TELECOMMUNICATION NETWORK MANAGEMENT

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Contents

Summary

Telecommunication systems have evolved tremendously since the 1980's. Their management has thus become an age old applied science that also underwent considerable changes not only in aspects of managed infrastructure and management functionalities, but also in the management scopes and focuses. In this book chapter, we try to give the readers a comprehensive overview of the telecommunication management field while providing lessons from the past and glimpse into the future. To this end, we start the chapter with an introduction to the basics of network management and the evolution of telecommunication networks. Then we briefly examine the prominent network and service management architectures and frameworks that are used

throughout this evolution and present key trends and technologies that are at some point in time a hot focus of management research activities. Finally we present the current trends in network and service management such as the push towards management automation. Because of the increased convergence of voice and data networks in the past decade, the readers may find that the management boundary between telecommunication networks and IP networks are sometimes blurred. This is a product of the telecommunication evolution rather than an artifact in the chapter presentation.

The emphasis of this book chapter is not only to inform the readers of what the telecommunication management field is all about, but more importantly, to give the readers a sense of past, current and future perspectives. A sizeable collection of literature references have been compiled with this chapter for interested readers seeking further information on particular topics covered in the chapter.

1. A Foundation for Network Management

In the late 1980s, the International Telecommunications Union (ITU) and the International Organization for Standardization (OSI) jointly published a set of network and system management standards under the X.700 series [X701, 1989] [X710, 1991] [X711, 1991] [X720, 1992]. This has since been known as the OSI Reference Model. The Telecommunication Management Network (TMN) [M3010, 1996] is a framework established based on the OSI Reference Model, and has become a prominent reference framework for network and system management. The OSI reference model introduces a number of fundamental concepts in network management. *A network management system is an application. Its aim is to analyze, control and manage network and service infrastructure in order to ensure its configuration correctness, robustness, performance quality and security.* The OSI model defines two types of entities in this system: the management entity and the agent entity. The agents are representatives of the network resources or end systems under management. They provide management information to the network managers and the managers monitor the agents and make management and control decisions accordingly. In such a model, the management intelligence is solely placed on the network managers. This is the principle model of computation at the time. With the advancements in distributed system architectures and the increasing popularity of peer-to-peer based systems, the role of managers and agents are becoming less and less distinct in that more intelligence is being distributed into the networks. However, we still use the terms manager and agent today in a looser manner, in that the assignments are used to conceptualize the roles a particular entity plays in a given operation or function rather than referring to the entity in general.

A strong distinction is made in the OSI reference model regarding the terms managed entity and managed object. A managed entity is a resource or end system that is being managed. It is a physical representation, be it an optical switch, a router, or a web server. Managed object refers to the informational view of the entity. It gives the relevant management information and the management capacities of the managed entity. For example, a router could have processing speed, buffer size, and number of I/O interfaces as part of its management information, as well as the set of configurable parameters as part of its management capacity. This gives rise to a bisected view of a managed entity in terms of what is functionally present and what is manageable.

Concerning the diverse set of resources and devices present in networks and systems today, it is immediately apparent that some sort of common information model is necessary to present such information in a consistent manner and a common communication medium must be present within which management information could be conveyed to the managers. Indeed the OSI reference model defines a management system based on three aspects: functional, communicational, and informational. The informational view of a management system defines the management information representation, how the entity is identified, how the management information is structured, what type of information can be made available, and what semantics are applicable on such information. The communicational view of a management system defines the type of communication channel used to transfer management information. In general, a reliable end-to-end communication protocol such as TCP/IP is necessary. Furthermore, a protocol is also designed to specify what types of management actions a manager could request from managed entities and what notifications and/or alarms could be initiated by the managed entities to the managers. The OSI reference model defines five functional areas of management: configuration, fault, performance, accounting, and security (FCAPS). Since its inception, the five areas of management functions have helped in structuring the network management research efforts.

- **Configuration**: concerns with resource configuration such as network path setup, resource provisioning, device configuration, etc. In telecommunication networks today, configuration may also include user terminal configuration, user profiling and service personalization.
- **Fault**: concerns with fault detection, identification, isolation, recovery, path protection, etc. The immediate cause and effect relationship between fault and service disruption makes fault management a highly regarded area of research. With the increasing distributeness of systems and resources, as well as the growing size and complexity of telecommunication networks, it is extremely difficult to identify network faults and be able to address them efficiently. Thus far, much research has been focused on path protection and restoration on optical networks.
- **Performance**: concerns with the quality of service delivery of network services, the monitoring of traffics, and traffic control techniques. With the telecommunication network shifting towards a full digital packet-switched infrastructure and the introduction of multimedia services spanning across both wireless and wired networks, performance management has gained increased attention.
- **Accounting**: concerns with charging and accounting of user traffics. This area of management has not been a major focus of network management research. However, works on pricing and charging in networks directly impact the way account management could be done. Furthermore, as more and more application service providers and usage-based premium services (e.g. real-time broadcasting) are being made available as part of the telecommunication service offering, effective accounting management becomes a necessity.
- **Security**: concerns with aspects such as authentication, authorization, security accounting, access control, encryption, etc. Although security management is an important area of network management, very little attention was paid in the past. This can be attributed to the fact that the traditional telecommunication network

was a tightly managed private network separate from the packet-switching Internet. With the convergence of communication infrastructures, and the increased severity of security attacks on networks and services, security management has become the management problem to be addressed.

An additional management function termed “common” is also defined in the OSI model. It is designed to contain management functions that are common to all other management functions. Event reporting is considered a common function. In section 3, we will present the prominent network management models in terms of their functional, communicational and informational aspects.

As the telecommunication network is a complex infrastructure spanning over networks, services, users, and business entities. The OSI model does not provide a top-down view of telecommunication network management. The Telecommunication Management Network (TMN) framework defines a layered logical architecture consisting of element management, network management, service management and business management. Figure 1 presents a combined model of telecommunication network management according to the TMN and OSI models. The TMN layered architecture is designed in the same spirit as the layered network model. Each layer above builds on the functions of the layer below and is considered an abstraction of the lower layer. Furthermore, the layers from network management up are considered vendor-independent.

- **Element management**: provides a view on the collection of network elements, usually forming a subnetwork. Also mediates data between the network element and the network manager. It is device and network technology specific.
- **Network management**: provides end-to-end network view of the managed resources and devices. It is device neutral.
- **Service management**: provides contacts with customers and service providers. Quality of service assurances, service orders, billing information and trouble ticketing.
- **Business management**: product and human resource planning. Business level view of the services and financial concerns.

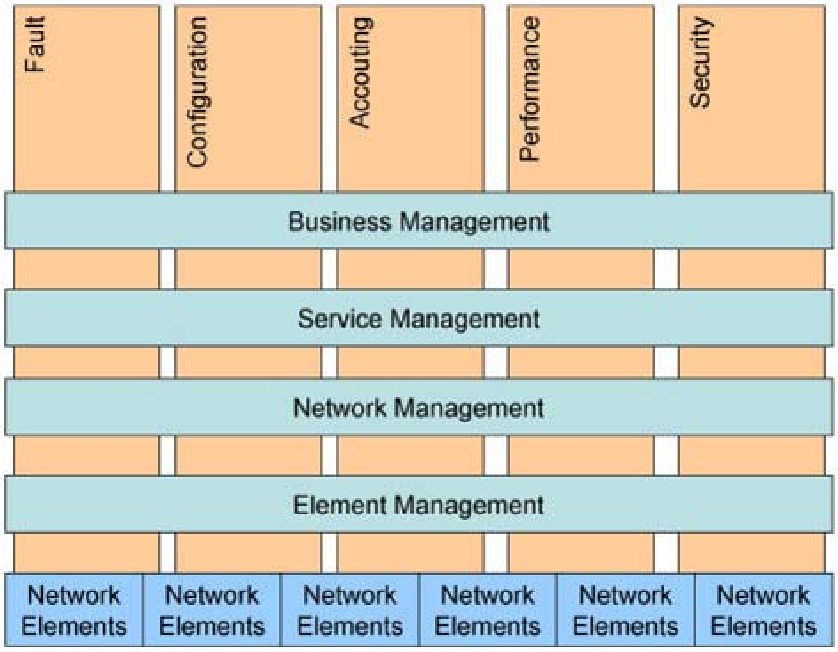

Figure 1: Telecommunication Network Management Model

Since its establishment, the network and element management layering has been adequate in structuring management views. However, as the telecommunication infrastructures evolved in the past fifteen years, the community's view concerning the upper layers of management have changed substantially. In particular, there is no representation of the customers in the TMN model. With the growing service differentiation and customization, the increased role of customers in management (e.g. user-directed management), and the necessity of user profiling for location and context tracking, there is an increasing requirement for representing the customers in the network and service management model. Furthermore, the service layer is growing "fat". In the traditional sense, service was referring to the few bundled telecommunication services that were offered in the 1990s. In today's telecommunication networks, one can see strong mix of multimedia services, personalized user services, and 3rd party applications. It is becoming difficult to maintain a uniform and consistent view of service in a single layer.

The telecommunication network has undergone tremendous growth and evolution in the last fifteen years, changing from a primarily wired circuit-switching closed infrastructure in the 1960s to a wireless packet-switching digital infrastructure today. This evolution has introduced constant change to network management research, and brought about new challenges and opened new issues in old problems along the way. In the following section, a short overview of the telecommunication evolution is presented.

2. Telecommunication Networks: Changes in Motion

The telecommunication network of the 1960s was a fully circuit switching analog based infrastructure. With the design of Pulse Code Modulation (PCM), analog signals were able to be converted to digital in the core network and converted back to analog at end points. Even though a circuit switched line was reserved for each end-to-end call session, the switching and signaling among control logics were performed over shared circuits. The Internationally Standardized Integrated Services Digital Network (ISDN) technology gave the telecommunication networks a face lift; creating true digital telecommunication networks will full digital interfaces, carrier loops and switches, without the analog-digital conversion of the PCM days. The history on these early days of the telecommunication network is well remembered by Andrews [Andrews, 2002]. By early 1990s, the popularity of the mobile telephones prompted a major shift in the telecommunication network service, from primarily providing wired communication to providing wireless communication. Global System for Mobile Communications (GSM) became blueprint architecture for building wireless communication networks. The architecture of GSM is simple and efficient, consists of the wired core network (ISDN at the time) and wireless access subnetworks. Each wireless subnetwork is controlled by a base station with a defined reach. The geographical region each base station encompasses is hence known as a "cell", which also became the catchy nickname of user mobile stations. Because a mobile is a wireless device that can roam freely, being able to track down user location became a major problem for routing incoming calls. The GSM introduced two entities for this purpose: home location registry (HLR) and visitor location registry (VLR). This architecture has proven to be quite effective and the Mobile IP protocol for the Internet is similarly designed. Unfortunately, routing incoming calls is but one of many problems mobility introduced to management. While in a call session, a user mobile could roam from one cell to another. Proper configuration and resource reservation operations must be carried out to ensure the user's call is maintained. This is called a handoff process. Handoff management has been a major area of research to date. The GSM system is now termed 2nd generation system (2G).

By late 1990s, the success of the Internet prompted the telecommunication business to seek services beyond voice communications and to somehow provide high speed Internet-based applications to the subscribers. The 2G system was deemed too archaic to meet this goal. The 3G telecommunication network was proposed with two major improvements over the 2G systems. One, the radio access technology at the access network was to be upgraded to achieve higher capacity (and hence speed). Two, the core network would be full packet-switching digital networks that eventually would converge with the Internet infrastructure. Because the changes were too drastic to be implemented and deployed in short terms, a "phasing" strategy was proposed in which, the 2G systems were to be upgraded first to 2.5G systems and then to 3G systems. The 2.5G systems were designed to provide data communication without changing the air interface. General Packet Radio System (GPRS) [GPRS, 1996] was a popular 2.5G system architecture. The GPRS system introduced a number of support nodes in the system, including a Gateway GPRS Support Node (GGSN) for interconnection with the Internet. In practice, the GPRS system has not seen much deployment success, because the architecture is overly complex and the actual speed enhancement is not as significant as projected.

The 3G systems, known as Universal Mobile Telecommunication Network (UMTS) consists of a core network and a UMTS Terrestrial Radio Access Network (UTRAN). The core network provides native mobile IP support and integration with IP networks.

The UTRAN access network primarily uses WCDMA and CDMA2000 access technologies depending on the country. Beyond 3G systems (B3G) promise to further increase capacity at the access with a series of new access technologies. [Jamalipour, Wada, Yamazato, 2005] With new high capacity telecommunication network in place, multimedia and Internet-based services are expected to become a major service mix in the near future, and add yet another layer of concerns to telecommunication network management.

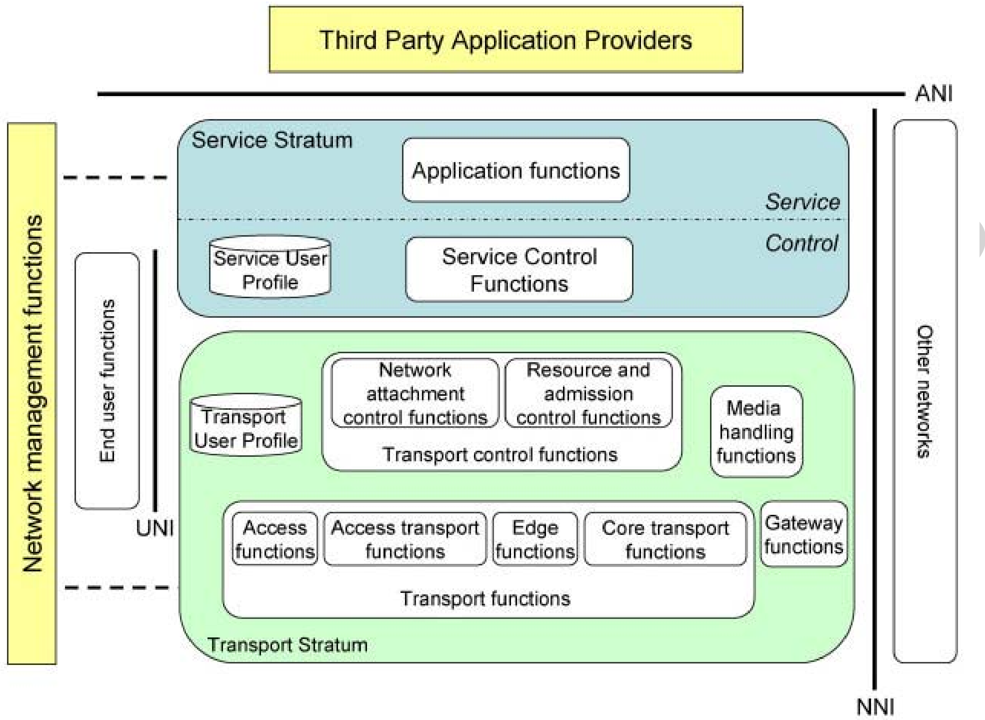

Figure 2: NGN Model Overview

With the convergence of Telecommunication networks and IP networks, the International Telecommunication Union Telecommunication standardization sector (ITU-T) has already begun the process of creating a new network and service model for the Next Generation Networks (NGN). [Y2001, 2004][Y2011, 2004]. The primary aim of this initiative is to create a manageable packet-based network capable of providing telecommunication services and using QoS-enabled transport technologies. The NGN model has a strong focus on service. To address the issues of mobility and network heterogeneity, a technology neutral transport layer is proposed that also support generalized mobility. Figure 2 illustrates the NGN model.

The NGN network model contains the transport stratum and the service stratum. The transport stratum is IP based, with additional access functions to inter-work with different access technologies and transport QoS controls. The service stratum supports both session-based and non-session based services, functions such as session control, subscribe/notify, instant message exchange, presence information, user profiling, application plug-in APIs are included. The service stratum also provides public switched telephone network capabilities and inter-working through PSTN/ISDN emulation. Management functions are distributed within both stratums, the specific on management components and models are yet to be specified. User control to NGN networks is facilitated both at the transport and the service stratums through User-to-Network Interfaces (UNI); Application interaction with the service stratum is facilitated through Application-to-Network Interfaces (ANI); Inter-workings with other networks are facilitated through the Network-to-Network Interfaces (NNI). Compared with the traditional TCP/IP layered model, the addition of service stratum allows for much stronger service-oriented control and management from the provider side. The type of services NGN network model is aimed at supporting are session-based services such as IP telephony and video conferencing, non-session-based services such as video streaming, and public switched telephone network functions (through software emulation). Additional considerations are made for multimedia support within the network through IP Multimedia Subsystem (IMS) consisting of core network functional entities and interfaces that can be used by network service providers to offer SIP-based services to subscribers. Much of the call session intelligence of the telecommunication services is to be supported in IMS.

With the rapid growth and evolution of telecommunication networks, and the introduction of diverse services and applications, there is an urgent need for telecommunication management systems to cope with scale, technology heterogeneity (both present and in the future), mobility, integration of systems both hardware and software in nature, provide quality of service at the network and the service level, and at the same time expand management scope to encompass applications, services, and users. Models such as NGN represent one of many such efforts in advancing the telecommunication network management to address the challenges of today and tomorrow's telecommunication business.

3. Network and Service Management Architectures

In this section, the prominent network and service management architectures in the past two decades are presented. In particular, the examination of these architectures is conducted from the architectural, communicational, and informational aspects and their influence on the network management community discussed. The architectures are presented roughly in chronological order. The early management architectures such as SNMP, TMN, TINA and WBEM target specific network infrastructures, either telecommunication networks or IP networks. This distinction becomes increasingly blurred as time progresses, partly due to the convergence of telecommunication and data communication networks, and partly due to the shift of focus from managing networks to managing services.

3.1. Simple Network Management Protocol (SNMP)

The SNMP management protocol [RFC1157, 1990] was proposed by Internet Engineering Task Force (IETF) in 1988 for IP network management. As the namesake, SNMP is a very simple protocol that works quiet efficiently over the networks typically on top of UDP. Architecture wise, SNMP assumes simple manager and agent relationships whereby the manager does the data gathering and process while the agent supplies the managed information.

The SNMP Management Information Base (MIB) [RFC1212, 1991][RFC1213, 1991] is derived from ASN.1, which provides a standardized form for data presentation, syntax, transmission, and encoding/decoding. In this case, resources are represented as objects containing a set of data variables, mostly scalar. A SNMP MIB is a collection of such managed objects. The definition of objects are standardized across resources of the same type, however proprietary extensions to these objects are also common. The values of variables are typically set by the agent on behalf of the manager.

The SNMP communication protocol has four simple commands: get, getNext, set, and trap. The get and getNext commands are used by the managers to retrieve specified variable values from the SNMP MIB at the agent side. The set command is used for setting variable values. The trap command allows for agents to send notifications to the manager unsolicited. A common performance improvement for SNMP is to have the manager perform get operations only at sparsely spaced time intervals and have the agent "trap" the manager with any variable value update. Because the manager has to send a separate get command per variable to be retrieved, SNMP can be very inefficient when operating over managed objects with large variable tables. The SNMPv2 is proposed to remedy this problem by adding the getBulk command which allows the manager to retrieve an entire list of variables (usually a complete table) with a single getBulk command. Furthermore, SNMPv2 promotes distributed management by defining manager-to-manager interactions. A inform command is defined for managers to notify each other and a manager-to-manager MIB is created to allow for defining management actions. The latest version of SNMPv3 further augments the SNMP protocol with additional security features. To date, SNMP has been one of the most popular management protocols for network management, especially for IP networks. A recent study on SNMP performance vs. CORBA based protocol [Gu, Marshall, 2004] suggested that SNMP is extremely efficient in performing management information access over small set of variables. When large tables are involved however, object oriented protocols such as CORBA fares better.

3.2. Telecommunication Management Network (TMN)

As per discussion in Section 2, TMN is a layered architecture consisting of business, service, network and element layers. Management entities at each layer serves as the manager for the layer immediate below and as agents to the layer immediately above.

The TMN information model used for defining managed objects provides the Guidelines for the Definition of Managed Objects (GDMO) specified in the ITU-T X.722 specification. [X722, 1992] Although GDMO uses ASN.1 for the definition of syntax and encoding of attributes, it is not derived from the ASN.1 as in the case of SNMP MIB. Compared with SNMP MIB, GDMO follows a stronger object-oriented approach that is far more complex and expressive. In particular, GDMO specifies managed objects as classes of objects, have provision for defining behaviors, attributes, and class inheritance. A GDMO managed object can contain attributes, attribute groups, actions, notifications, and behaviors. The attribute and attribute groups are used to specify resource attributes and could be associated a match property that defines how a filtered CMIP request could operate on the variable to determine whether it matches. Examples of such properties include equality, ordering, substrings, etc. The actions are used to define what types of management actions can be carried out on the GDMO object and the notifications are used to define the types of notifications it can send to the manager. The behaviors are used to provide textual descriptions about the behaviors of the managed entity the object represents.

The OSI Common Management Information Protocol (CMIP) [X711, 1991] is used as the communication protocol in TMN. Similar to SNMP, CMIP is an application level protocol; unlike SNMP, CMIP is anything but simple. It uses two other application level protocols: Association Control Service Element (ACSE) and Remote Operation Service Element (ROSE). ACSE is used to establish and release associations between application entities. For CMIP to operate, the two entities mush first associate with each other through ACSE. ROSE is the ISO equivalent of remote procedure call. CMIP uses this transaction-oriented service for all of its requests and responses and to invoke management actions remotely. ROSE also provides error report facilities. The Common Management Information Service Element (CMISE) defines the set of management operations CMIP could be used to perform. These operations could be broadly categorized into three groups. The first group is management association service that uses ACSE to associate and release two entities engaged in management communication, M-initialize, M-terminate, and M-abort operations are allowed where M-abort is used to terminate communications abruptly. The second group is management operation services, including M-get, M-set, M-action, M-create and M-delete. The M-get and M-set operations are used to retrieve and update managed objects. The M-action is used to perform remote operations. The M-create and M-delete operations are useful in creating and deleting an instance of a managed object. As TMN is the prominent management architecture for telecommunication management, GDMO and CMIP were quite popular among the telecommunication community.

3.3. Telecommunication Information Networking Architecture (TINA)

The TINA Consortium (TINA-C) was formed in 1993 to establish the TINA architecture [TINA, 1995] for telecommunication networks. TINA is a conceptual model that captures many essential aspects of the telecommunication operations: resources, networks, software, services and participants. However, the business process is not part of the TINA model. The TINA effort is strongly influenced by concepts of distributed processing environment of the time (e.g. most notably CORBA), it is evident in that TINA views all software and applications as consisting of distributed processing objects and the distributed processing environment is an integral part of the TINA architecture. The overall architecture can be viewed as a computing layering and a management layering. The computing layer is ordered bottom up as hardware, operating systems, distributed processing environment and applications; the management layering borrows from the TMN and is ordered bottom up as element, resource (corresponds to the element management and network management layers of TMN) and service. The concept of separation is applied in TINA to the management and service domains. Management separations follows the TMN functional areas while service separations divide service functions among participants of a service. For example, a point-to-point communication service can have participants taking the roles of consumer, network provider and service provider. The service access and setup is in the domain of the service provider while the service transport is in the domain of the network provider.

Four sub-architectures are defined in TINA: computing architecture, network architecture, management architecture and service architecture. The computing architecture specifies the design and development of TINA software components based on the enterprise, information, computational, engineering and technology views as defined in the ISO Open Distributed Processing (ODP) standard. The network architecture constructs a transport technology independent view of the network and connectivity with the Network Resource Information Model (NRIM). The management architecture is further divided into computing management which is the management of generic software components and distributed processing environment, and telecommunication management, as prescribed in their element, resource and service management layering. The service architecture [Kristiansen et al., 1997] is perhaps the most influential part of the TINA model. It contains the session, access and management concepts. TINA defines a session as a temporal period during which activities are carried out to achieve a goal. The types of sessions are service session, user session, communication session and access session. Service session represents an activation of the service; user session represents user(s) interaction with a service; communication session represents the connections associated with a service; and access session represents the user(s) attachment to the service. The access concept differentiates the user from the terminal, where the terminal is a collection of hardware and software component from which the user accesses a service. Session management includes create, activate, modify, suspend, resume and complete a session relationship.

Currently, TINA-C is inactive. The last TINA deliverable was released in 1999. Despite some research activities on TINA in the past, very little industry realization of TINA has been seen.

3.4. Web Based Enterprise Management (WBEM)

The WBEM initiative was first started in 1996 by Microsoft, Intel, BMC software, Compaq and Cisco systems. It was soon adopted by Desktop Management Task Force (DMTF). WBEM allows for transparent and location independent access to managed objects with a simple client side architecture, Figure 3.

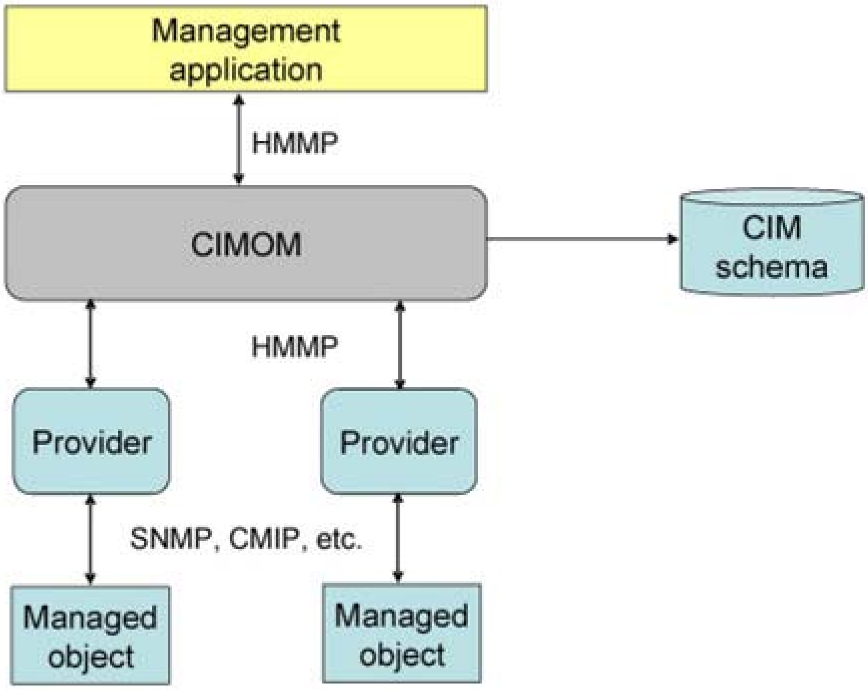

Figure 3: WBEM Architecture

The Common Information Model (CIM) [CIM, 1997] is central to WBEM as all object classes and interfaces are specified with CIM schema and their format defined with Managed Object Format (MOF) of CIM. The CIM Object Manager (CIMOM) serves as the mediator between management applications and providers. Since it interacts with both the manager and provider side with the same protocol, it is possible to construct nested CIMOMs between the providers and the managers. The management application is not directly aware of the CIMOM, instead the application interacts with a namespace that is provided by a CIMOM. Although a namespace is provided by a single CIMOM, there could be one or more sources (both providers and CIMOMs) that contribute to the namespace. Besides static objects which could be provided by the CIMOM directly, all other object manipulations are done with the help of providers. There are five types of providers in WBEM. Ordered by increasing levels of implementation complexity, they are: property provider, instance provider, class provider, namespace provider and standard provider. The Property provider returns the value of an object property; the instance providers can enumerate the instances of a class; the class providers enumerate classes as well as instances within the namespace of the CIMOM; the namespace provider is able to enumerate namespaces, more or less equivalent to a CIMOM; the standard provider can provision standards over set of classes.

The HyperMedia Management Protocol (HMMP) [HMMP, 1997] is an encoding protocol over other transport protocols, most commonly over TCP/IP. It provides access to the objects and classes constructed from the CIM model. The Format of encoding also follows MOF. Diverse range of operations is supported by HMMP corresponding to the possible object and class manipulations in CIM, such as class and instance creation, update, retrieval and deletion. The CIM query language, a subset of SQL, is used for querying. HMMP uses indications for event notifications. A client can register itself as a receiver of an event. When the event matching the condition triggers, the CIMOM would send indications to client. The HMMP has security features such as access control on managed objects, and authentication and authorization at the CIMOM.

The CIM model is a set of schemas for defining classes, properties, associations and methods. It is an object-oriented and extensible information model. Three levels of schemas are proposed in CIM: core schema, common schema and extensions schema. Core schema defines top-level classes and associations. Common schema defines series of domain specific but platform neutral class specifications for devices, systems, applications, databases and networks. The common schema extends from the core schema. The extension schema are used for defining platform or vendor specific extensions of the common schema. Associations in CIM are much richer than extension and inheritance relations, other association such as component, dependency, contains, etc. are also specified. To date, the CIM model is at version 2.5 and many existing managed entities are standardized and specified in the model. With the creation of CIM-XML [CIMXML, 1999] in 1999, the CIM MOF and HMMP have been superseded. HTTP is recommended as the transport protocol and xmlCIM defines the messages.

Although the WBEM architecture, more specifically the CIMOM and HMMP has not seen much deployment in practice, the CIM model, due to its extensibility and standardization effort, has remained as a favored information model in systems management domain today.

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