Simulation-based Command and Control Applications in a Service-Oriented, Cloud Computing Environment

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Abstract: *Modeling and Simulation (M&S) technologies have matured suitably to provide real time tactical utility to warfighting Command and Control (C2) computer system users, but C2 systems adoption of M&S in their native applications has been slow for design, acceptance, computing and procurement reasons. While extensive work has been done with simulation based planning, execution monitoring, logistics, visualization, data fusion, intelligence analysis, training, and hazard prediction these simulation-based applications generally have at best been linked to C2 systems, and usually exist as standalone systems. This separation from active C2 system databases and networks has kept them out of the tactical, time sensitive environment. Another consideration is the lack of locally available computing power in the austere tactical environment. The Service Oriented Architecture (SOA) in the U. S. Global Information Grid (GIG) and can breathe new life into these C2 oriented simulation-based applications as they are re-configured as service-based C2 Community of Interest (COI) enterprise services. These SOA-based C2 capabilities would support common C2 tasks in C2 COI sub-domains such as: planning, hazard analysis, execution monitoring, course of action analysis, visualization and training. The enabling of more sophisticated C2 services and applications by a cloud-computing local tactical architecture is also discussed. This paper examines the command and control process, C2 system design and use, these classes of simulation-based applications, and details the process of configuring of that simulation-based tactical mission capability into a C2 service, integrated via common SOA enterprise services and infrastructure to the warfighter user. Some lessons learned from previous embedded and federated simulations with C2systems will be discussed, as well as commercial analogs of these proposed GIG capabilities in operation on the Internet today.*

1. Background

Command and Control (C2) computer Information Technology (IT) systems (hereafter referred to here as "C2 systems") have evolved from their inception as essentially electronic “maps” displaying geographical position of known “friendly”, “unfriendly”, and “unknown” units and platforms (“tracks”) for a specific purpose (e.g. “surface”, “ground, “air” plot) to complex systems integrating into this electronic map; logistics, intelligence, planning, and other sorts of geospatial data. This geospatial integration of information into a map format is a natural, intuitive way for decision makers to see a summary of information with the all important element of force disposition preserved in the display.

This information combines in the C2 user’s cognition to become an informed awareness of the activities in the theater of action the user is interested in. Often called “situational awareness”, the informed user relies on his or her C2 system presentation of the operational area to help shape that awareness by relying on the computer systems:

- timeliness and accuracy of information presented,
- ability to transform “raw” information into information entities that convey meaning,
- ability to “distill” large amounts of information into smaller, more manageable units,
- and, information presentation that relays the important information, in an easily understood manner.

When that situational awareness, provided by a C2 system to the C2 user, becomes actionable for a decision making or warfighting purpose, then the C2 system has become a key part of the military command and control cycle: Observe, Orient, Decide, Act (OODA), a process as old as warfare itself. (see Figure 1)

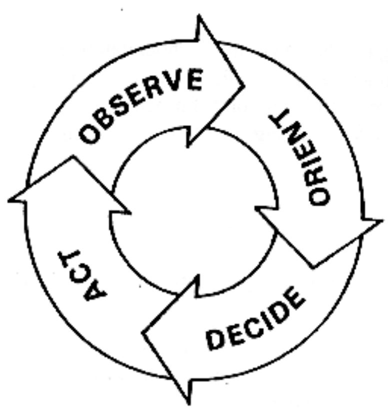

Figure 1: The OODA Command and Control Process

2. Command and Control

No single activity in military operations is more important than command and control. While it does not physically accomplish military objectives (military forces are required for that function), without effective command and control, campaigns, battles, and organized engagements are impossible, military units degenerate into mobs, and effective military force is replaced by random violence. In short, command and control is essential to all military operations and activities.

Command and control is the means by which a commander recognizes what needs to be done and sees to it that appropriate actions are taken. Sometimes this recognition takes the form of a conscious command decision; as in deciding on a concept of operations. Sometimes it takes the form of a preconditioned reaction; as in immediate-action drills, practiced in advance so that they can be executed reflexively in a moment of crisis. Sometimes it takes the form of a rules-based procedure; as in the reaction to radar detection by an enemy strike force. Some types of command and control must occur so quickly and precisely that they can be accomplished only by computer systems such as the command and control of aircraft in flight. Other forms may require such a degree of judgment and intuition that they can be performed only by skilled, experienced people (e.g. devising tactics, operations, and strategies).

Some forms of command and control are primarily procedural or technical in nature; such as the control of air traffic and air space, the coordination of supporting arms, or the fire control of a weapons system. Others deal with the overall conduct of military actions, on a large or small scale, and involve formulating concepts, deploying forces, allocating resources, supervising, and planning. [1]

Much has been written about military command and control process, theory, practice and implementation. Often in an analysis of how a military operation went wrong or right, military command and control is cited as either the culprit in a disaster or the key enabler in a successful outcome. As military command and control is a combination of people in key military roles; collectors of information, people and machines to process that information and display it, and human decision-makers who act on the information gathered and displayed for their cognition, there is plenty of blame to go around when things go wrong. The military command and control process is unforgiving, if any one part fails the results up the decision chain will be flawed and the wrong decisions can be made at the wrong time with disastrous results.

3. The Operational Picture

A key component of command and control, from the earliest origins of warfare is the “operational picture” This picture, based on a geospatial “map” representation of where own forces are and where enemy process are thought to be, is a geospatial representation of the tactical situation. A key attribute of both own, and enemy forces is their geographical position relative to each other. It is the single most important attribute, as it implies intent and threat or lack thereof. When augmented by strength and combat power estimates (e.g. numbers of soldiers, type of weaponry etc) this operational picture becomes the single most important tool in producing Situational Awareness (SA) for the commanders and other force decision makers

In ancient times there might have been Alexander, Hannibal or Caesar sketching their own, and enemy positions in the dirt with their generals before the battle started to help formulate maneuver strategy. For example, using the operational picture as a tool might be how Hannibal was able to so expertly position his forces before and during the battle at Cannae in the second Punic War, and annihilate the Romans despite their superior numbers. This is because a commander organizes military dispositions and strategy into a mental geospatial time based mental tableau, and history is full of stories of generals “dreaming” their strategy before a major battle. The operational picture is an extension of a natural way of thinking of battlefield events, and maps are a very important component, as are tallies or descriptions of unit numbers, capabilities, and intent if known.

The operational picture was driven for centuries by reports of spies, reconnaissance patrols, messengers and the like to create a perception of own and enemy force disposition and strength. This, while very time late, was the best technology could offer. In the 19th century however, airborne sensors (balloon observers) extended the “eyes” of the commander to contribute to the operational picture. In the early 20th, first the dirigible and airplane provided a greatly enhanced airborne sensor for the operational picture, then radar and other electronic sensors became capable of building perceptions of the battlefield “over the horizon”.

These "over-the-horizon" views of the operational picture became crucial as the fast moving airplane became the strike weapon of choice in the mid 20th century. As the ability to see more area in the operational picture became available, information systems became needed to process that information and display it in a timely manner for decision making processes, as air warfare and it’s speeds of hundreds of miles an hour compressed reaction times an order of magnitude from the speeds of maneuver on the ground and water. This in turn fueled the need for better and more accurate sensors, coupled to a faster reporting network, and optimum display tools.

In the late 1960’s manual plotting and display techniques gave way to modern computer C2 systems that automated much of the data processing and display to speed reaction time to fast moving air threats. These C2 systems at first relied on a local relative “tactical” picture, then evolved into large area geographic displays with integrated contact and report information for cooperative networks of reporting sensors and units spanning the globe.

For the purposes of this discussion, we will focus on C2 systems that are oriented toward presenting the “big picture” to commanders and decision makers. This over-the-horizon C2 operational picture was a major step forward enabling long distance strike warfare when introduced in the 1980’s. In following the classic operational picture geospatial paradigm and mimicking the human brain’s methodology in processing such information, much relevant information can be displayed as attributes of a geographic position. Alternate methods of integrating information other than a traditional geospatial “track” (force positions over time) into a C2 “operational picture” are possible by utilizing web portal types of presentations, but much like the Internet itself, portals tend to lead the user into an information environment centered around the functional purpose of the portal. If they are not integrated with the top level operational picture, portals can be just meaningless database queries when viewed out of the operational context in which they were made.

A more appropriate method of conveying mission critical information to the commander in the modern battlefield is not to increase the volume of information as has been the trend in the last 20 years, but to tailor that information to the role of the C2 user, and present it in a way that makes cognitive sense to the user. This should result in a high probability that the C2 user and decision-maker, working in a dynamic, stressful, environment with very short cycle times in the pace of modern warfare, will obtain the critical information, make cognitive sense of it, and be able to use it to perform a critical action or assist in a critical decision making process.

This requires a holistic view of the command and control process, that chain of information from sensor, through networks, via computational processing, to the end result of this process, the action or decision made by the commander.

4. Operational Picture Redefined

While a track-based operational picture is very useful, modern warfare requires, and technological advances offer, the capability to show different types of information in different domains for the commander, as well as fusing and correlating that information, (often from disparate sources), into understandable entities. The information-rich modern C2 system operational picture will utilize models or simulations to present synthetic views of that information, much in the same way modern radar presents processed video vice “raw” electromagnetic returns. When configured as adaptive views of the operational picture, models and simulations can enable cogent situational awareness of information beyond human cognition in that data’s raw state.

An example could be an embedded electromagnetic propagation simulation that processes electronic sensor performance, atmospheric conditions, and terrain features, to produce a three dimensional picture of sensor coverage around own forces in an operational picture format showing own force vulnerabilities in real-time. While these types of enhanced information processing have been available in stand-alone computer systems, their tactical use has been limited due to the lack of real-time integration with C2 systems.

A commander and/or subordinates need the ability to be informed of the tactical, operational, and strategic situation by information presented to all participating users simultaneously and in a geospatial or other appropriate format for easy cognition. These “views” of information can be tailored and based on the user’s role, mission objectives, and security constraints. When all users have the same fused “view” of the battlespace and the applications to interpret the data provided to them, they have attained shared situational understanding.

C2 IT capabilities (hereafter referred to in this paper as "applications") must be available to all users and distributed in the operating environment to enable the goal of a shared geospatial operational picture and supporting data presented in a cognitive format tailored to the user’s mission. C2 applications should fuse, present, and make sense of data to help users understand the different perceptions of the battlespace from various “sides” (i.e. friendly, un-friendly, non-combatant, etc.). These basic requirements for enhanced information processing in C2 systems dictate the development of processes for the use of models and simulations with tactical C2 via a new paradigm; “net-centricity”.

5. Net-Centric Warfare

The concept of network centric (net-centric) warfare was introduced to the U.S. Department of Defense (DoD) by David Alberts, Vice Admiral Art Cebrowski, and John Gartska in a series of articles and books beginning in the late 1990s. [2],[3]. Now commonly referred to as Network-Centric operations and warfare, it is a theory of war in the information age that seeks to translate an information advantage into a competitive warfighting advantage through the robust networking of well informed, and geographically dispersed forces allowing new forms of organizational behavior. This "networking" without the vertical hierarchical boundaries that mimic the doctrinal “Chain of Command” present in legacy C2 systems, utilizes information technology via a robust network to allow increased information sharing, collaboration, and shared situational awareness, which theoretically allows greater self-synchronization, speed of command, and mission effectiveness. This sharing occurs among elements “horizontally”, as well as “vertically” in structured, peer to peer, and ad-hoc arrangements as mission requirements and doctrine permit. Net-Centricity has three basic tenants:

- A robustly networked force improves information sharing.
- Information sharing enhances the quality of information and shared situational awareness.
- Shared situational awareness enables collaboration and self-synchronization, and enhances sustainability and speed of command.

Collectively these attributes dramatically increase military mission effectiveness.

In this information rich environment military forces and mission partners must have rapid access to relevant, accurate, and timely information. They also need the ability to create and share the knowledge required to make superior decisions in an assured environment amid unprecedented quantities of operational data.

The difficulty in achieving such a net-centric environment lies in two critical areas: knowledge management among humans, and technical connectivity and interoperability. Knowledge Management (KM) is the process of discovering, selecting, organizing, distilling, sharing, developing and using information to improve operational effectiveness. To achieve effective KM, there needs to be a shift from a "need to know" orientation to a "need to share" one, supporting dynamic organizational constructs and decentralized decision-making in a fluid environment.

The second critical area is technical connectivity and interoperability, two key enablers of net-centricity. Net-centric operations require a seamless sharing of required information and knowledge through an assured, protected network. Likewise, Intelligence, Surveillance and Reconnaissance (ISR) platforms ("sensors") and weapon systems need to be included in that network. This vision of a fully net-centric force in the U.S. DoD is referred to as the Net-Centric Operations Environment (NCOE). [4]

The U.S. DoD vision of net-centric warfare targets a Service-Oriented Architecture (SOA) model and associated extensive use of XML and other web service standards as per current commercial practice in the Internet today. [5]

6. SOA and Net-Centricity

Component-based software engineering is one method of providing net-centric capabilities. Component-based software engineering provides both a methodology and a process for developing software components that are self-describing, conform to a component model, and can be independently deployed and composed without modification according to a composition standard. These components follow a general component model for the architecture in which they are deployed, and are searchable, discoverable, and cataloged much the same way that data are described and behave in an enterprise data strategy and implementation. This distributed software functionality in a C2 system architecture allows the ability to "compose" a user capability (at time of use or predefined) out of software components located in parts of the architecture and from various functional groups or Communities of Interest (COI).

Composability is the ability to select and assemble those software services (i.e., components) in combination to satisfy a specific user functional requirement. This selection of services can be accomplished by the user at execution or predefined by the system developer in templates for a particular use, and incorporating doctrinal or policy constraints if desired. When these services are distributed throughout a software architecture, platform- and host-independent, loosely coupled (vice required to conform to a type system), and dependent on messaging or pre-defined schema to compose their integration at invocation, a SOA has been achieved.

Perhaps the most important difference between service orientation and object orientation is the way software integration is achieved. The concept of shared software components is fundamental to object orientated approaches; this is the case, for example, in the legacy U.S. Defense Information Infrastructure Common Operating Environment (DII COE). In general, a hierarchy of interfaces has to be agreed upon before software components can be integrated.

In contrast, service orientation allows services and their consumers to achieve integration through the exchange of messages or exercising a predefined schema. The only thing that is shared between them is the vocabularies used to define the structure of those messages, which (in the case of web services) are XML, and XML schema. The absence of a predefined type system enables loose coupling because no additional information needs to be shared among services and consumers prior to implementation and deployment.

A SOA supports net-centricity by providing a flexible, agile, composable, and platform and application independent manner of providing the operational picture and application functionality to the C2 user in a distributed, location independent delivery paradigm. Utilizing commercial practice; grid capabilities and a SOA implementation such as Web Services, and their lessons learned in design, acquisition, and deployment, the possibility exists to have diverse sets of developers in multiple C2 and modeling and simulation acquisition programs build toward a common interoperability, integration, and distributed functionality standard. [6],[7]. This could deliver to the DoD GIG for all operational users the desirable capabilities of High Level Architecture (HLA) federations.

7. C2 Service–Based Applications in a SOA

In a SOA environment, service-based C2 applications will provide flexible, scalable, platform independent mission essential functionality to C2 users, decision-makers, and commanders while deployed over large geographic distances, utilizing core enterprise services.

Service-based applications can be the user interface and supporting COI functionality available to the operational C2 user for a specific functional purpose. These COIs in the context of C2 could be natural functional communities such as: planning, meteorology, intelligence, logistics, etc., and the C2 COI itself could host service based applications for its basic functions that currently are imbedded in platform-based C2 systems.

These can be locally available (within the local network) or a WAN-based SOA services that interface directly with C2 decision makers and commanders for mission-specific tasks or processes. In each COI there could be application functionality provided to the operational user in a platform- or location-independent manner, via enterprise networks and services, with provisions for low-bandwidth or disconnected operations.

Service-based applications will enable the U. S. DoD and its mission partners to understand the tactical and strategic situation, plan and execute faster than the enemy, and seize operational and tactical opportunities.

Service-based C2 applications as envisioned in the NCOE will provide assured mission functionality by:

- Customizing the discovery, access, fusion, processing, and display of tailored information based on mission objectives and the role of the individual.
- Providing collaborative tools for dynamic planning and execution that leverage enhanced situational awareness of the battlespace, smart decision tools, machine-to-machine interfaces, and shared knowledge.
- Optimizing the ability of warfighters to share situational understanding, including the ability to quickly assess the situation and alternative courses of action.
- Supporting adaptive, distributed, cooperative, and collaborative decision-making.
- Allowing application-to-application interchange when time-sensitivity precludes access of centralized network resources.

This can be accomplished by removing doctrinal and architectural constraints from the information, network, and computing domains, enabling “point of use” applications where needed, not prescribed. Service Level Agreements (SLAs) negotiated and published in schema can enable the efficient and properly attributed exchange of data and functionality between C2 and COIs. This inherent flexibility will support asymmetrical warfare and will allow for changing doctrine, as well as providing role-based access to C2 and associated COI application capability for users regardless of their geographical location.

Service-based applications for C2 in a NCOE must be scalable, platform-independent, distributable, and able to use non-deployed databases and computing resources. They must be able to provide complex analysis and multiple courses of action, and simulate complex processes that directly support operations (e.g., logistics movement and support into and in-theater, Weapons of Mass Destruction (WMD) prediction and analysis, etc.). These types of advanced applications required for NCOE capability needs will utilize models and simulations at their core. By configuration of these models and simulations, and other application capabilities as services in an SOA, supported by a robust and scalable communications backbone, and utilizing data provided and indexed by core services, these service-based applications can provide the NCOE envisioned, net-centric C2 warfighting capability.

8. C2 and Modeling and Simulation Integration Approaches

Any discussion of how we wish to utilize models and simulations in C2 service-based applications should discuss the current state of practice, and where we wish to go.

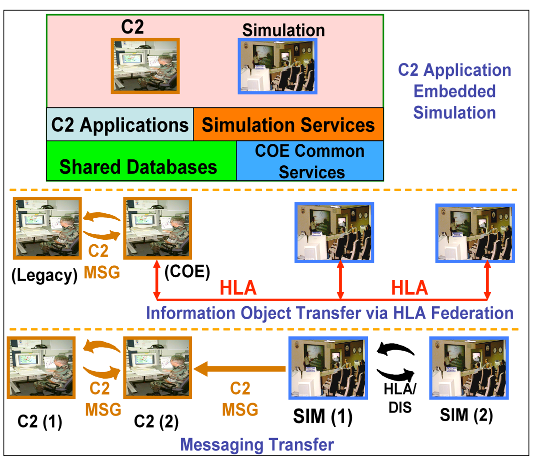

Figure 2: C2-Simulation Interoperability

8.1 Legacy Message-based Interfaces

A basic legacy interface between an external simulation and C2 system is shown in the bottom frame of Figure 2. Messages are constructed within the simulations to be identical to the message formats of the specific C2 system. In essence, the simulation mimics another C2 system.

This interface approach views a C2 system as a "black box" and makes a tacit assumption that legacy C2 systems cannot be modified to accommodate the input of simulated data other than native messages. The advantage is that it provides a simulation interface without requiring changes to the C2 system. For many applications though, there are severe limitations to relying on messages to pass simulated data. First, this approach is constrained to the limited sets of data supported by native C2 message formats. Second, the interface generally consists of one-way stimulation of the C2 system. Third, the C2 systems generally cannot function on an operational C2 network, but have to run off-line.

8.2 C4I Federates within HLA Federations

An evolution toward more robust interoperability has been achieved by integrating the HLA within a DII COE compliant C2 system. The approach, shown in the middle frame of Figure 2, allows the C2 system to be a participant (i.e., federate) within an HLA Federation. [8]

This interoperability method provides a simulation access to internal C4I functions and data not reachable by messages, such as the ability to interface with specific workstations and applications within an operational LAN. It also allows the simulation to use the display and application features of the C2 system.

C2 systems on the other hand, have access to computationally intensive simulations that could not reside on the C2 system platform. This arrangement also has the advantage of enabling "reachback" to a COI for a specific analysis or product.

8.3 Embedded Simulations

The third evolutionary step toward C2 use with simulations is shown in the top frame of Figure 2, embedding models and simulations into the applications of C2 systems The U.S. Navy Embedded Simulation Infrastructure (ESI) effort in the DII COE developed simulation services and object oriented interfaces between the DII COE C2 system architecture and embedded simulations within DII COE C2 applications. This allows the C2 system to harness the power of simulations in self contained applications. The difficulty in this approach is the effort and expense of developing new, monolithic applications for C2 systems, absence of a federation capability in C2 architectures (for "reachback" and distributed functionality), and C2 architectures of which have never been fully standardized despite the DII COE mandates and efforts.

8.4 Service-Based Applications utilizing Models and Simulations

The next evolutionary step is to combine the best practices of C2 interoperability and simulation HLA federation, and the ESI approach to building simulations directly into C2 applications. If we configure simulations themselves as SOA services or embed them in functional service-based applications, we harness all the power of embedded simulations, the ability to "reachback" to COI federated resources, data and computing power, as well as utilize the SOA SLAs and schema to allow integration of those simulations and simulation-based applications among a wide variety of COI's and C2 systems compliant with our SOA as shown in Figure 3. Such is the overall vision for transformational, net-centric C2 capability developments in the DoD GIG.

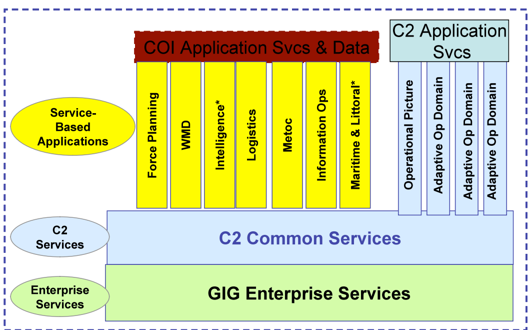

Figure 3: C2 Service-based Applications in a SOA

9. The need for Simulation based C2 Service-Based Applications

Forward looking concepts for U. S. C2 use in modern net-centric operations and warfare (e.g. Navy ForceNet, Air Force C2 Constellation, Army LandWarNet, Marine Corps MAGTF C2, C2 and Joint Staff concepts) [9] rely on accurate, ubiquitous, and timely access to C2 information and data.

Specifically, net-centric data sharing and C2 capabilities with advanced operational services will require that sensor data and other streams of non-textual data be available in their raw state. Powerful models and simulations must therefore be integrated into these C2 services to process this data and make it relevant to the tactical situation (tactical relevance is directly proportional to timeliness).

For instance, we wish to have access to all intelligence sensor and report data in a particular theater before analysis and dissemination as per normal doctrine. This is so we can, in a timely manner, pick and choose information of tactical relevance from that pool of "raw" data. However, just finding the relevant data in this "data overload" situation is daunting, much less retrieving and displaying it in time to be tactically significant or useful. (Excessively "time-late" data while interesting, is not tactically useful for decision-making.) Thus, we would need tuned 'sensemaking" simulation powered service-based applications to assist us in making "sense" of this seeming random "bucket of bits".

Other examples such as visualization of electromagnetic sensor coverage or Weapons of Mass Destruction (WMD) events and hazard prediction require Modeling and Simulation (M&S)-based functionality. C2 planning services have inherent requirements for M&S-based "engines" to produce meaningful planning scenarios, and to exercise them against relevant operational planning constraints in order to select the optimum plan. Similarly, such C2 capabilities as training, decision support, and Course of Action (COA) analysis require an integral M&S capability in their C2 services.

These C2 advanced capabilities require the utilization of information in varying time bases and the mixing of constructive M&S based and "real" C2 data in operational C2 systems. C2 tools and services will require a high level fusion capability to discriminate, separate, and integrate, data and information of real, virtual and constructive pedigree.

Specifically, the U.S. DoD NECC capability requirements imply the use of models and simulations as core engines of advanced NECC services for planning, visualization, decision support, sensemaking, COA analysis and training.

How those service-based applications are presented to the C2 user, and help him or her perform their function is also of utmost importance. In keeping with the overall C2 organizing paradigm of the "operational picture" a new construct is required for that information outside the traditional geospatial map-type track information This points to the development of new methods to process and display information beyond mere positions of "tracks". Situational awareness beyond the attribution of information into sets of data specific to a geographic location is the next step; "Adaptive C2 Operational Domains".

10. Adaptive C2 Operational Domains

One needs to look beyond the paradigm of the electronic map and think about the integration of mission critical information into an operational picture representing something other than entity geo-location over time. There is a need to analyze different facets of an operational situation or plan, visualize complex phenomena, or put organization to seemingly disparate data in the context of the operational situation for rapid human cognition.

For example, these other "operational domain" facets could include a superposition over a 2-D operational picture map of a schematic diagram of communications networks between sites and their current and projected operational loading. This would assist in both operational control of that network, and in situational awareness of the commander to his/her underlying command structure vulnerability due to network loading.
Decisions could be supported by this "Network Operational Picture" prompting the commander to problems, and alternative network routing or loading schemes reducing vulnerabilities.

Similarly, a 3-D geospatial view of the radar electromagnetic space surrounding a force, with platforms, sensors, terrain, and atmospheric conditions provided from the appropriate COI's, would provide the commander valuable insight for force defense if integrated real-time into the operational picture.

A broader "Electromagnetic Operational Picture" could provide situational awareness of own force vulnerabilities (i.e., detection versus counter detection for various emission control conditions, jamming effectiveness, etc.) to support decisions in strike planning against enemy targets and protection from hostile force activities.

Other adaptive operational domains could include: the acoustic domain, the WMD domain, the information operations domain, the logistics domain, etc. In all these cases M&S is at the core to produce information relevant to these domains from raw COI data and provide the resulting situational awareness and decision support in the C2 operational picture.

10.1 Decision Support Requirements

A key element of tactical decision support in operational C2 is timeliness and access to tactical information. Deliberative planning and analysis may not require real time access to C2 information or need to integrate with other COI applications. However, in order for decision support to serve the commander in tactical situations, timeliness requires a close coupling with the C2 and applicable COI data.

Tactical decision support can have many different flavors, from "what if" types of COA analysis, to a commander's inference from the insight of good situational awareness. Simulation based applications have traditionally been used in decision support in a "what if" war-gaming type of analysis. While this can be operationally useful, it is also subject to debate on validity of results. Using a model or simulation to provide a visualization or capability where there currently is none, is the easier route to acceptance.

Integrating a M&S capability with a C2 service-based application can help with the timeliness and tactical relevance but not with the validation of subjective results. Far more fertile for rapid adoption in C4I systems are deterministic models or simulations that can produce unambiguous results.

Adaptable C2 operational domains, utilizing deterministic simulations, can provide the commander valuable insight and information for decision based upon validated results. For instance; a C2 service-based application (based on a well validated simulation) that produces a time projected representation of a potential chemical contamination "cloud" and inserts it into the operational picture to interact with force positions and planned movements. This would be immediately tactically useful for force protection, operations planning, and maneuver control.

Other advanced C2 functionality based on models and simulations might assist the C2 user with "sensemaking" of the large volumes of data available in a net-centric environment. Such applications might search the data-sharing network for pertinent data to the C2 users current activity or priorities, find and process that data into human recognizable entities, and display those entities appropriately in an adaptive operational domain view of the overall geospatial operational picture

12. Managing Simulated Data in C2

The use, distribution, safeguards, and identification of simulated data within an operational C2 system has been the subject of much research and study. For the purposes of this discussion, simulated data refers to data similar to actual C2 or COI data; but produced by a simulation. It could also be real C2 data with a non-real-time base (i.e. archived data). In any event, the challenges of managing this data and presenting it to the user are the same.

The introduction of simulated data presents problems for the operator and C2 system in both the perception of the simulated data vis-à-vis real world data, and its interaction or relevance with data of a real nature or differing time base. This simulated data requires special handling and presentation in order to maintain cognitive linkage to, but distinction from, the current real world situation.

Methods and software incorporated in the DII COE ESI services already within the GCCS and GCCS/M have been used to routinely insert simulated data into operational C2 capabilities. These functions and interface links can be adapted and expanded to operate with service-based C2 applications.

12.1 Flexible Time Bases and Management

The C2 system must accommodate a simulation or model that operates in a time base different from the C2 system real-time. This leads to a requirement for the C2 system to be time agile and dynamically adjust it's time reference to the changing time base of a simulation running at faster or slower than real-time. This dynamic time reference shift from real-time is necessary for a simulation to do an operationally significant job. Some examples are:

- Projecting operations into the future for planning purposes or analyzing potential courses of action.
- Adaptive Operational Domains that influence the tactical situation. (e.g.: radar coverage, acoustic conditions, WMD effects, information operations etc.) These may require the simulation to operate faster or slower than real-time.
- A combination of both such as simulating a WMD event and time projections in the future to plan evasive action.

Obviously, a mechanism must be available in the C2 system to handle this dynamic time base, and to cue the user as to which time base is in effect. We need to allow various time bases to coexist, as long as the situational awareness safeguards are in place to distinguish that time base. Again, as we utilize the inherent benefits of an SOA and its schema, this capability should be enhanced.

In a properly designed C2 service-based application, a simulation engine must operate at any time base/ratio required quite independent from the C2 system time base during normal operations. The key "devil in the details" is how that resultant information is displayed, and how the input information is processed and handled. The U.S. DII COE ESI services are a clear example of how this could be accomplished in a net-centric C2 environment.

12.2 Protecting Normal Operations

When operating a simulation within an operational C2 system for training or other purposes involving simulated operational data, the entire C2 network must be protected from the inadvertent corruption of real-world operational data.

In order to use simulated data within an operational C2 network, a system to safeguard and "quarantine" the simulated data must be devised. The absence of such a C2 capability has limited operational use and confidence with simulation activity on "live" C2 networks to date.

Again, by building on past experience with these issues in the development and fielding of non-real-time simulation-based C2 applications, and utilizing the inherent advantages of an SOA and it's schema, methods for safely inserting some classes of simulated data into operational C2 networks can be accomplished. However, this is an area that will require considerable operational testing and validation before it can be routinely exercised.

13. Cloud-Computing Architectures

A major challenge is to implement the next generation of C2 Service-based applications, especially computationally intensive M&S-based decision support applications. These require a flexible and dynamic infrastructure to make these capabilities widely available to dispersed users, while supporting their critical mission needs at locations often far from well-resourced enterprise facilities. This requires a rethinking of how data, applications and services, and their supporting infrastructure and security are provided and managed in the information environment, as a continuum rather than discrete elements. Furthermore, it requires a fresh perspective and approach to support for applications, data, and services in the C2 computing environment, with no seams between the sustaining enterprise base and the tactical environment. Current evolving technology and common parlance calls this computing continuum a "cloud". A cloud computing environment consists of applications, data and services, and their supporting hosting infrastructure and security, bundled together as a service; where all these elements work together and transparently to the user in meeting operational user capability needs.

Computing in the 21st century is more than just the hardware box and software on the desktop, and the server supporting it. It is the dynamically agile way of providing IT capability to the user that is in excess of what is locally possible, with a user-transparent means of delivering it. The virtual "cloud" that the user connects with will provide shared, virtualized, computing resources that enable meeting peak transient computing demand through prioritization by need; and content delivery technology that moves enterprise IT capabilities closer to the user. This kind of computing appears to the end users or applications as one large, virtual computing capability or cloud. This transformation of computing recourses; from infrastructure, data, and services tied to specific systems and applications, to a shared computing cloud that directly supports a SOA, is enabled by virtualization and a utility-type cloud paradigm for infrastructure.

As the commercial internet goes to a cloud computing model to support advanced applications and services for the commerce and operation of industry, for military C2 functionality we should leverage those advances as much as possible to help us in day to day military operations. Both a seamless extension of enterprise administration, logistics, and other combat support capabilities to the tactical environment would be operationally significant, but also the development of a local, "tactical cloud" would advance service-based C2 applications previously not practical in the tactical, low and intermittent bandwidth environment.

13.1 The Tactical Cloud

Tactical computing environments must dynamically share computing capabilities to support proccessesing intensive, distributed services and applications that bring predictive warfighting and analysis, Intelligence, and other M&S tools directly to the operational user. Tactical users will need fused data from shared data, and net-centric services and applications to support them will require proccessesing power closer and closer to the tactical user to be operationally effective, and support real-time operations. This clearly requires a dynamically sharable cloud computing infrastructure.

Tactical clouds can also help with SOA and legacy C2 system use and operation by providing a virtualized hosting environment that scales, depending on C2 system usage and priority. Combat support applications and services can be hosted in the cloud, and be subject to prioritization of resources to allow additional computing capacity in the local tactical environment to respond to emergent needs. Far from a simple efficiency construct, a local tactical cloud would enable computing resource intensive M&S based decision support applications and services to be hosted and utilized on demand.

A tactical cloud would not have to be connected robustly or continuously to the larger enterprise IT environment. Rather, in the tactical environment itself, it would optimize modular computing resources, C2 hardware and data links, and local combat systems resources to obtain a C2 information rich, net-centric environment when disconnected from the enterprise.

Tactical cloud architectures would provide many benefits that would support simulation-based C2 applications, especially rapid, massive, scaleable computing capability on demand for M&S computing intensive applications as they are needed, real-time. They would also put the tactical focus on mission activities, and less on IT infrastructure with a reduced physical footprint, power requirements and logistics.

14. Summary

The technologies and concepts discussed in this paper are hardly unique to military C2 Commercially every day, we use in our Internet, an interoperable mix of SOA, legacy client-server applications, cloud computing, and a mix of architectures and platforms. For example, one can obtain a weather prediction map produced by a high performance "super" computer and delivered seamlessly to a handheld PDA through it's browser. There is no one mandated type system to accomplish that feat, just ubiquitous web services and a cloud infrastructure that make all these elements work together. They became interoperable because of a commercial need, and were done so with little cooperation and no central pool of funding or direction. In the military C2 functional area, we should surely be able to yield better results by utilizing the lessons learned from our commercial counterparts in implementing these revolutionary SOA and cloud technologies.

The approach advocated in this paper takes into account the advances in command and control theory and practice, U.S. DoD mandates to implement data sharing and net-centricity, and the need to accommodate the demands of net-centric concepts that will drive warfare well into the 21st century. To accommodate the capabilities required in the new generation of net-centric C2 systems, M&S functionality is required to be integrated in the routine, functional applications of C2. Adopting a service-based application approach will facilitate adoption of models and simulations integral to C2 services to provide advanced net-centric military warfighting capabilities.

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