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THE DISTRIBUTED HLA SIMULATION FEDERATION OF THE RDE 1ST APPLICATION – THE NETWORK ARCHITECTURAL DESIGN AND IMPLEMENTATION

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13. ABSTRACT *(Maximum 200 Words)*

In October 2002, the Research, Development and Engineering Command (RDECOM) was established by the Army Materiel Command (AMC) to integrate the research, development and engineering components of AMC subordinate Commands. A Virtual Distributed Lab for Modeling and Simulation (VDLMS) was initiated and selected to execute the RDE Command's First Application (1*st*App). This application was successfully executed in April 2003, and the goals were to provide insights into the Networked Fires process and performance for the Future Combat Systems (FCS). There were many participants in 1stApp; however, four main sites were chosen to host the experiment. These included: AMRDEC/RTTC (Redstone Arsenal), ARL (Aberdeen Proving Grounds), NVESD (Ft. Belvoir), and STC (Orlando, FL.).

See page ii.

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ABSTRACT (CONT)

A robust network had to be designed and implemented that would meet the stringent requirements necessary to support the 1*st*App. This report presents some of the network challenges, to include the design, implementation, and observations noted. The network was implemented over the Defense Research and Engineering Network (DREN). Distributed Interactive Simulation (DIS) traffic was hosted on the Local Area Networks (LAN), and High Level Architecture (HLA) simulation traffic was supported across the Wide Area Network (WAN). Network performance to include latency, bandwidth and multicast issues, and tools used will be discussed. Also, observations pertaining to the simulation network as an integration of the LAN, Metropolitan Area Network (MAN), and WAN will be presented with recommendations for future network infrastructure modifications.

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I. INTRODUCTION

In October 2002, the Research, Development, and Engineering Command (RDECOM) was established by the Army Materiel Command (AMC) to integrate the research, development, and engineering components of AMC subordinate Commands. A Virtual Distributed Lab for Modeling and Simulation (VDLMS) was initiated and selected to execute the RDE Command's First Application (1stApp). The objectives of 1stApp were to provide insights into the Networked Fires process and performance for Future Combat Systems (FCS), and to define the baseline capability of the VDLMS as it transitions towards the Modeling Architecture for Technology and Research EXperimentation (MATREX).

1stApp was a geographically distributed experiment. The innermost tier of operation was a co-located Distributed Interactive Simulation (DIS) network at a single site. The next tier was a co-located High Level Architecture (HLA) network bridged to DIS across a gateway. The outer tier was the distributed HLA connectivity to the other host sites. This approach ensured that connectivity or network performance roadblocks in outer tiers did not preclude execution of some major portion of the architecture to produce useful analytic results.

Geographic distribution of the event was accomplished by linking four simulation sites with one additional Wide Area Network (WAN) monitoring and collaboration server site, and physically bringing resources from the other VDLMS organizations to the four simulation sites, as follows:

A. WAN Monitoring and Collaboration Server Site

Defense Research and Engineering Network (DREN), Army Research Laboratory, Aberdeen Proving Ground, MD

B. Distributed Simulation Sites

Aviation and Missile Research, Development, and Engineering Center (AMRDEC), Redstone Arsenal, AL.

RDECOM Simulation Technology Center (STC), Orlando, FL

Communications and Electronics RDEC, (NVESD, CERDEC), Ft. Belvoir, VA

Redstone Technical Test Center (RTTC), Redstone Arsenal, AL

C. Remote Site Organizations

Armaments RDEC (ARDEC) – (at AMRDEC)

Army Research Lab (ARL) – (at Orlando)

Tank and Automotive RDEC (TARDEC) – (at RTTC)

CERDEC Monmouth – (at Redstone and Ft Belvoir)

Depth and Simultaneous Attack Battle Lab (D&SA BL) – (at AMRDEC)

A more indepth view of the RDE 1stApp from a simulation "lessons learned" perspective, can be found in Reference 1.

II. RDE 1STAPP NETWORK DESIGN APPROACH

The design approach for the RDE 1stApp was effected by the RDECOM Chief Architect, Mr. Max Lorenzo, and a team comprised of members from the simulation, network, and security communities at each site, the DREN, (to include technical support from WareOnEarth Communications Inc. and WorldCom/MCI), and also technical support from Cisco and Marconi. To begin the design process, network requirements were identified and design approach established.

A. Network Design Requirements

The simulation requirements mandated that HLA traffic be supported on the backbone, and that DIS traffic be contained locally at a site. Thus, multicast and TCP/IP traffic needed to be supported on the backbone and User Design Protocol (UDP) broadcast traffic contained locally.

Performance characteristics were derived based on previous experiments [2] and projected expectations. It was determined that latency from site to site should not exceed 40 milliseconds, and that local jitter should be less than 1 millisecond. Also, a guaranteed bandwidth of 20 Mb/s was sought for the simulation sites that could support this requirement.

Security was also an important design consideration, and the decision was made to encrypt the backbone of the network.

B. Network Architecture Design Approach

There were basically three main components to be considered in the design approach of the network used to support the RDE 1stApp: (1) The Local Area Network (LAN), which can be defined as the network equipment that provides support for a site's local system infrastructure, (2) The Metropolitan Area Network (MAN), which can be defined as network equipment that resides between the LAN and the DREN Service Delivery Point (SDP), and (3) The Wide Area Network (WAN) is defined as those devices that provide networking services connecting the distributed sites. The DREN was used to provide WAN services during the RDE 1stApp.

1. Local Area Networks (LAN)

Early in the design process, a generic LAN design was proposed. The design was established to allow flexibility so as to support Asynchronous Transfer Mode (ATM) and Ethernet connectivity. The utilization of two ATM switches, besides permitting ATM local services, also afforded a more robust opportunity to measure performance.

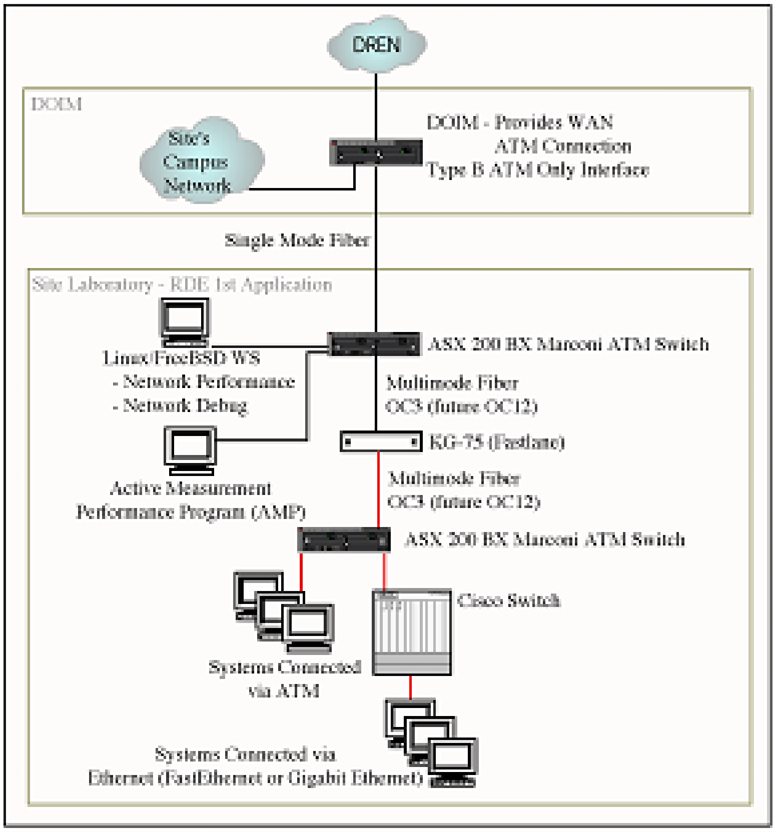

Figure 1. Proposed LAN Design

The basic LAN designs as implemented by the sites are as follows:

a. AMRDEC

This site provided support for around 90 systems and several printers. A new cable plant, enabled to support classified processing, was designed and installed on three floors to support this application. The Cisco 3500 switches on each floor supported the FastEthernet adapters on the systems. The switches were trunked with 1Gb/s connections. At this site only one ATM switch was supported. The Fastlane was connected to a Cisco 5509 switch. A standalone DIS network was installed. A gateway on this network connected it to the HLA network. The HLA network was connected to the DREN via an OC3 connection.

b. RTTC

RTTC supported two systems on the HLA network and one system on the DIS network. A Cisco 7204 (and an enhanced ATM adapter) was used to support the RDE 1stApp LAN. A secondary ATM switch was not available. An OC3 connection to the DREN was utilized.

c. ARL

Aberdeen Proving Ground (ARL-APG) hosted the FCS Advanced Collaborative Environment (ACE) system. A Cisco 7505 was used to support the LAN requirements. Marconi ASX-200BX ATM switches on both the encrypted and unencrypted sides of the Fastlane were installed. The Fastlane provided OC-3 ATM encryption. The OC-12 ARL-APG site is connected to the DREN. Unclassified lab systems were a Personal Computer (PC) for e-mail, and an SGI Octane for testing as needed.

d. NVESD

Night Vision configured three separate networks to keep the broadcast traffic down to a minimum. The Situation Awareness traffic was separated from the DIS Simulation network and propagated through an SA Server. The HLA traffic was translated into DIS for the simulation. About 13 systems were supported on the DIS network, and 3 systems supported on 2 independent HLA networks. A Cisco 5509 was used to support the HLA network. Two ATM switches were available for the support of this application.

e. STC

STC configured only six systems to communicate both HLA and DIS via a Cisco 3725 router. The DIS traffic was isolated using a single hub, and a MAK gateway. The traffic was translated from Ethernet/IP to ATM using a Cisco 3725 router. Only native HLA machines and the HLA network interface of the MAK gateway was connected to the Fast Ethernet ports on the router. This Fiber Interface was then connected using single mode fiber cables to the single mode OC3 Fiber Interface on the KG-75 Fastlane. The outgoing data from the Fastlane was encrypted and then sent out on another OC3 Fiber Interface to the LE-155 Marconi. And from there, the data was sent out to classified WAN over the DREN.

2 MAN/ WAN (DREN)

The DREN was chosen to provide WAN services. The DREN is a sophisticated, robust Department of Defense (DoD) communications network that incorporates the best operational capabilities of both the DoD and the commercial telecommunications infrastructure. DREN is DoD’s premier long-haul communication service provider for the High Performing Computing (HPC) community.

The DREN provides interoperable ATM and Information Processor (IP) services for video, audio, imaging, and digital data, and connects to other research and academic networks at Next Generation Internet Exchanges and GigaPops. The network links customer sites to DoD's four Major Shared Resource Centers (MSRC) and 17 Distributed Centers (DC). The DREN has over 70 IP sites with over 35 of these sites configured with additional ATM functionality to support AT-based encryption and applications. The current network provides Digital Service 3 (DS-3) through OC-48 connectivity.

Wide Area connectivity is provided by Layer-2 equivalent transport between protected SDP, utilizing a combination of Multiprotocol Label Switching (MPLS) tunnels and MPLS Label Switch Paths (LSP).

An ATM service is supported by the use of cell-relay tunnels across LSPs. DREN Core Nodes (DCN), another variation of the DREN SDP/PE router, are located at selected MCI/WorldCom vBNS+ network nodes. User ATM service interfaces are connected each through the cell-relay tunnels to a DCN, which provides a User Network Interface (UNI) service interface. The DCNs are fully meshed through LSPs, providing a Layer-2 equivalent transport "cloud" to all ATM service interfaces.

The decision was made to utilize a point-to-point spoke configuration rather than a full mesh because AMRDEC was centrally located and a focal point of the experiment; i.e., data was only required to be passed back and forth between each site and AMRDEC (the RTIexec was executed at this site), a spoke configuration significantly reduced the complexity of establishing connectivity to each site and a spoke configuration significantly reduced the amount of time spent troubleshooting a faulty data path.

A spoke configuration reduced the overall bandwidth requirement at each site's gate to the DREN and within each site's local infrastructure. A spoke configuration also provided AMRDEC with the capability to enable or disable Soft Permanent Virtual Circuits (SPVCs) to each site as necessary, thus conserving bandwidth when connectivity to a site was no longer required.

The DREN does have the capability to utilize SPVC throughout its core. Thus, use of Switched Virtual Circuits (SVCs) and/or SPVCs throughout the DREN Core is mandatory unless there are extenuating circumstances and all efforts to establish connectivity via SVCs or SPVCs have been exhausted. The DREN Program Manager must approve any deviation from this policy.

During the initial planning stages of this experiment, the decision was made to establish connectivity to each site via SPVCs and utilize bandwidth reservation through the use of Quality of Service (QoS) parameters settings provided by Marconi ATM Switch products within each site's local infrastructure. Also, it was decided to use Fastlanes to establish secure communications, by encrypting the ATM backbone, for this application.

Each SPVC was to be initiated by the AMRDEC. AMRDEC would establish an SPVC from the port on the Black ATM switch that was directly connected to the AMRDEC Fastlane cipher text jack to each the port at each site's Black ATM switch connected to the Fastlane cipher text jack.

A Permanent Virtual Circuit (PVC) would be created to carry the traffic through the Fastlane to the edge device at each site. The end device at each site consisted of a Cisco product. The Cisco products utilized did not have the capability to establish SPVCs.

The decision was also made to use Request For Comment (RFC) 2684 [3], which is "Multiprotocol Encapsulation over ATM Adaptation Layer 5," on the edge. RFC 2684 is a replacement for RFC 1483, and describes two encapsulation methods for carrying network interconnect traffic over AAL type 5 over ATM. The use of LANE (LAN Emulation) was considered, but according to Cisco and Marconi was not as efficient and would introduce unwanted latency. LANE is an ATM service defined by the ATM Forum specification "LAN Emulation over ATM," ATM_FORUM 94-0035. Classical IP (CLIP) as described in RFC 1577, or "Classical IP and ARP over ATM" was considered, but does not provide support for multicast traffic

To further simplify the structure of this network and reduce latency, the decision was made not to route. One IP range was assigned the backbone, and the traffic was bridged on the edge. The network was small enough that this was possible. Every effort was made to reduce latency, blend the MAN into the WAN layer, minimize the number of interim switches and routers in the path, and put the control on the edge, so that each site could effectively manage their site. This also served to simplify troubleshooting efforts, as the focus for network management was well defined.

III. RDE 1STAPP NETWORK DESIGN IMPLEMENTATION AND OBSERVATIONS

After the network design approach had been determined, the network team worked to implement and test the design at each site.

A Network Architecture Overview

Figure 2 provides a high level overview of the network that was deployed for the RDE 1stApp. Early in the design process, a configuration chart was drawn that depicted the models and operating system software levels of all the main ATM and Ethernet switches and routers to be used for the network. The equipment vendors' support teams were contacted to provide advice regarding any observable issues.

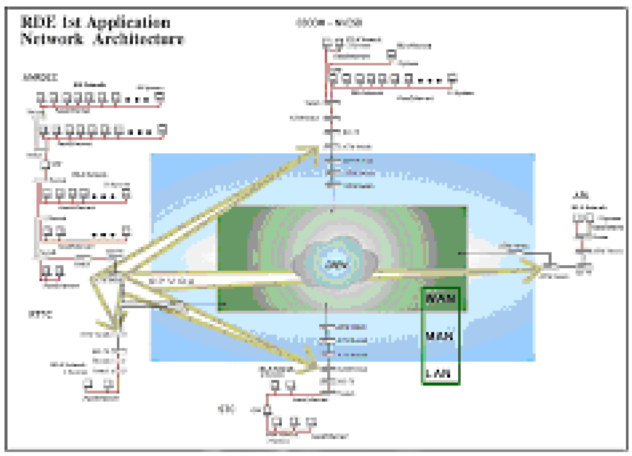

Figure 2. RDE 1stApp Network Overview

B Network Design Implementations and Observations

During the implementation phase, there were many challenges, and also interesting observations, that were noted during the establishment of the LAN and the MAN/WAN.

1. Network Design Implementations and Observations – LAN

Some site network design implementations and observations are as follows:

a. AMRDEC

In preparing the site equipment, the IOS on the Cisco 5509 was upgraded, and a new supervisor module was purchased for the existing black ATM switch. As a new cable plant had been installed for this effort, all drops and cables to be used for connecting systems were tested for continuity prior to the application. During the application, a new network performance tool called "Observer" was used to monitor the health and status of the LAN (the DIS and HLA networks).

Also to be noted, the Redstone DOIM ATM switch needed to be upgraded, though there were no resources at the time to support this. This was problematic, but did not have a detrimental effect on the exercise.

b. RTTC

RTTC upgraded the IOS on the 7204 router and also borrowed an updated enhanced ATM adapter to replace an older one in the unit. The ATM switch's operating system was also upgraded.

c. ARL

ARL-APG hosted the FCS program ACE software. With FCS ACE, presentations, applications, audio, and video can be shared from a presenter to up to 20 users. The users have interactive capabilities using audio, whiteboard, and text chat tool capabilities. The user presentations at Redstone were distributed to Orlando, Aberdeen, and Ft. Belvoir via the ACE server at Aberdeen.

Daily testing of the connection showed initial packet loss of 0.2 percent from the ARL site. Originally, the SGI O2 network test host was directly connected to the Cisco 7505 router using a crossover cable. Once the ACE client PC and the Ethernet switch were added, the packet loss in testing dropped to 0.0 percent. Ethernet Duplex settings and cable quality can be factors in any network installation. This lesson learned led ARL to implement a Fast Ethernet switch on the connection to the FCS ACE server.

d. NVESD

NVESD had introduced the use of the multicast conferencing toolset, to include SDR (VIC, and VAT, etc.) in an earlier joint exercise. This toolset was used in this environment and again provided multicast performance information and was also used to support presentation feeds by the FCS ACE.

There seemed to be a slight problem with entity propagation through the MAK gateway. There was a time delay and not all entities showed up. This could have been due to the TCP stack on the Windows MAK gateway platform. The network seemed fairly solid both on the LAN and WAN.

e. STC

STC installed a new Cisco 3725 in support of the RDE 1stApp. A Multi-Router Traffic Grapher was utilized to monitor active bandwidth usage from each of the routers, or Layer 3 switches, connected to the WAN. It was observed that simulation latency and anomalies did not occur due to network traffic. Bandwidth never reached critical levels at STC. Some delays of entity traffic from the MAK gateway and DIS side were observed, but these anomalies may be the result of gateway configuration issues.

2. Network Design Implementations and Observations – MAN/WAN

Originally, it was thought that a tool called NETPerf would be utilized to test performance on each point-to-point connection. However, as the implementation of the overall network design was performed, the results provided by NETPerf were insufficient to assist in troubleshooting the problems encountered. An alternative tool called NUTTCP[4] was utilized instead. NUTTCP is a throughput test that is used to send TCP or UDP packets from one site to another. NUTTCP 3.6.1 was utilized to validate that payload data transmitted at 18 Mb/sec could be sustained on the entire connection with little or no cell or packet loss. No other traffic utilized the SPVC while the NUTTCP tests were performed.

Because of overhead associated with ATM cells equals roughly 9 percent, to send cells at approximately 20 Mb/sec, NUTTCP was configured for a maximum of 18 Mb/sec, send and receive UDP traffic with a payload of 1440 bytes over a 10-second period, incrementing every second.

Both receive and transmit tests were performed to validate whether or not an 18 Mb/sec throughput could be achieved to and from NVSED, RTTC, ARL, and AMRDEC. A 4 Mb/sec throughput factor was used to test STC to AMRDEC.

C. Network Design Observations

As stated before, SPVCs are the connection of choice to quickly provide reliable dedicated point-to-point connectivity between sites. All SPVCs originated at the AMRDEC.

The use of SPVCs, as originally thought, would also provide the capability to establish dedicated bandwidth reservation from AMRDEC to each site. Bandwidth reservation was not a critical issue through the DREN cloud, but could be an issue on each site's LAN.

The establishment of QoS between the AMRDEC and each site was abandoned due to the inability of the utilized hardware at Ft. Belvoir, AMRDEC, and RTTC to establish a 20Mb/sec CBR PVC without any problems.

First, the Cisco ATM modules utilized at Ft. Belvoir and RTTC did not have the capability to configure a CBR PVC. To document this inability, rate shaping of a VBRnrt and a UBR+ connection was tested between Ft. Belvoir and the AMRDEC. A series of tests utilizing NUTTCP and ping were performed to note the problems that ensued.

If a UPC contract is applied to an SPVC, then Traffic Shaping at each edge device is mandatory. For example, if a UPC contract is configured for CBR and a 22.5 Mb/sec Peak Cell Rate enable on a SPVC, as was attempted in this experiment, and there is no rate shaping being performed by each edge device, then the edge device would attempt to send data at the line rate of its ATM interface card.

Thus, if a site is utilizing an OC3 ATM interface with no rate shaping, data would be transmitted to the SPVC at 155 Mb/sec. With a 22.5 Mb/sec Peak Cell Rate setting on the UPC contract, the data would be policed and, therefore, not passed.

Thus, in order for traffic not to be policed, edge device rate shaping must be configured so that bandwidth parameters are slightly below the PCR of a CBR UPC contract.

Since bandwidth was not an issue, the decision was made to go with UBR connections between all sites in the RDE 1stApp.

D. RDE 1stApp Network Performance

One tool that was provided was a system known as the Active Measurement Program (AMP). The DREN has deployed AMPs [5] at many of its major nodes over the past three years. AMP was created by the National Laboratory for Applied Networking Research (NLANR) which is funded by the National Science Foundation to instrument and measure the vBNS+ [6] and Abilene [7] networks. WareOnEarth Communications became a partner of NLANR in 1999, and has deployed AMP systems on the DREN [8], NIPRnet, and the Navy Marine Corps Intranet (NMCI) [9].

AMP collects long-term delay, loss, and routing information between a full mesh of measurement machines. On DREN, this is done primarily by sending four randomized "pings" per minute, and a traceroute every 10 minutes, between all pairs of measurement systems. This data is downloaded in near real-time to a central server, which can then analyze the data and display various results via a web server interface [10]. The DREN AMP systems also host numerous network testing tools, including end user accessible **NUTTCP** servers, and normally run a mesh of **treno** throughput and **mping** [11] load tests during early weekend hours.

For the RDE 1stApp, the decision was made to extend the DREN AMP system to include the four major sites involved. ARL already had an AMP system, but new ones were placed at Ft. Belvoir, Huntsville, and Orlando. Because RDE would be running almost all of its traffic over ATM, the AMP systems were equipped with both Ethernet and ATM interfaces.

Unfortunately, the AMP system at NVESD was not installed in time for the RDE 1stApp, and the system at AMRDEC/RTTC had unresolved ATM problems. This limited the amount of data the AMP system could collect during the experiment. It is hoped that deployment will be completed in the future to provide persistent long-term performance data.

An example of AMP data from the experiment is shown in Figures 3 through 5. All of the graphs show one day of data from Wednesday, 23 April, for the path between AMRDEC/RTTC and STC. The first shows the roundtrip time, which was very stable with a mean of 29.9 milliseconds and a standard deviation of 0.31 milliseconds. The delay distribution is shown in the second graph. The jitter was below one millisecond as desired. The final graph shows packet loss. Of the 5,760 probe packets (4 per minute) only 8 were lost, for a 0.14 percent loss over the 24-hour period.

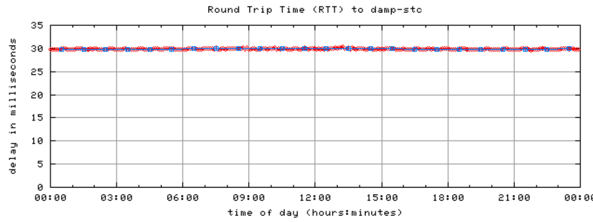

Figure 3. AMP Round Trip Time

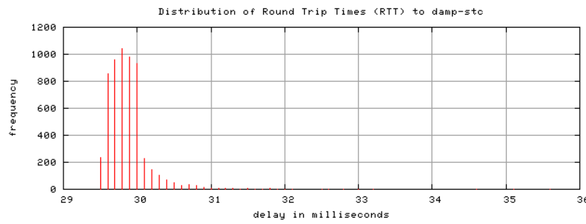

Figure 4. AMP Round Trip Time Distribution

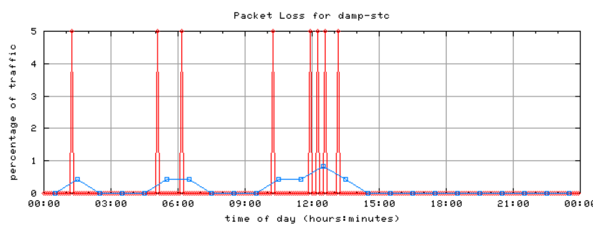

Figure 5. AMP Loss Data

During the RDE 1stApp "Runs for Record (which were conducted over a two-week period)," throughput, latency, and bandwidth tests were performed. Every morning each site performed ping tests to each of the other sites to measure latency. Also, NUTTCP was performed from each site to AMRDEC to test throughput. AMRDEC monitored bandwidth with the Observer tool. Figures 6 and 7 provide some representative data collected during the "Runs for Record." During Week 1 of the "Runs for Record," a three-hour vignette was run that consisted of over 2500 entities. Figures 8 and 9 provide bandwidth information that was collected on the DIS and HLA networks at AMRDEC.

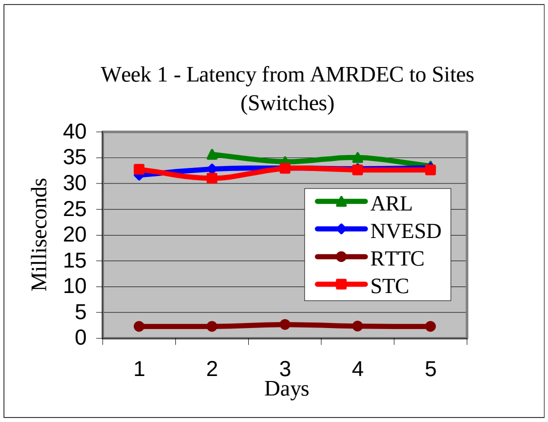

Figure 6. Latency from AMRDEC to Sites

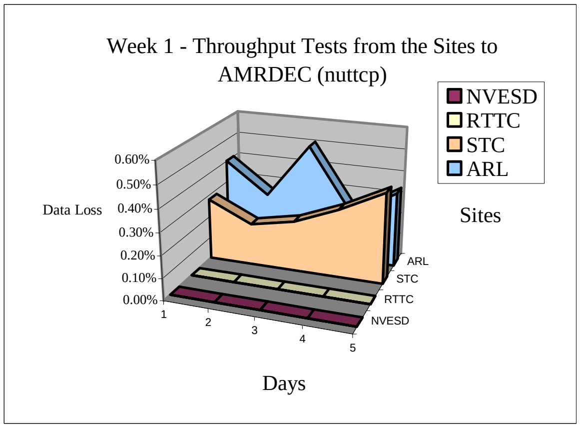

Figure 7. Throughput Tests from the Sites

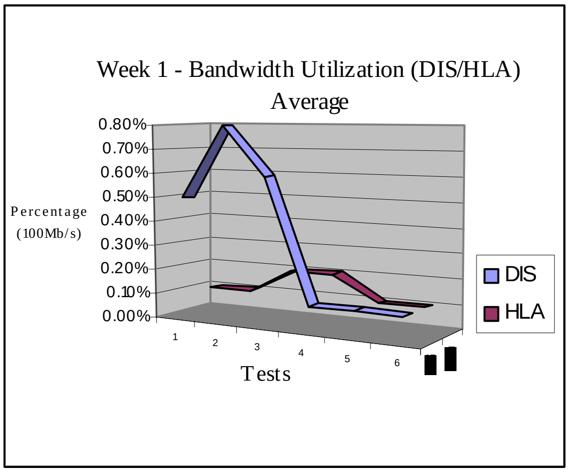

Figure 8. Average Bandwidth Utilization

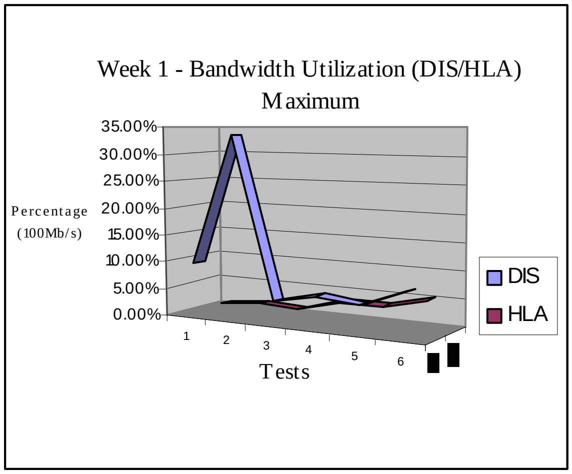

Figure 9. Maximum Bandwidth Utilization

IV. RECOMMENDATIONS

The network built for the RDE 1stApp provided a stable environment that contributed to the success of the "Runs for Record." Success for future distributed exercises lies in careful planning and preparations. Thus, it is important to address ways to improve the LAN and MAN/WAN architectures.

A. LAN

It is important that ATM QoS services be supported in the future. To accomplish this, it is recommended that network equipment that can fully support this be identified and installed at each participating site. Compatibility of equipment throughout the network is extremely important. It is recommended that a test laboratory be set up and equipment tested prior to being recommended and acquired. It is also recommended that a network toolset, that could address performance and management issues, be identified and installed at each site.

B. MAN/WAN

The architecture at the MAN layer at the sites is still problematic. A reduction in the number of switches, routers, firewalls, etc. is necessary. Ideally, a LAN would be only one hop away from an SDP's demarc point.

It is also recommended that, to support classified experiments in the future, sites join the SDREN. A discussion of the effort needed to acquire an MOA to support this application, was beyond the scope of this report. However, it proved to be a very difficult process. The SDREN affords many services to include support for Fastlane keying material, Fastlane technical support, and network management support to name but a few. There is a 12-step connection approval process required prior to joining the SDREN, and sites agree to fund a security team to visit their site for one week each year to validate security.

V. CONCLUSION

The network used to support RDE 1stApp was planned and implemented over a very short five-month period. The sites involved are extremely grateful and appreciative for the level of support that the DREN provided to this effort. As active members of the team, their efforts contributed significantly to the success of the RDE 1stApp effort. This effort was ongoing as the DREN was still in transition from an American Telephone and Telegraph company (AT&T) to a WorldCom backbone.

The future success of distributed simulation efforts are going to be dependent on research, and the provision of resources to support an integrated network architecture.

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