ABSTRACT: This paper explains the main concepts associated with the definition of an Integrated Network Management Environment (INME) using object-oriented network models, and it proposes an extension to the OSI (Open Systems Interconnection) Reference Model by using three different models that are specified in an integrated way. The extended model incorporates the “de facto” standards used for Internet network management. A basic knowledge of the Internet and OSI-based network management systems is assumed.

Introduction
The normal sequence for the use of a modeling methodology, based on the concepts described in [Bapa94], is as follows: 1) Study of Network Management, 2) Model of Network Management, 3) Formal Representation of Model, and 4) Notational Representation of Model.

The integrated model creation process starts with an identification of the elements in the model. The basic operations, the abstract notation used, the structure of the management information, the managed objects repository (Management Information Base or Management Information Tree), and the communication services implemented in each protocol. In the OSI system it is also possible to examine the architecture of the model. There is not equivalent architecture defined for Internet/SNMP (Simple Network Management Protocol).

This second step in the modeling sequence includes a detailed description of the object classes to be used, the specialisation and generalisation associations among the classes, the object inheritance and aggregation hierarchies, and the object behaviour and relationships.

The formal representation of the model is accomplished by using a combination of diagrams, symbols, and mathematical expressions in order to convey a formal modeling of the network objects, their behaviour, the protocols used for management operations, and the formal specification of relationships.

The fourth, and last step, relates to the process of using an abstract notation to express the information about the model in a form that is independent of machine representation. The logical choice, because of its adoption by both the OSI and Internet fields, is the Abstract Syntax Notation one or ASN.1.

Network Management Issues
One of the driving forces behind the upsurge of network management systems and tools is the increasing cost of network downtime. Networks have become critical to the working of many enterprises, and the management of these systems is essential to make sure organisations can continue offering the services required of them. Another reason for the demand for integrated management facilities is the complexity of current networks. Network administrators can not longer relay on a simple set of commands in order to manage a homogeneous system. More than likely the network will consist of systems from many vendors interoperating in different ways. A combination of LANs, central host, and WAN components is commonplace nowadays, and each part of the network introduces its own set of management tools. The traditional, manual network management is simply not coping. The picture of the network “guru” with five network management consoles in from of her is not a viable option for many companies, specially when that “set-up” is required in several locations at once.

The network management functions of interest should be defined during the design phase of the INME, and the model must show the way the integration is supported by the underlying management protocol and services. It is also important to keep in mind that each application domain will indicate the kind of attributes and functions of interest. For the purpose of this paper, the focus will be on the functions needed in designing integrated environments for network management.

Some of the object classes will be modeling physical entities, however it is possible, even necessary, to model abstract entities with object classes that will not have a physical equivalence. Examples of object classes with
A general view of a network management model is shown in Figure 1. The management information base will contain the network object classes. When the model is realised in any actual network, instances of the object classes will be created and named (mapping of physical entities to network object classes).

The Network Management System communicates with the network devices using the management operations. These operations can be classified as queries/responses and traps (or events). Both the OSI and the Internet management models follow the generic model depicted in Figure 1.

One of the problems with existing network management architectures, is that they are not always properly defined. The architecture for Internet Management, for example, is not even documented. The management protocol is clearly described but without the benefit of a complementary architecture. There are architectures with well-defined concepts, but the application of these concepts in the associated management models is done in an inconsistent way. This last problem creates situations in which vendors produce standard-compliant products that do not interoperate!

Another important problem is the proliferation of managed objects being introduced by the different network management standards groups. The problem is not the quantity of objects available, but the lack of structure. It is increasingly complicated to determine which objects to use in a particular situation.

Another factor to keep in mind is the requirement for coexistence. In that case, it is assumed that multiple levels of complexity are required to model network management. The combination of Internet and OSI management requires the use of different network management protocols working with different levels of modeling complexity. The Common Management Information Protocol (CMIP) requires the use of a full OSI stack for implementation while the SNMP protocol operates with the lower layers of the stack. CMIP has been designed to scale as networks grows, i.e., the ability to perform "manager" or "agent" functions permit managers to reconfigure the Network Management Systems in order to cope with the increasing complexity of networks, however, both SNMP and CMIP lack a hierarchy for exchange of information and cooperation between managers [Greg95].
Finally, neither model (Internet or OSI) specifies procedures in order to react to management events or changes. It is important, however, to be able to model the additional capabilities needed to implement problem-solving, or decision-support systems.

**Integrated Environment for Network Management**

Other authors have discussed the idea of integrated network management based on separate models:

Aiko Pras has presented [Pras95] an integrated architecture that combines two models. One for “primary network functions”, and a second one for “management functions”. The rationale behind his idea is to split the functionality of a computer network into basic functions (thus called “primary”), and network management-related functions. The main goal of this work is to demonstrate that both kind of functions can be expressed in the architectural concepts and rules as used by the OSI Reference Model. It provides a different conceptual view on the role of management functions.

Subodh Bapat suggests [Bapa94] that an integrated network management system may be represented by three information submodels: a protocol-oriented information submodel, a user-oriented information submodel, and a database-oriented information submodel. His protocol-oriented submodel is a simplified information model intended to work with a low-overhead network management protocol such as SNMP. The user-oriented submodel is used to represent summary information on data gathered by performance management applications. Finally, the purpose of the database-oriented submodel is to hide the complexity of the data structures used to store network management objects. These submodels are in reality three different projections of the same information model, and the intention of that information model is to provide a simpler framework for network management. The framework presented does not try to integrate existing “open systems” network management systems.

Heinz-Gerd Hegering and Sebastian Abeck from the Munich Network Management team argue [Hege94] that the different dimensions of network management in a heterogeneous environment require an architecture that includes four submodels: an information model (description of managed objects), an organisational model, a communication model (communication procedures for management purposes), and a functional model (management functions).

The authors use this framework to study the various existing network management architectures. This classification tends to separate network management tasks along functional lines. For example, an OSI network management system would be represented by components in all submodels: managed objects in the information model, CMIP/S (Protocol and Services) in the communication model, the five management functional areas in the functional model, and issues regarding domain management in the organisational model. This framework is useful as a benchmark instrument, but it burdens the integrated network management platform with implementation-specific aspects; notably those related with management functions and organisational concerns.

The purpose of this paper is to represent the inherently different views of network management, based on a modeling approach, while keeping in mind the goal of coexistence of the predominant “open” network management systems. In order to achieve that goal this paper proposes to distinguish between a protocol-oriented network management model, an interoperability model and an element-oriented network management model. Figure 2 illustrates the concept of the integrated network management environment.

**Individual Components**

- Protocol-Oriented NM Model
- Interoperability Model
- Element-Oriented NM Model

**Integrated Approach**

**Figure 2- INME**
The protocol-oriented network management model is used to represent the existing “open” network management systems which support the coexistence requirement (OSI and Internet). A high degree of modularity is achieved by dedicating a separate model to represent these systems. The principle of modularity facilitates the specification of systems that, even while interoperating, are independent of all other systems and independent of internal details. Thus, the object specification in the companion models (Interoperability and Element-Oriented) only needs to be concerned with the view on the interface, hiding the details of the implementation. Enhancements can then be incorporated into the existing protocols systems without affecting their interaction with the rest of the models in the integrated network management environment.

The element-oriented network management model will represent the components that are used within individual network systems. It describes the managed objects, the platform MIB APIs and associated library functions and definitions. This model also includes the translation mechanisms needed to support the interaction between OSI managers and Internet agents. Some of the aspects covered are: the packaging of Internet variables and tables, the handling of CMIP and SNMP requests, and the functional and name mapping required for coexistence.

The interoperability model will be used to represent the underlying communications infrastructure supporting network management. The communications between agents and managers is represented with this model by using the required protocol stacks (OSI or TCP/IP), and by depicting the interconnection between the entities using the network management functions.

The models suggested are classified into three areas that are susceptible to be upgraded as a whole: management protocols and services (Protocol-Oriented model), communications (Interoperability model), and coexistence mechanisms (Element-Oriented model). An example of such upgrade would be the migration of a computer network from a Ethernet/X.25 technology base, at the LAN/WAN levels, to a global ATM network. This significant change can be added to the integrated model by modifying only the Interoperability model. Hence, it is a definite advantage to be able to model those areas in a separate way (facilitating extensibility, programming, implementation, and maintenance) while specifying an integration framework that brings them together. This integrated framework has numerous advantages. Among them:

1) The ability of different network management systems to communicate without overloading the management applications.
2) The flexibility to define new managed objects without notifying all the systems that need to interact with them.
3) A common set of network management procedures based on standards.
4) A general, top-down view of the integrated multi-vendor network.
5) An structured list of network management objects.

The most important reason for having three separate models is the fact that network management activities are found in several levels throughout a computer network. The basic connectivity requirements are very different to, for instance, the requirements of accounting management or performance management. Even within the network management functional areas it is possible to find a great disparity in terms of the classes needed for a particular function, the relationship among classes and, in general, the type of information that needs to be represented in a model.

The approach taken in this paper also has the additional advantage of leaving out platform-independent elements such as the network management functional areas (which are covered by each standard system) and organisational aspects. This characteristic adds to the portability of the framework. This classification also provides a richer level of abstraction facilitating the coexistence requirement, allowing different levels of modeling complexity, and organizing the access to managed objects. The use of the three models also contributes towards the structuring of the ever-growing list of managed objects in current network management systems.

Conclusions and Related Work
An Integrated Network Management Environment designed according to the structure outlined in this paper would greatly facilitate the task of managing heterogeneous computer networks, reducing the complexity inherent to those systems, and allowing efficient communication between management systems and network resources. Special emphasis had been given to the coexistence between OSI and Internet management systems. An Object-Oriented model, that fulfils many of the requirements outlined here, has been
proposed to represent an integrated network management system [Guti96].

References