

## State-Based Network Management:

### *From the Electricity Grid to the Global Information Grid*

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#### Abstract

The architecture of the Global Information Grid with respect to Network Centric Operations is being established and refined through successive Reference Models, whose communities of interest are geographic in nature. The general problem domain of network operations represents a challenge, given the primitive nature of COTS components. A latent problem of dynamic network reconfiguration and resource allocation exists, for which a cross-industry model is being developed.

State-Based Network Management introduces an object-oriented framework for operating data networks that uses Hayes-Roth's concept of *Valued Information at the Right Time* (VIRT). Traditional network management requires a static topology and extensive heuristic filtering of redundant data to identify the origin of faults. SBNM instead relies on publish-subscribe mechanisms for horizontally-organized systems for the most efficient "push and pull" of information.

Data stores necessary for SBNM include application-specific, geographically-located data flow information with service quality requirements, as well as an inventory of available links and nodes. An SBNM engine will regularly compile network topology and, upon some network alarm event, recommend a new topology to meet application-location requirements.

Some regions in the U.S. electricity grid are adopting a similar XML messaging scheme, as well as synchronized and standardized instrumentation and telemetry. This approach develops appropriate definitions for system state

and stability but does not maintain detailed demand or load requirements. In this regard, network SBNM will hold an advantage.

State-Based Network Management is an application that can be a leading exemplar of network centric information sharing at the application layer. Through the Worldwide Consortium for the Grid, the development of SBNM can affect standards and policy in both government and commercial sectors.

#### 1. Introduction

NCO has been the emergent theme in recent military communications development [1]. Correctly, the emphasis has been on the study of end-to-end delivery of what Hayes-Roth has termed, "valued information at the right time." [2] The commercial sector, particular in public utilities, has incrementally developed information sharing models for their communities of interest. In particular, management of the electricity grid has largely been effective based on local notions of system state and horizontal fusion of critical information.

This research focuses on the management of communications infrastructure as the primary object of model-based communications. Network management is in itself a valid application space within the information grid, much like coordination of other logistical information or command and control messaging.

The components and techniques of network management have not yet advanced into a broader ontology or even a complete taxonomy. The state-of-the-art is a limited set of web services for vendor interactions – well short of

the kinds of dynamic resource allocation necessary for an agile military. The overall objective of this research is to organize the taxonomy of network elements for realtime *provisioning*, to outline the forms of messaging necessary to implement same, and to influence consortium members to incorporate such concepts into their products.

The origin of this research was an examination of a massive electricity blackout centered in Ohio on August 14, 2003. The proximate cause of this blackout was a deadly embrace over a file by concurrent processes in a realtime control system, abetted by deficient management both technical and financial. Further examination of the situation revealed a fairly robust distributed control system that normally worked to optimize business outcomes and to maximize power system *security*. [3]

This paper begins with discussions of the needs within the network management application and global information grid spaces, followed by an examination of the extensible concepts from management of the electricity grid. From this information, we then introduce the framework known as State-Based Network Management as a solution to the problems of interest. Within SBNM, we examine the concept of operations and high-level functionality. We conclude by identifying the next steps in this research program.

## 2. Network Management

Network management has advanced incrementally along two distinct paths: network monitoring using the Simple Network Management Protocols (SNMP) for packet networks; and operational support systems for telephone-circuit based networks. This section posits that neither path has provided a suitable framework for supporting the requirements anticipated for emerging and future networked applications.

In the former case, management of telephone carrier operations is performed through a suite of Operational Support Systems (OSS) whose components include billing, customer management, field inventory, order entry, provisioning, trouble ticketing, and so on. As a consequence of U.S. telephone industry deregulation, carriers modernized these systems (e.g., from facsimile to EDI) to enable

coordination between incumbent firms and new competitive entrants. Major accomplishments in this genre include common databases, GIS location of network elements, and implementation of web interfaces. In 2005, a consortium of vendors in the Telemanagement Forum announced the definition of a common messaging approach for a very limited scope of remote configuration tasks based on CORBA technology[1].

Network management is normally associated with the latter case, exemplified by the HP Openview product suite, based on functions associated with SNMP. The primary function enabled through SNMP is passive monitoring of events triggered in the field and able to be transmitted across the (remaining) network. Advanced implementations of SNMP tools have the capability to correlate and filter events, perhaps with the ability to isolate and diagnose a fault. Interfaces report faults on behalf of circuit and link elements; depending on the failure location, the disconnected node may either create a flood of *traps* or none at all [4].

A more significant shortcoming of existing network management models concerns topology or network layout. Network management functions are concentrated in a single host with a single vantage point, with the potential of a hierarchy of similar managers (i.e., Manager of Managers) or relationships with subsystem Element Management Systems (EMS). Thus the network management architecture can be bound by the physical topology of the underlying network – which may not match its actual logical structure. More importantly, the presence of node status information a map of any kind is the product of a task that is largely manual, subjective, and static.

A significant gap exists not only between the expectations and current capabilities of OSS as well as those for SNMP monitors. Integration between these two software suites is also lacking – limited to automatic issuance of trouble tickets within the OSS database upon fault isolation within the SNMP manager[5].

## 3. Global Information Grid

Network Centric Operations (NCO) have been identified as foundational to force transformation, and the Global Information Grid has been defined as its infrastructure for

information sharing. This infrastructure contains and subsumes network infrastructure for connection and internetworking, with the goal of application-to-application and end-to-end distributed processing. This research asserts that the task of managing telecommunication resources is a viable application and mission thread within the NCO space.

At this time, numerous organizations and consortia are organizing to solve, respectively, the problems within NCO of research, standards, and dissemination. The Association for Enterprise Integration (AFEI), in the area of research, has goals of identifying best practices and influencing policy for NCO and system development. The Net Centric Operations Industry Consortium (NCOIC) assists government clients with evaluating requirements and assessing architecture reference models. The Worldwide Consortium for the Grid (W2COG) uses the open consortium model to “harmonize” disparate GIG development efforts and to encourage experimentation. This project is aligned with the W2COG with the intent of a demonstration on its GigLite testbed developed at the Naval Postgraduate School.

The authors anticipate a set of “emerging requirements” for management of telecommunication resources appropriate to support GIG service-oriented applications in a NCO setting. The global information grid requires broader vision for network management that is based on military needs, the most robust requirements possible. The primary need is to provide to deliver network services over changing topologies while maintaining service quality. The means to fulfill this objective will be found in the grid itself using compact messaging at the network management application level among peer systems in a publish-subscribe format. This task incorporates not only timely reallocation of network resources at the edge, i.e., agile mobile stations, but throughout the core, i.e., carrier-provided fixed infrastructure.

At a conceptual level, the processes of analysis and design normally occur once in the lifecycle of a network. This paper proposes that networking platforms maintain internal models of system state and cooperate to reallocate resources to maintain connectivity and quality goals – essentially repeating the network design cycle constantly. This approach is already

embraced in the electricity transmission grid, many of whose ideas are easily extensible to telecommunications.

#### 4. The Electricity Transmission Grid

Control systems employed in the newly-deregulated U.S. electric industry provide interesting insight into solving network management issues for telecommunications. These are high-performance, mission-critical systems that have been refined over several versions. These control systems both cooperate loosely with neighboring peers, they also rely heavily on sensor networks and their telemetry networks.

The context for this section of the paper is the study of the electricity transmission networks that are meshed sparsely among regional retail distribution companies. Both are nominally separate from generation companies, some of which only exist to sell into the grid.

Characteristics of power transmission that are relevant to telecommunications include:

- Aggregated points of demand
- Reasonably well-defined service quality parameters
- Sparse, meshed network interconnections
- Time-varying, somewhat-predictable demand
- No ability to buffer or inventory resources
- Dynamic topologies due to outages

This line of research commenced upon study of recent, massive outage near the author. The research revealed, as expected, a latent deficiency in control systems and supervision. Unexpectedly, this inquiry identified a very efficient distributed control system that utilized “radio discipline” to coordinate firms involved in blackouts, recoveries, and the nuances of operating in a deregulated setting.

On August 14, 2003, a sequence of conditions and events converged to form the single largest electricity outage in the history of North America. On a “macro” scale, this outage spread from one company to another from Ohio, around Lake Erie, ultimately reaching New York City. On a “micro” scale, lacking correct status of direct inter-company connections, the operators

of a single Ohio company could not interpret a combination of computer and alarm failures and ultimately could not communicate their issues to neighboring utilities. The consequences of the outage were enormous and the resulting inquiry was comprehensive. Fifty million people lost over sixty megawatts of power as more than four hundred generating units went offline. Economically, millions of labor hours were lost, with cost estimates exceeding ten billion dollars[7].

Full-service electric companies, those who provide generation, transmission, and retail distribution, operate at least two kinds of Energy Management Systems (EMS): System Control and Data Acquisition (SCADA) and Automatic Generation Control (AGC). The goal of the electric system at this level is to deliver energy to aggregated endpoints at the bus level, with the ability to operate in the absence of individual components (e.g., generating units, transmission paths); this concept is known as “(N-1) Security.”. System members have contractual agreements to re-calculate flow models, a perpetual state modeling exercise, on almost a minute-by-minute basis and not to take actions that would violate system security. Moreover, these firms must identify contingency scenarios in depth and re-calculate these models on at least an hourly basis[9].

In the overall context of network management, however, the electric industry is well-advanced. Interconnected firms that share transmission lines also exchange information among themselves in order to maximize flows without compromising security. Generation firms and transmission entities in effect publish extensive market and technical operational data in real time, often using web portals and data “push” technology[8].

Many useful lessons can be learned from the EMS domain and applied to network management in general. The notion of system state provides ongoing descriptions of aggregated supply and demand that are geographically located that should have predictive powers. The state model is concerned with interconnections with other systems and operates, in the energy context, completely out-of-band. While an abundance of information is available in each firm, the amount of information exchanged is limited; the lack of information, in this case, propagated system failure.

In conclusion, the current operational concept for telecommunications network management has been infrastructure-focused, failure-oriented, based on static topologies, with great respect for layered protocol architecture. System failures are characterized by an abundance of messages that must be filtered or correlated. Best practices in electricity suggest that an adaptable management approach with knowledge of applications that is capable of control and willing both to cross layer boundaries and to establish centralized functionality can be very effective, based on the exchange of a modest amount of essential information between firms.

## 5. State-Based Network Management

To support information sharing in the Global Information Grid, the task of network management must have the capability to allocate resources dynamically, especially following loss of component links or nodes. The method we propose to deliver this capability involves a service architecture with two new characteristics:

- Providing each network platform with an intrinsic state model, and
- Providing each network element with a information interface for control and status

We have termed this approach State-Based Network Management, SBNM.

In the former case, we equate the term network platform with network node and would generally describe it as a point-of-presence or service aggregation point; in a reference model, it would be a network-network interface (NNI). The state model for a network platform would contain both its relevant requirements as well as how they are fulfilled. The model shall indirectly or directly contain:

- Characterization of each application present, in terms of bandwidth, latency, jitter, error tolerance, etc. (e.g., Quality of Service, QoS).
- A list of all user locations (e.g., endpoints) associated with that node
- A cross-reference of endpoints and their associated applications. Note that this cross-reference data element may aggregate flows of the same characteristics with common nodes.

- Per this cross-reference, information regarding what facilities infrastructure is dedicated to that flow specification

This information accurately captures the demand for network resources from the platform perspective. The platform shall be aware of its demand state and how it is fulfilled; moreover, it must be aware of any lack of resources to fulfill connectivity or QoS requirements. Upon detection of a change in requirements, a change in topology, or an interruption to service, the platform's SBNM engine will seek information and obtain resources to re-acquire its state objective. In short, the platform will redesign its connectivity effectively continuously, as opposed to only once in its lifecycle[10].

The companion element of SBNM is to provide an information interface to each network element, which can include physical or virtual network circuits (including their operational parameters) as well as circuit-terminating and switching/routing devices. These assets comprise the "supply" side of SBNM and would include those elements both currently dedicated and those available in inventory for allocation to our communication needs.

A necessary facet of the "supply" side is adherence to a service-oriented architecture. Our concept of operation for these devices is that they would publish both status information (currently feasible under SNMP) and provide a control interface. Functionality for the latter case is limited to console configuration utilities, not interactive web services with posting capabilities. For demonstration purposes, included devices may require a front-end processor. An industry forum has announced a very limited CORBA-based suite of intercarrier provisioning protocols toward this end.

There are two significant consequences to the introduction of state information into network processing: application (un-)awareness, and layer independence. While the adoption of the Internet has been hastened by these two premises, they have served to constrain the management of networks and inhibit their performance.

Internetworking has been based on a protocol architecture that has been rigorous in peer relationships and transparent in its vertical, service dimension [6]. In short, peer layers

such as TCP and IP cooperate across Internets as needed, while their inner workings have been concealed from application software. This has advanced interoperability among applications but prevented them from customizing service quality for communication.

This constraint must be relaxed in order for the SBNM network management application to acquire and configure resources from the network. The electric grid model performs its signaling and control "out-of-band" using fibers colocated with transmission lines; our initial thinking on SBNM places signaling and control in-band.

Another premise for internetworking has been the strict adherence to layered protocols, with easy substitution of layers as a matter of configuration but little flexibility for resource customization at runtime. The approach for introducing this flexibility is termed cross-layer design (CLD), which is best embraced by the multiservice Asynchronous Transfer Mode (ATM) protocol suite. ATM possesses numerous *adaptation layers* that are parameterized for sensitive applications such as realtime uncompressed video.

Consider some region inside the U.S. affected by natural disaster or military conflict. Under normal conditions, communications would rely on SONET/SDH and dedicated satellite infrastructure both for voice interconnection and broadband transit data links. Assume that large portions of this network are offline; remaining platforms with their SBNM engines and telemetry are intact. Assume that part of the remediation to this problem is deployment of some tactical field force that is mobile and largely reliant on wireless voice and data communications. Field communications, though infinitely agile, would appear as aggregated flows with known QoS at one or more network points-of-presence (POPs).

Systems under SBNM will be informed of new requirements, topology changes, component failures, and each SBNM engine will be recommending the allocation of resources at the physical, link, network, and connection/transport levels. Specifically, the database of applications instance and service quality data will provide immediate rankings of candidate resource allocation schemes. If all applications were IP-packet based, SBNM could devise and deploy

MPLS forwarding information to routers as soon as lower-layer facilities were available to support them, for instance. In an advanced but hypothetical setting, SBNM could help select among candidate WAN buildouts that would maximize connectivity with respect to service quality.

## 6. Conclusions and Future Work

Network management is a very practical setting for implementing network centric operations since it is foremost a high-performance information sharing application with important roles for human operators. State-Based Network Management is a viable means for providing capability for emerging requirements, primarily dynamic re-allocation of network resources to meet endpoint, application, and QoS objectives. SBNM is in its conceptual phase, coalescing ideas from a variety of vendor and customer points of view, with an opportunity to influence standards.

The next phase of activity is development of ontologies for energy and telecommunications critical infrastructure in coordination with NCOIC, TMFORUM, and PJM, the leading electric grid operator. With these semantic models in place, an emulation of SBNM on the W2COG GigLite testbed will follow.

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