.

There are a few verification tools, based on Petri nets, for Estelle specifications which have been able to verify only a verification-oriented subset of Estelle, or a variant of Estelle. Dimitrov and Petkov [3] presented an approach to automatic verification of communication protocols specified in an Estelle subset. Their approach is to limit Estelle specifications to a verification-oriented subset which could be easily translated into Petri nets. Azema et al. [4] presented a prototype for a Petri net based verifier, PIPN, which uses an underlying model for Estelle, based on Labelled Predicate/Transition Nets embedded into a logic programming environment. The main limitation of this tool is that only a static hierarchy of modules is considered. Saqui-Sannes and Courtiat [5] described

the use and design of ESTIM, a tool for the validation of protocols specified in Estelle*, which is a variant of Estelle enhanced with rendezvous mechanism.

In our previous work [6, 7], we proposed an approach to verifying standard Estelle specifications by translating them into Numerical Petri Net (NPN) specifications. In this approach, each Estelle module, consisting of a module header definition and a module body definition, is modelled independently as an indivisible NPN net which is very compact. The dynamic behaviours of an Estelle specification can be adequately modelled. However, *exported variables* and some Estelle statements were not included in our previous work, which is therefore not sufficient for modelling Estelle specifications in most cases, as communication entities usually use *exported variables* to communicate between a parent module and its associated child module; and with the information embedded in the exported variables, the parent module is able to know when to release its associated child module instance, and when to connect, disconnect, attach or detach the links. To address this limitation, we have extended the work to include *exported variables*, *all* and *forone* statements, and an *exist* expression in the NPN model. However, the Estelle *priority* and *delay* clauses, and dynamic loops are not supported using our approach.

The ISO ROSE protocol is chosen for verification because its Estelle specifications contain nearly all the Estelle keywords, like *exported variables*, *all* and *forone* statements, so that the viability of our approach to verifying Estelle specifications can be demonstrated. This paper describes the verification results for the ISO ROSE Estelle specifications using our techniques. The results were obtained by translating the ISO ROSE Estelle specifications into those of Numerical Petri Nets (NPNs) [8, 9], which can then be verified by a proven automated verification tool, PROTEAN [10].

2. NUMERICAL PETRI NET (NPN)

Numerical Petri Nets (NPNs), developed originally by Symons [11], are one of the many extensions of Petri nets. It has been found possible with NPNs to retain the basic principles, symbols and modes of operation of Petri nets, while adding a considerable amount of modelling convenience.

NPNs contain the following extensions :

- Tokens can have any finite number of attributes, each of which may be one of several different types;
- Global variables can be associated with the net;
- The transition enabling conditions refer not only to the tokens in the input places but also to the global variables;
- The firing of a transition not only removes tokens from the input places and inserts new tokens into the output places, but may change the values of the global variables.

NPNs have been successfully used in modelling some ISO protocols [12, 13].

3. NPNS MODELLING ESTELLE

The details of some of the techniques described in this section, for modelling an Estelle specification using NPNs, can be found in [6, 7]. In this model, all module bodies and all the interaction points in the module header of any corresponding module body become

places in an NPN, and transitions in the module body become transitions in an NPN. Tokens in NPN places indicate that the message and state belonging to the module instance will be processed by one of the enabling transitions in the module body. Transitions are fired to represent transitions being executed in the module body. The net result is the exchange of tokens or interactions from place to place, and a new marking is obtained. The mapping of Estelle components onto NPNs as dealt with in this paper is shown in Table 1.

3.1. Translating Estelle statements

Conditional statements in an Estelle transition block are transformed to two or more NPN transitions each of which represents a distinct control path of the original conditional statement. The transition condition of each NPN transition is modified to reflect the condition of each control path. However, we need to assume that there is no boolean expression of the conditional statement which contains variables assigned before the conditional statement.

Loop statements in an Estelle transition block are transformed by repeating the loop statement body for each value of the index variable. It is assumed here that the number of iterations can be statically determined.

Function/procedure call statements are replaced by the body of the corresponding procedure/function. In replacing the call statement, each formal parameter is symbolically replaced by an actual parameter.

With statements, which are used for record variable access, are eliminated by appending the *with* structure at the beginning of each record access within the statement's scope.

The generic form of all-statement, forone-statement and exist-expression is [1]:

- **all** domain **do** STATEMENT;
- **forone** domain **suchthat** BOOLEAN-EXPRESSION **do** STATEMENT-1
[**otherwise** STATEMENT-2];
- **exist** domain **suchthat** BOOLEAN-EXPRESSION;

The domain can be the set of either (i) all child instances of the same module-type, or (ii) vectors of values of ordinal-type(s). The details of the modelling are set out below.

All-statement It is a *repetitive statement* which allows iteration over an ordinal-type or over a set of module instances. In order to model this, the all-statement is eliminated by repeating the body of the STATEMENT for either each value of the ordinal type or each child instance in the domain.

Forone-statement It is a *conditional statement*. To model this, the forone-statement in an Estelle transition block is transformed to two or more NPN transitions each of which is for each element in the domain, or for the **otherwise** clause. The transition condition of each NPN transition is modified with the BOOLEAN-EXPRESSION whose variables defined in the domain are substituted with either a module instance or a value of the ordinal type in the domain. Modelling the transition representing the **otherwise** clause is different from the other cases in that instead of using a normal input arc, we use an *inhibitor arc* from the input place which holds tokens whose attributes appear in the BOOLEAN-EXPRESSION. This inhibitor arc together with the number of input tokens on the arc equal to *zero* means that the

Estelle	NPN
a module body	a place
an external interaction point	a place
an internal interaction point	a place
a transition	a transition
a from-clause	an enabling condition
a provided-clause	an enabling condition
a transition block	transition operations
A WHEN-Clause	an in-message token
an output-statement	an out-message token
an exported-variable-declaration part	a place
the module-initialization part	a transition
a module instance and its state	a state token
a connection status	a link token
an attachment status	a link token
a set of exported variables	an exported token
an init-statement	a control token
a release-statement	a control token
a terminate-statement	a control token
a connect-statement	a control token
an attach-statement	a control token
a disconnect-statement	a control token
a detach-statement	a control token

Table 1
Mapping of Estelle components onto NPNs

transition will be enabled when there are no input tokens specified on the arc in the input place.

Exist-expression Modelling the exist-expression is similar to the forone-statement except that the exist-expression does not have the **do** clause and the **otherwise** clause. However, it should be stressed that all variables defined in the domain are substituted with either a module instance or a value of the ordinal type in the domain.

4. ISO ROSE PROTOCOL

The ISO ROSE (Remote Operations Service Element) protocol [14, 15], which is an application service element (ASE), drives the general purpose protocol for invoking and reporting the returns of arbitrary operations. The ROSE protocol needs a *transfer service* to pass information in the form of ROSE APDUs between peer application-entities, and, if a connection package is involved in the contract, an *association service* to establish and release associations between the application-entities. Two mappings are permitted on to underlying services. ROSE may either map directly on to Association Control Service Element (ACSE) and the presentation service, or may map on to Reliable Transfer Service Element (RTSE). At present MHS is the principal user of ROSE.

Basically the ROSE service consists of establishing an application association (*bind*), sending a request (*invoke*), possibly getting a reply (*result* or *error*), and terminating the association (*unbind*). Each of these has service primitives associated with it. During the performance of an operation, the performance can invoke *linked operations*, intended to

be performed by the invoker of the original operation. ROSE can also operate *recursively*; in this case the performer may initiate a further ROSE association with a third entity (a child entity) which will actually perform the operation.

Figure 1 shows the protocol model of ROSE. In this model, a connection package is involved in the contract, so the ACSE service is used to establish and release associations between the application-entities. In addition, this model is concatenation-prohibited; that is, each TRANSFER request corresponds to a single P-DATA request.

5. ESTELLE SPECIFICATION OF ROSE

Figure 1 shows the environment and the module structure in which the Estelle specification of ROSE protocol has been considered. The USER module represents an application above ROSE. Since ACSE is the association realisation which provides services for the establishment and release of associations, the transfer realisation is based on the use of P-DATA to transfer the APDUs. The PS module represents the presentation service provider which provides transfer services to the ROPM module. The ROPM module specifies the ROSE protocol machine which consists of four modules: (i) BROPm (ROPm providing basic ROSE services), (ii) AROPm (ROPm providing association establishment and release), (iii) TROPm (ROPm providing information transfer) and (iv) ACPM (Association Control Protocol Machine). These four modules are created and released dynamically.

The Estelle specification has about 3500 lines, and contains more than 100 transitions. Thus, it is not possible to list in this paper the whole Estelle specification. Instead, the association establishment described in Estelle can be found in Appendix A. The following features were not included in the Estelle specification: linked operations, recursive operations and concatenation-permitted transfer services.

6. TRANSLATING ROSE INTO NPN

Each Estelle module is translated independently into an indivisible NPN net and later all of these nets are integrated. As shown in Appendix A, the Estelle specification is composed of 4 sibling modules, BROPm, AROPm, TROPm and ACPM, all of which are under one parent module, ROPm. Figure 5 gives the global NPN net of the Estelle specification.

In the NPN net representing the BROPm module, there are 5 NPN places: BROPm_body representing the module body identifier; BROPm_BROSE, BROPm_ABROSE and BROPm_TBROSE representing the associated interaction point identifiers BROSE, ABROSE and TBROSE respectively; and BROPm_EXPORT representing the associated exported-variable-declaration part. Six Estelle transitions in the BROPm module, ESTreq, RO_BINDind, RO_BINDcnfA, RO_BINDcnfE, ESTrspA and ESTrspE, are translated to be six NPN transitions; and there is one additional NPN transition, InitBROPm, for the initialization part of the module.

In the NPN net representing the AROPm module, there are also 5 NPN places: AROPm_body representing the module body identifier; AROPm_ABROSE, AROPm_AROSE and AROPm_ATROSE representing the associated interaction point identifiers ABROSE, AROSE and ATROSE respectively; and AROPm_EXPORT representing the

Figure 1. Protocol Model of ISO ROSE

associated exported-variable-declaration part. Six Estelle transitions in the AROPM module, A_ASSreq, ESTind, A_ASSrspA, A_ASSrspE, ESTcnfA and ESTcnfE, are translated to be six NPN transitions; and there is one additional NPN transition, InitAROPM, for the initialization part of the module.

In the NPN net representing the TROPM module, there are also 5 NPN places: TROPM_body representing the module body identifier; TROPM_TBROSE, TROPM_TROSE and TROPM_ATROSE representing the associated interaction point identifiers TBROSE, TROSE and ATROSE respectively; and TROPM_EXPORT representing the associated exported-variable-declaration part. Four Estelle transitions in the TROPM module, Start, P_DATreq, TRANSind and Stop, are translated to be four NPN transitions; and there is one additional NPN transition, InitTROPM, for the initialization part of the module.

In the NPN net representing the ACPM module, there are 4 NPN places: ACPM_body representing the module body identifier; ACPM_ACSEIP and ACPM_PSIP representing the associated interaction point identifiers ACSEIP and PSIP respectively; and ACPM_EXPORT representing the associated exported-variable-declaration part. Six Estelle transitions in the ACPM module, P_CONreq, A_ASSind, P_CONrspA, P_CONrspE, A_ASScnfA and A_ASScnfE, are translated to be six NPN transitions; and there is one additional NPN transition, InitACPM, for the initialization part of the module.

In the last NPN net representing the ROPM module, which is the parent of the modules mentioned above, there are 4 NPN places: ROPM_body representing the module body identifier; and ROPM_BROSE, ROPM_TROSE and ROPM_PSIP representing the associated interaction point identifiers BROSE, TROSE and PSIP respectively. Three Estelle transitions in the ROPM module, CreateChildrenA, CreateChildrenB and ReleaseROPMChildren, are translated to be three NPN transitions; and there is one additional NPN transition, InitROPM, for the initialization part.

In order to integrate all of these NPN nets, there are:

- one input arc from the NPN place ROPM_BROSE to the NPN transition CreateChildrenA;
- one input arc from the NPN place ROPM_PSIP to the NPN transition CreateChildrenB;
- four input arcs from the NPN places BROPM_EXPORT, AROPM_EXPORT, TROPM_EXPORT and ACPM_EXPORT to the NPN transition ReleaseROPMChildren;
- eleven output arcs from the transition CreateChildrenA and also from the transition CreateChildrenB to eleven NPN places: BROPM_body, BROPM_ABROSE, BROPM_TBROSE, AROPM_body, AROPM_AROSE, AROPM_ATROSE, ACPM_body, TROPM_body, ROPM_BROSE, ROPM_TROSE and ROPM_PSIP;
- eight output arcs from the transition ReleaseROPMChildren to eight NPN places: BROPM_body, BROPM_EXPORT, AROPM_body, AROPM_EXPORT, TROPM_body, TROPM_EXPORT, ACPM_body and ACPM_EXPORT;
- three NPN transitions: Link_ROMP_BROPM, ROPM_BROPM and BROPM_ROMP, to integrate the net representing the ROPM module and the net representing the BROPM module;
- three NPN transitions: Link_BROPM_AROPM, BROPM_AROPM and AROPM_BROPM, to integrate the net representing the BROPM module and the net representing

the AROPM module;

- three NPN transitions: Link_BROPM_TROP, BROPM_TROP and TROP_BROP, to integrate the net representing the BROPM module and the net representing the TROP module;

- three NPN transitions: Link_AROPM_ACPM, AROPM_ACPM and ACPM_AROPM, to integrate the net representing the AROPM module and the net representing the ACPM module;

- three NPN transitions: Link_AROPM_TROP, AROPM_TROP and TROP_AROPM, to integrate the net representing the AROPM module and the net representing the TROP module;

- three NPN transitions: Link_ROMP_TROP, ROMP_TROP and TROP_ROMP, to integrate the net representing the ROMP module and the net representing the TROP module;

- three NPN transitions: Link_ROMP_ACPM, ROMP_ACPM and ACPM_ROMP, to integrate the net representing the ROMP module and the net representing the ACPM module.

7. VERIFICATION RESULTS

After translating the Estelle specification into NPNs, the behaviour of the protocol is analysed using an automated verification tool, PROTEAN (PROTOCOL Emulation and ANalysis) [10], developed by Telecom Australia. PROTEAN is a proven verification tool for verifying complex application layer protocols [16]. The verification technique employed by PROTEAN is Reachability analysis [17]. The methods of using PROTEAN for verifying protocols are described in [18]. The verification exercises revealed that the protocol functions without any deadlock or livelock in all the normal cases when collision does not occur. However, in the case of an association-release with collision but without any operations in the “unbind pending” state, 10 deadlocks and no livelock have been uncovered.

The details of each deadlock are set out below:

7.1. DEADLOCKS 1, 2 AND 3

Figure 2 shows a sequence of service primitives leading to deadlock 1. This happens when the association-responder ROSE user, UB, issues a RO_UNBDreq primitive, and *simultaneously* the association-responder BROPM issues a RO_UNBDind primitive after receiving a RELind primitive. Then, UB changes to the “local unbind pending” state, whereas the association-responder BROPM changes to the “remote unbind pending” state in which it does not accept any service primitives from UB other than a RO_UNBDrsp primitive. Once UB receives the RO_UNBDind primitive, it understands that there is a release collision, but the association-responder BROPM does not. So, UB will not issue a RO_UNBDrsp primitive, but will change from its current state to the “association-responder-unbind-collision” state in which it expects to receive a RO_UNBDcnf primitive. As a result, a deadlock occurs.

The causes of deadlocks 2 and 3 are similar to that of deadlock 1, except that deadlock 2 occurs between the association-responder AROPM and its service-user and deadlock 3 occurs between the association-responder ACPM and its service-user.

Figure 2. A sequence of service primitives causing Deadlock 1

7.2. DEADLOCKS 4, 5 AND 6

Figure 3 shows a sequence of service primitives leading to deadlock 4. This happens when the association-initiator ROSE user, UA, issues a RO_UNBDreq primitive, and *simultaneously* the association-initiator BROPm issues a RO_UNBDInd primitive. Then, UA changes to the “local unbind pending” state, whereas the association-initiator BROPm changes to the “remote unbind pending” state in which it does not accept any service primitives from UA other than a RO_UNBDrsp primitive. Once UA receives the RO_UNBDInd primitive, it understands that there is a release collision, but the association-initiator BROPm does not. So, UA will change from its current state to the “association-initiator-unbind-collision” state in which it will issue a RO_UNBDrsp primitive, and then expect to receive a RO_UNBDcnf primitive. After the association-initiator BROPm receives the RO_UNBDrsp primitive from its service-user, it issues a RELrsp primitive to the association-initiator AROPm, and then changes from its current state to the “unbound” state in which the association is released. But the association-initiator ROSE user, UA, is still waiting for a RO_UNBDcnf primitive. As a result, a deadlock occurs.

The causes of deadlocks 5 and 6 are similar to that of deadlock 4, except that deadlock 5 occurs between the association-initiator AROPm and its service-user and deadlock 6 occurs between the association-initiator ACPm and its service-user.

7.3. DEADLOCKS 7, 8, 9 AND 10

Figure 4 shows a sequence of service primitives leading to deadlock 7. This happens when both the association-initiator ROSE user, UA, and the association-responder ROSE user, UB, issue a RO_UNBDreq primitive, and only the association-initiator side recognizes that there is a release collision while the association-responder side does not. The reason is that the P_RELInd primitive issued by the association-initiator side is *lost*, or is received by the association-responder ACPm *after* the P_RELcnf primitive which was issued by the association-initiator side in response to the release request from the association-responder side. That is, the association-initiator side understands that there is a release collision, and is waiting for an unbind confirm from the association-responder side; whereas the association-responder side understands that there is no collision, and

our method described here provides a viable approach to verifying real ISO protocols specified in standard Estelle.

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Figure 5. An NPN graph for the ROSE association establishment

Appendix A

Estelle Specifications of ROSE Association Establishment

```

module ROPM.type systemactivity;
ip
  BROSE : BROPM.Channel.type (provider);
  PSIP : Pres.Connect.Channel.type (user);
  TROSE : Pres.Data.Channel.type (user);
end;

{
  Start of the ROPM module body definition
}
body ROPM.body for ROPM.type;
module BROPM.type activity (id : integer);
ip
  BROSE : BROPM.Channel.type (provider);
  ABROSE : AROPM.Channel.type (user);
  TBROSE : TROPM.Channel.type (user);
export release.req : boolean;
end;
module AROPM.type activity (id : integer);
ip
  ABROSE : AROPM.Channel.type (provider);
  ATROSE : ATROPM.Channel.type (user);
  AROSE : ACPM.Channel.type (user);
export release.req : boolean;
end;
module TROPM.type activity;
ip
  TBROSE : TROPM.Channel.type (provider);
  ATROSE : ATROPM.Channel.type (provider);
  TROSE : Pres.Data.Channel.type (user);
export release.req : boolean;
end;
module ACPM.type activity (id : integer);
ip
  ACSEIP : ACPM.Channel.type (provider);
  PSIP : Pres.Connect.Channel.type (user);
export release.req : boolean;
end;

{
  Start of the BROPM module body definition
}
body BROPM.body for BROPM.type;
var
  bad.number : integer;
  roestrq : ESTRQ.TYPE;
  roestrp : ESTRP.TYPE;
  robindin : RO.BINDIN.TYPE;
  robindcf : RO.BINDCF.TYPE;
state
  STA01, (* unbound *)
  STA02, (* bound *)
  STA03A, (* local bind pending *)
  STA03B, (* remote bind pending *)
  STA04A, (* local unbind pending *)
  STA04B, (* remote unbind pending *)
  STA04C, (* unbind collision - responder completion *)
  STA04D; (* unbind collision - initiator completion *)
initialize
  to STA01
  begin
    bad.number := 0;
    release.req := FALSE;
  end;

  trans
    FROM STA01 TO STA03A
    WHEN BROSE.RO.BINDreq
    PROVIDED (id = 1)
    NAME ESTreq;
    begin
      roestrq := event;
      Output ABROSE.ESTreq (roestrq);
    end;
    FROM STA01 TO STA03B
    WHEN ABROSE.ESTind
    PROVIDED (id <> 1)
    NAME RO.BINDind;
    begin
      robindin := event;
      Output BROSE.RO.BINDind (robindin);
    end;
    FROM STA03A TO STA02
    WHEN ABROSE.ESTcnf
    PROVIDED (id = 1) and (event.Outcome = RESULT)
    NAME RO.BINDcnfA;
    begin
      robindcf := event;
      Output BROSE.RO.BINDcnf (robindcf);
    end;
    FROM STA03A TO STA01
    WHEN ABROSE.ESTcnf
    PROVIDED (id = 1) and (event.Outcome = ERROR)
    NAME RO.BINDcnfE;
    begin
      robindcf := event;
      Output BROSE.RO.BINDcnf (robindcf);
      release.req := TRUE;
    end;
    FROM STA03B TO STA02
    WHEN BROSE.RO.BINDrsp
    PROVIDED (id <> 1) and (event.Outcome = RESULT)
    NAME ESTrspA;
    begin
      roestrp := event;
      Output ABROSE.ESTrsp (roestrp);
    end;
    FROM STA03B TO STA01
    WHEN BROSE.RO.BINDrsp
    PROVIDED (id <> 1) and (event.Outcome = ERROR)
    NAME ESTrspE;
    begin
      roestrp := event;
      Output ABROSE.ESTrsp (roestrp);
      release.req := TRUE;
    end;
end; (* End of BROPM *)

{
  Start of the AROPM module body definition
}
body AROPM.body for AROPM.type;
var
  aroestin : ESTIN.TYPE;
  aroestcf : ESTCF.TYPE;
  aroassrq : A_ASSRQ.TYPE;
  aroassrp : A_ASSRP.TYPE;
state
  AA01, (* unassociated *)
  AA02, (* associated *)
  AA03, (* association pending *)
  AA04, (* release pending *)
  AA05; (* release collision *)

```

```

initialize
  to AA01
    begin
      release_req := FALSE;
    end;
trans
  FROM AA01 TO AA03
  WHEN ABROSE.ESTreq
    NAME A_ASSreq:
    begin
      aroassrq.User_Info := event;
      Output AROSE.A_ASSreq (aroassrq);
      Output ATROSE.Start;
    end;
  FROM AA01 TO AA03
  WHEN AROSE.A_ASSind
    NAME ESTind:
    begin
      aroestind := event.User_Info;
      Output ABROSE.ESTind (aroestind);
      Output ATROSE.Start;
    end;
  FROM AA03 TO AA02
  WHEN ABROSE.ESTrsp
  PROVIDED (event.Outcome = RESULT)
    NAME A_ASSrspA:
    begin
      aroassrsp.Result := ACCEPTED;
      aroassrsp.User_Info := event;
      Output AROSE.A_ASSrsp (aroassrsp);
    end;
  FROM AA03 TO AA01
  WHEN ABROSE.ESTrsp
  PROVIDED not (event.Outcome = RESULT)
    NAME A_ASSrspE:
    begin
      aroassrsp.Result := REJECTED;
      aroassrsp.User_Info := event;
      Output AROSE.A_ASSrsp (aroassrsp);
      Output ATROSE.Stop;
      release_req := TRUE;
    end;
  FROM AA03 TO AA02
  WHEN AROSE.A_ASScnf
  PROVIDED (event.User_Info.Outcome = RESULT)
    NAME ESTcnfA:
    begin
      aroestcnf := event.User_Info;
      Output ABROSE.ESTcnf (aroestcnf);
    end;
  FROM AA03 TO AA01
  WHEN AROSE.A_ASScnf
  PROVIDED not (event.User_Info.Outcome = RESULT)
    NAME ESTcnfE:
    begin
      aroestcnf := event.User_Info;
      Output ABROSE.ESTcnf (aroestcnf);
      Output ATROSE.Stop;
      release_req := TRUE;
    end;
end; (* End of AROP M *)

{
  Start of the TROP M module body definition
}
body TROP M.body for TROP M.type;
var
  trotrain : TRANSIN.TYPE;
  trodatrq : TRANSRQ.TYPE;

  state
    TP01, (* inactive *)
    TP02, (* active *)
  initialize
    to TP01
      begin
        release_req := FALSE;
      end;
  trans
    FROM TP01 TO TP02
    WHEN ATROSE.Start
      NAME Start:
      begin
        end;
    FROM TP02 TO TP02
    WHEN TBROSE.TRANSreq
      NAME P_DATreq:
      begin
        trodatrq := event;
        Output TROSE.P_DATreq(trodatrq);
      end;
    FROM TP02 TO TP02
    WHEN TROSE.P_DATind
      NAME TRANSind:
      begin
        trotrain := event;
        Output TBROSE.TRANSind(trotrain);
      end;
    FROM TP02 TO TP01
    WHEN ATROSE.Stop
      NAME Stop:
      begin
        release_req := TRUE;
      end;
  end; (* End of TROP M *)

{
  Start of the ACPM module body definition
}
body ACPM.body for ACPM.type;
var
  pconrq : P_CONRQ.TYPE;
  pconrp : P_CONRP.TYPE;
  aassin : A_ASSIN.TYPE;
  aasscf : A_ASSCF.TYPE;

  state
    STA0, (* idle *)
    STA1, (* awaiting AARE *)
    STA2, (* awaiting A-ASCrsp *)
    STA3, (* awaiting RLRE *)
    STA4, (* awaiting A-RLSrsp *)
    STA5, (* associated *)
    STA6, (* collision assoc init *)
    STA7, (* collision assoc rsp *)
  initialize
    to STA0
      begin
        release_req := FALSE;
      end;
  trans
    FROM STA0 TO STA1
    WHEN ACSEIP.A_ASSreq
      NAME P_CONreq:
      begin
        pconrq := event;
        Output PSIP.P_CONreq (pconrq);
      end;
    FROM STA0 TO STA2
    WHEN PSIP.P.CONind

```

```

NAME A_ASSInd:
begin
  aassin := event;
  Output ACSEIP.A_ASSInd (aassin);
end;
FROM STA2 TO STA5
WHEN ACSEIP.A_ASSrsp
PROVIDED (event.Result = ACCEPTED)
NAME P_CONrspA:
begin
  pconrp.Result := P_ACCEPTANCE;
  pconrp.User.Data.Result := event.Result;
  Output PSIP.P_CONrsp (pconrp);
end;
FROM STA2 TO STA0
WHEN ACSEIP.A_ASSrsp
PROVIDED not (event.Result = ACCEPTED)
NAME P_CONrspE:
begin
  pconrp.Result := USER_REJECTION;
  pconrp.User.Data.Result := event.Result;
  Output PSIP.P_CONrsp (pconrp);
  release_req := TRUE;
end;
FROM STA1 TO STA5
WHEN PSIP.P_CONcnf
PROVIDED (event.Result = P_ACCEPTANCE)
NAME A_ASScnfA:
begin
  aasscf.Result := event.User.Data.Result;
  Output ACSEIP.A_ASScnf (aasscf);
end;
FROM STA1 TO STA0
WHEN PSIP.P_CONcnf
PROVIDED not (event.Result = P_ACCEPTANCE)
NAME A_ASScnfE:
begin
  aasscf.Result := event.User.Data.Result;
  Output ACSEIP.A_ASScnf (aasscf);
  release_req := TRUE;
end;
end; (* End of ACPM *)

{
  Main body of ROMP module
}
var
  AROPM_FREE, BROPM_FREE,
  ACPM_FREE, TROPM_FREE : boolean;
(* Module Variable Declaration Part *)
modvar
  AROPM : AROPM_type;
  BROPM : BROPM_type;
  TROPM : TROPM_type;
  ACPM : ACPM_type;
initialize
begin
  AROPM_FREE := TRUE;
  BROPM_FREE := TRUE;
  ACPM_FREE := TRUE;
  TROPM_FREE := TRUE;
end;
trans
WHEN BROSE.RO_BINDreq
PROVIDED AROPM_FREE and BROPM_FREE and
  ACPM_FREE and TROPM_FREE
NAME CreateChildrenA:
begin
  init AROPM with AROPM.body(1);
  init BROPM with BROPM.body(1);
  init ACPM with ACSE.body(1);
  init TROPM with TROPM.body;
  connect BROPM.ABROSE to AROPM.ABROSE;
  connect AROPM.AROSE to ACPM.ACSEIP;
  connect BROPM.TBROSE to TROPM.TBROSE;
  connect AROPM.ATROSE to TROPM.ATROSE;
  attach BROSE to BROPM.BROSE;
  attach PSIP to ACPM.PSIP;
  attach TROSE to TROPM.TROSE;
  AROPM_FREE := FALSE;
  BROPM_FREE := FALSE;
  ACPM_FREE := FALSE;
  TROPM_FREE := FALSE;
end;
trans
WHEN PSIP.P_CONInd
PROVIDED AROPM_FREE and BROPM_FREE and
  ACPM_FREE and TROPM_FREE
NAME CreateChildrenB:
begin
  init AROPM with AROPM.body(2);
  init BROPM with BROPM.body(2);
  init ACPM with ACSE.body(2);
  init TROPM with TROPM.body;
  connect BROPM.ABROSE to AROPM.ABROSE;
  connect AROPM.AROSE to ACPM.ACSEIP;
  connect BROPM.TBROSE to TROPM.TBROSE;
  connect AROPM.ATROSE to TROPM.ATROSE;
  attach BROSE to BROPM.BROSE;
  attach PSIP to ACPM.PSIP;
  attach TROSE to TROPM.TROSE;
  AROPM_FREE := FALSE;
  BROPM_FREE := FALSE;
  ACPM_FREE := FALSE;
  TROPM_FREE := FALSE;
end;
trans
PROVIDED exist X1:BROPM_type suchthat X1.release_req
NAME ReleaseROMPChildren:
begin
  forone X1:BROPM_type suchthat X1.release_req do
    forone X2:AROPM_type suchthat X2.release_req do
      forone X3:TROPM_type suchthat X3.release_req do
        forone X4:ACPM_type suchthat X4.release_req do
          begin
            release X1;
            release X2;
            release X3;
            release X4;
          end;
        end;
      end;
    end;
  end;
end; (* End of ROMP *)

```