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SIMULATION METHODS FOR ANALYSIS OF TRAFFIC PROCESSES IN ATM NETWORKS

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ABSTRACT

This paper presents efficient simulation methods for analyzing modern, large-scale networks and evaluating their performance attributes. Characterizing traffic flows from multiple sources and applications is key in assessing overall network performance measures. It is essential to have quantitative network cost and performance measures in order to plan, design, and implement modern, large-scale networks such as the Advanced Distributed Learning Network (ADLN). ADLN requires integrated, multimedia network services for distributed, collaborative processing among globally dispersed users. ADLN will interconnect multiple categories of users and provide integrated voice, video, and data services, which can be enabled through the use of Asynchronous Transfer Mode (ATM) technology (ATM Forum 1992). Through efficient multi-plexing and networking, ATM can interconnect multiple classes of users and transport ADLN applications cost-effectively with guaranteed per-formance. A combined approach of simulation and analysis is used to assess the performance of the large-scale, distributed network such as ADLN. Topics include the multi-source traffic characterization, performance analysis of ATM networks, capacity sizing, and optimal allocation of network resources.

1 INTRODUCTION

The Department of Defense (DoD) supports a full spectrum of joint distributed training and advanced learning services for peacetime and warfighting activities. It is currently developing architectural plans for the information transport segment to support worldwide joint distributed exercises. The Advanced Distributed Learning Network (ADLN), which will enable DoD joint training and advanced distributed learning, will support modern multimedia applications, such as Web-based training and collaboration, federated simulations, digital libraries, image-intensive data, voice, and video. The Defense Information Systems Network (DISN) provides emerging Asynchronous Transfer Mode (ATM) technology and support for integrated voice, video, and data transfer. Since the network under consideration is so vast in dimension and serves multiple types of traffic, innovative analytical and simulation techniques must be used to produce metrics to quantitatively assess the cost and performance of ADLN. Furthermore, in designing and implementing new ADLN services, one must analyze the traffic characteristics for multiple ATM-specific applications and the network capacity required for acceptable performance levels. This paper presents a combined approach of simulation and analysis to plan and design the evolving ADLN.

High capacity communications networks with intelligent multiplexers, concentrators, high-speed switches, and guaranteed services are needed to meet the growing demands of the ADLN. ATM is a technology for consolidating voice, data, and video traffic over high-speed, cell-based links and has gained widespread support in both industry and the military over the past few years. The main benefit of ATM is that it provides a common switching and transmission architecture for all traffic types required by ADLN users. ATM uses intelligent multiplexing and buffer-ing methods to accommodate traffic peak processes with surge capacity. One of the primary advantages of ATM is its capability to support truly integrated voice, data, and video traffic with guaranteed quality of service (QoS) for all traffic types. The schematic view of the DISN ATM communications architecture using the Broadband Integrated Services Digital Network (B-ISDN) and its network implementations is shown by Figure 1.

In order to help develop, implement, operate, and maintain the ADLN, modeling and simulation techniques were developed to characterize traffic, plan bandwidth capacities, analyze performance, and evaluate the behavior of the integrated processing.

These techniques are used to determine the network architecture that will effectively serve ADLN applications and process average and peak traffic flows at various points of the network. Modeling and simulation, one class of ADLN applications, are federated through the High

Level Architecture (HLA) (DoD 1999) for sharing and exchanging live simulation objects in an efficient manner. The ATM network can provide requisite information transport capabilities for ADLN applications and a global grid for government and commercial networks. Since ATM networks enable total, integrated communications services for all end users, virtual connections among all ADLN users will be realized.

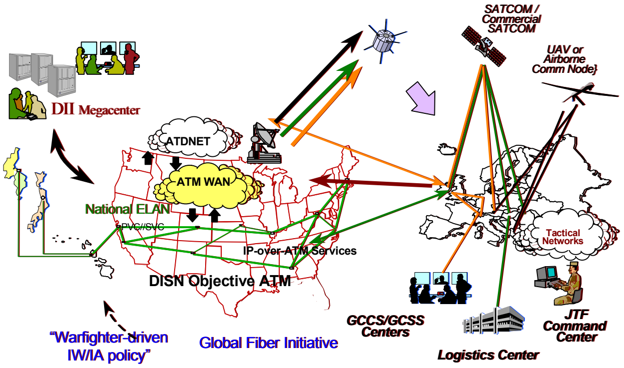

Figure 1: Network Architecture via ATM Services

The metrics devised by the modeling and simulation methods help size bandwidth capacities of the backbone and access capacities at source nodes. Direct analysis of the traffic flows from multiple sources and applications is complex and even simulation of these flows results in numerical obstacles. The methods introduced by this paper are used as an alternative to make the problem numerically tractable. In addition, simulation and analysis can be combined to model existing and future traffic types and to estimate the aggregated traffic flows that predict the realism of the ADLN environment.

The bandwidth capacities of source nodes must be appropriately set to enable cost effective services with guaranteed performance. The user source nodes will be first connected to the nearest ATM backbone nodes through local networks or IP connections. If necessary, ATM can also resort to emulated LAN services to implement ADLN requirements. The bandwidth capacity and required interfaces for ATM connections will determine the access costs. For long-haul information transport services, ATM and SONET are suitable for ADLN. The traffic usage of the backbone network must be estimated to assess backbone network transmission costs. Modeling and simulation tech-niques will be used to determine the network capacities and to estimate backbone traffic loads. Modeling and simulation methods developed have been used for capacity sizing, performance analysis, and assessing the network traffic loading behavior.

Concentrators and interface devices will be employed wherever appropriate for connection to DISN ATM nodes and this will make virtual network services realized among all users. Since ATM networks with multi-protocol services are potentially core components for the planned ADLN, this paper presents ways to evaluate performance measures of ATM networks.

Upon characterizing traffic data and determining bandwidth capacities, modeling and simulation techniques will be again applied to assess all performance attributes that are needed to implement new ADLN services. For various types of communication applications, simulation will aid in the network design and evaluation of performance attributes. Innovative analytical techniques are combined with simulation methods to effectively evaluate the performance of networks and the level of quality of service. Alternative approaches will be applied to conventional simulation methods that often run into difficulty numerically obtaining required performance attributes.

2 GLOBAL JOINT DISTRIBUTED EXERCISES VIA ATM NETWORKS

Currently, heterogeneous network services are widely used in the various networks within DoD that support distributed training and education. The inter-operability of these networks with ATM-based com-munication entities is limited. In order to implement a more interoperable, fully distributed, collaborative learning environment with high-speed multimedia communication services, ATM virtual private network concepts need to be assessed. Moreover, efficient methodologies for capturing the real-world dynamics of ATM networks need to be used to measure traffic characteristics and performance attributes that are key factors in ADLN planning. ATM technology will allow the target ADLN to provide global multimedia on-demand services more effectively with high performance and guaranteed QoS. ADLN applications include Web-based training and collaboration, federated simulations, digital libraries, image-intensive data, voice, and video. The resources for new applications will be assigned incrementally according to the ADLN design plan. Modeling and simulation will assist in determining the amount and the location of network resources that need to be allocated. As ADLN evolves, estimation of existing and planned traffic requirements will constitute an essential part of designing and managing the network.

ATM can provide cost and performance benefits to the entire spectrum of ADLN users. ATM provides more bandwidth efficiency with the capability to handle bursty traffic, which occurs frequently during exercises. ATM not only offers the capability to support the time-sensitive traffic such as voice and video, but also offers enhanced delivery options such as multicasting and broadcasting. ATM allows user traffic at rates and degrees of burstiness compatible with specific applications in progress, not at predetermined rates convenient to the network. Aided by a short, fixed cell size, ATM leads to a generation of very high-speed self routing switches, extensible in both size and speed to meet modern communications requirements. Through the use of ATM, ADLN will be more flexible, since ATM provides a vehicle for virtual private networks, bringing to data traffic the same advantages of carrier-based private networks. ATM will bring about lower operation and management costs than conventional digital networking due to efficiency, high performance, and speed.

There are over 500 estimated ADLN user sites across the world that are grouped into seven hierarchical categories as illustrated by Figure 2. The volume and priority level of traffic will be dependent on the types of facilities communicating with each other. There are 8 modern network application types to be handled by ADLN. The total end-to-end traffic demand is estimated by simulation to be around 1.6 Gigabits per sec (Gbps). Access bandwidth capacities of seven types of ADLN nodes have to be set to meet all offered traffic demands. They range from 896 Kbps to 10.8 Mbps depending on facility types. Simulation approaches were used to assess bandwidth capacities for all ADLN nodes and to evaluate ATM network performance attributes. Issues such as multiple-level security, autonomous network management, and standardization are also being addressed as part of the ADLN architecture efforts.

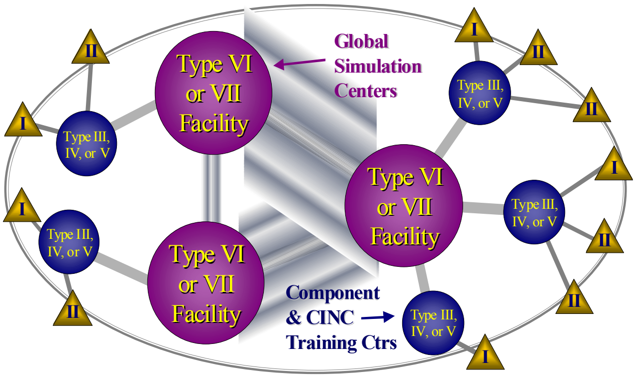

Figure 2: ADLN Facility Hierarchy

For multiple hierarchical levels, virtual connection communications among user sites at the same or different levels must be effectively provisioned through ATM. Such a connection is referred to 'virtual' because a fixed physical path between connected sites may not actually exist through the network. Establishment of a virtual connection is the functional equivalent of placing a connection prior to beginning a communication session. The connection is established and disestablished using special cells having a unique bit stream not containing user data.

Traffic among user nodes can be continuous or intermittent and bursty. For a continuous data stream, an ATM switch provides a circuit-like connection, creating cells continuously and using a fixed amount of network bandwidth. However, unlike a true circuit connection, if data is transmitted in bursts rather than streams, ATM creates cells only when there is information to send instead of using dedicated bandwidth. Thus, since this technique is a form of packet switching, an ATM switch uses less bandwidth than a circuit switch to support the same information transfer. This concept allows ATM to carry all types of traffic, without needing to know the type of traffic beforehand. Synchronous Optical Network (SONET) will also work with both ATM and synchronous transfer mode used by circuit switches. SONET simplifies connection to switching nodes for long-haul, high-speed lines since remote terminals can now connect directly to the switching nodes at the prevailing optical rate. The ATM/SONET network should provide services and characteristics that fulfill the general requirements of ADLN. Such services include commonality of backbone technology, high-speed transmissions, small cell size, protection against data loss, multiprotocol standards, and assured network access during periods of congestion.

To incorporate the ATM/SONET technology, DoD has embarked on building a worldwide communica-tions network architecture that meets all ADLN demands. The planned ADLN network is illustrated by Figure 3. This network will interconnect end users to ATM nodes, routers, Web stations, power hubs, and ATM/SONET switches. The network contains links of up to OC12 rate and proves significant economies of scale not only for consolidating all heterogeneous network services, but also for supporting the high data traffic volume expected of the ever-growing requirements for ADLN services.

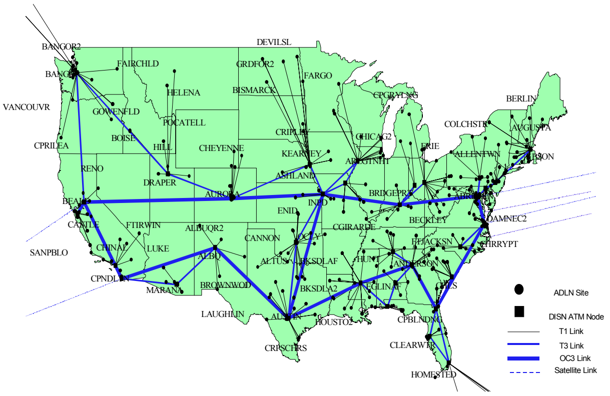

Figure 3: ADLN Interconnected by ATM Networks

There are a number of factors that have a major impact on bandwidth requirements of ADLN. For each traffic type, the assigned bandwidth will be set so as to minimize the average delay not only for that type of traffic but also for all traffic types. The bandwidth will be set through modeling and simulation so as to handle peak traffic rates originating from many user nodes. In this iterative process, the assigned band-width also affects the network delays since IP and ATM routing mechanism will use the newly changed bandwidth capacities.

ATM will use automated routing via available redundant paths, in addition to flow control and error-recovery systems. Routing will then distribute and deliver messages so as to minimize delays throughout the network. The access link sizing is adjusted to accommodate the routing mechanisms which change traffic flows. Other key elements to be considered for operating ADLN are high-speed electronic switching (up to multi-giga bit rates), optical switching, protocol transparent networking, control algorithms, interoperability, reliability/avail-ability, and global grid. All of ATM communications elements will work in concert to operate the ADLN cost effectively with high performance and conform to modern architecture standards and requirements. Through this, the ADLN will play a vital role for the DoD. This paper will next discuss modeling and simulation techniques of evaluating the performance of ATM networks.

3 SIMULATION APPROACH TO ATM NETWORK SYSTEM ANALYSIS

This section presents simulation methods for assessing the performance of large-scale ATM networks with multiple types of communications applications. To this end, traffic flow from multiple application sources must be characterized. Such traffic flows were generated by simulation to assess the performance and to determine minimum bandwidth capacities for user nodes to satisfy the performance requirement. ATM traffic flows constitute a range of fixed and variable rate processes that will be processed by nodes in an integrated manner. In ATM, new types of virtual path routing mechanisms are used to transfer large amount of data traffic volumes seamlessly. Traffic is assigned to different classes depending on its priority and origin-destination pair. ATM networks use hierarchical routing to serve multiple types of traffic traversing the network transmission media and high-speed switches, hubs, and routers.

To implement the network services for the planned ADLN, user or network interfaces need to be deployed wherever appropriate to be interoperable with ATM switches. ATM/SONET network architecture layers serve as the foundation to interconnect various subnetworks involved. ATM cells of fixed sizes will transport all information messages. ATM protocols effectively perform flow control, error handling, message segmentation, and handling of continuous/ bursty traffic. For backbone network routing, ATM cross-connect switches are used as key network components of the ATM/SONET architecture.

In the new high-speed environment of ATM switches and SONET media, queueing delays may be almost negligible but the time required to set up a connection path may be more significant. Messages requesting a direct path must wait in buffer at an initiating node until a path is available to them. Aided by high-speed transmission media, virtual path routing may be readily attainable for most end users. It has been proven through simulation that, as the average message length gets larger, the virtual path routing begins to show better performance. ATM technology will bring forth high performance for ADLN through virtual path services which handle modern high volume traffic with lengthy messages.

Major ATM services are supported by different ATM adaptation Layers (AALs). They are: constant bit rate (CBR) service with end-to-end timing, connection oriented; variable bit rate (VBR) service with end-to-end timing, connection oriented; connection-oriented VBR with non real time; available bit rate (ABR), connectionless data transfer with no timing; and unspecified bit rate (UBR) service. Each application originating from a user node will be mapped to one of the AAL layer application types for ATM transmission.

The first step to assess the performance of ATM networks is to model the existing and future traffic demands, including user requirements. Modeling and simulation techniques have been used to generate traffic flows from a large number of sources and to destinations. A flow from user to destination is defined to be the Markov-Modulated traffic process (see Onvural 1995 and Walrand and Variya 1996) that can be continuous or discrete as illustrated by Figure 4. If continuous, it is called Markov-Modulated Poisson Process (MMPP), and if discrete, the Markov-Modulated Bernoulli Process (MMBP). In practice, a mixture of these two traffic processes is considered. The Markov-Modulated traffic process can be used to model various ATM sources, such as video and voice, as well as characterizing the superposed traffic. Next, a methodology of how to generate the superposed traffic, consisting of eight types of applications, is presented.

Traffic requirements for ADLN applications are either time sensitive, requiring synchronization between media streams, or time insensitive, merely being continuum of each data stream. These properties require exchanges of operations information between various nodes in the network to coordinate the multiple traffic operations and management. The resources such as nodes, links, routers, and gateways that are allocated to a traffic type can be static at the time of connection setup, or dynamic being changeable during the life cycle of the traffic. Static vs. dynamic resource allocation also has implications with respect to connection control/autonomy, communications link routing, and bandwidth allocation.

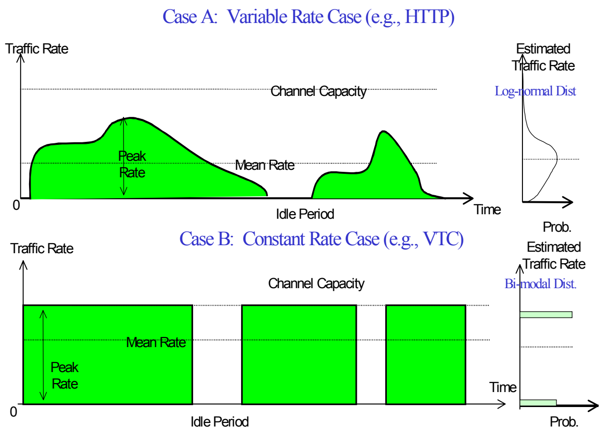

Figure 4: Traffic Flows between End Users

Access bandwidth capacities can be determined after predicting average flow rates. Let Y_{ij}^m be the actual traffic rate of application type m from node i to node j. Then the total expected traffic flow at source node i is

$$\lambda_i = E\left[\sum_{j=1}^{N}\sum_{m=1}^{M} Y_{ij}^m\right]. \qquad (1)$$

The actual access bandwidth capacity must be set as close to the aggregated average rate of each source node to take advantage of multiplexing. This will allow the access link not to be sized too large. Multiplexing is more desired than buffering to cope with the bursty peak traffic more effectively. Let Y_{ij} be the total flow summing Y_{ij}^m over all m. The capacity of user node i, c_i, must be set so that

$$P\{Y_{i1} + Y_{i2} + \ldots + Y_{iN} > c_i\} \le \delta \qquad (2)$$

where δ is predetermined tolerance limit. The value of δ can be as small as 10^{-9} to guarantee that peak traffic rates will be accommodated through multiplexing. It is required that c_i is larger than λ_i for stability. The value of c_i can be determined by applying the Bahadur-Rao theorem (see Walrand and Variya 1996) to (2) and it is readily seen that, the smaller δ is, the larger c_i becomes. For N larger than 120, it has been computed by simulation that c_i can be as small as 45% of the peak rate of the aggregate traffic at node i which represents the worst case scenario. If N is 50, c_i should be 56% of the total peak rate. This rule of thumb has been used to set the recommended access capacities for various types of ADLN nodes.

Bandwidth allocation of backbone network is determined by the routing mechanisms in operation. ATM nodes will perform Public-Network Node-Interface (PNNI) routing algorithms (see McDysan and Spohn 1995) to provide virtual connections from a source node to a destination. ATM networks will attempt to allocate bandwidth more dynamically by providing users access to the entire communication channel when they need it, for as long as they need it. If the channel is in use, a newly arriving user may wait to gain access. There are a number of factors related to ADLN applications that will have a major influence on bandwidth assignments. At the very highest level, they include the total number of simulation entities, mixture of entity types, types of exercise or scenario, security and encryption requirements, and concurrent video requirements. For each traffic type, the assigned bandwidth will be set so as to minimize the average delay. The assigned bandwidth, in turn, affects network delays because the routing algorithm will be affected by the changed bandwidth.

Routing can be simulated on a cell-by-cell basis, which is time consuming. An efficient alternative is to assign end-to-end traffic flows using dynamic routing during simulation and then estimate performance measures for cells through analytic approaches. Methods to simulate the ATM routing are discussed next. ATM network nodes perform automatic routing via alternate virtual paths. As opposed to traditional dynamic adaptive routing, ATM nodes use specific routing mechanisms for each channel of wideband link using a high speed path with minimum path delays. This routing falls into a class of virtual circuit switching. All data sent between session endpoints will be transmitted on a fixed path or virtual path for the entire duration of the session.

The dynamic routing uses metrics to find the optimum path given each source-destination pair. For connectionless traffic, the routing can be done in a classical sense. Let $D_n^m(i,j)$ denote the shortest delay metric for type m traffic along a path from node i to node j in the network. Then $D_n^m(i,j)$ is recursively computed by

$$D_n^m(i,j) = \min_{k \varepsilon N(i)}[d_{n-1}^m(i,k) + D_{n-1}^m(k,j)] \qquad (3)$$

where $d_{n-1}(i,k)$ is the routing metric for link (i,k) at time n-1. The routing metric takes into account such factors as delays, link costs, balanced utilization, and addressing.

For virtual path (VP) routing, a different algorithm can be used for ATM. The optimum path for cells or messages originating from source i and destined for j is determined by

$$D_n^m(i,j) = \min_{p \varepsilon P_{ij}}[D_n^m(i,j \mid p)] \qquad (4)$$

where P_{ij} is the set of all paths connecting nodes i and j. Each message or cell will follow a series of nodes along the optimally selected path p*. The routing metrics in (4) may have any arbitrary forms, so $D_n^m(i,j \mid p)$ is a non-linear function of delays, distances, utilization levels, and link capacities involved in path p. For connection-oriented VP routing, any generalized version of (4) can be used.

ATM connection-oriented routing enforces limits on access to transmission. ATM peak cell rate and sustainable cell rate are handled via traffic control functions (i.e., leaky bucket configurations) to provide virtual connections. ATM congestion control uses network characteristics such as queueing strategy, service scheduling policy, discard strategy, route selections, propagation delay, processing delay, and connection mode. ATM networks implement flow control, which may be window-based, rate-based, or credit based. Data flows may detect and react to congestion on either a link-by-link basis, or an end-to-end basis. The reaction to congestion may be controlled at the receiver, transmitter, or both. ATM routing capabilities will further automate the flow control process to reduce data retransmission.

It is important for network planners to know the bandwidth capacity to be allocated at each ADLN user's site and in the backbone. The total bandwidth capacities for the backbone network can be sized by network optimization as shown by Jo and Sykes (1992) and Kleinrock (1976), and the total bandwidth capacities for the backbone network can be pro-visioned by DISN ATM. Simulation can be used to measure the traffic flows given end-to-end traffic demands and to compute all associated performance attributes. For the integrated architecture design model of ADLN, simulation is used only for allocating network demands and measuring network flows at each node or link. Then analytical methods will be used to compute performance attributes. These attributes can also be computed by simulation but only after consuming an enormous amount of simulation time for large-scale networks such as DISN ATM.

A combined approach of simulation and analysis will also determine reliability and availability attributes with great effectiveness**.** The reliability of the ATM network can be maintained by rerouting and using intelligent system diagnostics to renetwork the system. In case of a network failure, network restoration will be done expeditiously.

The grade of service will be measured in terms of the virtual path reliability. There are R_{ij} total number of virtual paths available from node i to node j. For the *r*th virtual path there are $M_{ij}(r)$ links in series. Let p_s denote link availability for link s. Then the reliability of the virtual path (i,j) is computed by

$$p(i,j) = \prod_{r=1}^{R_{ij}} (1 - \prod_{s=1}^{M_{ij}(r)} p_s) \qquad (5)$$

This virtual path reliability and availability information will be used for a number of related performance attributes.

4 ATM NETWORK PERFORMANCE ANALYSIS

Network performance evaluation methodologies for ATM networks that can be used during simulation are discussed by this section. To implement ATM services, concentrators can be introduced to provide regional networks services. Routers will then be used to connect user nodes to ATM switches via concentrators. Traffic and performance analyses are required for transitioning from IP to ATM. Intelligent network management concepts are used to enhance the performance level and innovative simulation techniques are used for the future network design.

The network under consideration is large in dimension, thus making the direct simulation compu-tation almost impossible. To overcome the compu-tational process, simulation and analysis are combined to analyze network performance. Quasi-simulation, approximations (see Jo and Sykes 1992), and decomposition techniques are recommended for the global network design and analysis. For multiple types of messages or sessions, the developed models measure queueing and processing delay, and add appropriate processing delays. The analysis routine uses the link utilization to check for convergence.

The average type-m traffic rate from i to j, is defined to be λ_{ij}^{m}. Let R_{ij} be the number of alternate paths available from the routing table for traffic from source i to destination j. Define $M_{ij}(k)$ to be the number of links (hops) for the *kth* available path from node i to node j. Assume that, among the available alternative paths, the path with the minimum routing metric will be selected. Another feature of the routing metric is to assign path k, out of R_{ij} paths, for type m traffic, with probability $p_{ij}^{m}(k)$. By proper assignment of $p_{ij}^{m}(k)$ values, splitting, bifurcation, and multicasting of traffic can be handled. Given exogenous traffic arrival rates at all source nodes, the input traffic rate into the *s*th link of path k, λ_s, can be determined. Let Δ_s^m be the total average link delay for type m traffic at link s. Then the end-to-end average message delay from node i to node j for type m traffic is

$$T_{ij}^{m} = \sum_{k=1}^{R_{ij}} p_{ij}^{m}(k) \sum_{s=1}^{M_{ij}(k)} (\Delta_s^m + \gamma_s) \qquad (6)$$

where γ_s is the sum of node processing times, transmission delays, and propagation delays. Now, the network traffic-weighted average message delay for type m traffic, given the total aggregated type-m traffic load, Γ^m, is computed as

$$T^{m} = \sum_{i=1}^{N} \sum_{j=1}^{N} \frac{\lambda_{ij}^{m}}{\Gamma^{m}} T_{ij}^{m} \qquad (7)$$

For a wide variety of networks such as LANs and long-haul networks, it has been proven by the previous literature (see Kleinrock 1976 and Schwartz 1987) and simulation results, that the delay T_{ij} is convex and increasing in λ_{ij}.

Whenever simulation is used for a given network system and the average number of messages of type m originating from node i and destined for node j is computed to be L_{ij}^m, then T_{ij}^m can be obtained by using the Little's law (Kleinrock (1976)), as

$$T_{ij}^{m} = L_{ij}^{m} / \lambda_{ij}^{m} . \tag{8}$$

In ATM networks, the grade of service can be measured in terms of the cell loss probability. There are a total of M different traffic types with type 1 being assigned the highest priority. Let $q_m(i,j)$ be the cell loss probability for type m traffic at link (i,j). Assuming independence of cell loss probabilities among different links, the reliability of path (i,j) for type m traffic, r_{ij}^m, is computed to be

$$r_{ij}^{m} = \sum_{k=1}^{R_{ij}} p_{ij}^{m}(k) \prod_{s=1}^{M_{ij}(k)} (1 - q_m(s)). \tag{9}$$

The reliability of the network will be enhanced by rerouting and intelligent diagnostics to renetwork the system. Since ATM uses virtual connection manage-ment concerns, the management of virtual path and channels can be automated without being concerned with unnecessary network details. In case of a system failure, network restoration will be done expeditiously. The supporting communication network will provide sufficient redundancy (bi- or tri-connectivity) and the appropriate backup mechanism will be provided both at hardware and software components.

5 SUMMARY

This paper has presented modeling and simulation methods for assessing the performance attributes of the future ADLN through ATM services. Advanced analysis and simulation methods for performance assessment of ATM networks have also been discussed. ATM networks with integrated data, video, and voice traffic were considered to provide cost effectiveness and high performance for the planned ADLN. The simulation allows the traffic characteristics of different network designs to be contrasted. The dimension of the ADLN network presents a challenge to using simulation-only methods to assess the system performance measures. Therefore, the use of simulation aided by analysis is warranted. One of key advantages of using simulation is that access capacities are set to cope with peak traffic rates with guaranteed performance without oversizing them. With large communication capacities and fast processing times of ATM, virtual path connection and routing can deliver much better performance than traditional methods. Architecture analysis and performance evaluation methods closely follow the technology advances in ATM. Modeling and simulations are combined with analysis to create performance evaluation methodologies tailored for the ATM network.

DISCLAIMER

This paper is based on the project report "Assessment of DoD Joint Training Network Requirements" by the authors. The results and findings of this paper do not necessarily reflect the official policies and positions of the Department of Defense.

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