Formal Design of a Platform for Telecommunication Heterogeneous Network Management

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Abstract: This work presents a formal design of the Telebras Practical Platform. This platform was conceived in order to solve several dificulties of the telecommunications carriers related to integrated network and services management. Essentialy, these dificulties are related with distributed management in telecommunication heterogeneous networks. In the Telebras Practical Platform formalization was used with a design methodology that includes the FDT LOTOS - a ISO standard, as well as, tools for analysis, validation (e.g., simulations, testing and verifications) and translation of the LOTOS specifications to implementation code. Specifying this platform formally significantly contributes in the sense of providing a rigorous approach to the description and validation process, thus collaborating toward its exactness, mainly in the studies that aim at attesting the conformity between the product obtained and the description of the requirements which were considered.

Keywords: Heterogeneous network distributed management, Generic platforms, Generic applications, TMN, FDT LOTOS, LOTOS tools.

1. Introduction

At the present, there are many technologies suitable for solving the complex task of providing tools that enable the cooperation among the management of systems which are based on different architectures. X/Open - NMF (Network Management Forum) identified three key technologies:

- CMIP (Common Management Information Protocol);
- SNMP (Simple Network Management Protocol); and
- CORBA (Common Object Request Broker Architecture).

SNMP has been very much used in the computer market in general. The CMIP is mandatory in the telecommunications area due to the TMN standard; and CORBA is recognized as an emerging standard that allows distributed object oriented programming. Each technology has its own importance. Consequently, complete interoperability may allow the designers to select the most appropriate technology for each need.

In order to provide this complete interoperability and faciliting the applications development, a layer software (platform) - between the applications and the operational system/basic and utility software layer - is designed. In addition, formal tools are used for specifications validation, as well as, to translate from LOTOS code to C code. This work is being developed under CNPq/ProTeM-CC-II/PLAGERE Project (680072/94-2).

This work is organized as follows: in section *two* the management system specification is presented, which includes both the platform and the management applications; in section *three* the formal specification of a platform service is presented; in section *four* the formal specification of a protocol platform is presented; in section *five* the use of LOTOS tools for specifications validation and translation are presented. The conclusions (section *six*), acknowledgements (section *seven*) and references (section *eight*) then follow.

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2. Specification of the Platform (highest level of abstraction)

With the goal of solving troubles related to the distribution of processes (such as resource management, parallel processing, adequate communication services and independence of resource allocations, for instance) and supplying the necessities of the telecommunication carriers associated with the efficient development of management applications, a platform is here defined to support management applications [West 94] [Lore 96] [PeLo 96] [WeRi 96] [NoRi 96,a,b,c,d].

A mode of characterizing the Telebras Practical Platform composed of management systems is to see it as a software layer (in the Application layer context) that:

- offers specific services to a particular class of management applications using open and standard interfaces (APIs - Application Program Interfaces). The use of APIs facilitate applications development and permit their portability and reuse. An API describes the method of accessing a specific service. In order to obtain source code portability, the standardized service is not enough, for it is also necessary to standardize the access to the service. Therefore, from the user`s point of view, the establishment of standardized APIs enable the integrated use of multisuppliers´ products and will demand less effort to obtain portability of management applications.
- utilizes services available in the lower layers of relevant protocols.

In conformance with the design methodology presented in [Nota 95] [NoRi 95], the formalization is started considering the high power of abstraction [QuCu 94] allowed by the FDT (Formal Description Technique) LOTOS (Language of Temporal Ordering Specifications) [ISO 8807] - and then, develop the design using stepwise refinement approach. In addition, the design methodology consider the object orientation benefits [MoCl 93], as well, the constraint and resources orientation [ViSc 88], that guarantee specifications more homogeneous, readable and exact.

Using the FDT LOTOS the APIs can be described as communicating gates (gates **l**, **f**, **t**, **c**, **p**, **s** and **ops**) that are used by both **ManagementSystem** subprocesses: the **ManagementApplications** subprocess and the **ManagementSystemsPlatform** subprocess. In such gates events occur which are related to: log (**l**), fail (**f**), topology (**t**), configuration (**c**), performance (**p**), security (**s**) and operational system (**ops**), for instance. See Figure 2.1.

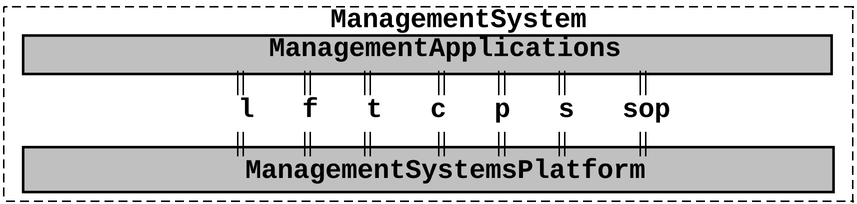

Figure 2.1 - Management System.

By using basic LOTOS, e.g., the part of LOTOS that is oriented exclusively to the representation of the dynamic aspects of the systems, the Management System, at the highest level of abstraction, can be described as follows:

```
specification ManagementSystem[l,f,t,c,p,s,ops]:noexit
   behaviour
       ManagementApplications[l,f,t,c,p,s,ops]
       |[l,f,t,c,p,s,ops]|
       ManagementPlatform[l,f,t,c,p,s,ops]
   where ...
endspec
```

This specification describes the parallel composition of two processes: The **ManagementApplications** and the **ManagementSystemsPlatform**. The **ManagementSystemsPlatform** process represents the platform formally. This process can be described in a constraint-oriented version (**ManagementPlatformC**) or in a resource oriented version (**ManagementPlatformR**). The **ManagementPlatformR** is a refinement of a **ManagementPlatformC** specification.

3. Specification of the Platform Service

The Management System Platform service can be structured using the constraint-oriented specification style. In this specification style, each communication gate comprehends a set of constraints associated with events which occur in these gates (such gates provide **ManagementPlatformC** process communication with the external environment).

Each constraint of a **ManagementPlatformC** process can, in its turn, constitute a LOTOS process (e.g., can constitute a subprocess of the **Management PlatformC** process). By using the constraint-oriented specification syle, each communication gate of a platform can be associated with a particular set of constraints. Then, gate **l** is associated with log control, gate **f** with the fail area, the **t** gate with the topology area, gate **c** with the configuration area, gate **p** with the performance area, gate **s** with the security area and the **ops** gate for interface with the operational system.

```
specification ManagementPlatform[l,f,t,c,p,s,ops]:noexit
       behaviour
              ManagementPlatformC[l,f,t,c,p,s,sop]
       where
       process ManagementPlatformC[l,f,t,c,p,s,sop]:noexit:=
              Log[l] ||| Fail[f] ||| Topology[t] ||| Configuration[c]
                     ||| Performance[p] ||| Security[s] ||| OS[ops]
              where  ...
       endproc
endspec
```

The platform specification in the resource oriented version (see section four) corresponds to a refinement in the specification of this platform in the constraint-oriented version.

4. Specification of the Platform Protocol

In order to refine the platform specification, the resource oriented style can be used. In this specification style, attention is paid to the platform interior, where the following composite resources are identified: The **TmnPlatform**, **BasicAndUtilitySoftware**, **OperationalSystem** and **Hardware**. Each one of these resources can constitute a subprocess of the **ManagementPlatformR** process. See Figure 4.1.

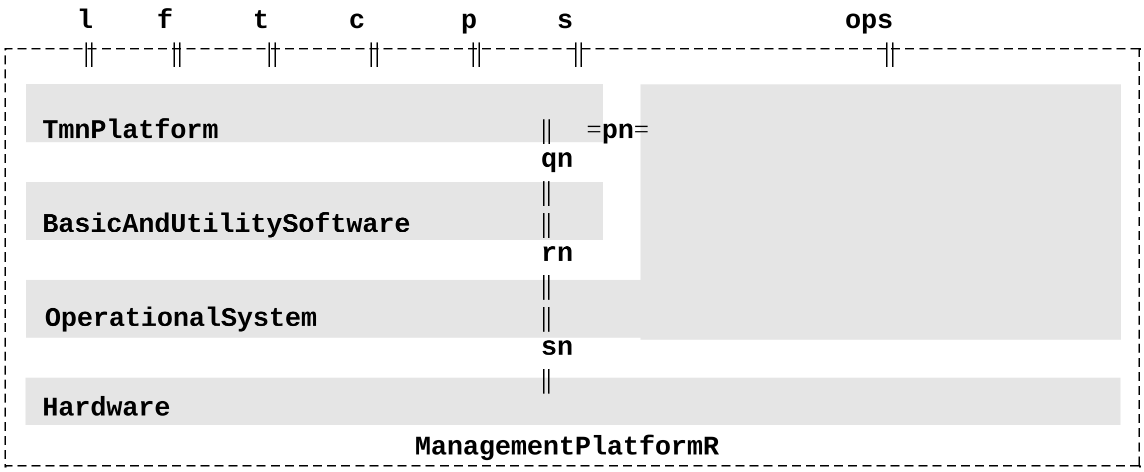

Figure 4.1 - Management System Platform (Resource definition).

The platform resources constitute subprocesses that have gates for communicating with another (other) subprocess(es). Thus, the **ManagementPlatformR** process has internal communication gates. The qn gate is used for communication between the **TmnPlatform** process and the **OperationalSystem** process. The **TmnPlatform** communicates with the **OperationalSystem** process using the **pn** gate. The **rn** gate links the **BasicAndUtilitySoftware** to the **OperationalSystem** process. The **OperationalSystem** process also is linked with the **Hardware** process through the **sn** gate.

In order to verify the observational equivalence (see section five) between the two processes (one at a higher level - **ManagementPlatformC**, and the other being more refined - **ManagementPlatformR**) the ´**hide...in**´ operator is used in the following specification to hide the internal gates from the **ManagementPlatformC** process.

```
specification ManagementPlatform[l,f,t,c,p,s,ops]:noexit
      behaviour
            ManagementPlatformR[l,f,t,c,p,s,ops]
      where
      process ManagementPlatformR[l,f,t,c,p,s,ops]:noexit:=
            hide p,q,r,s in
            TmnPlatform[l,f,t,c,p,s,q,p]
            |[p,q]|
            (BasicAndUtilitySoftware[q,r]
            |[r]| OperationalSystem[p,r,s,sop]
            |[s]| Hardware[s])
            where ...
      endproc
endspec
```

Each resource (e.g., LOTOS process) that constitutes the **ManagementPlatformR** can be successively refined (using the specification syles) until one obtains the detailing necessary for the system implementation. Some information relevant to these resources (**Hardware** resource**, OperationalSystem** resource**, BasicAndUtilitySoftware** resource and **TmnPlatform** resource) is presented below:

4.1 Hardware Resource

The hardware resource of the Management System Platform must have sufficient processing capacity to offer the performance specified for the management applications which will be executed in the platform. This hardware must already be modular and expansible, allowing the addition of new modules, access points, components and peripherals to provide for network expansions and inclusion of new functions in the management system and OA&M (Operating, Administration and Maintainance) of the network.

To attend the processing necessities of the management system, the hardware of the platform can be include more than one RISC (Reduced Instructions Set Computer) workstations. In addition, to remote access to the System, X-Terminal or microcomputer with X-Window terminal emulator can be used.

Considering these informations of the **Hardware** resource, a possible next stepwise refinement of the **ManagementPlatform** specification, is presented below.

```
specification ManagementPlatform[l,f,t,c,p,s,ops]:noexit
   ...
      process Hardware[r,x,e]:noexit:=
            Risc[r] ||| X-Windows[x] ||| X-WindowEmulator[e]
            where  ...
      endproc
   ...
endspec
```

4.2 OperationalSystem Resource

It is recommended that the basic platform should use the UNIX operational system because it is a multiuser, multitask and multisupplier operational system. These characteristics permit the implementation or addition of new functions to the Management System. The most used UNIX versions are those which use the SystemV approach (AT&T SystemV, HP-UX, IBM AIX and Sun Solaris 2.0). Each UNIX version presents its own applications programming interface, which difficults the purchase or development of new functions through different suppliers.

With the goal of guaranteeing the portability of an application, at the source code level, the interface between the applications and the operational system must be in conformance with the POSIX standard [ISO 9945-1].

Considering these informations of the **OperationalSystem** resource, a possible next stepwise refinement of the **ManagementPlatform** specification, is presented below.

```
specification ManagementPlatform[l,f,t,c,p,s,ops]:noexit   ...
      process OperationalSystem[px,sv]:noexit:=
            Posix[px] ||| SystemV[sv]
            where
            process Posix[px]:noexit:=      …   endproc
            process SystemV[sv]:noexit:=
                  AT&T SystemV[attsv] ||| HP-UX[ux] |||
                  IBM-AIX[aix] ||| SunSolaris2.x[suns]
                  where …
            endproc
      endproc                                           ...
endspec
```

4.3 BasicAndUtilitySoftware Resource

The following software can be included in the **BasicAndUtilitySoftware** resource:

- Software which shares files - compatible with the NFS (Network File System); Software for network communication with the TCP/IP protocol;
- Software compatible with the X-window/Motif (version 1.2 or later) standard;
- Software to manage print queues that provides transparent access to the printers or plotters and which is independent of the equipment suppliers; and
- Relational and commercial DBMS (in some cases, distributed storage can be recommended to achieve better performance and security levels).

Considering these informations of the **BasicAndUtilitySoftware** resource, a possible next stepwise refinement of the **ManagementPlatform** specification, is presented below.

```
specification ManagementPlatform[l,f,t,c,p,s,ops]:noexit      ...
      process BasicAndUtilitySoftware[fs,tcp,ws,qp,db]:noexit:=
            FilesSharing[fs] ||| NetworkCommunicat [tcp] ||| WindowSoftware[ws]
            ||| QueuePrinterMang[qp] ||| RelationalDBMS[db]
            where  ...
      endproc        ...
endspec
```

4.4 TmnPlatform Resource

The **TmnPlatform** resource interfaces with the following services and facilities: OSI (Open Systems Interconnection) access module, non OSI access module, generic management applications, human-machine interface services and object storage services. In addition, a development environment is considered.

Considering these informations of the **TmnPlatform** resource, a possible next stepwise refinement of the **ManagementPlatform** specification, is presented below.

```
specification ManagementPlatform[l,f,t,c,p,s,ops]:noexit      ...
      process TmnPlatform[l,f,t,c,p,s,qn,pn]:noexit:=
            (OsiAccessModule[oam] || NonOsiAccessModule[noam])
            |[oam,noam,gma,hmis,oss,de]|
            (GenericManagementApplications[gma]
            ||| HumanMachineInterfaceServices[hmis]
            ||| ObjectStorageServices[oss]
            ||| DevelopmentEnvironment[de])
             where ...
      endproc                                     ...
endspec
```

4.4.1 **`OsiAccess`** Module

The OSI access module of the TMN platform includes inferior layer and superior layer protocols and basic management functions.

The OSI access module permits the management of resources that implement the Q3 interface. The [ITU-T Q.811] and the [ITU-T Q.812] (International Telecommunication Union - Telecommunication Standardization Sector) recommendations define both the service and the protocol of each layer of the OSI model for the Q3 Interface implementation. The ITU-T Q.811 recommendation defines the lower layers (1 to 3) protocol profiles. The ITU-T Q.812 defines the upper layers (4 to7) protocol profiles for the transaction service (CMISE - Common Management Information Service Element) and for the file transfer service (FTAM - File Transfer, Access and Management). The CMIS/ROSE (Remote Operations Service Element) implementation must be in comformance with the [ISO 11183-2] (AOM12 - Enhanced Management Communication) profile and with [ISO 11183-3] (AOM11 - Basic Management Communication). The ACSE Session and Presentation implementations must be in conformance with [ISO 11183-1]. The file transfer service must be offered by means of the FTAM protocol. The FTAM implementations must be in conformance with the [ISO 10607-x] (x from 1 to 6) standards. The management communications support protocols implement the OSI model layers 1 to 4 for different types of data transfer networks. The TMN platform must enable OSI management communication with at least the connection oriented transport services and the non-connection oriented services.

In order to complete the Q3 interface specification, the X.73x recommendations define the basic management functions. The basic management functions, offered by the TMN platform to facilitate the development of generic management applications, include a group of support objects (EFD - Event Forwarding Discriminator, Log, Record, Alarm Record, etc) and facilities for manipulating these objects. These functions must be in accordance with the OSI management functions´ profiles (AOM2nm), which are: AOM211 - General Management Capabilities; AOM212 - Alarm Reporting and State Management Capabilities; AOM213 - Alarm Reporting Capabilities; AOM221 - General Event Report Management; AOM231 - General Log Control; AOM24nm - Security Management Profiles; and AOM25nm - Performance Management Profiles.

The main international organizations that produce standards relevant to TMN are ISO (International Organization for Standardization) and ITU-T (International Telecommunications Union - Telecommunications Standardizations Sector). The specifications of international standards permit those doing the implementation to choose one of many options, which makes the interoperability between the systems more difficult. The objective of the profile is to remove the ambiguity introduced by these options, making the choices in a consistent manner. The profiles can be seen, then, as standardized agreements between the implementors. Therefore, the OSI access module of the OSI TMN platform is defined in this document based on standard international profiles called ISP (International Standardized Profiles).

Considering these informations of the **`OsiAccessModule`** module, a possible next stepwise refinement of the **`ManagementPlatform`** specification, is presented below.

```
specification ManagementPlatform[l,f,t,c,p,s,ops]:noexit      ...
          process OsiAccessModule[oam]:noexit:=
               q811[q81] |[…]| q812[q82] |[…]| x73x[q83]
               where …
          endproc                                            ...
endspec
```

4.4.2 **`NonOsiAccess`** Module

The non-OSI access module permits the management of resources that implement protocols and/or proprietary models of information. This module offers facilities to convert specific messages to standard messages and vice versa. Thus, the management applications implemented on a TMN platform act upon the managed resources as if these maintained a Q3 interface.

Considering these informations of the **`NonOsiAccessModule`** module, a possible next stepwise refinement of the **`ManagementPlatform`** specification, is presented below.

```
specification ManagementPlatform[l,f,t,c,p,s,ops]:noexit      ...
            process NonOsiAccessModule[noam]:noexit:=
                  …
            endproc                                            ...
endspec
```

5. Using LOTOS Tools for the Platform Validation

The Eucalyptus toolbox [Gara 96] is a graphical user-interface (GUI) based on X-Windows. Although the Eucalyptus toolbox groups different tools developed by different partners, extensive efforts have been done to achieve a smooth integration, by making tools compatible with each other, by developing gateways that allow different tools to interoperate, and by providing a unified user-interface. The funcionalities of the Eucalyptus toolbox include tools for:

- **analysis** (contains frontend tools performing lexical, sintactic, and static semantics analysis);
- **simulation** (the toolbox supports various forms of simulation, such as interactive simulation (step-by-step execution with backtracking), symbolic expansion (in which input values are handled symbolically), goal-oriented simulation, and random execution);
- **exhaustive verification** (the toolbox allows to generate the LTS corresponding to a LOTOS description. LTSs with millions of states and transitions can be generated, within the limits of memory available. These LTSs can be analyzed and verified in several ways. They can be minimized and compared modulo various equivalence (bissimulations) and preorder relations); At the present, the platform LTS has 37233 states and 75450 transitions. Was generated the reduced LTS, that becames with 18 states and 30 transitions.
- **compositional verification** (due to the well-known state explision problem, exhaustive generation of LTSs is not always possible. The Eucalyptus toolbox allows to divide a LOTOS description into parallel processes, to generate the LTSs corresponding to these processes, to minimize these LTSs modulo a bissimulation relation, and to build the LTS for the whole system by recombining these reduced LTSs); In our old machine (Sun workstation with 32 Mb of RAM), was not possible generate the full LTS, occuring insuficient memory. Now, in the actual machine (Sun workstation with 128 Mb of RAM), was possible generate the full LTS of the platform (with 37233 states and 75450 transitions).
- "**on the fly" verification** (as an alternative approach to avoid the state explosion problem, the Eucalyptus toolbox allows certain properties to be verified without generating the whole range from simple properties, such as deadlock detection and search of particular execution sequences, up to more elaborated properties such as "on the fly" comparisons of LTSs modulo bissimulation relations);
- **graph drawing** (the toolbox contains several tools to display the LTSs generated from LOTOS descriptions. For small LTSs (e.g., with less than one hundred states), these tools generate automatically a PostScript representation); The platform LTS has 37233 states and the reduced LTS becames with 18 states - and then, possible of graphic representation.
- **test generation** (from the LOTOS descriptions, one can automatically generate test sequences, which will be used to assess the conformity of real implementations with respect to the original descriptions);
- **trace analysis** (the Eucalyptus toolbox allows to verify whether a given trace (execution sequence) can be obtained from a LOTOS description); and finally,
- **code generation** (there are compilers to translate LOTOS types and process definitions into C code that can be executed and/or embedded in application programs).

Below can be observed the procedure to get the correction proofs between the service and protocol specifications using equivalence rules. The generation of state graphs (in Aldébran format) is presented - for both platform processes (**`ManagementPlatformC`** and **`ManagementPlatformR`**). With these state graphs it is possible to prove an observational equivalence between the two processes. The verification of observational equivalence of both processes (the **`ManagementPlatformC`** and the **`ManagementPlatformR`**, which are in the graph state format), is presented below, using the Aldébaran tool in Eucalyptus toolset (using the Cæsar tool, with the **`-aldebaran`** option). See the Figure 5.1.

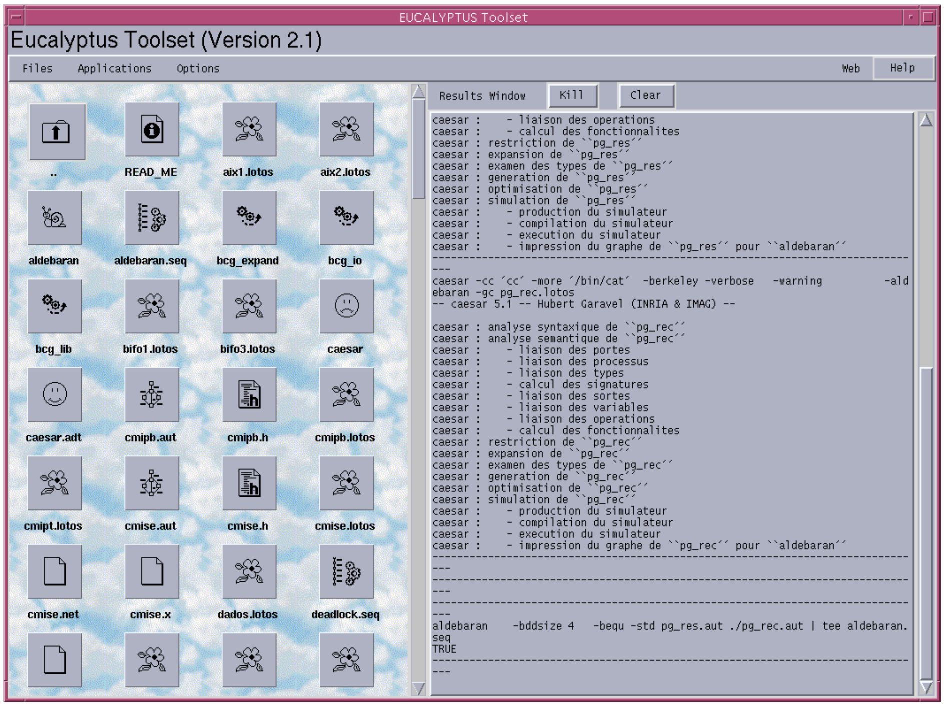

Figure 5.1 - Observational Equivalence between service and protocol specifications.

The ´**TRUE**´ result says that both processes are observational equivalent, i.e. the refinement is proved correct. Along the process of the refinement of these specifications, the verification of equivalence must be repeated, thus proving that each refinement made is equivalent to the previous specification.

The main files generated using the Eucalyptus tooset can be observed below.

```
-rw-r--r--    1 msman    plagere  1486002 Feb 17 10:43 plat.aut
-rw-r--r--    1 msman    plagere   107314 Feb 17 11:17 plat.bcg
-rw-r--r--    1 msman    plagere   125666 Feb 17 10:23 plat.lotos
-rw-r--r--    1 msman    plagere   163527 Feb 17 10:58 plat.net
```

Using TOPO tool (www.dit.upm.es) the LOTOS specifications is translated to C code automatically. See the Figure 5.2.

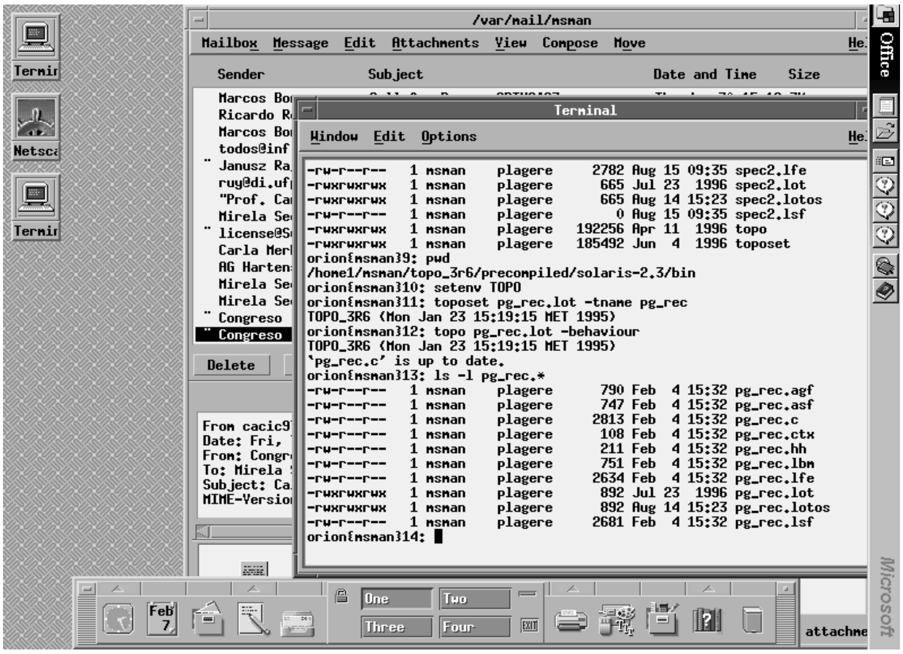

Figure 5.2 - Translation from LOTOS specifications to C code.

The main files generated using the TOPO tool can be observed below.

```
-rw-r--r--   1 msman    plagere    22413 Feb 18 08:53 plat.agf
-rw-r--r--   1 msman    plagere    22366 Feb 18 08:53 plat.asf
-rw-r--r--   1 msman    plagere   100276 Feb 18 08:53 plat.c
-rw-r--r--   1 msman    plagere      106 Feb 18 08:41 plat.ctx
-rw-r--r--   1 msman    plagere     1127 Feb 18 08:53 plat.hh
-rw-r--r--   1 msman    plagere    42283 Feb 18 08:53 plat.lbm
-rw-r--r--   1 msman    plagere   142031 Feb 18 08:53 plat.lfe
-rw-r--r--   1 msman    plagere   125496 Feb 18 08:52 plat.lot
-rw-r--r--   1 msman    plagere   152620 Feb 18 08:53 plat.lsf
```

6. Conclusions

This work presents the formal specification of the technical guidelines supplied by the CPqD-Telebrás to aid the telecommunications carriers to elaborate their tasks lists and to analyze the proposals of the suppliers associated with the generic management platform [ITU-T M3010]. Adopting a generic management platform for the elaboration of a list of tasks will allow the further acquired management systems to maintain open system facilities, allowing the integration and interoperability of new applications.

The formal platform specification significantly contributes towards correct description and rigorous validation process, thus increasing its exactness, mainly in the studies that aim at attesting the conformity between the product obtained and the description of the considered requisites. Then, both CPqD and supplier companies can better and more safely define their requirements. The LOTOS tools used for specification validation (with formal proofs of correctness) constitute an advance in scientific research. In this work, an actual ISO standard technique is used, as well as a rigorous development methodology. The methodology provides for greater legibility, security and facility of specifications development, and permits validation proofs during all the stepwise refinements of the process (from the highest abstraction specification level until the complete refined specification).

The development of telecommunication protocols and distributed systems can be improved by the use of formal methods supported by appropriate software tools. Aims at providing a formal validation of the management system specifications (e.g., the platform and the applications), LOTOS tools are used. The main features of the LOTOS tools can be performed using Eucalyptus Toolset [Gara 96].

The scientific importance of the formalization of the dynamic aspects (behaviour) should be here high-lighted. At the present moment, a great number of works treat the static aspects (abstract data types) only, leaving the behaviour without formal treatment, and in most cases are simple informal descriptive comments. This work aims at presenting a secure way of platform development by suggesting how the work can be continued. In the mid and long term, this work aims to contribute towards the enlightened use of formalisms and in the transference of technology from the research environment to the industrial environment.

As a continuation of this work, ADT (Abstract Data Types) aggregations are predicted, by an investigation of the relationships between the abstract LOTOS data types, the data types in C++ and the specifications in ASN.1/GDMO. Also forecasted is the investigation of the C code execution (source generated automatically from the LOTOS specifications). Finally, foreseen is the investigation of the use of the Java language for the purpose of obtaining and guaranteeing interoperability.

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8. References

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