

Architecture and Algorithms for Network Management using Web Services

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***Abstract*—This paper describes an architecture for network management that bridges the domains of operations support systems (OSS) and network monitoring systems (NMS) by means of information grid concepts and web services practices. Central to this architecture are the expanded definition and use of system state and the expanded reliance on rule-based intelligence. Emerging requirements for network management come from U.S. defense needs and emerging products like MPLS. The recent availability of open and collaborative tools will accelerate the development of the system described herein, known as State-Based Network Management.**

***Keywords*-Service Oriented Architecture, OSS, NMS, SBNM, VIRT, XML.**

I. INTRODUCTION

Management of telecommunications networks consists of two distinct sets of functions, operations support systems (OSS) and networking monitoring systems (NMS), and this research program has proposed to bridge them in a service-oriented architecture (SOA). In State-Based Network Management (SBNM), a network operator – either enterprise customer or provider – possesses a plan for fulfilling services and uses the architecture and algorithms herein to deliver network resources to meet objectives[1].

This paper represents a work in process that integrates both the best current working in the OSS and NMS fields as well as some emerging reasoning tools based on the semantic web that resemble artificial intelligence. The past motivation for this work was a critical comparison of network management automation in, respectively, the electric transmission and

telecommunications industries; management of the electric grid achieves stability and security through realtime models for topology and load that are mostly effective but have had notable failures[2]. The current motivation for this work is collaboration with the Worldwide Consortium for the Grid (W2COG), a group sponsored by the U.S. Department of Defense, that considers Quality of Service *to be the right information in the right place at the right time* [3].

The notion of *state* that we propose for the context of network management consists of disaggregated applications requirements per endpoint, provider inventory (assuming the network edge reaches the enterprise SBNM user), those assets provisioned to fulfill these requirements, and the SNMP-structured indicators per component. SBNM introduces an “engine” to add, change, and delete physical or virtual WAN resources in order to fulfill applications requirements, which may be dynamic themselves. This approach assumes a substrate of traditional SNMP element managers that report to layer known as *VIRT*, which stands for Valued Information at the Right Time. *VIRT* is being developed by Hayes-Roth at the Naval Postgraduate School and Oracle as a project within the W2COG. In the SBNM architecture, *VIRT* interfaces downstream with traditional element managers and upstream via web services to SBNM; SBNM, in turn, will interact with provider operational support systems (OSS) for inventory and provisioning as well as maintain its unique store of applications requirements.

Intended for an ITERA audience, this paper has many complementary objectives: to review the scope of OSS and NMS functionality; to introduce the semantic web as well as the *VIRT* model; to discuss SBNM, especially in the context of current projects including

open source; and to work through the algorithms and interfaces between essential SBNM modules.

The setting for State-Based Network Management is somewhat different from what currently exists in North America but is clearly the trajectory for known providers and their services. Geographically, SBNM is relevant only for metro- and wide-area networks and is not involved in-building infrastructure. The methods describe herein can cover SONET and TDM transport, but they are intended to cover not only packet networks but especially virtual services such as MPLS and VPLS. We assume that, in the future, the edge of a provider's network will attach directly either to enterprise customers or resellers, and that these entities will interact directly with the provider's management systems. Arguably, a significant advantage of next generation networks will be that management systems will interconnect; to make these systems interoperate using common metadata and ontologies is the goal of this project and its collaborators.

II. NETWORK MANAGEMENT FUNCTIONS

A recent analysis estimated that carriers spend \$30 billion dollars per year on operations support systems, the majority of which funds custom development that is largely not standards-based or compatible with other firms' software [4]. One-third of this market is held by vendors of Commercial Off-the Shelf (COTS) packages, each of which has some functional advantage over its competitors. The U.S. Telecommunications Act of 1996 required that incumbent local carriers to open their OSS systems to resellers as a condition of entry into new markets, forcing many improvements. Categories of OSS components include:

- Product Inventory
- Pre-Order; Order Entry
- Provisioning
- Service Activation
- Service Level Agreement Management
- Customer Management
- Billing
- Trouble Ticketing

These systems have evolved from interfaces with manual data entry and fax to Electronic Data Interchange and finally to web services and XML documents. The reader is directed to Terplan [5] for details regarding OSS component functions and data models.

The Telemangement Forum (TMF) is a consortium of software vendors in the OSS market, and it has produced and refined a comprehensive reference architecture for a "Next Generation" OSS (NGOSS) that defines transaction processes and provides a corresponding data model. NGOSS compliance is voluntary for software vendors, and the organization has recently encouraged the use of XML documents and development of open source module interfaces.

In contrast to OSS systems, the demand for network monitoring software is met largely through COTS packages that are configured for the customer's network. NMS systems may stand alone or in a hierarchy with subordinate element management systems. NMS is intrinsically an Internet tool, with native capability to receive or poll event information from remote devices and interfaces; the Simple Network Management Protocol (SNMP) defines a series of standards for processes and information. Although IP-based, an out-of-band physical or virtual infrastructure may connect the manager with remote nodes. The reader is referred to Mauro and Schmidt [6] for details of theory and practice of network management using SNMP.

The host or network monitoring station contains management software with the following capabilities:

- Receive event traps from remote devices
- Poll structure information from devices
- Control network interfaces within devices
- Correlate events to remove duplicates
- Archive event data to a data base
- Discover network topology
- Optionally, create an OSS trouble ticket

Interaction with remote devices takes place with a small vocabulary of action verbs but requires detailed knowledge of the structure of managed information.

II. ARCHITECTURE JUSTIFICATION AND OVERVIEW

The notion of state in networking has been seen as overly simplistic and a constraint on scalability. As an industry, we have held strongly to the position that networks not be application-aware and vice versa. From another perspective, network element and configuration data, which also constitute state, have been rigidly maintained in potentially non-accessible, non-interoperable, information *silos*. This research defines a

more inclusive version of network state: the current value of each of the following models:

- The set of all application requirements per endpoint, aggregated only for similar quality of service
- The set of all network elements in provider(s) inventory and their general availability
- The set of all provisioned (i.e, assigned) resources, which is a cross-reference of the previous items
- The set of generic templates for configuring network monitoring all classes of devices and elements

The scope of state includes those requirements, elements, and services under the control of a single network operations center containing an instance of SBNM – either for the enterprise user, the provider, or both. The entire SBNM concept is to support the distributed collaboration of SBNM nodes arrayed in a wide geographic grid, perhaps sharing state information and working with different specific providers at each location.

The architecture proposed by this research introduces a centralized state engine, the SBNM node, whose objective is to exactly fulfill the current set of telecommunications requirements by acquiring provider resources and monitoring them. This can be considered a *bridge* function between the two domains of network management: operations and business support systems (OSS/BSS) and network monitoring systems (NMS). Moreover, this engine is proposed to automate previously manual tasks based on an emerging heuristic approach being developed primarily for defense and homeland security applications that is different from conventional closed-loop control.

In order to deliver grid functionality, SBNM must implement not only interconnection among peers, it also must provide interoperability among collaborative systems. The current network management paradigm, polled and driven by events, has been organized around centralized intelligence, perhaps organized in a hierarchy of element managers. The increase of processing power and memory in network devices has not been used to alter this paradigm. We propose to inject concepts from the information grid to the management plane based upon the following[7]:

- Insightful messaging between nodes
- Local state maintained within each node
- Local resources, functionality, and self-awareness
- Ability to coordinate passage of transit traffic

While the syntax and coordination of messaging among nodes is important, it is the semantic web that provides the true power of SBNM. This system will provide intelligent reasoning that is able not only to translate ideas that are represented in different ways, it will be able to reason toward new conclusions when asked. At this time, there are two areas where semantic reasoning will improve network operations :

1. Interpretation of requirements into services
2. Interpretation of spatial location information

In the first case, it is a creative activity not only to match requirements with network elements in inventory but also to consider alternative designs to meet the requirements. From the perspective of a vendor, a customer's request acquire bandwidth between a pair of endpoints can be fulfilled in a variety of ways, subject to service quality specifications – SONET/TDM, VPN, Frame Relay, and so on. Thus the first task is, for each application {telephony, best-effort data, realtime nonbursty data, and so on}, that it be characterized into detailed QoS parameters such as datarate, latency, jitter, error tolerance, and so on. A superclass of solutions can refer both to the set of facilities in inventory and applications requirements suites, rendering advice to the network operator or designer for one or more feasible solutions.

The second case involves the translation of street address information to both vertical and horizontal coordinates as well as latitude and longitude so that GIS can locate available resources, enabling solutions with existing plant or the least possible construction.

The key enabler for this will be a service-oriented architecture and a semantic web created for the telecommunications management domain, which implies a common taxonomy and ontology accepted by participants. In either the management or control planes, the ability for autonomic devices to carry out their full spectrum of duties without operator intervention is the long term vision of this project.

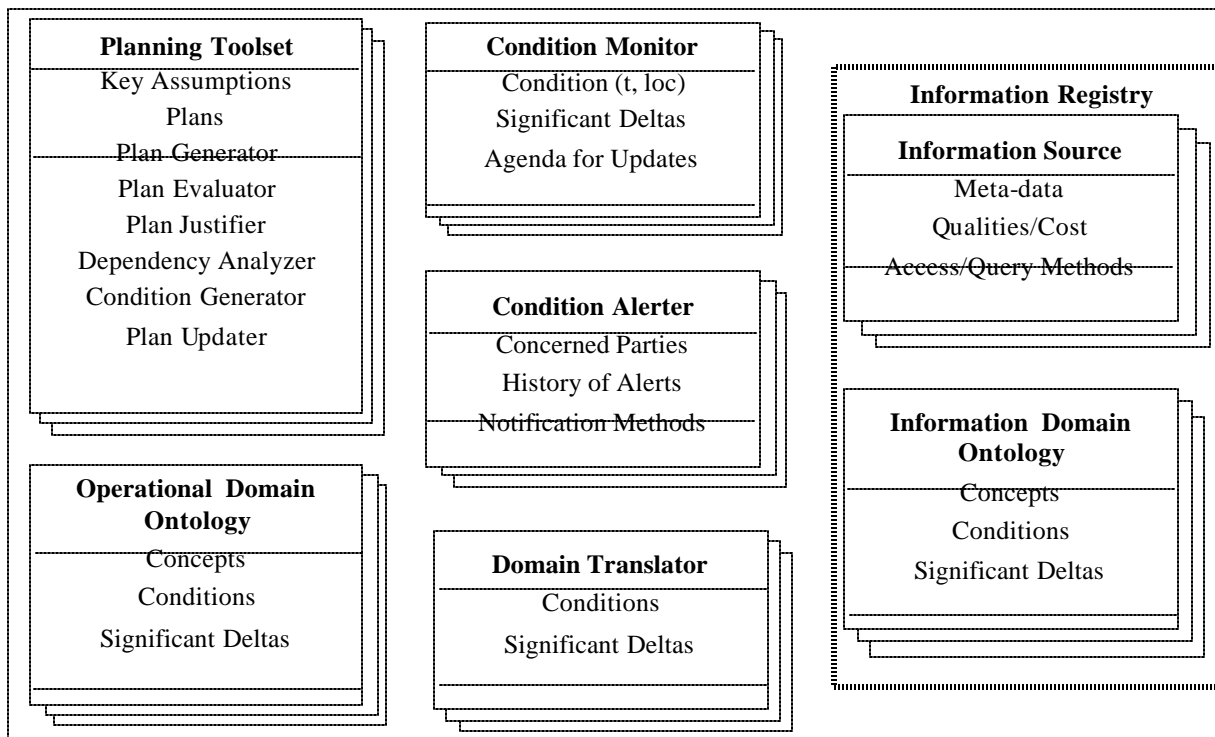


Figure 1. VIRT Architecture. Source: Hayes-Roth, "Model Based Communication Networks and VIRT," 2005.

Whereas in the current telecommunications paradigm, information is pulled into the network manager for action, this research embraces "smart push" between the NMS and the state engine. One motivation for this is the mitigation of the problem of massive (and duplicated) data sent to managers. The volume of messages increases all forms of latency: congestion delays, queuing delays, processing delays in the host operating system, and processing delays in the management application itself. Event correlation and filtering, in this design, remain delegated to the element manager software, but responsibility for topology, state, and action will reside in the state engine model.

The formal model for this "smart push" implementation is called Valued Information at the Right Time (VIRT), whose original motivation was lessen the task of high-consequence operators such as pilots, who often receive burdensome volumes of raw data that is often late and cannot be used to adapt the mission in progress [8]. VIRT is project led by Hayes-Roth within the Worldwide Consortium for the Grid (W2COG).

VIRT incorporates a broad notion of state that contains information about both goals and conditions, with the capability to obtain sensory information, to

provide ontology-based translation on its inputs, to derive the difference between plans and conditions, and to recommend changes to the current plan.

Figure 1 provides a more detailed representation of VIRT. Note the reference to temporal and spatial (cf. *t*, *loc*) data that is pertinent to the aviation use case which is entitled "track."

While most details in Figure 1 are somewhat self-explanatory, the planning toolset merits special attention. The VIRT process can be viewed as always alert and able to execute a procedure when a state-changing event is detected. The basis for logical reasoning within VIRT is both the current plan and the justification for selection of that plan with respect to assumptions. Within VIRT, a set of heuristic rules would be developed that concern the stability of the assumptions and the dependency of the plan upon them. In the author's use case, assume that a flight mission (i.e., plan) requires the use of certain navigation instruments, hence the selection of a certain airplane. If the instruments or the assigned aircraft are unavailable, the mission planner must be alerted – and perhaps VIRT can recommend an alternative plane, another destination, a delay for better (e.g., VFR) weather, etc.

Defense and homeland security expectations are driving new requirements for network operations and management. The U.S. Defense Information Systems Agency (DISA) has engaged a pilot project to demonstrate a “service-based, commercially-managed, and commercially hosted” model known as Net-Centric Enterprise Services (NCES) [9]. These ad hoc and persistent applications and infrastructure capabilities are considered most valuable by the Government:

- Session Management
- Text Messaging within a web conference
- Whiteboarding
- Application Sharing
- Audio (within a conference session)
- Presence and awareness (of others attending)
- File Transfer
- Voting and Polling
- Video, shared live or playback
- Recording
- Instant Messaging
- Chat rooms
- Virtual Spaces (for asynchronous collaboration)

Moreover, this model is intended to apply to U.S. and coalition forces, for classified and classified purposes, and for the spectrum of intermittent through well-connected users.

Equivalent cases can be constructed for network management. We will consider two cases involving, respectively, new and existing services, with respect to the reference architecture presented in Figure 2. The first case is to turn up a new WAN service (e.g., ISDN PRI) between a pair of customer endpoints, where a U.S. competitive local exchange carrier (CLEC) is obtaining facilities from its incumbent carrier. The second case is a circuit outage for some future enterprise customer that can manipulate virtual resources to restore services.

The drawing below represents the information flows between components the architecture proposed by our research. Nodes will be discussed below, and information flows are labeled by their protocol (e.g., XML or SQL) and an identifier that will be used to describe the use cases.

- The central engine maintains state as defined previously and executes the VIRT process – basically to monitor conditions in order to maintain state, and to obtain resources necessary to fulfill requirements.
- The rightmost box represents the agent acting on behalf of the customer. In the management grid, it manages information about users, applications, and locations and must transact with the central engine in terms of aggregated demand and service quality.
- The upper node represents the database local to the central engine. It is currently depicted as a SQL relational database, but we anticipate the availability of native SOA-complaint software.
- The leftmost box represents the collective OSS/BSS capability of one or more providers. The scope of these interfaces is intentionally limited in our subsequent examples.
- The bottom node contains the NMS for monitoring and event correlation. This icon represents use of SNMP as well as perhaps a subtree of other element managers. Northbound messaging via XML is expected to be filtered and terse, passing information only about faults with high confidence.

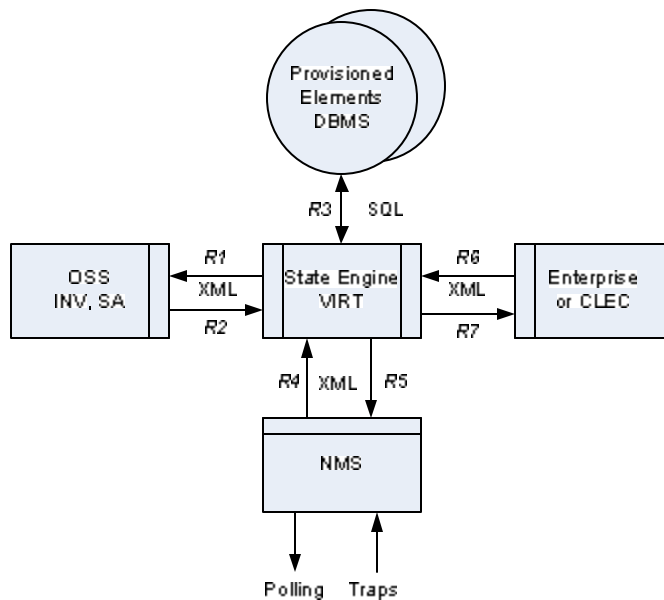


Figure 2. SBNM Components and Flows.

The following two cases provide insight into the processes of VIRT.

Example 1 – Normal Processing

1. Agent requests service on behalf of customer: need capacity for 4 concurrent IP voice trunks and two whiteboarding sessions between 123 Main St. Norfolk and 234 Broad Street Pensacola. Tag in XML and send over R6
2. SBNM node translates order into two virtual circuits with appropriate QoS parameters, producing a list of alternative solutions. Also may translate location to telco coordinates.
 - a. SBNM creates document to queries availability in OSS inventory of said service from one provider at a time over R1
 - b. OSS function is probably beyond scope of this task. OSS reduces service requirements to a bill-of-material and seeks available facilities; responds over R2
 - c. Process repeats until solution is found in inventory
 - d. Single exchange over R1 and R2 to transact order for specific customer
 - e. Status of order is maintained in local database throughout this step.
3. SBNM updates internal network topology and notifies NMS of new network elements to monitor over R5 and R4. Emerging best practice is to create element configuration files as XML documents.

Example 2 – Exception Processing

1. NMS uses SBNM and MIBs to detect and confirm normal event. Process involves both polling and asynchronous traps. Note: this takes place over IP but not necessarily is in-band. We use this approach to monitor everything from router interfaces to security violations to fuel levels and to tower lights. A variety of cheap low-cost ADC and digital IO points can be monitored.
2. SBNM upon receipt of said failure begins the above process at Step 2

III. SBNM Semantic Processing

The following two panels provide a insight into the development of the semantic capabilities of SBNM. The source of Figure 3 is Protégé, whose purpose is to develop the ontology for SBNM elements as well as the metadata to organize the in a hierarchy. Figure 4 shows the corresponding XML document for these components.

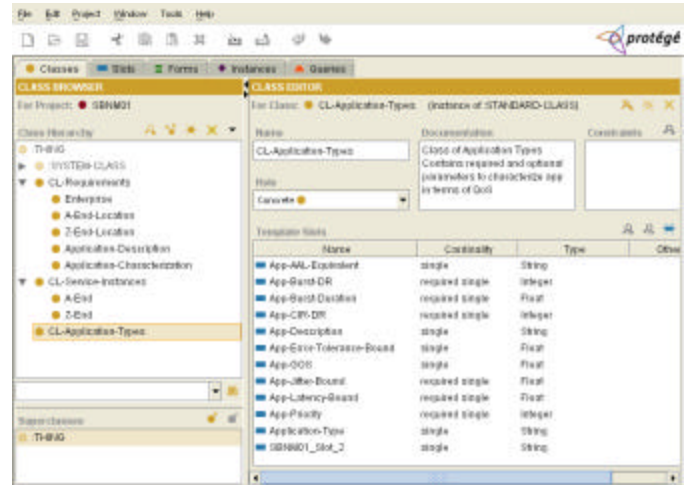


Figure 3. Protégé display of SBNM Applications information.



Figure 4. XML versions of three SBNM elements.

IV. CONCLUSIONS

Telecom providers and enterprise customers expect “Next Generation” of network management systems to interoperate, but no entity has tried to model this activity as a grid. Network design is difficult, costly, and infrequent; exploiting the structure of network information across a grid of business entities, semantic reasoning could optimize network design and enable ad hoc redesign in response to events. We are *spoiled* by TCP/IP networks, which adapt, retry, and work around infrastructure flaws; infrastructure is overbuilt by a factor of three, and installation intervals are 30-45 days. My concept of State Based Network Management proposes a constant cycle of designing, provisioning, and monitoring. Telecom carriers would like to marry the rollout of packet-core virtual services with high-function operations/business support systems – in the medium term (2-5 years) concurrent with standardization.

Semantic processing can play the primary role in advancing telecom management. We are burdened by acronyms and jargon as well as functional isolation of staffs. We spend lots of effort translating one form of *dog speak* to another, and consequently work products and processes are inefficient.

Many existing projects are developing components that have been identified in the proposed architecture above. These include: OpenOSS, OSS/J (Java), OpenNMS, and KING. The first two projects listed incorporate the efforts of the Telemanagement Forum, a consortium of vendors; the two “open” projects make source and executable files available through public licenses. Open source development implies uninhibited free access to source code and collaboration

among self-selected developers; technical support ranges from ad hoc and voluntary to, such as Red Hat Linux, professional and paid.

The development effort for State-Based Network Management collaborates with the W2COG and the architects of VIRT. The application of semantic processing to provide reliable communications is an important use case to validate the architecture and algorithms for VIRT. Given that the SBNM project possesses open source versions of critical applications products, when VIRT code becomes available, the bridge between OSS and NMS will be able to be completed.

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