AN INTELLIGENT APPROACH FOR A NETWORK MANAGEMENT SYSTEM: ARCHITECTURE AND DESIGN ISSUES FOR ATM COMPUTER NETWORKS

Mariana Hentea, Martha Evens
Illinois Institute of Technology
Chicago, IL 60616-3793 USA
mwe@math.nw.edu

ABSTRACT

The analysis and control of performance in networks based on Asynchronous Transfer Mode (ATM) technology is a difficult problem due to their complex dynamic behavior and real-time constraints. Substantial improvements can be obtained by using intelligent systems based on novel techniques from Artificial Intelligence (AI) for the identification, classification, and interpretation of the performance measures. The paper presents a hybrid model that integrates components based on traditional methods with components based on AI techniques such as artificial neural networks, knowledge-based expert systems, and fuzzy logic. The main objective of the design is to build an intelligent system that efficiently evaluates the network performance and provides feedback to the network operator for real-time decision-making.

KEYWORDS
ATM, performance, network management system, decision support system, intelligent system, artificial intelligence.

1. NETWORK MANAGEMENT SYSTEM

1.1 OVERVIEW

The merging of computers and communications technology has influenced the way computer systems are organized and used. The choice of the architecture and technology is based on many factors, but one of the most important is performance. A particular concern is the behavior measured by throughput and response time of the network under heavy load. However, understanding the network performance is difficult because of multiple connections and complex dynamic interactions in real-time. The complexity of the computer networks dictates the use of automated network management tools.

A network management system contains an integrated set of tools for network monitoring and control, so it includes the following key elements: management station, agent, management information base, network management protocol (Stallings 1997). The management station serves as the interface for the human network manager and contains a set of tools for data analysis, fault monitoring and control. The software agent is installed on key platforms. The agent responds to requests for actions from the management station or asynchronously provides the management station with important information. All the resources in the network are represented as objects. The collection of objects is referred as a management information base (MIB). The management station performs the monitoring function by retrieving data from MIB objects or causes an action to take place at an agent, or changes the configuration settings of an agent by modifying the value of specific variables. The link between management station and agents is via a network management protocol such as Simple Network Management Protocol (SNMP).

In the traditional centralized network management architecture, the management station is typically a stand-alone device with one or more management stations in a backup role. This type of scheme does not work when the network grows in size and the traffic load is bursty. If every single agent reports all the data to the network management station, than the station is overburdened. The distributed scheme marks the next evolution of the network management scheme. This scheme implies multiple top-level management stations that are called management servers. Each management server can directly manage a pool of agents or may delegate responsibilities to an intermediate manager. The intermediate manager may monitor and control the agents under its responsibility. Also, it provides information and accepts requests from the higher-level management server. Although this type of architecture spreads the processing, it is still insufficient because of functionality gaps and performance problems that can develop when coordinating multiple technology layers and interfaces. Also, current fault management implementations rely on human expertise to check threshold levels on the measurement variables being collected. If the isolation of a fault requires manual detective work for getting the information from different records and if it takes too much time, the isolation and identification of the fault can be obsolete. This approach is expensive as well as ineffective.

A network management system was implemented as a prototype software system for the Advanced Technology Demonstration Network (ATDNet) by the Advanced Research Projects Agency (ARPA). The architecture of this network management system is based on integrated network management capabilities, multi-tiered and multi-protocol architecture, distributed object-oriented computing architecture (Bajaj et al. 1996), (Doverspike et al. 1996). By using a graphical interface, the network manager can obtain and manipulate detailed information about resources and performances for ATM and SONET layers. Although graphical distributed processing was implemented to alleviate the burden on the network management station, it increases the traffic and decreases the bandwidth due to management cells. Also, it lacks the capability to supply useful knowledge or advice to the network operator when problems occur in the network. When networks become complex and changes to resources, planning, or scheduling occur more frequently, a network operator experiences difficulties in maintaining a sufficient level of expertise. For example, the trend for multimedia applications requires more flexibility for controlling connections, interactions, payload type, transmission rates (Armbruster 1995). Also, the wide area network services need reliable network management systems (King 1998). The need to reduce the operational costs associated with multiple platforms (e.g., ATM, Frame Relay, or SMDS over the same network) requires managing multiple services from the same platform. Also, provisioning an ATM network is slow when the operators are not provided with intelligent tools to learn and use the switch capabilities. Provisioning is difficult especially when the switches are provided by different manufacturers, e.g., the installation of JAMES networks from Europe (Clarke et al. 1998). The following section describes performance monitoring and control problems for ATM networks.

2. PERFORMANCE MONITORING IN ATM NETWORKS

Performance monitoring implies continuous collection of measurement data for evaluation of network behavior. Performance monitoring is more important in ATM networks because ATM services are more demanding than simple dial tone services in telephone networks or best-effort service in packet-switched networks. Measurement data is used for control, network planning, provisioning, maintenance, and billing. It does not suffice to measure the overall performance of ATM networks. It is necessary to monitor the performance of each specific connection because a different Quality of Service (QoS) is guaranteed.

2.1 EXAMPLES OF PERFORMANCE PROBLEMS

Understanding ATM network performance is a combination of science and heuristics. Common factors that impact end-to-end performance are described by (Tanenbaum 1996), (Washburn and Evans 1996), (Wilcox 1996). (Long et al. 1998), (Siegel and Stunkel 1996). However, stability, controllability, and observability are the most important properties when dynamic systems are analyzed (Doshi et al. 1998), (Xie and Rubin 1998). The following are examples of performance problems:

a. Congestion caused by temporary resource overloads.
b. Inappropriate resource use, e.g. a fast line attached to a low-end device.
c. Overloads synchronously triggered; e.g. a broadcast storm, simultaneously rebooting of hundreds of machines after an electrical power failure.
d. Overruns due to lack of system tuning; e.g. not enough memory allocated for buffer space causes overruns to occur and Transport Protocol Data Units (TPDU) will be lost.
e. Retransmissions or delays due to timeout settings; e.g. if the timer is not set correctly, retransmission may occur if the timeout is set too short, or delays will occur if the timeout is set too long.
f. Receiver's delay caused by inappropriate window size; e.g. the receiver's window size must be at least as large as the bandwidth-delay product.
g. Low utilization of the pipe does not justify the costs for a gigabit line.
h. Jitter for audio and video; having a short mean transmission time is not enough, a small standard deviation is also required.

i. Majority of ATM traffic is not amenable to flow control. For example, voice and video traffic sources cannot stop generating cells even when the network is congested.
j. ATM networks are more volatile in terms of congestion and traffic control because of very fast switching and transmission.
k. Application architectures, by their very goals, are not network product oriented, but they establish the requirement base for all data networks. For example, the network demands are modest for an application GUI based on X-window system compared to a GUI application that requires pixel-based transmission of graphic images.
l. All modern application architectures are retrospective attempts to standardize an environment that is already running in many businesses. In other words, the network services and the interfaces supporting these applications become more complex.
m. Scaling the ATM network always uncovers undiscovered problems.
n. Simultaneous call arrivals cause higher delays.
o. Performance of signaling is an essential component of ATM networks performance since ATM technology supports connection-oriented services.
p. Call setup delay and call release delay increase with the number of ATM switches involved.
q. The characteristics of ATM switch architecture have different relationships with performance measures such as call setup delay, call release delay, and response time to the user.
r. Topology of the ATM network adds more to the complexity.
s. The effect of the propagation delay and transmission rate ratio is determining an upper bound on link utilization. For high-speed networks, the utilization suffers.
t. The throughput is limited by the network deficiencies such as end to end delay, buffer overflows due to stochastic nature of the traffic and protocols, etc.
u. The video and multimedia traffic are contributors to bursty traffic causing performance problems in the network.
v. Performances are limited by the ATM switches characteristics such as architecture, e.g. time division versus space division, memory speed, possible output port contention, cell routing mechanism, buffering strategy, handling of multicast connections.

2.2 PERFORMANCE AND FAULT MANAGEMENT FUNCTIONS

The Open Systems Interconnection (OSI) reference model defines the following functional areas for network management: fault management, configuration management, accounting management, performance management, and security management. ATM standards exist at the ATM layer and they treat the ATM network as private lines by recommending the use of Operations, Administration, and Maintenance (OAM) cells. Currently, OAM cells have a special format and specific functions for fault management and performance management (McDysan and Spohn 1998).

However, the management functions for faults and performance are limited to monitoring and reporting of events. Also, lack of complete standardization of management protocols and interfaces allows room for proprietary implementations for the network management system functions. There are different architectures such as the monitor model, the manager-agent model, etc. In monitor model, some probe is used to monitor the network and the control of the network is very limited. In manager-agent architecture, a network management application monitors and controls the network elements by communicating with agents resident on the network elements. The communication between manager and agents is carried out by a standard protocol. Chen et al. (1996) suggested a framework for use of management cells that are defined to distinguish the broad class from OAM cells. While the management cells take advantage of the ATM transport facilities by providing a fast vehicle to carry control information, there is a cost increase due to additional bandwidth and processing overhead at the network nodes. However, a network management system should support the human operator's needs. The next section describes an intelligent approach to the design of network management system.

3. INTELLIGENT APPROACH – TRENDS AND NEEDS

The network load due to management traffic is significant because SNMP is a polling protocol. The number of management messages generated in a time unit is almost two times more than number of agents that send SNMP messages. One approach is to reduce the number of agents but there is a danger that unsupervised nodes may experience congestion that may go undetected. Also, when an agent monitors more node elements, more data is collected. Fault management requires a mechanism for fault detection and prevention. Network configuration, applications, and traffic distribution can alter the type and nature of possible faults, which makes the traditional control unsuccessful. Fault management based on measurement thresholds can be used following the conventional statistical methods. In addition, the time window to send traps can be made variable and a filter criterion may be implemented to send only alarms and threshold crossing alerts that indicate a threshold of abnormality. This approach reduces the number of traps sent to network management system. However, if the thresholds are not set up properly, then problems may go undetected. On the other hand, if the thresholds are exceeded too often, then there is a danger of flooding the network manager with false alarms.

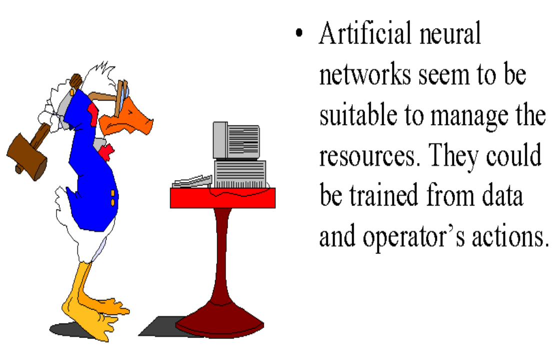

Figure 1. Performances Analysis

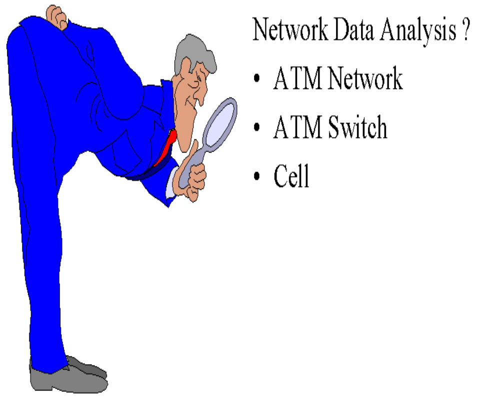

Figure 2. Network Operator's Frustration

Packet loss, mean and variance of end to end packet delay are the major performance measurements in ATM networks. Direct measurements of cell delay and cell loss are useful for verifying the QoS received by users. However, when managing a network, the operator needs other measures such as queue lengths or buffer occupancies at each switch, or utilization (load) factor on each link. In general, the network operator needs to understand the distribution and the trend for each measure as well as the relationship between performance measures before taking any action. For example, congestion monitoring is straightforward in early implementations of ATM switch based on First-In-First-Out (FIFO) queues, but it is more difficult in later-generation ATM switch. In early switches, cell delays and queue lengths are directly correlated, and congestion can be measured by queue length threshold crossings. However, managing the network performances in the case of later-generation ATM switch requires correlating different measurements and data from the system.

When a network performs poorly, the users ask for improvements. Therefore, the operators must determine and analyze huge amount of data (see figure 1). Also, the network operator has to manage and make decisions under the pressure of time. The operator could make better and faster decisions when using a knowledge-based expert system to advise on recovering and tuning parameters such as timeouts, TPDU size, etc. Also, networking knowledge of the users varies from the level of experts to novices and the usage of performance measures from very serious to very casual. As a result, the administration of the network is a difficult and frustrating task (see figure 2). A significant portion of system failures may be caused by operational errors. This emphasizes the importance of network management capabilities to assist the human operators. Artificial intelligence techniques, which include artificial neural networks, fuzzy logic, knowledge-based expert systems, learning and rule based induction, have provided opportunities to solve complex problems for other dynamic systems (Hentea and Evens, 1997). A similar approach is applied to network management.

ATM switches transmit data at such a fast speed that conventional control engineering strategies are inadequate at coping with the control of connection admission, congestion, and routing. Intelligent control builds and enhances the conventional control methodologies instead of providing substitutes. An intelligent control system can autonomously achieve a high level goal while its components and control laws are not completely defined, either because they were not known or because they change unexpectedly.

The main task of an intelligent network management system is to provide specific control actions that make network behavior satisfactory while the network environment significantly changes. The network environment depends not only on the network devices working conditions, but also on human involvement. The network operator is part of the system. As a result, human involvement can make the network perform better or worse. The design of a network management system that can be effectively adapted to the changes of the network performances is one of the most important issues in exploring novel control strategies and algorithms. If the solution to network control and management involves a search or analysis of facts related to control actions known in advance, then decisions must be made under certainty. However, many devices and elements in a network have uncertainty factors. The uncertainty is governed by the combination of traffic characteristics, link usage, nodes congestion, quality of the service. As a result, the huge number of combinations causes difficulty in defining the network management system bounds. The application of pattern clustering with supervised or unsupervised learning can reduce the number. The network management system should support an adaptive control by automatically upgrading the parameters of the network when the environment changes with uncertainty. The design of the intelligent network management system is based on adaptive mechanism. This implies identifying the knowledge of the network environment from different sources such as mathematical model, rule base model, fuzzy model or neural network model. The modeling of a network management system combines the description and integration of network quantitative and qualitative behavior as well as human involvement.

4. HYBRID ARCHITECTURE AND DESIGN ISSUES

From a system point of view, the information resources for construction of a network model can be grouped into the categories of ATM technology, performance data and human knowledge. Based on various types of knowledge, an integrated hybrid model can be implemented for a network management system (see figure 3). A model is selected based on the characteristics of the problem under consideration. For example, a neural network can provide quantitative knowledge, a fuzzy model may provide qualitative knowledge, and a knowledge-based expert system may inference heuristics to support decision making process.

Fault detection and diagnosis are essential in order to maintain the network under a normal and stable status. Traditionally, a mathematical based model can be used for fault detection. However, due to the complexity of many interactions, it is difficult to develop a realistic mathematical model. Rule based expert systems have been recognized as one of the most effective tools in performing fault detection and diagnosis. Particularly when a system has a set of "IF -THEN" statements, a knowledge base with an inference mechanism can be developed to detect and diagnose the faults. Generally, rules are available from an expert. When the expertise is not available, the applications of neural networks, fuzzy logic, and pattern recognition techniques are used to discover rules.

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Artificial intelligence is concerned with improving algorithms and employing problem-solving techniques used by humans. There is need for filtering data and refining knowledge that can be used by a network operator when managing the network. Figure 4 shows the evolution of knowledge from data to advice. The distributed computing environment associated with a network complicates the user's ability to locate and integrate data for decision support. One solution is to use data from a network node after applying a transformation process that may involve summarization, filtering, and aggregation of the data. Then, this data can be saved in a data warehouse. Data mining techniques may be used to derive knowledge and new rules (Berry and Linoff 1997). Due to the massive amount of data available, classification and analysis by a human is impossible. Analysis is difficult even with computer assistance because complex relationships exist among features that are difficult for humans to discover.

A number of intelligent computing methods applied to ATM traffic control are identified and compared by Cullen et al. (1998). Artificial neural networks have been applied for classification of network connections, connection admission control, traffic control, congestion control, quality of service prediction, dynamic routing (Douligeris et al. 1998), (Necker et al. 1994), (Sarajedini et al. 1996), (Mars et al. 1996). The control mechanisms can be viewed at the network level concerning the network topology and routing, further on the call level, the so called call admission control, and on the lowest level, namely the cell level. However, the implementation and use of artificial neural network methods is still limited. First, the researchers used training and testing data that was generated by simulators and the results were not compared with benchmarks to show their effectiveness. Second, due to the characteristics of ATM networks as dynamic system in a huge state space, the application of artificial neural networks is more suitable for control at the network level. The neural networks require to be trained with data. The data may be extracted from the current and historical databases containing measurements data, network state information, control information, and administrative information. A distributed network information database containing composite time-labeled objects is needed. Modeling various network resources, functions, and variables as objects with attributes, interrelationship and behavior is essential.

Success has been reported in the areas of connection admission control and usage parameter control where neural networks and fuzzy systems have been implemented (Pitsillides and Sekercioglu 1997). Fuzzy systems are particularly useful for adapting the Usage Parameter Control (UPC) because of the ability to view the link occupancy in shades of gray as opposed to black and white.

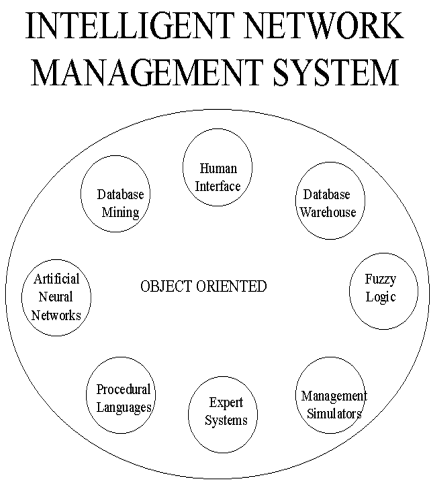

Figure 3. Hybrid Model

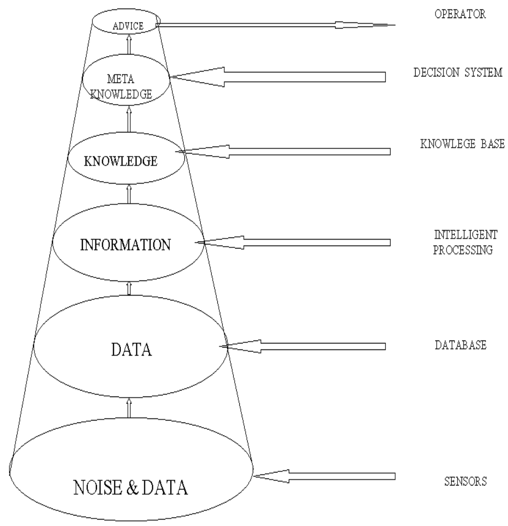

Figure 4. Hierarchy of Knowledge

5. INTELLIGENT MANAGEMENT – CASE STUDY

Faults in a network node may be classified in the following categories: timing faults, semantic faults, resource sharing faults, and hardware failures. In the traditional process control, a controller is designed for each category of faults. In addition, an intelligent module based on artificial neural networks and fuzzy rules may be used to recognize congestion in the node. Then, this information should be refined to generate an action. If the action is advice it should be communicated to the network operator via user interfaces; otherwise the collecting of more measurements should be initiated automatically. One action could be to initiate collecting cell loss measurements more frequently about the condition of the object that is suspected for failure. Figure 4. Hierarchy of Knowledge

Usually, congestion causes poor performance in a network. When a network is congested, cells are lost, bandwidth is wasted, and many delays are introduced. However, recovering from congestion takes time and the availability of the network is reduced. Reasoning with a fuzzy expert system, the congestion condition might be recognized for the later generation ATM switch. This type of switch has a sophisticated architecture that consists of separate virtual queues for different traffic classes and dynamic space allocation between the queues.

The rules to recognize congestion could be implemented in a system that is installed in the network management system. Assume that the congestion is distinguished in time and space. Time and space congestion might occur independently in a complex buffer system. Time congestion is recognized by long delays for low-priority-service. Space congestion may be caused by buffers filling up and overflows. The severity of congestion is judged by the interval between the measured cell delays and the agreed cell delay bound that is specific to each type of service. Also, the linguistic variables (normal, low, high, and critical) are used instead of exact measures for delay and buffer occupancy. Fuzzy logic supports an approximate reasoning that is neither exact, nor totally inexact such as a pure guess. In a very simple form, the following rules may be used:

IF cell delay for low-priority-service is low AND cell delay for high-priority-service is low THEN Time-congestion is normal;
IF cell delay for low-priority-service is high AND cell delay for high-priority-service is low THEN Time-congestion is high;
IF cell delay for low-priority-service is high AND cell delay for high-priority-service is high THEN Time-congestion is critical;
If queue-buffer-filling is less than max-allowed THEN Space-congestion is normal;
If queue-buffer-filling is equal or greater than max-allowed THEN Space-congestion is high;
If queue-buffer-filling-status is equal to overflow THEN Space-congestion is critical;
If Time-congestion is critical AND Space-congestion is critical THEN Display congestion detected AND severity is critical;
If Time-congestion is critical AND Space-congestion is high THEN Display congestion is detected AND severity is critical;
If Time-congestion is high AND Space-congestion is critical THEN Display congestion is detected AND severity is high;
IF Time-congestion is high AND Space-congestion is high THEN Display congestion detected AND severity is high;
If Time-congestion is low OR Space-congestion is high THEN Display congestion detected AND severity is low;

Queue length is not a reliable measure of congestion. More rules can be added to represent the human knowledge for dealing with different kinds of traffic from constant to burst load. If a congestion condition develops faster than the interval of time between management cells response time, than there is a need to prevent congestion by using mechanisms to predict the fault occurrence. Artificial neural networks are good for classification and prediction.

The intelligent modules enrich the functions of the network management system. The implementation of such system is facilitated by the inherent object-oriented architecture of the network management system. It is important to mention that management cells may be represented as objects that could be classified by type of information they may carry such as: measurement data, network state information, control information, administrative information, configuration information. The object representation -Object-Attribute-Value (OAV triples) is convenient and easy to use for listing knowledge to build a semantic net to be used in a knowledge-based expert system. OAV triples are especially useful for representing facts, and the patterns to match the facts in the antecedent of a rule (Giarratano and Riley 1989). The semantic net for such a system consists of nodes for objects, attributes, and values connected by HAS_A and IS_A links.

6. CONCLUSION

Currently, network management systems consists of a little more than instrumentation. Instrumentation allows to detect and to report failures without telling the cause of the problem. Without knowing the cause of a problem, human operators cannot take remedial action. As networks increase in size and complexity, even the experts are not able to manage networks effectively. As network management system evolve from instrumentation to the use of intelligent system approach, a network operator will be using a knowledge base to aid in solving problems. The degree of problem solving is based on the quality of the data and rules obtained from expert or discovered automatically from current and historical databases. Once this automation is achieved, it is possible to build management simulators. The simulator can be used to forecast the costs associated with interoperability and scalability. Reconfiguring the virtual paths and channels due to changes to the business transactions, or integrating with another enterprise network are typical uses of management simulators.

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