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THE CALIBRATION EXPERIMENT NETWORK ARCHITECTURE

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13. ABSTRACT *(Maximum 200 Words)*

In September 2001, a Calibration Experiment (CalEx) of the Army Materiel Command (AMC) Research, Development, and Engineering Center (RDEC) Federation was performed. Participants included members of the AMC RDECs, the Army Research Laboratory (ARL), and the Simulation, Training, and Instrumentation Command (STRICOM). The objective of this High Level Architecture (HLA)-based distributed simulation collaboration was to demonstrate the analysis capabilities of the AMC RDEC Federation. The AMC RDEC Federation is a distributed engineering and engagement level modeling and simulation environment.

This report presents some of the network challenges that were experienced during the course of CalEx. Seven sites were connected via the Defense Research and Engineering Network (DREN). Network performance to include latency and bandwidth, multicast issues, Run-Time Infrastructure (RTI), firewalls and router issues will be discussed. Also, observations pertaining to the simulation network as an integration of the Local Area Network (LAN), Metropolitan Area Network (MAN), and Wide Area Network (WAN) will be presented with recommendations for network infrastructure modifications.

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I. INTRODUCTION

The Army Materiel Command (AMC) Research, Development, and Engineering Center (RDEC) Federation (referred to as the Federation henceforth) is a distributed engineering and engagement level modeling and simulation environment. The Federation is a persistent High Level Architecture (HLA)-based collaboration of US Army RDECs, Army Research Lab (ARL), and Simulation, Training, and Instrumentation Command (STRICOM). These participants include the Aviation and Missile Command's (AMCOM) aviation and missile simulations and data collection tools; the Tank, Automotive, Research, Development and Engineering Center (TARDEC) ground vehicle and armament simulation; the Communications and Electronics Command's (CECOM) Command, Control, Communication, Computers & Intelligence, Surveillance, Reconnaissance (C4ISR) sensor simulations; the ARL vulnerability/lethality assessment models, human engineering models, HLA utilities, and Dismounted Infantry STRICOM simulation support technologies such as the Computer Generated Forces model OneSAF Testbed. The collection of federates participating in any individual event of the Federation is based upon customer needs and technical objectives with capability to extend and interoperate with battle and campaign level models and simulations.

The usable product of the Federation is a distributed, collaborative, composable modeling and simulation environment with robust Model and Simulation (M&S) capabilities and an architecture sufficient to support analysis of the Objective Force. The initial objective of the Federation is to develop an HLA compliant test bed to support Future Combat Systems (FCS) analysis and experimentation. Key efforts include the linking of each RDEC/Laboratory's engineering level models and establishing a federated data collection/analysis capability so that an integrated distributed collaborative M&S environment is established which is capable of supporting system-of-system and cross-functional area tradeoffs and assessments.

The first integration of the Federation was demonstrated at the SMART Conference in April 2001, in Orlando, Florida. During this conference, all Federation players came together and successfully demonstrated the integration between sites and did some preliminary analysis using data collection tools. However, the vision of the Federation was for all players to be able to play distributed from their own facilities. During the second test of the Federation called the Calibration Experiment (CalEx), which this report discusses, the goal was to successfully demonstrate the capability of the Federation to operate in a distributed environment over a Wide Area Network (WAN) and expand upon the capabilities of the Federation demonstrated at SMART. Another major goal was to be able to conduct data analysis on the results obtained.

During the SMART conference, two separate networks were maintained for DIS and HLA traffic. For the CalEx, HLA was the primary communication mechanism and DIS systems were connected to the network via multiple Mak Gateways. This report will discuss the network architecture of the CalEx and the challenges encountered during the integration and testing of the experiment using the Defense Research and Engineering Network (DREN). The report will discuss the Local Area Network (LAN), Metropolitan Area Network (MAN), and WAN challenges encountered during CalEx, how these challenges were dealt with, and also present some recommendations for moving forward and conducting future HLA experiments using the DREN.

II. CalEx SIMULATION EXPERIMENT

To understand the complexities presented by CalEx, an overview of the simulation, system, and network architecture will be discussed as well as the test procedure methodology that was employed.

A. Simulation Architecture

The simulation architectural backbone of CalEx was HLA. Appending that backbone at the appropriate LAN level was tactical C4ISR and DIS networks to support RDEC federates utilizing those protocols. The tactical C4ISR network interfaces are compatible with the evolving Army Tactical Command and Control System (ATCCS) standards and versions, and will stimulate tactical C4ISR equipment. In addition, there were some custom C4ISR interfaces to Research and Development (R&D) devices used to explore future C4ISR concepts, as defined by CECOM.

The RDEC Federation backbone currently utilizes the DMSO Run-Time Infrastructure (RTI) 1.3NG v3.2. The primary RDEC Federation Object Model (FOM) is a superset of the Real-Time, Platform Reference (RPR) FOM version 1.0, with extensions to allow exchange of server data and target acquisition data. The Federation is following the "Guidance, Rationale, and Interoperability Modalities" (GRIM) guidelines for enumerations and implementation of RPR-FOM where possible. The servers currently supported are the Missile Server (AMCOM), Active-Protection System (APS) Server (AMCOM), Mobility Server (TARDEC), and the Vulnerability Server (ARL).

In addition to the primary FOM being implemented for CalEx, the Federation supports the use of multiple FOMs with bridges. A bridge was used to link the RPR-based primary FOM with the Paint-The-Night and SWISS Together! (PST) FOM. The PST FOM consists of interactions allowing distributed control of sensor views from controls and switches in remote locations. The PST architecture also uses External Data Representation (XDR), which is not supported by the primary architecture. The lack of XDR support did introduce some integration hurdles.

The Federation DIS network currently operates in accordance to DIS Version 2.04. Some non-standard PDU traffic is also allowed on a case-by-case basis to allow DIS simulations to call and receive server information. The DIS traffic is connected to the HLA backbone through an HLA gateway. The gateway used was MAK's Gateway version 3.4, which is compatible with RPR FOM 1.0 and is designed to ignore extension data to that FOM without dysfunction.

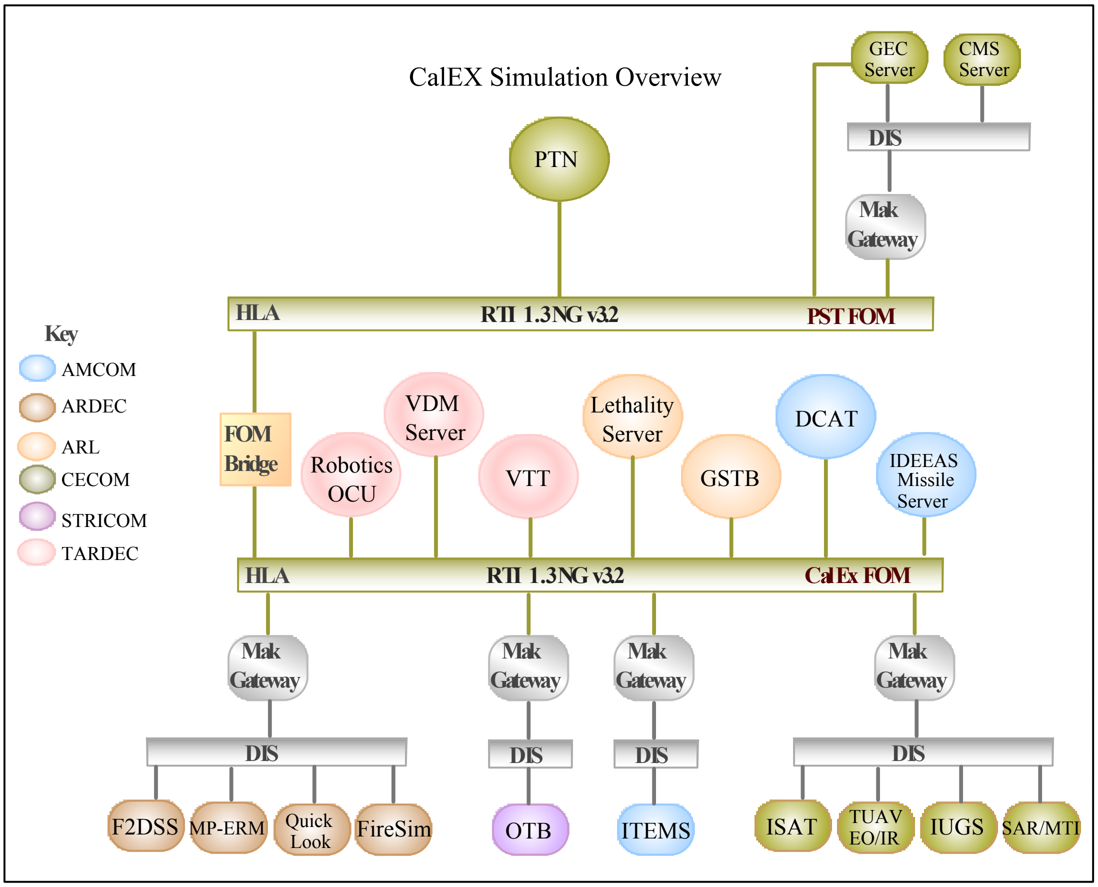

Figure 1. CalEx Simulation Overview

B. Systems and Network Architecture

The Federation integrates several federates from each of the participating RDEC sites. The integration of all these simulation systems at these sites provides a comprehensive, robust representation of the modern Army warfighting environment. This includes system representations ranging from Sensor and Target Acquisition Systems, C4ISR, and multi-purpose Computer Generated Force (CGF) simulations. Also, system performance and effects servers modeling physical effects such as mobility and lethality were incorporated to accurately portray these effects over the generic representations available in CGFs. Finally, the data produced by these systems was captured and analyzed by specialized logging and analysis applications focused on capturing the results pertinent to the Federation requirements. Figure 1 provides an overview of the simulations used in CalEx. Some of the major components are described as follows:

1. The following is the list of platform simulations used for CalEx:

a. **OneSAF Test Bed (OTB).** OTB is the primary platform level simulation used in the federation, representing all the red platforms and many of the blue ground forces.

b. **Interactive Tactical Environment Management System (ITEMS). ITEMS** is a commercial platform level simulation used by AMRDEC to represent rotary-wing assets. ITEMS provided the primary aviation models used during the CalEx scenario runs, representing the attack Rotary Winged Aircraft (RWA), (Apache AH64D) systems, as well as two A-160 Unmanned Aerial Vehicle (UAV) systems. ITEMS Version 6.0 is DIS compliant, and an RPR-FOM based HLA version is under development.

2. The following is the list of virtual prototypes used for CalEx:

a. **VETRONICS Technology Testbed (VTT).** The Embedded Simulation (ES) VTT is a crewstation architectural design that was provided to the FCS Consortiums. The ES system allows for the functional simulation interface with the crewstation controls to perform such mission functions as embedded training, mission rehearsal, operational enhancements, and virtual Test and Evaluation.

b. **Robotics Controllers**. The Robotic Operator Control Unit (OCU) provides interactive representation of the mission planning functionality for the RSTA sensor robotic scout vehicle, modeled by the VDM mobility server (below).

3. The following is the list of C4ISR simulations used for CalEx:

a. **Communications**. The RDEC Federation includes CERDEC's Tactical Internet Model and Next Generation Performance Model (NGPM) to provide noise and message dropouts to simulate realistic digital communications and the appropriate degradation of Global Positioning System (GPS) and SA performance

b. **Command and Control**. The Commander's Interactive Display (CID) is a CERDEC research testbed for future command and control functions and displays. The CID displays tactical information fused from simulated sensor and reconnaissance sources to provide the warfighter-in-the-loop with advanced situational awareness, and provides decision support tools to support execution of commands in coordination with Battle Planning and Visualization tools. CERDEC also provides FBCB2 stimulation tools.

c. **Sensor Suites**. Paint The Night (PTN) is a CERDEC Night Vision and Electronic Sensors Directorate (NVESD) high fidelity Electrooptical/Infrared (EO/IR) virtual imaging simulation which can drive remote displays in response to remote control inputs, allowing it to provide sensor views to virtual prototypes such as VTT on-board Target Acquisition Sensor, Unmanned Ground Vehicle (UGV) imaging sensors, and Infrared (IR) Unmanned Ground System (UGS) sensors.

The CERDEC NVESD also provides Generic Entity Controller (GEC), a common control capability to represent and allow operator interaction with multiple entities such as UGS Imaging (cameras) and Non-Imaging sensors (Seismic/Acoustic/Magnetic), command-activated mines and non-lethal munitions.

The CERDEC NVESD also provides the Comprehensive Mine Simulation (CMS), which produces mine fields using the Compact Terrain Database (CTD).

4. The following is the fire support simulation used for CalEx:

Fire Support. ARDEC provides a Future Fires Decision Support System (F2DSS) which receives tactical target report messages and calls for fire, provides decision support to a man-in-the-loop operator, and sends out the appropriate simulation network calls to missile and munitions servers.

5. Simulation Servers

a. **Vulnerability Server**: ARL contributed the Vulnerability/Lethality server, which provides a monitor and tracking capability of damage state changes on the federation.

b. **Mobility Server:** The Vehicle Dynamics and Mobility Server (VDMS) is a complete, interactive ground vehicle platform model that executes on the TACOM-TARDEC High Performance Computing (HPC) Distributed Center assets and communicates over a network with other entities in a larger distributed simulation. The VDMS ground platform provides a high fidelity model of vehicle subsystems, including powertrain, suspension, steering, etc.

c. **Missile Server**: AMRDEC has developed the missile server as an outgrowth of the Interactive Distributed Engineering Evaluation and Analysis Simulation (IDEEAS) simulation. The missile server receives fire requests from tactical or simulated entities and instantiates missiles in flight using high fidelity kinematics and seeker models, and detonates missile warheads in accordance with accurate fusing.

For a more in depth view of CalEx from a simulation "Lessons Learned" perspective see Reference 1.

III. NETWORK PERFORMANCE OBSERVATIONS

A. Network Architecture

Figure 2 provides an overview of the network used during CalEx. Basically, there are three components, as previously mentioned, the LAN, the MAN, and the WAN. The LAN is defined as all of the machines and network devices that supported or were dedicated to each site operation. The MAN is defined as the networking devices that supported the base or installation, and through which each site had to traverse to reach the DREN. The WAN is defined as the long-haul networking devices which each base or installation traversed to reach all other bases and installations.

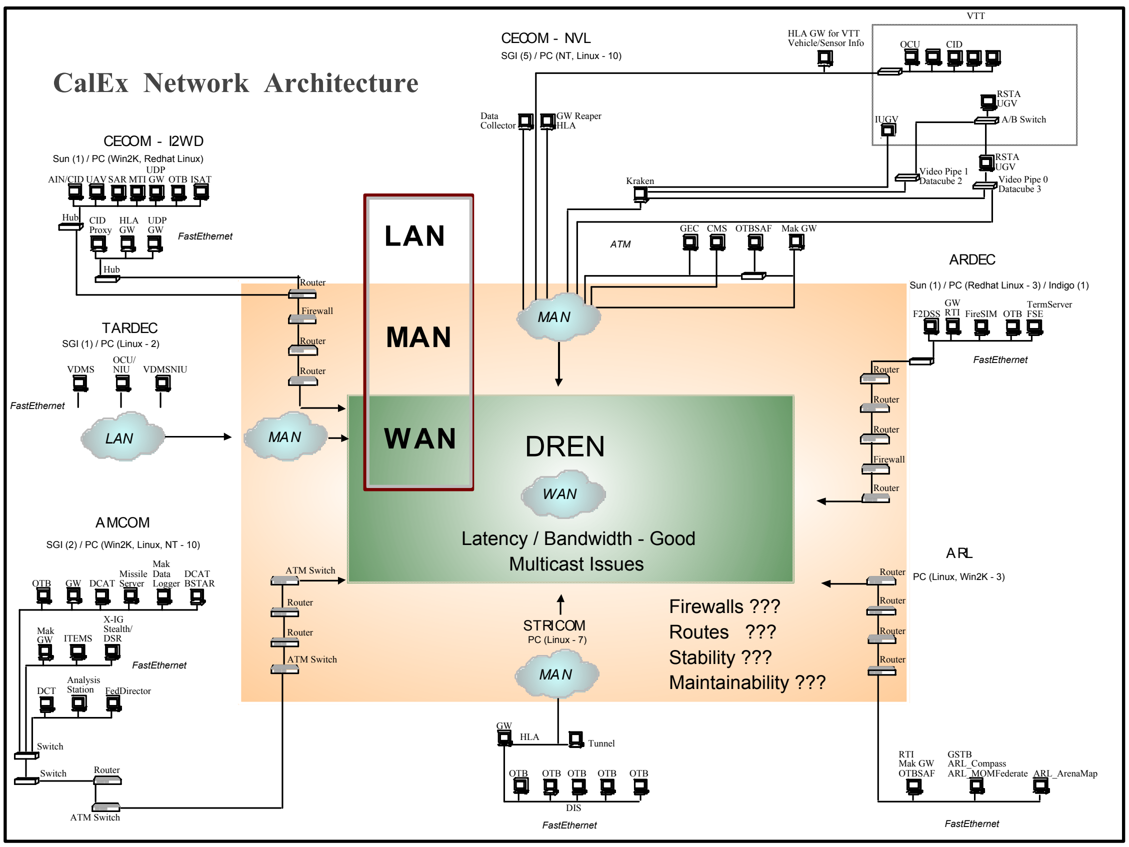

Figure 2. CalEx Network Architecture

The LAN was supported at most sites by Ethernet(802.3) technology. For CalEx, each site was requested to be in switched, full duplex mode to minimize any collision overhead. For readers interested in more information, visit http://www.rware.demon.co.uk/ethernet.htm. The Ft. Belvoir site was unique in that it used mostly Asynchronous Transfer Modulation (ATM) technology. ATM is a switched technology, which provides Quality of Service (QoS) and is capable of extending through the WAN/MAN/LAN environment. For more information on ATM technology, visit http://www.atmforum.com.

B. Network Tools

A number of network tools were used to monitor the health and status of the network on a daily basis. To determine the status of multicast, the mtrace, mrinfo, and sdr utilities were used. Mtrace provided the most useful information on how the path along the IP multicast tunnel was configured. It was optimal to run mtrace from both directions to ensure each path was symmetric. Problems that could be identified using mtrace included network configuration changes that resulted in asymmetric routing or routes that did not properly run over the DREN. Both of these problems resulted in large latencies or lack of connectability of the federates over the DREN. Another tool that was quite useful isolating problems was mrinfo. Mrinfo returned the status of the tunnel endpoints. The sdr utility, though not a performance tool, was also run and was used as an indicator of the stability of the multicast tunnels. To test the health and status of TCP/IP, the ping and traceroute utilities were used. Also, to check for overall bandwidth, SGI's Netvisualizer and Fluke lanmeters were used.

C. Requirements

The RDEC Federation required that all participants integrate using a direct connection over the DREN. The STRICOM Orlando site connected initially via the Internet; however, they were successful in connecting to the DREN approximately a month before the "Runs for Record." A star configuration for IP multicast tunnels was implemented and ARL served as the central connection site. Each multicast tunnel was set to default configuration, which included a 10-mbits/sec allotment.

The requirement for the DREN was to ensure each site had sufficient bandwidth with minimal latency. A latency of no more than 50msec round trip was required. Sites connected on using FORE ATM equipment included: ARL, CECOM-NVL, TARDEC, ARDEC, and AMCOM. Sites connected on the DREN using Cisco Border routers included: CECOM-I2WD and initially STRICOM. Each site connection had a minimum of 45mbits/sec bandwidth with some fraction available to the RDECs.

D. Problems Encountered

There were many network problems encountered. Some of the more significant ones were as follows:

1. The tunnel endpoint systems were overwhelmed by the traffic produced by the CalEx network traffic. In discussions with DREN personnel, it appeared that the CalEx effort was one of the largest exercises that used the DREN, both in the number of sites connected and the amount of traffic generated.

2. The initial Multicast tunnel configurations were insufficient to handle network traffic generated during CalEx.

3 Fedex and rtiexec processes run on underpowered systems or from sites with insufficient bandwidth introduced latency or connectability problems.

4. Each site was required to interface using the HLA RTI 1.3NG v3.2 and the RPR FOM. Some sites used native HLA in connecting to the federation while others used the Mak Gateway to translate DIS to HLA. During integration for CalEx, the Federation experimented with using reliable (tcp/ip) versus best effort (multicast) transport mechanisms. While reliable guaranteed delivery of packets, its usage also introduced a severe load on the network due to acks and retransmits. On occasion, the reliable traffic was introducing 2 mbytes/sec (~16mbits/sec) network storms, which caused large latencies in the simulation. Early attempts to run in best effort mode resulted in large packet losses.

5. Sites changed firewall settings quite often over the course of CalEx. Most of this was as a result of the events of 11 September 2001, and the subsequent security alerts. Sites that on one day had superb connections, on the next day could neither be seen nor heard by a number of the participating sites.

6. Probably the most frustrating problem encountered was network stability. A large amount of resources were dedicated to sites that had connectivity problems other than those discussed above. These usually were tied to configuration of the routers/switches at each site. Many times, once a site was debugged it was fairly operational for a few days. However, there were many changes (routing and access control list modifications) made at the MAN level. They were numerous, and during this time period, usually were made in efforts to enhance security due to the tragedy of 11 September 2001. These changes were usually not coordinated with the administrators at the LAN or WAN level, and the result was a very unstable and inoperative network.

E. Solutions

To help alleviate the problems enumerated above, the following actions were initiated:

1. There are two tunnel endpoints at ARL, one connecting to Ft. Belvoir and the other connecting to all the other participants. On review of the tunnel endpoint systems, it was determined that they were overwhelmed by the traffic produced from the CalEx Federation. The solution was to upgrade both systems to systems with higher performance hardware.

2. IP multicast tunnel bandwidth was increased from 10 mbits/sec to 30 mbits/sec for all sites.

3. For optimal distributed simulation performance, the fedex and the rtiexec processes needed to run on systems with sufficient processor strength, as well as run at sites with sufficient bandwidth. This helped ensure that the fedex and rtiexecs processes were not the bottlenecks. The ARL site was selected as the primary site for running the fedex and rtiexec processor with Ft. Belvoir designated as a backup site.

4. The best effort mode proved to be the optimal transport method in the distributed exercise once networking issues had been resolved.

5. Firewalls needed to have ports and sites identified to ensure that the various federations could communicate across sites. Unfortunately, the requirements that were mandated by the RTI were never clarified, and many sites had difficulties resolving this issue.

6. Networking stability was not resolved sufficiently during the CalEx exercise. However, for distributed simulations to work properly, it is clear that network hardware intended for technical work cannot be shared with network hardware used for administration purposes such as web surfing and email. There must be a clear physical separation of hardware to ensure one side does not create problems for the other. The technical networking must also have an appropriate process in place to ensure that changes are not made without awareness and approval of technical personnel requiring network stability.

The DREN personnel were called in to help investigate some of these problems. The DREN team was very supportive of CalEx and their assistance was greatly appreciated.

IV. RECOMMENDATIONS

The success of a distributed WAN simulation exercise is heavily dependent on the Network that is used to provide the backbone support. The WAN, MAN, and LAN should not function as independent structures, but instead as tightly coupled components to form one efficient and reliable Network.

Throughout the course of the CalEx exercise, many network-oriented challenges were encountered. The most significant challenges were observed at the MAN level; however, it must be noted that some of these were in part influenced by infrastructure policies at the WAN level. The following discussion serves to provide recommendations

A. WAN Structure

The central point of control of a network should be at the WAN level. At this level it is much easier to monitor and maintain control of a WAN distributed simulation exercise. The WAN drives the technology and sets the standards and policies for those sites that desire to join.

During CalEx, the DREN was used to provide the WAN support. One recommendation to be made is that, in the future, the DREN be capable of offering an unclassified network service, a separate interface that would provide a transparent encrypted ATM backbone that would not touch the Internet or any other similar commercial network. The desire would be that this network interface offering would be used only to serve the unclassified simulation community. Sites that would want to use this interface would agree, via a Memorandum of Agreement (MOA), not to place firewalls or security routers in its path, but would use it to directly connect the simulation participants. Every firewall and security router employed increases latency on the Network. The DREN would be solely responsible for establishing the security practices and procedures of the new interface. Note, the current service provided, which peers to the Internet and other general purpose networks, is valuable and should be continued as an offering. However, this new interface would be of great value in the simulation community and would help to eliminate some of the latency that is so detrimental in the simulation environment.

Another recommendation would be that the DREN be staffed to support a technical staff that would be responsible for the following:

1. Scheduling resources, tracking and providing consistent technical support for large distributed WAN simulation exercises.

2. Maintaining network documentation and Points of Contact (POCs) of participating sites down to the LAN level. During CalEx it was noted that MAN sites did not desire to share basic configuration information regarding their networks (i.e. note, all the "clouds" in the CalEx network diagram). There needs to be a central point of control, which is aware of the entire structure of the network. It is impossible to debug problems without this knowledge. The LAN, MAN, and WAN network have to be looked at as just "one" efficient and

stable Network. There has to be at least one group in charge that has access to the configuration and structure of the "whole" Network.

3. Provide pre-engineering support to provide equipment recommendations, latency, and routing capacity planning for new sites. Also, provide performance information prior to large-scale exercises.

4. Continue to provide research and encourage newer more efficient technologies. For example, to lead the effort away from the use of Distance Vector Multicast Routing Protocol (DVMRP) multicast tunnels and encourage the use of Protocol Independent Multicast (PIM) sparse mode for multicast support.

B. MAN Challenges

The MAN provided the greatest challenges during CalEx. Communication with this level for the WAN and LAN network managers was very difficult. The MAN administrators are responsible for the network activities on an entire base. Their priorities oftentimes are in direct conflict with those of a Project trying to execute a WAN distributed simulation. There needs to be an infrastructure put in place that will effectively support the needs of the simulation community as well as that of the general administrative community. Also, there appears to be no commonality of MAN network structures between the bases. This is so important to structuring an effective network. There should be a commonality of equipment, standards, policies, and practices that are operative and mandated at all bases.

C. LAN Disposition

The technology used on this level was a minimum of fast Ethernet on all sites. The greatest challenges on this level were that of the applications. Unfortunately, the other network challenges overshadowed those on this level. However, there were challenges noted with the RTI [2,3] and the Gateways. Whether these were caused by overall network latency, or problems within the applications themselves, specific causes could not be determined.

V. CONCLUSION

Distributed simulation of long haul networks can and does work well if the network remains stable. There is sufficient bandwidth at most Army RDEC sites to handle reasonably sized exercises. However, as the DREN becomes more critical, perhaps there should be an Army investment in infrastructure to ensure all Army research centers are connected to the DREN.

Infrastructure needs to be addressed properly by Army leadership to ensure that the modeling and simulation community can execute the Army vision of SMART. Investment needs to be made in networking as noted above as well as HLA as the environment that will support interoperability.

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ACRONYMS

AMC	Army Materiel Command
RDEC	Research, Development, and Engineering Center
ARL	Army Research Laboratory
STRICOM	Simulation, Training, and Instrumentation Command
HLA	High Level Architecture
DREN	Defense Research & Engineering Network
RTI	Run-Time Infrastructure
LAN	Local Area Network
MAN	Metropolitan Area Network
WAN	Wide Area Network
TARDEC	Tank, Automotive, Research, Development & Engineering Center
CECOM	Communications & Electronics Command
C41SR	Command, Control, Communication, Computers & Intelligence, Surveillance, Reconnaissance
M&S	Models & Simulation
FCS	Future Combat Systems
DIS	Distributed Interactive Simulation
ATCCS	Army Tactical Command & Control System
FOM	Federation Object Model
RTI	Run-Time Infrastructure
GRIM	Guidance, Rationale, and Interoperability Modalities
RPR FOM	Real-Time Platform Reference FOM
APS	Active-Protection System
PST	Paint-the-Night and SWISS Together!
XDR	External Data Representation
PDU	Protocol Data Unit
CGF	Computer Generated Force
OTB	OneSAF Test Bed
ITEMS	Interactive Tactical Environment Management System
RWA	Rotary Wing Aircraft
UAV	Unmanned Aerial Vehicle
VTT	Vetronics Technology Testbed
ES	Embedded Simulation
OCU	Operator Control Unit
CERDEC	Communication - Electronics Research, Development, and Engineering Center
NGPM	Next Generation Performance Model
CID	Commander's Interactive Display
PTN	Paint the Night
NVESD	Night Vision & Electronic Sensors Directorate
EO/IR	Electro-Optical/Infrared
UGS	Unmanned Ground System
GEC	Generic Entity Controller

ACRONYMS (Cont.)

CMS	Comprehensive Mine Simulation
CTD	Compact Terrain Database
F2DSS	Future Fires Decision Support System
VDMS	Vehicle Dynamics & Mobility Server
HPC	High Performance Computing
IDEEAS	Interactive Distributed Engineering Evaluation & Analysis Simulation
ATM	Asynchronous Transfer Modulation
QOS	Quality of Service
DVMRP	Distance Vector Multicast Routing Protocol
PIM	Protocol Independent Multicast

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