Private Overlay Multicast for the Defense Threat Reduction Agency Collaboration Center (DCC)

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Abstract

Growing demand for use of Internet/Web-based services in real-time distributed virtual simulation (RT-DVS) and other real-time applications is fueling extensive interest in overlay multicast protocols. These applications demand Quality of Service (QoS) and many-to-many multicast services that are not available in underlying Internet services today. This paper describes a common user Architecture for Private Overlay Multicast to support efficient communications for the Defense Threat Reduction Agency (DTRA) collaborative environments and distributed simulations. Many of the processes and applications that support the DTRA operational environment require group communications, which means some form of multicasting where one process sends to a group of other processes. Multicasting, therefore, is a critical element in the deployment of scalable networked collaborative and simulation capabilities for DTRA.

1. INTRODUCTION

The DTRA Collaboration Center (DCC) engages research, development, integration and distribution of new and operational technologies in order to facilitate a successful, rapid transition of combating Weapons of Mass Destruction (WMD) capabilities to the warfighter and civil authority first-responders. The DCC conducts experiments and explores new concepts for provisioning of net-centric technologies, decision support, situational awareness, and unique analysis capabilities.

To further this objective, George Mason University C4I Center has been engaged to develop an architecture for the integration of an easy-to-deploy overlay multicast system with commercial Web security (as used for e-commerce, capable of supporting For Official Use Only (FOUO) messaging) into the DCC. The objective is to have a network service that can efficiently support distributed simulation and collaboration over existing IP networks.

Internet Protocol (IP) multicast over the Internet was introduced in 1993 [1], however, it still is not widely available as an open Internet service primarily because it is difficult to manage multicast services at the IP layer in a cross-domain network environment. DTRA's network environment has similar properties in that DTRA does not have network management domain control of the various users of DTRA products. To overcome this limitation, DTRA is investigating use of an end-host service to provide similar capabilities.

Early research efforts, though primarily in one-to-many overlay multicast [2, 3], offered considerable promise to provide the many-to-many multicasting across multiple domains and heterogeneous networks that are needed for cross-domain networking environments similar to the needs of DTRA. By organizing end hosts into an overlay to act as relay agents, multicast can be achieved through message forwarding among the members of the overlay using unicast across the underlying network(s) or Internet. Here, a transport-layer overlay establishes group communications on top of the underlying network(s) independent of the need for IP layer multicast service.

This paper describes an approach for DTRA to achieve overlay multicasting that meets two fundamental needs:

- The message traffic must travel over an arbitrary collection of Department of Defense (DoD), other Federal and local governments, and commercial Internet paths without regard to whether the network operators are willing to implement multicasting protocols.
- It must be possible to ensure privacy of the communications, at least to the level associated with ecommerce Web transactions, which can be used with For Official Use Only (FOUO) traffic.

2. BACKGROUND

The mission of DTRA is to provide quantitative WMD information to operational forces including not only Department of Defense Forces but also other Federal Agencies, State and local agencies, U.S. coalition partners and first responders. The set of tools that enable DTRA to meet mission objects include the ability to collect real-time sensor data, analyze the data, and provide real-time information dissemination to the operational forces in a useable context that supports situational awareness in the operational force C2 systems.

The approach to meet the WMD Communities of Interest (COI) requirement for quantitative information is through provision of net-centric technologies, with a scalable topology and process management architecture enabling decision support, situational awareness, and a unique analysis capability. A key issue to the early success for real time information sharing in this interagency, coalition, joint operational environment, is cross domain information networking solutions that support distribution of large amounts of data.

2.1. DTRA Collaboration Environment

The DTRA DCC proposes to deploy a robust multiparty collaboration environment with improved visualization that will foster a large number of organizations and staff interacting. Networks supporting this environment must distribute large amounts of data within the bounds of human interaction time supporting a large number of participants. These participants are expected to dynamically join and leave the communicating groups across the myriad of public and private networks that make up the DCC user community networks. Because each of these networks is independently managed, the DCC applications cannot solely rely on these networks to deliver necessary network services that are derived from the IP or lower layers of open networking.

Similar limitations apply to running any application that requires group communications across networks made up of independently managed domains like the Internet. Our prior research efforts [4] have demonstrated support for use of overlay multicast as a means to overcome these limitations. These prior efforts were focused on real time distributed simulation with group communications across the Internet where all multicast services are provided by the end system rather than by lower layer network services. This environment has similar characteristics to that of the DCC applications needs to include requirements for improved delay performance and throughput for users who desire to experience advanced visualization and collaboration services.

In the end system or overlay concept, all functionality of multicast, including group management and message replication, are performed in the end host. In addition, these end system approaches include optimization of the overlay by adapting to network dynamics and are able to take application performance into consideration [2].

The fundamental requirement is to provide a managed multicast service across the many independent Autonomous System (AS) domains that make up the DCC network environment which crosses Military and Federal Civil Agencies as well as State and Local Authorities' networks. To achieve these performance objectives, every AS domain (network) manager must have an incentive to maximize performance across their managed domain. The choices made by each manager must not be hindered by any other AS in order for the end-to-end system application to achieve desired results across the network. Overlay multicasting is a way to provide independence from AS domain management. With this independence of AS, an overlay multicast protocol is able to take advantage of the service offered by QoS facilities (e.g. Multiprotocol Label Switching (MPLS) or Differentiated Services (DiffServ)) in the AS without the necessity of knowing that the AS is using this underlying technology. This approach provides the network independence necessary for near real-time information exchange in a distributed interactive environment such as that of the DTRA DCC.

2.2. Concept of Operations

The operational concept for DTRA is to accept real-time sensor information from events that are generally described as WMD events (These events can be real or simulated events that can be used for planning purposes.) and integrate the event information with real-time environment information through the use of simulation tools. The environmental information can include weather, population or operational force characteristics, urban structural characteristics, collateral facilities, etc.

The simulation tools include realistic physics-based weapons effects and environments. The simulation components provide target management, physics calculations and visualization of the results. These physics models include such items as cratering, penetration, external blast, contaminant expulsion and downwind transport from the target into the atmosphere. The models use real time data sources such as weather, transportation systems, local population densities, etc. in preparing visualization results to the Command and Control (C2) systems of the responding or operational forces.

Initial concepts for creation of this environment are being developed through experimentation in coordination with the Joint Forces Command (JFCOM) Experimentation Center. The framework for the experimentation effort is Urban Resolve (UR2015), a robust urban simulation environment. The overall goal is to eventually move beyond experimentation to that of providing real-time support to the operational force. Key attributes of the operational support include:

- Establish an operational hierarchy and horizontal information sharing.
- Enable global arbitration of priorities/requirements.
- Provide global situational awareness.
- Interact in shared visualization space with C2 systems.
- Provide active links between information products, analyses, and sources thereby enabling rapid drill-down and update, with tailorable information awareness.

Figure 1 presents a realistic scenario of the concept of operations for the DTRA DCC. The figure embraces the idea that there are a very large number of users of the same information that range from combat commanders to knowledge producers that use data sources to create information through analysis and simulation.

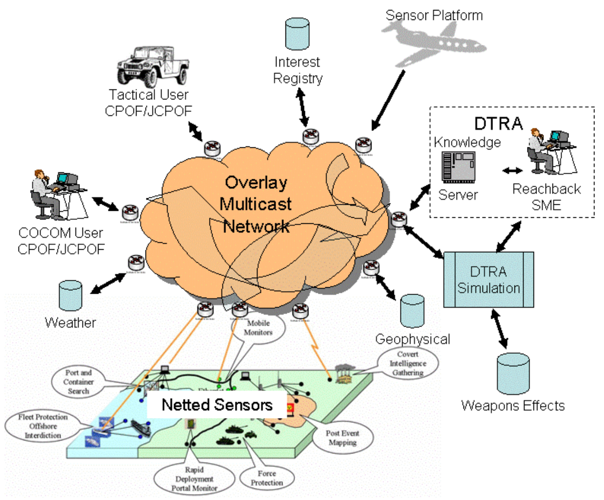

Figure 1. Concept of operations for overlay multicast

C2 systems enable commanders to discuss and collaborate when processing information, share ideas, and attend virtual meetings without assembling at one place. Commanders attending the virtual meeting do not have to attend in the same location, or even the same country, to discuss and draw on the same map. Modern C2 systems use advanced visualization tools such as multi-screen video wall, video and audio conferencing and online collaboration tools, allowing commanders to communicate, collaborate and share information. The commander's “battleboard” is interfaced to the system supporting all communication, collaboration, and information feeds he needs.

C2 systems are maintained as liquid information in database format, which separates the data from the viewing space. The system gathers real-time and near-real-time feeds from multiple C2 applications. Constant monitoring of the battlefield is provided by tracking the combat elements on maps or satellite photos and video feeds from battlefield or strategic sensors, following enemy forces through intelligence reports, ground observations, forward units or unmanned aerial vehicles (UAVs). The commander’s staff uses the information for current operations C2 as well as planning for the next operation.

In either case of planning or C2 operations, consider the case where a source sensor alerts the commander to a WMD event. Within the C2 system, the staff launches a request for services to perform an assessment on current operations. This request uses a Web service to discover and launch a WMD effects simulation. This simulation in turn captures updated weather information, force deployment information, updated geospatial information and characteristics of the WMD event. The simulation returns an overlay visualization of the assessment to the C2 system and provides continuous updates based on simulation cycle updates not only to the requester, but also to any other registered interest user using overlay multicast services.

When the simulation process begins, it transparently spawns a process on a remote machine. As the simulation process runs, it updates its local database and queues update commands for the processes, which are sent over the multicast network. A device handling process is also spawned, which streams updates of multiple trackers to both the simulation and rendering (display) processes associated with all interested/subscribed users. The rendering process needs the information in order to draw the environment and the simulation process needs it because some objects in the hierarchical database are "attached" to trackers for their current position and orientation on entities of interest. Discrete input devices, such as sensors, send events over the multicast network to the simulation process. The simulation processes provided by DTRA are launched and provide the results via commands to the rendering processes to render the graphics for the C2 system and other registered interest users. This process is transparent to the C2 system users or any registered interest users. Updates are streamed automatically across the overlay multicast network.

3. VALUE CONTRIBUTION OF OVERLAY MULTICAST

The DCC approach represents a different strategy to building and fielding situational awareness and C2 Systems integrated with WMD effects analysis. It recognizes that a user's information needs are dynamic. The ability to integrate real sensor data from many sources into an analysis environment based on simulation tools recognizes that it is the users themselves who are best able to define their requirements yet separates the users from the need to know where or how the information is assembled. The users need only register their “interest” using the registry services in the overlay multicast network. The approach offers unprecedented access to information from many global sources; real sensors and many potential processes/simulation tools distributed across the network using an efficient networking capability called overlay multicast. Many benefits result:

- Improved situational awareness.
- Better and faster decision-making - the right information to the right people at the right time based on registered interest.
- Instantaneous global collaborative communities efficiently using network resources.
- Increased reach of DTRA products.
- Provides decoupling of information among producers and consumers.

- Allows many end users to receive content via point-to-multipoint as it is published based on registered interest.
- Integrates with Defense Information Systems Agency (DISA) Netcentric Enterprise Services (NCES) Service-Oriented Architecture Foundation services for enhanced security and administration.

These attributes imply the need for distribution of large amounts of data from many sources to many recipients in real-time across many network domains. Today, in the experimentation environment of JFCOM and UR2015, networking is accomplished using the DREN which provides a large network capacity for experimentation. In the operational environment, cross domain networks are likely to include limited capacity at the edge of the battlefield or at the front lines of first responders.

In UR2015, data distribution implementation is based on tagging simulation state updates with an interest vector [5] and using a network of Interest Management Processors (IMPs) to route the information between federates [6]. Each federate in UR2015 is connected to a single IMP and the IMPs are connected into a hierarchal tree structure. A federate expresses it interests in an interest vector that is propagated around the tree so that each federates' output link knows what the listeners on the other side of the link have subscribed to and only those data items matching the subscriptions are sent forward. This strategy can be described as a "pseudo" form of multicast.

In overlay multicasting, no constraints are placed on how federates are connected to the network other than to state that each subnet hosting a federate/simulation or viewer client must also host an instance of the multicast relay. With this approach, federates can take advantage of standard Internet multicast protocols on the local subnet without the need for any special application interface other than the application must be multicast enabled. By being multicast enabled, the application is using standard protocols of the host operating system and local area network protocols without the necessity of having knowledge of the overall network. These means that any information application can use overlay multicasting and need only announce its interest via a Web service registry for discovery of information sources/interests. The result is an approach more in line with the DISA Service oriented Architecture (SOA) and the Netcentric Enterprise Services (NCES) strategy, where the NCES offers a Web based discovery service and registry service and source information mediation.

The value of following a strategy consistent with DISA's is that the NCES is providing an environment where people who have information can announce the information through global discovery and people who need information can discover and have delivered to them the information they desire. The approach provides better access to information, enhancing its reach, richness and depth, as a way to promote superior decision-making.

4. CROSS-NETWORK OVERLAY MULTICAST

The George Mason University Cross-Network Overlay Multicast (XOM) system is a software overlay network that provides efficient multicast communications services for applications that require distribution of information from many sources to many recipients. The XOM provides self organized logical channels for group communications as a service to applications using the efficiency of multicast to reduce network stress.

The XOM can be viewed as a network layer service, independent of user application. Figure 2 presents the operational topology of how the XOM provisions overlay multicast. Because it is an overlay service, it is also independent of managed network domain and the underlying IP network. The approach applies the more than 20 year old concept of moving complex functions and services [7] upward in a layered design, closer to the application(s) that use them. The result is increased flexibility and autonomy of the service to apply those functions and services to the specific needs of the application.

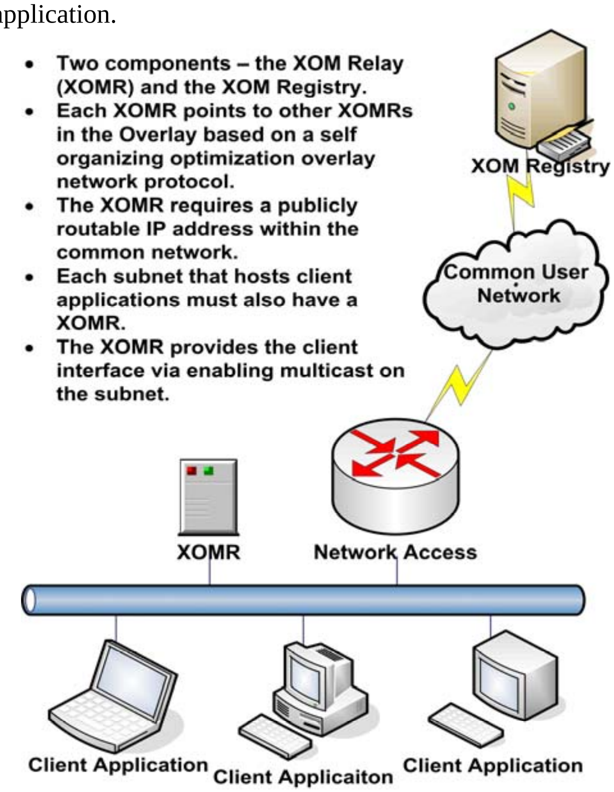

Figure 2. XOM operational topology

XOM provides an efficient mechanism for many users to subscribe to a content flow while minimizing network traffic loading. Users announce their content interest via the registry. Then the registry computes an efficient distribution scheme for all subscribed content users and periodically makes adjustments as user demands and underlying network conditions change.

4.1. DTRA Functional Requirement

The core system requirement is to provide efficient network pathways for distribution of large amounts of source data from many sensors to many recipients in an open cross domain network environment. The requirement is to optimize both the available capacity and the delay for all participants or group members in the distribution. The system must also provide a service to register interest and efficiently organize information distribution for group members. The system must support these key DTRA requirements:

- Real-time media streaming support that optimizes both the available capacity and the delay for group members.
- Support large-scale groups without relying on any predetermined intermediate nodes.
- Enable a collaborative environment for development and experimentation.
- Provide an array of global communications pathways that allow flexibility to include coalition partners, allies, US Federal and local civil authorities.
- Support both concepts of information push and information pull. Information push implies either subscribed to senor source with dynamic event generation as well as subscription to results from analysis or assessments. Information pull implies ability for asynchronous requests for information.

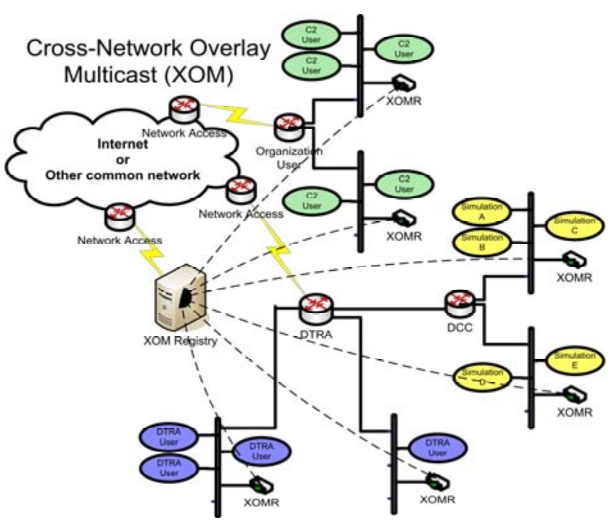

Figure 3. DTRA XOM deployment

The overlay system must support collection of data from across all DTRA mission campaigns and external sources in order to distill a coherent, operational, situational awareness for the decision maker. The DTRA operational mission entails receiving, collaborating, coordinating, and disseminating raw data, refined information, and packaged analytic products efficiently based on user community of interest. Figure 3 provides a picture of how the overlay system will be deployed. The overlay system will enable efficient information exchange with applications that support situational awareness for combating WMD.

4.2. XOM Architecture

The XOM is being developed to support large-scale groups without relying on any predetermined intermediate network nodes, in that the overlay multicast is solely constructed by end hosts on each subnet that provides service to an interested party or application. The approach is referred to as many-to-many multicast where many-to-many multicast is defined to mean that many senders simultaneously can send to all of many interested receivers.

Providing robust multicast services for real time data and information distributed is an important requirement to enable use of Web based services across open networks such as those that are likely to support DCC operations including collaboration. The information exchange can be described as a stream where subscribing to an information source implies subscribing to a "stream" of messages. A stream is a sequence of messages that have a common schema. Streams are either event streams or control streams. Messages in event streams contain information about the system state. For instance, a temperature sensor measures the temperature in the environment and generates an event stream in which each message contains a temperature reading. A temperature measurement is information about the system state. Messages in control streams contain control commands. For instance, control messages to a temperature sensor may specify the frequency with which the sensor should send event messages.

Early prototype vs new features

XOM is an overlay protocol that provides many-to-many multicast for real-time distributed information exchange. The objective is to provide multicast service over a unicast network environment using TCP or UDP. From the multicast sender and receiver's point of view, each XOM Relay (XOMR) looks like an IP layer multicast router and performs as a multicast "relay agent" for any application located on the same subnet as an instance of the XOMR.

Our approach is based on the notion of a multicast host (XOMR) in each subnet as indicated in Figure 2. The XOMR uses unicast protocols to communicate with its peers on other subnets and controls all aspects of the subnet's group communications.

A functional diagram of the XOM is presented in Figure 4. The core of the XOM is the XOMR. The XOMR is software that runs on a local host in the subnet. It provides for the communications path management and developments and manages the routing table to be used in making message forwarding (routing) decisions. Receivers issue a request to join existing groups using a unique connection identifier that is pre-assigned by the registry. Using this approach, an application is able to control or specify which sources of information are of interest. Group membership control also helps protect an individual application from receipt of unspecified or undesired information flows and also aids in minimizing overall network traffic load.

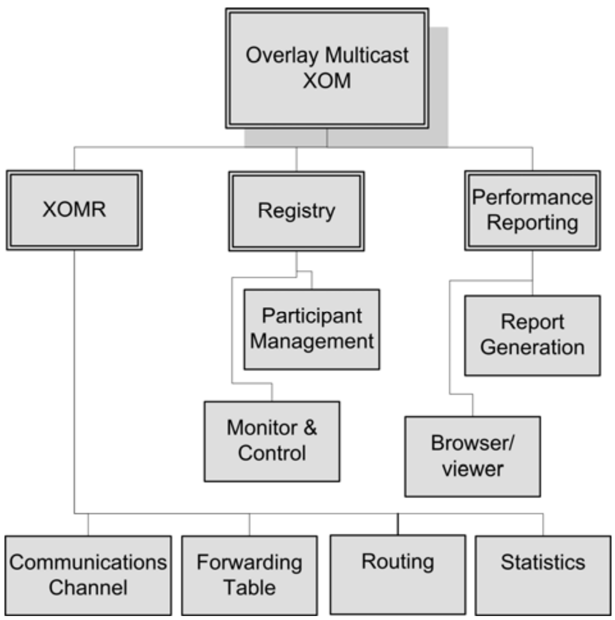

Figure 4. XOM functional diagram

The group membership approach assumes that a group definition is based on a specific application running behind an XOMR on the local area network. Multiple instances of an application are supported behind a XOMR, each of which may have different group membership characteristics to include membership in multiple groups. It is also feasible for an application to have membership in more than one group. The approach also implies no explicit set-up processing between the sender and the receivers prior to the establishment of group communications. The XOMR mechanism is required to pass the multicast group (IP/group tag) address to the XOMR of the associated receivers. The receivers' XOMR must have established "filters" for the address prior to transmission in order to receive the data.

We use a decentralized algorithm to construct an overlay by searching for potential existing XOMRs as nearest neighbor in the overlay with which to form a connection. This decentralized algorithm relies on information provided by the registry to the joining XOMR as an aide in the establishment of a connection. In this process, we employ two mechanisms that contribute to global service guarantees and help manage the construction of path overlays. The first is that we put a limit on the out degree of an XOMR using Bollobas [9] definition of the degree of a vertex. That is, we do not allow the construction of more than *n* connections to other XOMRs where *n* is determined by the resources of the XOMR and access capacity of the underlying network. This serves to limit the processing demands and network access capacity of individual XOMRs in the overlay and therefore establishes lower bounds on the performance.

The second is that we create a threshold for the end-to-end overall path delay from a sending XOMR to a destination XOMR and only offer best effort above this threshold to joining XOMRs that do not successfully find an existing XOMR node that is adequate to maintain end-to-end path delay thresholds

While XOMRs function as peers for multicast data distribution, they are connected to a central registry for management and performance monitoring. The registry implements Web services, deployed in servlet containers. This is illustrated in Figure 5. The latest stable versions of Apache Tomcat and Axis are used for implementation.

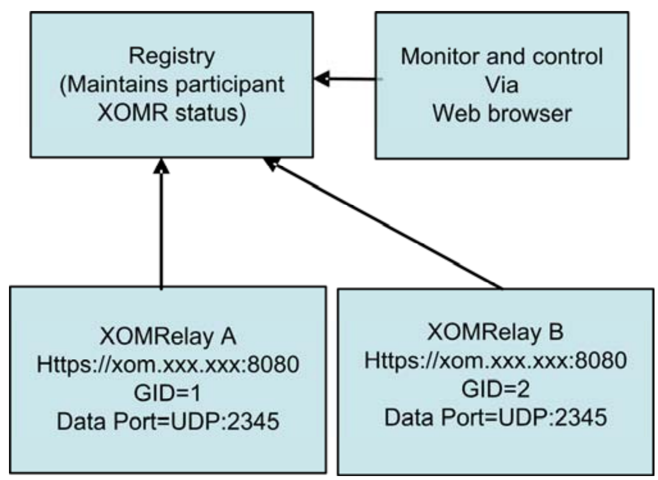

Figure 5. XOM Registry and Relay relationship for overlay management and monitoring

The registry is responsible for keeping track of relay participants in the overlay network. On startup, a relay contacts the registry via SOAP-RPC. The registry returns a list of all the other participants in the overlay network, the TCP keepalive and routing update interval. It then posts the new connection in its tables for query by the other participating XOMRs. In the enhanced version of the XOM, all communications between the registry and the relays will use the Hypertext Transfer Protocol Secure (https), which implements the Secure Sockets Layer (SSL). The XOMR data comes to the Registry by periodic update at the configured update interval. All XOMRs update latency and throughput data to the overlay at this interval.

Finally, we include a performance reporting function to allow local users and a global manager to manage the overall performance of the overlay. Statistics are gathered from local XOMR via a reporting function and the resulting statistics are made available through a Web browser.

4.3. XOM Performance Model

The overall performance of any overlay network is fully dependent on the performance of the underlying network. Even though this dependence exists, it is possible to define metrics that are associated with individual nodes of the overlay and that also can be used in the construction of the overlay. These metrics along with suggested objective measures are presented in Table 1. In our earlier work [8], we demonstrated the use of these metrics in overall performance measure of a multicast overlay and used the measurement approach to predict performance of individual nodes in the overlay. We showed that these metrics can be used as a guide in overall system design.

Performance Requirement	Metric	Objective	Attribute
Message Loss	% Loss	Maximum 0.1%	(1 – messages transmitted/messages offered)*100. Applies to each XOMR in the system
Overlay Diameter	Number of nodes	Maximum 10	Number of nodes on the longest single path across the overlay
Node Degree	Number of message replications	Maximum 5	The number of replications of a single arriving message required for forwarding in the overlay
Latency	msec	Maximum 150 msec	End-to-end delay across the overlay system

Table 1 Overlay Multicast Performance Metrics

In our overlay design, we desire to limit overall message loss to not be greater than one percent. This implies that if we have a 10-node overlay diameter, then we need to allocate on average, no more than 0.1 percent message loss per node where message loss is a measure of what per cent of arriving messages are not received by the receiving node.

We define overlay diameter as the number of hops or nodes from a sender node to the farthest receiver node for an optimal path between the nodes. Since each node is potentially a sender, then each node will have its own measure of diameter that it sees in the overlay.

The degree of a node is a direct function of the processing resources of an XOMR host. It is a specific performance measure of message throughput of the receive/send (relay) function of a node. It represents the maximum throughput capability of node in terms of how many replications of a message a node is required to make in order to satisfy the routing distribution of an arriving message. The metric is commonly referred to as the *n*-degree of a node or the number *n* of reflect messages that might be achievable from an XOMR. The *n*-degree factor is a significant parameter as it represents the ability of the XOMR to replicate messages to multiple paths or channels, therefore a driving force behind overall path construction and path optimization.

Latency represents the sum of the processing delays of the nodes in the path as well as the link transmission delay across the underlying network between the overlay nodes. Link transmission delay is a sum of the processing delay in each node of the underlying network plus the delay associated with the speed of light in media times the physical distance required to travel.

5. CONCLUSIONS AND FUTURE WORK

This paper describes a strategy for implementing overlay multicast for the efficient distribution of information in support of the DTRA distributed modeling, simulation, and analysis environments. We describe our motivation for overlay multicast and provide a description of the architecture of the XOM protocol and how it supports the DTRA mission.

In future work, we intended to demonstrate in the DTRA DCC experiment environment, the capability to include a robust collaborative environment that is enabled by overlay multicast services. The strategy is to develop the capability to use the existing George Mason University Network EducationWare (NEW) conferencing/training system (audio, whiteboard, access/floor control, optional video) across an open network using the XOM system for efficient multicast services.

The current prototype for overlay multicast relies on UDP and offers no capability for security. Fundamental to improving the security posture and providing a service that meets minimal security for information transfer within the DOD is to add commercial security capabilities by using the SSL Web security protocol. We are developing the capability to add TCP as a user choice in configuration of the overlay so that TCP tunneling can be employed in order to allow the use of SSL.

6. ACKNOWLEDGEMENT

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Biography

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