NETWORK REQUIREMENTS FOR DISTRIBUTED TACTICAL TRAINING

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ABSTRACT

The Department of Defense (DoD) has many individual and crew trainers that provide high-fidelity full- and part-task training for a specific element or subelement of its weapons system. With the exception of the Simulation Network (SIMNET) suite of tank trainers, most DoD trainers are not sufficiently interconnected to provide simulated battle environment tactical training. Recently, in workshops such as Standards for the Interoperability of Defense Simulations, the DoD emphasized the need for interoperable training systems across the Armed Services. To satisfy this demand, the DoD and industry are currently working together to develop a real-time network protocol standard that has major implications on the development of future training systems. Network simulation is an innovative and exciting solution to many training needs, which have a broad range of network requirements. The network requirements need to be specified for each training application to determine the implications of interoperable simulation.

This paper will define some network requirements for tactical training. We will first discuss the user's needs that we determined from our involvement with the Naval Training Systems Center, the Project Manager of Training Devices, the Naval Oceans System Center, the Naval Sea Systems Command, the Integrated Systems Test, and the current standards process. From the user's needs, we will specify network requirements that address the issues of mediums, interfaces, bandwidths, costs, latencies, protocols, and expansion. Finally, we will discuss our experience of integrating commercial technologies, government standards, and university research into a network prototype to study the effects of network simulation.

INTRODUCTION

In the past, the DoD simulators were built to train a student to use a particular weapons system. The student was usually a novice who needed to understand what the tactical equipment would be like before being exposed to it. In order that the student would be properly prepared for using the actual equipment, the simulators would be built to provide as realistic an environment as possible. But the environment would be limited in most cases to the functional training for which the student was being taught. Thus, the simulator needed few external connections to other simulators. To train at more than the functional level, there is a need for an interconnection of these simulators to provide the tactical environment.

After such functional simulator training, the student was then prepared to begin training on the actual hardware. This training provided the student with the capability to understand what to do in a tactical environment with the complete team in which the student would be associated in a war-time situation. This type of training required operation of very complex and expensive equipment. Because of the complexity and cost of the training, the number of hours that the student could be exposed to tactical training was limited. Recently, cuts in the defense budget, as well as environmental concerns, have placed even more pressure on such training. To enhance the limited training on tactical hardware, the DoD wants to use simulation as an additional means to prepare its forces for tactical situations.

Simulated tactical training provides the necessary audio, visual, communication, and psychological effects that replicate the tactical environment to better prepare personnel for realistic tactical engagements. The two possible solutions for providing simulated tactical training would be: 1) build one system that meets all possible tactical situations, or 2) network many simulation systems that satisfy different aspects of the tactical situations to create a distributed tactical trainer. The cost of constructing several high-fidelity trainers to meet all possible tactical situations would be unacceptably high. Networking of simulators will provide a low-cost solution to the DoD's training needs. This paper discusses some requirements and their possible implementations to accomplish network simulation.

NETWORKED TRAINING SYSTEM

Networking technology has grown considerably in the last 10 years and is an important element that enabled distributed tactical training to become a reality. Network simulation provides the flexibility to create the environment for tactical training by interconnecting the full set of components associated with tactical training. Some of the components of a networked training system include the man-in-the-loop simulators; semiautomated forces (SAFOR); master scenario consoles; elements of the tactical, administrative, and logistics operations; and the after action review (AAR). See Figure 1. Man-in-the-loop simulators provide platforms for the student to experience the tactical environment. These simulators include aircraft cockpit trainers, armored vehicle trainers, and combat control simulators. The semiautomated forces allow multiple friendly and foe vehicles or persons to be simulated and controlled to provide an augmented Blue Force or an opposing Red Force. The AAR system, including its associated data recording function, provides the ability, during and after a training exercise, to review the training session and how well the students implemented the new doctrine, tactic, weapon, vehicle, or training lesson. A network training system integrates these components to provide the flexibility and fidelity of tactical training.

To accommodate the military's diverse training environment, many simulators with different functions and capabilities, located at diverse continental United States (CONUS) and outside the continental United States (OCONUS) sites, will need to be networked together.[1] In addition, as the concept and value of networked simulation expands and new simulators are conceived, interconnection of heterogeneous systems of simulators will be required. The committee for the Standards for the Interoperability of Defense Simulations (SIDS) is leading the development of a standard application protocol to ensure a homogeneous means of providing information between the heterogeneous systems.

Tactical training components will exist at various sites throughout the world. To achieve the largest benefit at the lowest cost, the network system must be able to interconnect simulators located at individual sites on a local area network (LAN), and must be able to interconnect the individual CONUS and OCONUS sites by way of terrestrial and satellite wide area networks (WANs). The system will be required to provide interconnection between both commercial and military networks and their associated communication protocol suites. For example, commercial open systems interconnect (OSI) standard protocols may need to communicate with the military's Link 11 protocol to train using antisubmarine warfare data. To provide these interconnections, intelligent network interface units may need to be developed.

The networked training system must provide real-time communication of the necessary information between all of the simulators to convey the audio, visual, and psychological effects of the tactical world. In this area the critical element is not necessarily the physical medium used, but rather the communication protocol suite selected. The overhead, measured in terms of protocol data units (PDUs) exchanged, must be minimized. Current research is ongoing in both 1) the development of effective low overhead protocol implemented in the traditional hardware and software partitioning of the past, and 2) the development of very

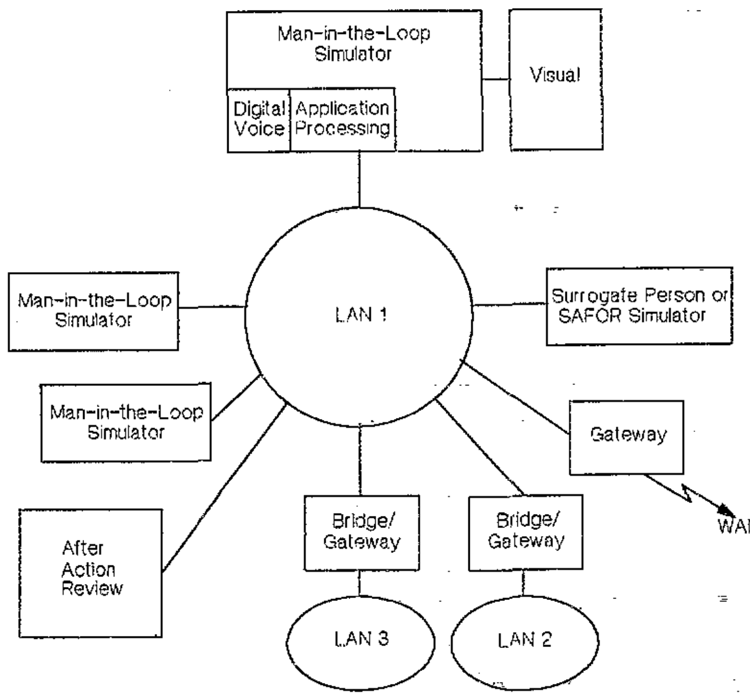

Figure 1. Networked Training System

large scale integration (VLSI) chip sets that will implement the functionality of multiple layers of the OSI model. The Xpress Transfer Protocol®, currently being developed by Dr. Greg Chesson at Protocol Engines Inc., is the most advanced example of the second research area addressing real-time communications.

The networked training system must provide communication methods that support simulated tactical training. These communication methods include connectionless or datagram service and connection-oriented service. The datagram service can be used where the guarantee of message delivery is not required. Much of the data passed between simulators is repeated at either fixed or variable intervals of time. For these cases where the loss of one packet of information is overcome by the receipt of the next or newer packet, the minimum bandwidth and delay nature of the datagram service is an ideal communication service. There are other classes of message traffic where the single PDU nature of a datagram or the uncertainty of delivery cannot be tolerated and for these cases a connection-oriented service is required. Initialization of a tactical training simulator, or updates to the terrain databases or to the simulator software are specific examples where a connection-oriented service is required. The current SIMNET protocol incorporates a transaction service that operates effectively as a selective responding broadcast service. In this service, the originator designates a specific recipient for its message who responds directly to the originator. All other simulators receive and process both the originators' message and the recipients' response message. The transaction service provides the certainty of a connection-oriented service along with the broadcast nature of datagrams; however, it does not require the creation and deletion of a communication session. Setting up the initial conditions for an exercise is a typical example of the need for this type of service. The master controller needs the assurance that the activated vehicle simulator received its initialization commands and data, and all other vehicles on the network were made aware of the presence of the new vehicle.

The physical network must provide adequate bandwidth with an acceptable bit-error rate to communicate the necessary information without undue frame loss or frame repetition. The requirements in this area seem to break out according to whether it is a LAN or WAN requirement. For LANs, in keeping with the low-cost nature of the networked training system, commercially available LAN physical media should be used rather than attempting to fund the development of physical media with some trainer-specific combination of bandwidth and error rate. The commercially available ethernet, 4- or 16-megabit token ring, 80-megabit Proteon, or the forthcoming American National Standards Institute (ANSI) 100-megabit fiber-distributed data interface (FDDI) have bandwidth and error rates that more than satisfy specific tactical training requirements. It will be most beneficial in terms of commonality of components and reduction in gateway processing if all simulators at a given site are interconnected by a common physical media.

For the WAN that interconnects multiple LAN-based tactical training simulation systems, there are cost trade-offs to be made in the selection of bandwidths and error rate. There is no requirement that a WAN interconnecting two sites have the same bandwidth as the LANs. Modeling and analysis can be effectively used to evaluate the complexity and cost of a LAN-to-WAN gateway as a function of the WAN bandwidth and error rate.

Bandwidth must be viewed as a resource of the networked training system and as such requires careful engineering to ensure that the available bandwidth of today is not consumed completely when a new element of the networked training component is brought into the system. For example, a vehicle position prediction method, such as the SIMNET dead reckoning algorithm, can be used to reduce the required bandwidth by not requiring network updates each time changes occur to a vehicle's position. Using a position prediction technique also provides an update mechanism in cases when a broadcast packet is lost or corrupted. Associated with the use of position prediction techniques is a requirement to be able to dynamically adjust the value of the error thresholds of a new position PDU. Aircraft tactical simulators require significantly smaller thresholds than armored vehicle simulators; however, it will not be uncommon to have these two types of vehicles participating in the same tactical exercise. As such, the network must provide a means to update the dead reckoning algorithm error thresholds between pairs of vehicle simulators, and provide a means to accommodate overlapping or conflicting threshold changes.

The networked training system must provide a means for each simulator to compensate for the communication delays in the system. As the extent of the networked training system expands, the magnitude of the delays will similarly expand. These delays can significantly affect tactical training in areas such as close formation flying, and in the realistic determination of weapon fire impact on a target. Dr. Amnon Katz proposed in one of the workshops associated with the standards activity an absolute time-stamp mechanism that would be applicable for CONUS-based simulators.[2] An absolute time stamp would be transmitted in each PDU containing dynamic information allowing each receiving simulator to extrapolate the data over the delay period between when the data was transmitted and when it was received and processed.

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The network training system must be able to support *multiple training scenarios* that may be conducted concurrently at local training sites or by way of interconnected training sites. Simulators at different sites may be part of the same unit in a training exercise or they may be participating in multiple exercises over the WAN interconnections. The configuration of the training scenario should be considered to optimize the effectiveness of the networked training system. For example, multiple fixed-wing aircraft flying in formation may need to be located at one site to avoid the inherent delays created by the WAN. But another group of aircraft that is not part of that winged configuration may not need to be located at the same site in order to support the training activity.

Additional areas where requirements are just beginning to emerge are in the communication of electromagnetic effects, packetized voice, environmental effects, and enhanced scenario control. The use of electromagnetic lumination varies significantly among the services, and the communication services and PDU requirements are just beginning to be enumerated. The quality of tactical radio network communications has a definite affect on the training process. With the increasing availability of inexpensive digital signal processors (DSP) it will be possible to provide distance and obstruction effects on the received network channels provided that the data is in an acceptable format for processing by a DSP. The ability to create real-time environmental effects such as clouds, morning fog, rain, and snow in segments of the gaming area will serve to enhance the quality of the training session and will more closely simulate the real world environment. The creation and control of environmental effects as well as the start, stop, reset, and return to a specific time of an exercise are all control measures associated with a training exercise. The ability to perform these control measures in a networked training system distributed over many sites requires additional investigation.

The networked training system has many diverse network requirements from the application PDUs needed to communicate the information among simulators to the protocol suites needed to provide communication functions between the simulators on various networks. Using the SIMNET application PDUs as a baseline, the committee for the SIDS is determining standard application PDUs for tactical training.

APPLICATION PROTOCOL

Since the simulators must be able to interact as realistically as possible, the network must provide real-time communication of the necessary information between the simulators to provide the effects of the battle environment to the student. This is the heart of the network simulation requirements. The networked system must provide the media, protocols, and interfaces to distribute the information in a method in which all of the simulators can communicate the tactical training situations.

Through the Defense Advance Research Projects Agency's (DARPA) SIMNET program, Bolt Beranek and Newman, Inc. (BBN) researched many of the issues concerning this requirement. Under this research, BBN developed 1) the SIMNET protocol that handled the communication of the information, 2) the databases that provided the simulators a homogeneous platform under which to understand the information, and 3) the simulators that provided the effects of the information to the student. Even though the issues concerning the databases and the simulators are very important to the complete system, they are beyond the scope of this paper.

The SIMNET protocol consists of 1) an application protocol that provides communications between the simulators, and 2) the protocol suite to communicate the information across the network. In the conferences on SIDS, the committee is using SIMNET as a baseline to determine a standard application protocol for interoperable simulation. As shown in Figure 2, SIMNET's application protocol consists of two sublayers that are the simulation protocol and data collection protocol in one sublayer, and the association protocol in the other sublayer. The association protocol provides the means of communicating the simulated world, contained in the simulation PDU, between simulators.

Simulation and Data Collection PDU

Ver	Protocol Kind	Exercise ID	00	Data

Association PDU

Ver	Kind	Length	Group ID	Protocol ID	Addr	Data

Figure 2. SIMNET's Application Protocols

In communicating the information of the simulated world, the SIMNET simulation protocol provides services to initialize or withdraw vehicles for an exercise, describe the appearance of vehicles, identify firing and impact of projectiles, and provide supplies and repairs between vehicles. The simulation PDUs contain both static and dynamic information fields. The static information is most often used when a change in the state of the simulated world's configuration occurs, that is, initialization. Once the static information has been used to delineate a particular vehicle, the vehicle identification (ID) can be used to index the capabilities of the vehicle that exists in the database. The vehicle ID distinguishes the site, host computer, and particular vehicle among all others in an exercise. After initialization occurs, the simulators only need to communicate dynamic information—referenced to the vehicle ID—to accurately depict the simulated world. The static and dynamic information is used in a particular architecture to ensure the communication of the simulated world.[3]

As mentioned, the association protocol provides communication services to support the simulation protocol. In essence, the association protocol provides the common application service elements to communicate between simulators. The association protocol provides a datagram service and a transaction service for the simulation protocol to communicate between simulators. The datagram service is a nonconfirmed service that is used to transfer data in a point-to-multipoint configuration using a multicast address. The datagram service is used to communicate appearance PDUs that update the state of the vehicles during an exercise. The transaction service is a confirmed service communicating a message from the originator to a designated recipient that must confirm its reception of the message, while the originator's and recipient's messages are broadcasted to the other simulators (see Figure 3). The transaction service can be thought of as an acknowledged broadcast service. The transaction service is used for the activation of a new vehicle.

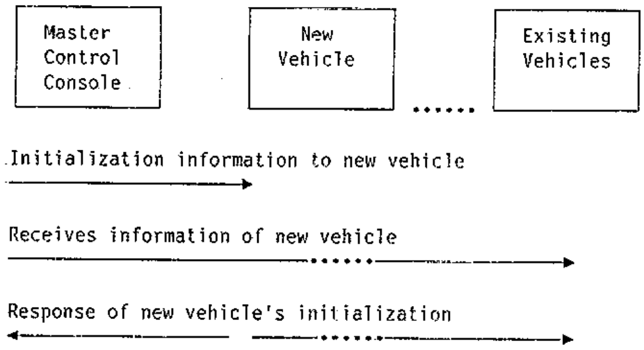

Figure 3. SIMNET's Simulator Activation

All of the existing vehicles receive the information that describes the newly activated vehicle. Since the appearance PDUs contain the static information to fully describe the vehicles, the newly activated vehicle learns of the existing simulated world by receiving the appearance PDUs that are broadcast from all other vehicles at a required minimum update rate.

Another method of communicating the simulated world would be for the appearance PDUs to only contain changes to the vehicle's appearance. This alternative uses the same method of initializing the new vehicle to the existing vehicles on the network. But instead of requiring static information in the appearance PDUs to bring the new vehicle to the existing training state, this method uses a connection-oriented service to bring the new vehicle to the current status (see Figure 4). Since this method requires the appearance PDUs to contain only dynamic information, the appearance PDUs can be reduced by more than 20%. Although this method requires an additional connection service for reconfiguration, it can be assumed that reconfiguration does not happen with great frequency during a simulation exercise. Also, reconfiguration can be performed within an allotted amount of time to ensure no overloading of the network. To determine which method produces the best performance results for the networked system, the two methods must be compared using some modeling techniques and tested on a network testbed that can demonstrate the two methods in a distributed training application.

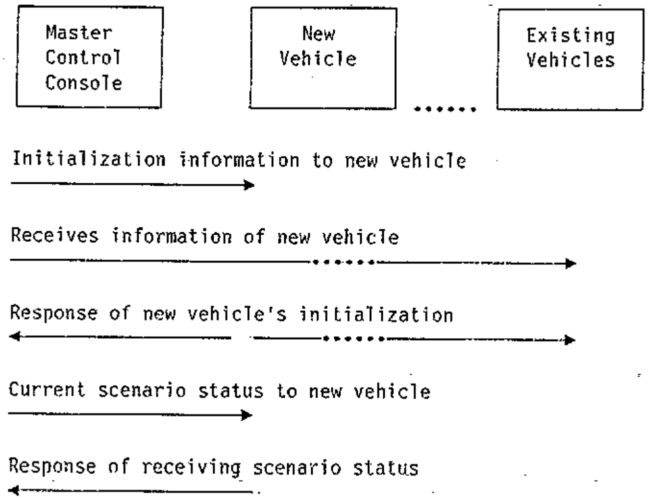

Figure 4. Alternate Simulator Activation

PROTOCOL SUITE IMPLICATIONS

The current standards process for interoperable simulation is concerned with standardizing an application protocol, which is defined as the seventh layer in the International Standards Organization (ISO) OSI reference model. The seven layers of the ISO OSI network architecture are from top to bottom: application, presentation, session, transport, network, data link, and physical. Each layer provides a function that the upper layers can use to communicate information across the network. Between each pair of adjacent layers there is an interface that defines services that the lower layer offers the upper layers. The set of layers and protocols is called the protocol suite. The functions provided are:

Application — Provides interface between a user and a network architecture.

Presentation — Provides the data syntax independently of the application processing.

Session — Organizes or synchronizes the conversations between applications.

Transport — Provides transparent and reliable transfer of data.

Data link — Provides reliable transfer of data across the physical link.

Physical — Provides the mechanical, electrical, functional, and procedural characteristics to communicate the data.

Network — Provides upper layers with independence from the data transmission functions such as routing.

Even though the standards process is determining the application layer and not the protocol suite for interoperable simulation, some significant considerations should be noted on the usefulness of each layer for interconnecting between multiple networked training systems. For a distributed training system, the main objective is to communicate the data as quickly as possible to minimize latency effects on the training. Thus, *in general, the network architectures for interoperable* simulation will consist of the minimum amount of layers needed to provide the required communication functions for interconnecting the distributed simulators. Also, when trying to interconnect different distributed training systems (that is, battle force in-port training [BFIT] and close combat tactical trainer [CCTT]), communication between different network architectures will be an important design issue.

To allow two distributed training systems to communicate with incompatible protocols, intelligent gateways are required. The function of the gateway is to convert packets from one protocol to another; however, the conversion process can be time consuming, and it is a potentially significant factor in message latency. The complexity of the gateway is dependent on the protocol suite to which the gateway is specified to interconnect. Since the network layer of the ISO OSI reference model provides the routing function, gateway implementation is usually performed at the network layer. Currently, the SIMNET protocol interfaces to the data media access control sublayer of the data link layer of ethernet. The current SIMNET protocol suite does not contain a network layer, resulting in a potentially more complex gateway to perform the interconnection between the SIMNET protocol suite and future protocol suites of network training systems. By specifying a standardized protocol suite, the DoD would have some control over the complexity of interconnecting the systems.

Currently, the government has standardized a protocol suite called Government Open System Interconnect Profile (GOSIP). Beginning 15 August 1990, this protocol suite will be mandatory for all federal programs, both DoD and non-DoD, unless an exemption is granted for a particular application for which the protocol suite is not acceptable. An example of an exempted application is mission-critical applications like the U.S. Navy programs supported by the SAFENET protocol suite. The current standards process for interoperable simulation must either conform to GOSIP or evaluate its usefulness and justify why it would not be an appropriate standard for networked simulation. Figure 5 shows an example of GOSIP-compliant protocols as defined by FIPS publication 146.

ISO Layers	GOSIP-Compliant Protocols
Application	X.400
Presentation	X.400
Session	Section 5.6, FIPS PUB 146
Transport	TP4
Network	CLNP
Data Link	
LLC	802.2
MAC	802.3, 802.4, 802.5
Physical	8802/3, 8802/4, 8802/5

Figure 5. GOSIP-Compliant Protocols

Referencing the ISO OSI layered architecture (see Figure 6), the protocols in each of the layers in Figure 5 communicate with the protocols in the adjacent layers through interfaces. As mentioned, interfaces define services that the lower layers offer the upper layers. The interfaces act as access points between adjacent layers. For example, a media access control (MAC) sublayer provides the interface between the logical link sublayer and the physical layer. The physical layer provides actual communications and the upper layers provide virtual communications between the machines. During transmission, the upper layer adds a header containing control information used by a protocol at each respective layer to the message (M). At the receiving node, the headers are stripped off as the message is moved up the layers. The headers for the layers in Figure 6 do not reach the upper layer. The headers contain service access points (SAPs) that provide a link between the lower and upper layer. This method means that like layers of a protocol suite on one node communicate with like layers of the same protocol suite on another node.

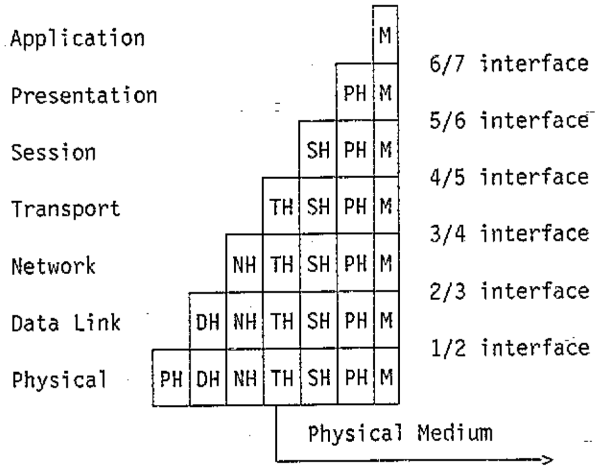

Figure 6. ISO OSI Layered Architecture

In comparison to the ISO OSI network architecture, the current SIMNET protocol consists of an application layer protocol on top of a MAC sublayer protocol (see Figure 7). The association protocol lies directly on top of the ethernet protocol, which lies in the MAC sublayer of the ISO OSI data link layer. For the current SIMNET protocol suite to be GOSIP-compliant, it would have to have its application layer protocol accepted into GOSIP, and include GOSIP-compliant protocols for the logical link, network, transport, session, and presentation layers or obtain an exemption for those layers. If all of those layers are nulled for a fast protocol suite, the SIMNET protocol suite would not be able to take advantage of the many commercial products that support interconnection according to the ISO OSI network architecture.

ISO OSI Layers	SIMNET Protocol Suite
Application	Simulation/Data Collection Association Protocol
Data Link MAC sublayer	 Ethernet

Figure 7. SIMNET Protocol Suite

The Institute of Electrical and Electronics Engineers (IEEE) Project 802 has been working actively on the development of a local network standard. While working in the bottom two layers—physical and data link—Project 802 has divided the data link layer into the logical link control (LLC) sublayer, responsible for the usual link control and logical connection, and below it, the MAC sublayer, concerned with a station's physical access to the link. As noted, SIMNET only uses the MAC sublayer. The LLC provides a uniform data link service to the next layer, so that the upper layer is not affected by the distinctions among the different LAN types. For example, the 802.2 LCC layer uses a concept known as link service access point (LSAP) to provide SAPs from the MAC sublayer to the network layer (see Figure 8).

DSAP	SSAP	Control

Figure 8. IEEE 802.2 LSAP

Because of the growing number of applications using IEEE 802, including GOSIP, as lower layers, an extension was made to the IEEE 802.2 protocol in the form of the subnetwork access protocol (SNAP). It is an extension to the LSAP header to accommodate the growing number of applications using IEEE 802, and its use is indicated by the value 170 in both the SSAP and DSAP fields of the LSAP frame (see Figure 9). Many LANs include the LLC functions on the LAN adapter interface card. Also, the Consultative Committee on International Telephone and Telegraph (CCITT), ISO, ANSI, and IEEE are studying a proposal of adding the IEEE Project Standard to X.25, which would provide a homogeneous gateway solution to the problem of linking and interfacing LANs with WANs.

DSAP=170	SSAP=170	Control	2 bytes

Figure 9. IEEE 802.2 SNAP

There are commercial bridges that interface the MAC header of one LAN to the LLC header of a different LAN. For example, IBM has a LAN bridge (8209) to perform a token ring with the LLC sublayer to ethernet without the LLC sublayer conversion and vice versa. In the conversion, the routing information (RI) and the destination service access point (DSAP), source service access point (SSAP), control (CONT), and protocol ID contained in the SNAP header are extracted from the token-ring frame and discarded. The destination address (DA), source address (SA), and information fields (TYPE and INFO) are copied into an ethernet frame and sent to the ethernet LAN.

In the conversion from an ethernet frame to token-ring frame, DA, SA, and information fields are copied into the respective fields of a token-ring frame. The IBM 8209 then retrieves the source routing information associated with the token-ring destination address and inserts these fields and the fixed hexadecimal values AA AA 03 00 00 00 (SNAP header) representing the DSAP, SSAP, control and protocol ID fields into the frame, before sending the frame to the token-ring LAN. As seen from the implementation of IBM's 8209, routing information is lost when bridging between the 802.2 LLC header and the ethernet MAC header and back (see Figure 10).[4]

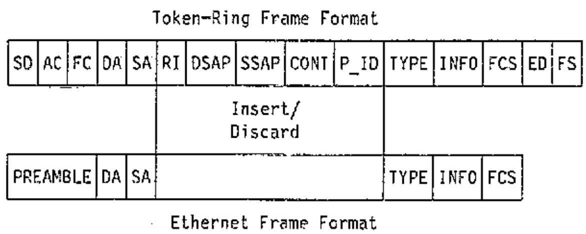

Figure 10. Token Ring to Ethernet Conversion

Although the 8209 LAN bridge performs a conversion between token ring with an LLC sublayer and ethernet without an LLC sublayer, we are unsure whether there are commercially available bridging products for all other standard networks, present and future. By providing an LLC header requirement in the future standardization process for interoperable simulation, the training application standard protocol can use standards specified by Project 802. Also, the LLC header provides functions that are very useful to the distributed training application. For instance, the receiving simulator could check the LLC DSAP to see which application PDU is being sent, and filter frames of information, if the LLC is on the adapter, before they are accepted by the host processor. This filtering could alleviate processing by host simulators and gateways. The effects of the additional latency by the LLC sublayer should be nominal. Thus, the LLC sublayer can provide an important filtering capability, ensure that commercially available bridges and gateways interface future network architectures, and does not detrimentally degrade the performance of the network for distributed training.

This paper justified the need for the 802.2 LLC sublayer to be included into the SIMNET protocol suite. Even though a similar justification could possibly be made for other GOSIP-compliant protocols, we have concluded that further research into using particular ISO OSI layers for interoperable simulation should be performed. To determine the effects of protocol suites on interoperable simulation, a testbed that contains the protocols of the ISO OSI layers could be used to demonstrate performances between simulators. From this information, the DoD and industry can make educated decisions regarding the use of protocol suites for interoperable simulation.

SUMMARY

The objective of a networked training system is to communicate the necessary information as quickly as possible between the simulators that provide the effects of the battle environment to the trainee. This requires real-time networking of heterogeneous systems that are distributed across the world. To create a homogeneous environment for the simulators to communicate, the networked training system requires a standard application protocol that is currently being addressed by the SIDs. To ensure the necessary communication functions between simulation systems, the training community must address the virtual communications of the networked training system by researching protocol suites. From this, it can be determined if the future networked training systems can comply with GOSIP.

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