Intercloud for Simulation Federations

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ABSTRACT

Education training and experimentation networks (ETEN) are an important application area for the cloud computing concept. An ETEN is an infrastructure that consists of advanced distributed learning, collaborative working and distributed simulation systems, and can be designed as an intercloud of many global and private clouds. Intercloud approach introduces new opportunities to improve the performance and to increase the utilization of distributed simulation systems in an ETEN. These improvements also imply significant reduction both in the initial investment and operations/maintenance costs of ETEN. Our new ETEN intercloud concept including challenges and their technical solutions are introduced. We also carried out a large standalone experiment and tests during exercises. The preliminary results from these experiments are presented.

KEYWORDS: Simulation, training, shared scenarios, exercise, experiment, computer assisted exercise, cloud computing, virtualization.

1. INTRODUCTION

In recent years, modern armed forces have been developing their persistent networks for training, education and experimentation. The US Joint National Training Capability (JNTC) [5], which provides a persistent network for joint (i.e., multi-service, army, navy, air force and marines together) training services, is an example. The North Atlantic Treaty Organization (NATO) is also designing a persistent training capability for NATO, its nations and partners, called NATO Education and Training Network (NETN) [1, 2, 10]. The NATO Modeling and Simulation Task Group MSG-068 has been tasked to develop NETN standards and recommendations and to demonstrate their practicality.

NETN will deliver to the Alliance and its Partners a persistent, distributed education and training capability that supports training spanning from strategic down to tactical level across the full spectrum of operations, leveraging national expertise and capabilities. NETN connectivity should be flexible in the sense that nations and organizations that have access to the NETN infrastructure will be able to perform exercises or experiments in different configurations. In some cases all nations may want to join a specific event, in other cases, a (small) number of nations may use NETN for a particular training exercise or mission preparation event. The preparation time to set up a particular event should be minimized as a result of the permanent character of NETN.

The following applications are foreseen in NETN:

- Simulation systems (including simulated radio and data links), possibly with hardware in the loop for training purposes.
- Event planning and management applications.
- Command and control (C2) systems, mainly identical to the applications that are used operationally.
- Video teleconferencing (VTC) for exercise mission briefings, mission planning and after action review. VTC is also used for technical briefings, technical planning and technical after action review.
- VoIP for technical management and control (before, during and after the exercise).
- Network remote management, control and monitoring.
- Network time synchronization (using Network Time Protocol NTP).
- Various e-mail, web and ftp applications.

The MSG-068 NETN TG has already completed its work and submitted its technical report [10]. The report can be obtained from NATO Research and Technology Organization, and include recommendations for the infrastructure, collaborative working environments and federation agreement and object model design for a distributed simulation reference federation architecture for NETN.

NETN can be designed as a global education, training and experimentation cloud (ETEC). NETN can be perceived as a very large cloud public to accredited sites in nations, and also connects other national private clouds like JNTC. It can provide:

- Shared resources applications like joint exercise

management module (JEMM) and joint exercise scenario tool (JEST), simulation systems like joint theater level simulation (JTLS), joint conflict and tactical simulation (JCATS) and virtual battlespace simulation (VBS2)[4] in the form of software as a service (SaaS) [4].
- Central Runtime Infrastructure (RTI) component of HLA [4], HLA federation execution control tools, exercise logging services, database management systems and web services in the form of platform as a service (PaaS).
- CFBLNet [10], video teleconference (VTC), voice over IP (VoIP), network control and monitoring, network time protocol servers and other infrastructure elements in the form of infrastructure as a service (IaaS).

ETEC can provide not only IaaS, PaaS and SaaS but also other services like exercise/training planning and management. Therefore, ETEC is a very attractive concept for NETN. However security is a major challenge for the realization of ETEC concept. The security challenges and their solutions for a subset of these challenges are presented in our previous paper about ETEC [2]. In this paper we explain that ETEC is actually an intercloud. In Section 2, the conventional approach proposed by MSG-068 and our ETEC approach are introduced and compared. In Section 3, we explain why ETEC is an intercloud and how it is different from a typical intercloud. Virtualization of services that will be available in NETN ETEC has already been implemented and tested in large NATO exercises. Technical design of this test and experimental results obtained are given in Section 4. We also provide our results from a large international standalone experiment, which are related to intercloud approach, in the same section. We conclude our paper and explain future work in Section 5.

2. ETEC ARCHITECTURE FOR NETN AND ITS ADVANTAGES

In the first quarter of 2009, MSG-068 completed the technical recommendations for NETN, and the Taskgroup tested the practicality of the recommendations in experiments throughout 2009. The current design of NETN is depicted in Figure 1.

MSG-068 recommends CFBLNet as the networking infrastructure for NETN. CFBLNet is a network built and maintained by its members [10]. The network consists of sites, national *Point of Presence* (PoPs), infrastructure, services and knowledge management. The national/organizational PoP is the connection from the national/organizational *Wide Area network* (WAN) to the international part of the CFBLNet WAN. The CFBLNet *BlackBone* (i.e., Black backbone) provides a common, closed, unclassified IP routed network layer implementation using a mixture of both ATM and IP bearer networks. Its primary purpose is to transport encrypted traffic throughout the network. *Enclaves* are the cryptographic protected networks on top of the CFBLNet BlackBone. Each enclave has a *classification* and a *marking* indicating security level and the countries allowed connecting. CFBLNet enclaves can be accredited up to NATO Secret level events. The classification, i.e., NATO Secret, NATO Restricted, NATO Unclassified and Unlimited, of an enclave can change from one event to another. However, an enclave can only have a single classification level at a time. It is possible to connect an enclave to other NATO networks. In this case guards (data-diodes) and firewalls are used to apply strict flow control mechanisms.

MSG-068 also recommends an RPR2 based FOM [1] and HLA 1516-2009 [8, 9] for federating live virtual constructive simulations. The Reference Federation Agreement and FOM Document (FAFD) for NETN was completed in May 2009. Since this topic is outside the scope of this paper, we do not give the details about FAFD. Interested reader can find more detailed information about FAFD in [1, 10].

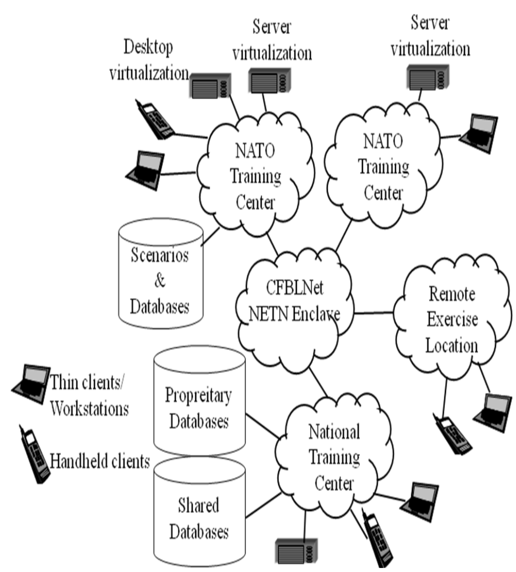


Figure 1. NETN as it is designed in MSG-068 [10]

The local area networks (LAN) of NATO Training Centers are important parts of NETN, and they consist of completely virtualized services. These networks and all the virtualized functional area services (FAS) running on them will be carefully designed and accredited for each event, i.e., an exercise or experimentation, through a process, which typically lasts 12 months.

Most challenging services in this environment are related to computer assisted exercise (CAX) support. There are four classes of CAX services: CAX planning and management, complex military simulation systems, interfaces between simulation and C2 systems and experimentation services. Especially the simulation tools are different from typical services. They are a very complex set of processes that work together and interact with each other. Therefore, NATO Training Centers are rigorously testing virtualization environments (VMware ESXi and VMware View) for the simulation tools. We provide the performance results from a major exercise where we tested virtualization for CAX services in Section 5.

In the following years, a new set of services will be introduced with NETN. The services that include also the new tools can be categorized as follows:

- Advanced distributed learning tools and databases
- Shared scenario and database resources
- NATO training federation (NTF), i.e., an HLA federation made up of constructive and virtual simulation systems (Note that NTF was already successfully used in a major exercise) [3, 4]
- NATO live virtual constructive (NLVC) federation for high resolution tactical training [4]
- Exercise/experiment planning and management tools, such as joint exercise management module (JEMM) and joint exercise scenario tool (JEST) [4]
- All kinds of functional area services (FAS), such as command and control (C2) systems, logistics systems and operational planning tools

The infrastructure for NETN is already partly available in NATO Training Centers. NETN will extend it mainly with distributed exercise control (EXCON) capabilities and an architecture that allows national simulation and C2 systems to join NTF or NLVC.

Figure 2 shows our ETEC approach for NETN, which can further increase the efficiency and flexibility of NETN. The facilities in NATO Training Centers and infrastructure allow quick adaptation of the ETEC approach. National private ETECs can also join the NATO ETEC to create more flexibility and extensive usage. Therefore, we can perceive the overall architecture as a hybrid cloud that has both public and private components. Propriety databases can also be used with this cloud. They may remain outside of the ETEC, but can become available through a controlled access from inside the ETEC. A NATO ETEC can reduce the cost of NATO exercises and experiments considerably because:

- Handheld devices and terminals cheaper than typical client workstations can use all the services in ETEC without any configuration requirement as long as they can gain access to the ETEC.
- Hardware for servers is procured for only one site.
- Software licenses are obtained for only one site. Licenses may be shared between users that don't require permanent use. For example, VBS2.
- Software and hardware configurations and upgrades are carried out at only one site. Therefore operations and maintenance costs are reduced.

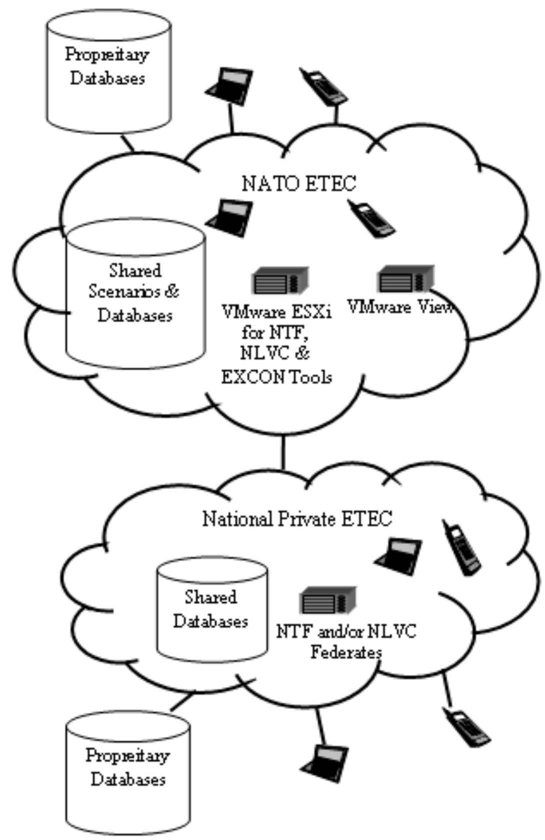


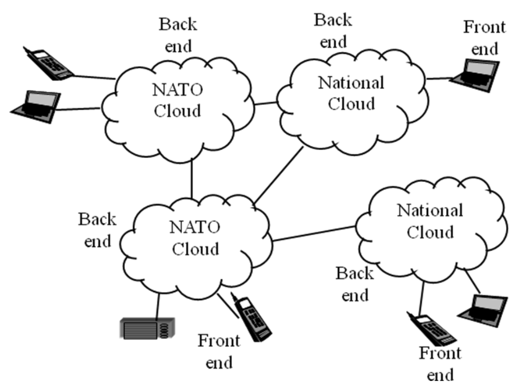
Figure 3. NATO education training and experimentation cloud

Nations and Partners can use this architecture not only for NATO exercises but also to train their tactical forces for Alliance/coalition operations more efficiently and less costly. For example several nations can train their tactical forces for a coalition operation without involving any NATO Headquarters by using NATO ETEC. Moreover, such an ETEC can be opened for UN and other international governmental and non-governmental organizations, which cannot afford to procure and maintain such a complex training and experimentation cloud.

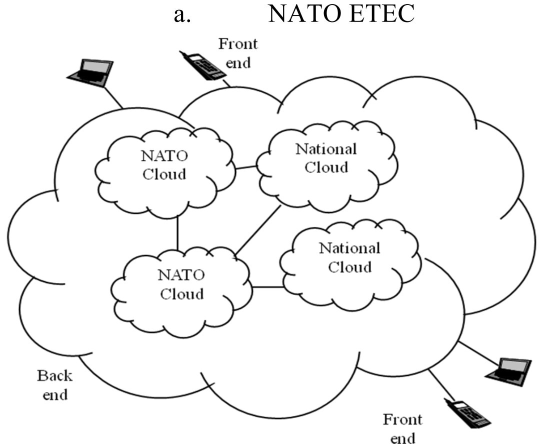
Please note that the ETEC approach for NETN has many challenges and most of these challenges are related to security, especially to multi-level security. We explain the security challenges of ETEC in [2]. Please also note that most of those security challenges can be dealt with procedures and static solutions, which may hinder the utilization of all advantages introduced by ETEC concept. However, ETEC is still more advantageous and cost effective comparing to the conventional approach [2].

3. INTERCLOUD APROACH FOR ETEC

From this point on, we call the intercloud approach for ETEC as the Intercloud. ETEC and the Intercloud are compared in Figure 3. In ETEC front end is a part of an individual cloud and services are designed and configured manually among the clouds. In the Intercloud the front end is connected directly to the Intercloud and the structure of the individual clouds and their interrelations are transparent to the front end. The services for the front end are autonomously composed from multiple service modules available in the Intercloud.



a. NATO ETEC



b. NATO Training Intercloud

Figure 3: Comparison of ETEC and intercloud for ETEC

The additional capabilities introduced by the Intercloud comparing to the ETEC can be summarized as follows:

- Cloud transparent service set creation: End users (i.e., the front end) can subscribe and use a set of services composed of modules provided by multiple clouds in the Intercloud. For this the end users do not need to know which cloud offers which module. For example a user may need to simulate the consequences of a flood and may need a model for the flood, a model for internally displaced people (IDP) and a model for an epidemics in an IDP. The Intercloud may locate each of these models in different clouds and provide the service as a complete set.
- Intercloud service management: Intercloud autonomously composes the service for the front end from the service modules available in various clouds as explained in the previous paragraph. During the execution, service modules can be changed from the service modules in one cloud to the ones in another, or migrated from one cloud to another based on parameters, such as, the workload and quality of service provided by the underlying infrastructure.
- Intercloud platform mobility: Platforms such as runtime infrastructure (RTI) for high level architecture (HLA) [4, 8, 9] for the execution of a simulation federation can be started in one of the clouds for the execution of a simulation federation. In hybrid architectures, multiple platforms and exchange platforms (e.g., a gateway between HLA and distributed interactive simulation (DIS)) can be run in multiple clouds part of the Intercloud. Moreover, a hierarchical and hybrid architecture can be created by using multiple platforms and gateways. These platforms can also be migrated from one cloud to the other automatically based on the quality of service requirements and the execution performance of the federation.

These capabilities can introduce a breakthrough for simulation based experimentation and training both for military and civilian purposes because these capabilities imply the following improvements:

- Much better utilization of the hardware, platform and software services
- Promotion of interoperability and reusability
- Better collaboration and increased simulation capabilities for the individual front ends

They also exacerbate already well known challenges, as well as, create new challenges, which include the following:

- Composability/Interoperability: This is a field that has been studied extensively for more than a decade. A pure composability is seen to be unreasonable [7]. However, the composability requirements for the Intercloud can be addressed by interoperability, and modular approach in HLA 1516-2010 [8] provides new opportunities to tackle with this issue. Composability means more or less creating a simulation system by using models from different simulations. On the other hand interoperability allows using multiple simulations for the same event. Both composability and interoperability require compatibility in syntax, semantics, pragmatics, assumptions and validity [7]. We tested interoperability of 11 simulation systems from virtual and constructive domains in a large distributed standalone experiment by using NETN Reference Federation Architecture in October 2010 [10]. Once the interoperability of the simulation systems is established for a set of functionality, which took several weeks after developing the federation agreement and federation object model (FOM) design, composing a federation to simulate a vignette (i.e., a case) could be managed in a short time, in the order of minutes. However, the Intercloud requires further standardization (i.e., syntactic, semantic and pragmatic) and ontology development in the following fields:
  a. Standardized definitions of the functionalities: Front end should be able to define which functionalities (i.e., models) needed, and the Intercloud should clearly map these requirements to the service modules available in the Intercloud.
  b. Standardized definitions of resolutions: The same function can be provided in various resolution based on different parameters, such as geographic information and entities. For example line of sight calculations by using a terrain model that has 1 meter accuracy is different from the calculation when a hexagon based terrain model with 5 km accuracy is used. Therefore, front end should clearly define the resolution together with the function.
  c. Federation agreement and FOM design (FAFD): An internationally recognized FAFD is also required. MSG-068 NETN FAFD is an important step for this. However, MSG-068 NETN FAFD needs to be further developed. NATO Research and Technology Organization (RTO) is starting an MSG-068 follow on technical activity for this purpose.
- Data mapping and preparation: Data mapping is the most important issue noted during MSG-068 standalone experiment in October 2010. As stated also in the previous paragraph data mapping has five levels: syntax, semantics, pragmatics, assumptions and validity [7]. MSG-068 NETN FAFD can be accepted as a reference for the data mapping in the syntax level. However, the other levels still need to be addressed. One other issue related to data is the availability of data. NETN provides the architecture to share the data and collaborate for preparing the data. However, still front end needs to prepare data specific for the its requirement and the Intercloud should provide the interfaces and tools to prepare and validate the data.
- Service module registration and discovery: Service discovery has been extensively studied for more than a decade for the Internet. Techniques developed for service discovery in the Internet are also applicable for the registration and discovery of the modeling services available in the Intercloud.
- Autonomous service and federation management: Federation management in the Intercloud introduce additional capabilities comparing to a conventional federation execution, which also imply additional challenges to tackle with. These challenges include the following:
  a. Federation creation and initiation: Services (platforms and simulations) needs to be located and organized into a federation.
  b. Joining and retiring federates to and from federations: During the execution new platforms and simulations can be introduced and architecture (i.e., the hierarchy of the platforms and simulations) can be changed.
  c. Federate (i.e., simulation software part of a federation) migration from one server/cloud to another server/cloud: A federate can be moved from one cloud to another within the Intercloud.
  d. Platform (RTI, exchange gateway, etc) migration from one server/cloud to another server/cloud: Platforms can be moved from one cloud to the other during the federation execution.
  e. Management of entity ownership among the federates: The ownership of the entities or some attributes of the entities can be changed from a simulation in a cloud to a simulation in another cloud.
  f. Registration and subscription for the entities simulated by the federates [9]: Federates can register and subscribe for new entities.
  g. Perception management (i.e., registering and updating only the entities that other federates

are interested in): To reduce the data traffic, federates only register and subscribe based on the need to know concept.

- Front end user interfaces: Finally user friendly interfaces, common tools and C2 consoles should be available as SaaS for the front end.

4. EXPERIMENTAL RESULTS

NATO computer assisted exercise (CAX) support tools, which make the majority of future NETN services, were run in a completely virtualized architecture during major exercises. These exercises were the first step for the realization of the NETN Cloud concept, and proved that all NETN services can be virtualized. Moreover, the virtualization of these services is more cost effective, easier to prepare and administrate, and performs better than the conventional approach, i.e., not virtualized architecture. In this section we first explain the virtualized architecture for the tests, than provide memory and CPU utilization data from the exercise.

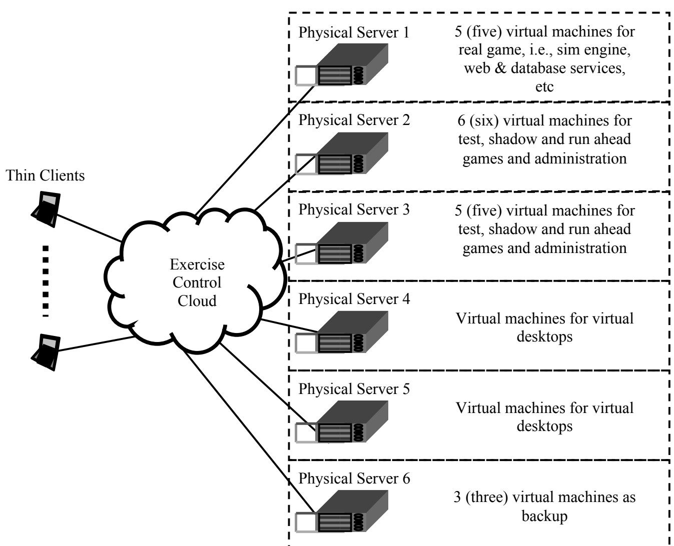


Figure 4. Virtualized simulation services during a CAX

The virtualized architecture used during the exercise is depicted in Figure 4. We used 6 servers each with 32 GB of RAM and 1 TB of HD in this architecture. One of these servers was for backup. Three of the servers were for the simulation server processes. The other two servers were for virtual desktops. VMWare ESX was used for server virtualization and VMWare View was used for desktop virtualization. We also used 27 thin clients to provide the end users with CAX services. Each virtual machine for end users were dedicated 3 GB of RAM in our server pool. In conventional architecture, i.e., not virtualized, we use 11 powerful servers with 16 GB of RAM and 512 GB of HD in the average, and 27 powerful PCs.

After the exercise we recommended to increase the number of servers from 6 to 8, and use one of the additional servers as virtualized data center. Please note that five server architecture is already providing the required level of performance as shown in Figures 6-9. Additional servers are for further improving the performance and providing redundancy for fault tolerance.

Figures 5-8 give the hourly averages of memory and CPU utilization for servers day by day throughout the exercise. Some parts of the graphs indicates 0% utilization. Those parts of plots are for night, when the exercise stopped, and therefore servers were not utilized.

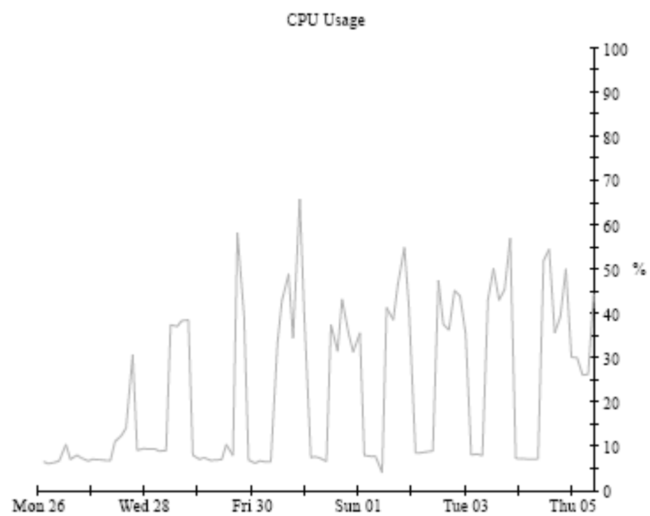


Figure 5. CPU utilization of one of the servers used for VMWare ESX

When the exercise was running, the CPU utilization of servers for CAX services was typically around 40%. The utilization was never close to 100%. The CPU utilization was flat, i.e., not bursty and in 35-55% band. On the other hand, the memory utilization was always above 85%. Still it never became over 95%. We can conclude that three powerful servers were sufficient to run the CAX servers comfortably.

The utilization of servers for virtualized clients was different from the utilization of servers for virtualized servers as shown in Figures 7 and 8. The load created by virtualized clients was burstier. The utilization was sometimes close to 100% both for CPU and memory. Still it very seldom became a bottleneck and for only short time periods. Moreover, the users could hardly notice that.

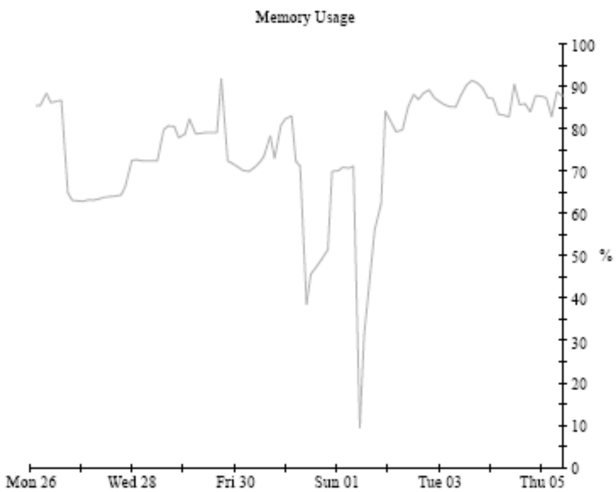


Figure 6. Memory utilization of one of the servers used for VMWare ESX

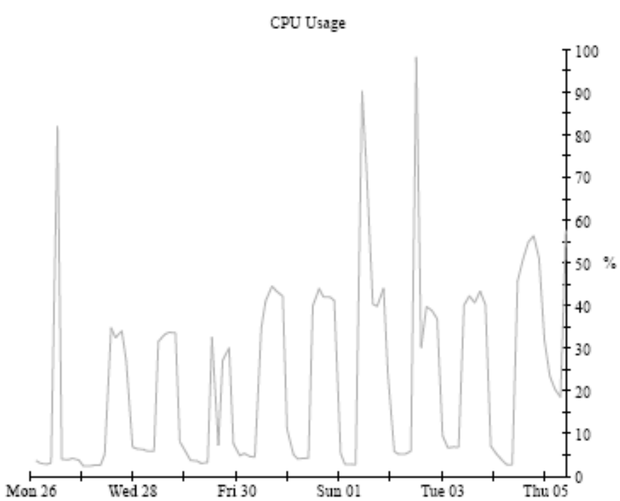


Figure 7. CPU utilization of one of the servers used for VMWare View

Our tests show that virtualization is practical and more cost effective for distributed simulation environment. We also investigated the results of the intercloud approach for distributed simulation. There are important parameters that depend on the location of a service (i.e., software and platform), such as the time required starting a federation and the capability of federation to keep up with real time. These metrics is mostly related to the quality of service (QoS) parameters (i.e., delay, jitter, throughput and reliability) and especially delay as shown in Figure 9. Therefore, we designed also an algorithm that dynamically assigns the platforms and services to clouds within an intercloud based on the number of entities registered by a simulation and the delay in transferring a registration message among the clouds. Due to space considerations we cannot elaborate this algorithm in this paper. However, we can conclude that intercloud approach can improve the performance of distributed simulation because the intercloud approach allows selecting and migrating the platforms and software within intercloud based on the QoS parameters.

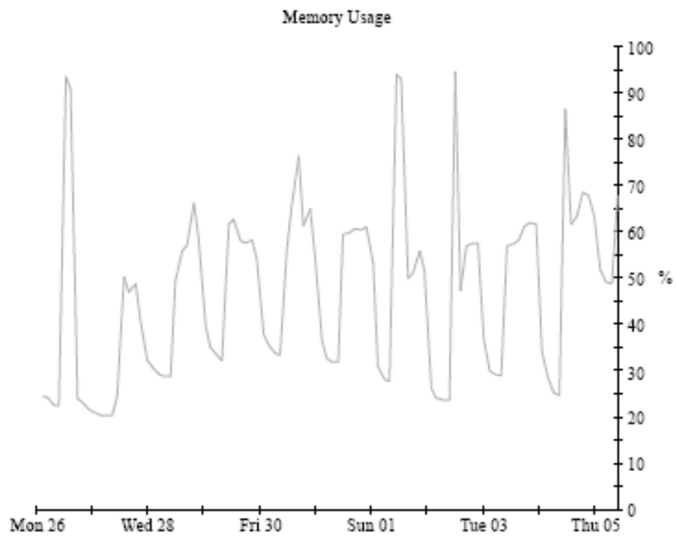


Figure 8. Memory utilization of one of the servers used for VMWare View

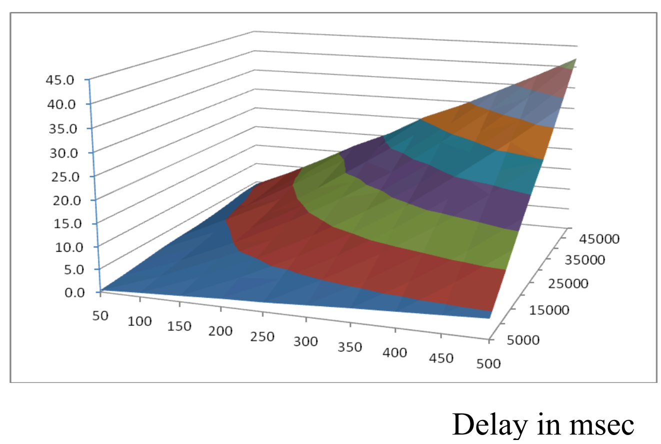


Figure 9. Time in minutes to start a federation

In Figure 9, one of the horizontal axes gives the number of entities registered by a simulation and the other gives the average delay between the simulation and RTI. The vertical axis is the time in minutes to start a federation of two simulations if another simulation subscribes for all the entities registered. We assume that there is no delay between the second simulation and RTI. When there are

50000 entities to register and 500 msec delay between the simulation that registers the entities and RTI, it takes more than half an hour to start this federation. Therefore, if we can locate the simulations that register or subscribe for higher number of entities into clouds which has lower delay for the cloud where the RTI is, we can improve the performance of the federation. This is possible when we can migrate the simulations inter cloud.

5. CONCLUSION AND FUTURE WORK

NETN aims to deliver a persistent network that consists of ADL, shared scenarios and live, virtual, constructive simulation capabilities. MSG-068 NETN TG developed standards and recommendations for the future NETN. Technical recommendations are completed and tested. Virtualization is also tested for NETN during large military exercises. Our tests and experimentations show that a cloud approach is viable and advantageous for large scale experimentation and training architectures. Moreover, if inter cloud collaboration and management is available the performance of distributed simulations can be improved further.

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