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Authors: James B. Michael, Man-Tak Shing, Mitchell R. Perrett[*],
Joon H. Um[*]

Point of Contact: Man-Tak Shing

Name of Organization: Naval Postgraduate School

Complete Address:
Department of Computer Science, Naval Postgraduate School,
833 Dyer Road, Monterey, California, 93943-5118, USA

Telephone/Fax: 831-656-2634 / 831-656-2814
DSN 756-xxxx

Email: shing@nps.edu

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[*] Graduate students

Comparative Analysis of C2 Structures for the Battle Manager of a Global Ballistic Missile Defense System

James B. Michael, Man-Tak Shing, Mitchell R. Perrett and Joon H. Um
Computer Science Department
Naval Postgraduate School
833 Dyer Road, Monterey, CA 93943, USA
{bmichael, shing, mrperret, jhum}@nps.edu

Abstract

Global ballistic missile defense (BMD) is a new type of warfare that is characterized by its fast tempo and little force movement. Time budgets for executing kill-chain tasks during an engagement are highly constrained, making it necessary to rely on high degrees of automation of all aspects of decision-making except in cases in which a tracked object requires the attention of a human operator. This paper examines three C2 structures for BMD: (i) a hierarchical structure based on current organization, (ii) a compressed structure with one global commander and separate regional commanders, and (iii) a flattened chain of command in which all resources are allocated directly to a single commander. We develop simulation models for the three command structures using the OMNeT++ software, and compare their effect on the effectiveness of a BMD to engage threats based on the number of messages generated and processed among the nodes in the structure, and the threat processing time under three scenarios of increasing difficulty. Our results indicate that a compressed chain of command produces the fastest time, although the flattened chain of command produces the least amount of message passing.

1. Introduction

There is an urgent need for DoD to develop a global Ballistic Missile Defense System (BMDS) to protect the United States and its allies against multiple concurrent hostile missile attacks. The BMDS will provide a layered global defense against ballistic missiles of all classes (short-, medium-, and long-range). The BMDS is a system-of-systems made up of an amalgam of sensor networks, track databases, weapons systems, and command and control (C2) systems. The command and control/battle management of the BMDS is a core element of the system-of-systems; this element is called the Command and Control, Battle Management, and Communications (C2BMC) system. The C2BMC system is a globally distributed, real-time, software-intensive battle-management system that must exhibit highly predictable system-software behavior, in which the system receives sensor information from land, sea, air, and space, and commits land-, sea-, air-, and space-based weapons to fire at identified targets.

Global ballistic missile defense (BMD) is a new type of warfare that is characterized by its fast tempo and little force movement. Due to the speed of engagements, quantity of battle-related information, and complexity of the decision processing, all or which must adhere to strict time budgets for executing battle plans, it is necessary for battle commanders to rely on high degrees of automation of all aspects of decision-making except in cases in which a tracked object requires the attention of a human operator.

BMD does not easily fit into the traditional military molds. Future missile defense battles may involve simultaneous threats to be fought in multiple regions and theaters. The speed of engagements and amount of information to be processed necessitate weapons-target pairing, launch decisions, and engagement control to be performed locally, while the need to accomplish the global missile defense objectives requires system-wide coordination of threat engagement responsibilities and national resources among regional commanders in real-time. Moreover, a successful BMD engagement can involve resources that are owned by other commands and located outside of the region in which the battle is fought. Existing C2 structures need to be modernized to streamline the real-time coordination of battle responsibilities and engagement resources.

There are few instances of such a global battlespace control. The Nuclear Triad is one possible example of global centralized C2, but that organization has never had the numbers of elements that the BMDS will have. The use of Special Operations Forces (SOF) teams in the Global War on Terror (GWOT) is another possible example, but the SOF teams do not, generally, have interdependencies that extend more than the range of the longest artillery round or the longest standoff weapon. Therefore, the operation of the BMDS is deemed to be different than that of other forms of modern warfare; to that end, the application of a conceptual model is also different.

A key element in all aspects of a successful global missile defense battle is the conservation of time. Time is the most critical resource in missile defense and therefore each element of the system must be optimized to expend the minimum time possible. As each phase of the kill chain (detect, track, assign weapon, engage, assess kill) is examined to wring out wasted time within the automated systems moving the data, so too must the human decision process be examined for time-economy. Just as we seek the best system architecture, we must also seek the best C2 structure.

This paper examines three C2 structures for BMD: (i) a hierarchical structure based on current organization, (ii) a compressed structure with one global commander and separate regional commanders, and (iii) a flattened chain of command in which all resources are allocated directly to a single commander. Our study builds on two prior research effort conducted at the Naval Postgraduate School, the first of which proposes and compares three distinct command architectures [5] and the second providing a methodology for modeling message passing within components of the C2BMC [3]. We develop simulation models for the three structures using the OMNeT++ software [4], and compare their impact on the effectiveness of a BMD system to engage threats based on the number of messages generated and processed among the nodes in the structure, and the threat processing time under three scenarios of increasing difficulty.

The rest of the paper is organized as follows. Section 2 examines the information flow in a global missile defense battle and establishes a baseline for what information needs to be passed between the various components of the BMDS regardless of C2 structure. Section 3 presents a simulation model of the existing BMD C2 structure to identify its limitations. Section 4 presents the simulation models of two proposed BMD C2 structures designed to mitigate the limitations of the existing BMD C2 structure. Section 5 discusses the simulation results and Section 6 draws the conclusion.

2. Essential C2 Messaging Requirements for BMD

In order to model a C2 architecture, we must first determine what messages we expect to be passed between the components. Administrative messages may vary depending on the level of coordination and reporting criteria set forth by the commander. Connectivity messages (e.g., pings, weapons heath and status) are highly dependent on the network implementation and specific to the sensors, weapons and other technologies utilized in the system. Our primary interest is not on administrative or connectivity messages but instead to discover and fine-tune those messages that are tactically essential and must be passed between elements regardless of the C2 structure, commander's expectation, or network design.

Our evaluation of efficiency is, to some extent, dependent on how these messages are handled in each model. In other words, we want to determine which structure handles these messages most efficiently while avoiding redundancy, minimizing traffic volume, and increasing the overall speed of the process. The search for these essential messages leads us back to the kill chain. Although there are many different versions of the kill chain (one for each service and one expressed by the Joint Chiefs of Staff), we will use the one presented by Caffall [1] that incorporates aspects of each: *Plan*, *Find*, *Fix*, *Track*, *Target*, *Engage*, and *Assess*, because it captures each element of the BMD mission. After all, the overall goal of any C2 structure is to aid completion of these military tasks quickly and accurately. Our analysis resulted in the identification of the following essential message types:

1. Cueing Data
2. Sensor Tasking
3. Track Data
4. Weapon Assignment
5. Weapons Order Acknowledgement
6. Weapons Order Refusal (CAN'T CO)
7. Weapons/Sensor Pairing
8. Weapons inventory update (weapon fired)
9. Engagement Status (subordinate to senior)

By identifying the essential messages, we can eliminate unnecessary traffic; this task is as important as choosing the right C2 structure for BMD. Notice also that there are some messages one could expect to be listed under a typical C2 structure that are missing from our list.

Since planning will be conducted via a variety of means (e.g., e-mail, phone calls, conferences) and is conducted prior to battle, we will focus on the remaining set, the performance of which constitutes battle in the BMD context. We wish to see how a particular structure facilitates C2 functions during the battle itself when time constraints are most radical, not during preparations when they are less a factor. We also choose to eliminate the classic senior/subordinate interaction such as requests for permission/permission-granted messages. We argue that given the limited time to prosecute an engagement, such messages which rely on serial communication are simply impractical. The decision to engage must take place as soon as it is clear that an enemy threat is unfolding (the cueing stage). In fact, it is our contention that each of the messages we have listed can and should be automated, much like how a warship can enable its air defense system or enables a programmed, automated pre-planned response. Once things are set in motion, the only decision for commanders is to allow things to continue, or stop the process due to concerns over safety of friendly forces or a sense that an error has occurred.

3. Analysis of the Existing BMD C2 Structure

To understand the existing BMD C2 structure, one must start with the Unified Command Plan (UCP). The UCP clearly delineates military combatant commands, missions, functions, and geographic Area of Responsibility (AOR). Further, it promotes a streamlined planning process between commands at levels in the command hierarchy. The UCP distinguishes the combatant commanders (COCOMS) under one of two categories: geographic missions as defined by AORs or regions, and functional commands which provide specific capabilities to execute particular missions worldwide. The COCOMS under the constraint of regional missions are the U.S. Northern Command (NORTHCOM), the U.S. European Command (EURCOM), the U.S. Southern Command (SOUTHCOM), the U.S. Central Command (CENTCOM), and the U.S. Pacific Command (PACOM). Other COCOMS, such as the U.S. Strategic Command (STRATCOM), the U.S. Joint Forces Command (JFCOM), the U.S. Special Operations Command (SOCOM), and the U.S. Transportation Command (TRANSCOM), fall under the umbrella of functional commands and are usually in the supporting role to the supported COCOMS that have cognizance over specific AORs [2].

Under the current UCP, the overall BMD operations will fall under the supervision of NORTHCOM because NORTHCOM has been charged with the overall responsibility for homeland defense. Both STRATCOM and NORAD, along with other COCOMS, will assume the roles of supporting commands. The supporting commands will in turn have tactical control of units with an arsenal of sensors and weapons. Ultimately, NORTHCOM is responsible to the Unified Command System (White House, Pentagon), which maintains total authority over all decisive courses of action. Although other COCOMS are in a supporting relationship to NORTHCOM, each COCOM has a direct link to the Unified Command System to provide redundant C2 capability from the highest echelon of command should a link latency or even failure from NORTHCOM to any of the supporting commands threaten successful prosecution of a missile. Regional commanders, COCOMS that have responsibility over a specific region, maintain tactical control of units with numerous resources including an assortment of sensors and weapons that are networked through the region. Under the current C2 structure, when a missile launch is anticipated by an intelligence source, cueing data will initiate the flow of information. It is important to note that the model we have adopted represents only one of many possible scenarios particularly with respect to intelligence.

3.1 The Simulation Model of the Existing BMD C2 Structure

Figure 1 shows the OMNeT++ simulation model we constructed for the existing BMD C2 structure. OMNeT++, which stands for Objective Modular Network Testbed in C++, is an object-oriented discrete-event simulator primarily designed for the simulation of communication protocols, communication networks and traffic models, and models of multiprocessor and distributed systems. OMNeT++ provides three principal constructs (modules, gates, and connections) for modeling the structures of a target system. An OMNeT++ simulation model consists of a set of modules communicating with each other via the sending and receiving of messages. Modules can be nested hierarchically. The atomic modules are called simple modules; they are coded in C++ and executed as co-routines on top of the OMNeT++ simulation kernel. Gates are the input and output interfaces of the modules. Messages are sent out through output gates of the sending module and arrive through input gates of the receiving module. Input and output gates are linked together via connections. Connections represent the communication channels and can be assigned properties such as propagation delay, bit error rate and data rate. Message can contain arbitrarily complex data structures and can be sent either directly to their destination via a connection or through a series of connections (called route.)

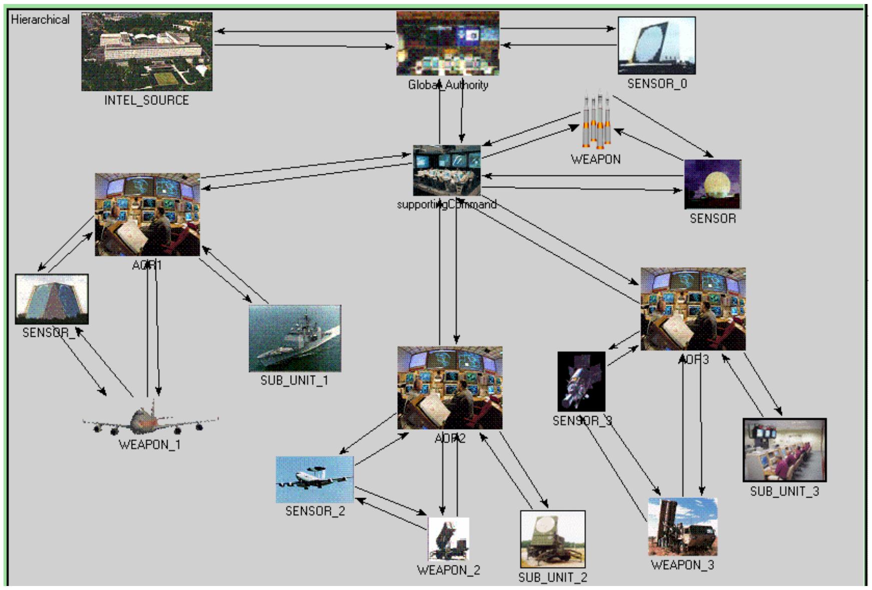

Figure 1. Model of Current C2 Structure.

The model shown in Figure 1 consists of 18 modules: an intelligent source (*INTEL_SOURCE*), a global missile defense command (*Global_Authority*), a supporting command (*Supporting_Command*), three regional commands (*AOR1*, *AOR2*, *AOR3*), three tactical missile defense units (*SUB_UNIT_1*, *SUB_UNIT_2*, *SUB_UNIT_3*), five sensors (*sensor*, *sensor0*, *sensor1*, *sensor2*, *sensor3*) and four weapons (*weapon*, *weapon1*, *weapon2*, *weapon3*). The model, which is based on unclassified information, represents the hierarchical levels through which the United States will conduct missile defense where

- INTEL_SOURCE represents the National Command Authority (Unified Command System)
- Global Authority represents NORTHCOM
- Supporting Command represents Missile Defense Authority (STRATCOM, NORAD)
- AOR represents supporting regional COCOM
- SUB_UNIT represents units under tactical control of Regional COCOMS

Our model shows intelligence flow from the top to the bottom, but this intelligence may be received at the middle or lowest levels and we assume that it would then be sent up and back down along with appropriate orders. Once cueing data is received by units with sensors, those sensors are tasked to direct energy towards the threat axis to improve the chance of detection. After detection, track data is passed up through the chain of command and detecting sensors are paired with organic weapons[1] at the COCOM level first, and at the national level (NORAD) next. Throughout this flow of data, the data is processed by appropriate authority at each level of command to ensure proper target discrimination as well as de-confliction of any duplicate tracking of the missile. Between the regional COCOM and the unit commander, proper coordination takes place in the form of one or more of the message types specified in Section 2. Should the assigned prosecuting commander be unable to execute the mission, the appropriate message (CAN'T CO) will be passed back through the chain of command to the appropriate level in order for either the regional COCOM or higher level of authority to decide whether to reassign of sensors and weapons.

Our simulation of missile defense via the current C2 structural model will be executed under three different scenarios:

(i) Single threat missile, single AOR
(ii) Multiple threat missiles, multiple phases of flight, same AOR
(iii) Multiple threat missiles, multiple phases of flight, multiple AORs

The single threat missile/single AOR scenario depicts the simplest case in which a single missile is launched from a single nation state. The multiple threat missiles/multiple phases of flight/same AOR scenario replicates the possibility of multiple missiles being launched at staggered times from the same region, possibly from the same nation state. The last scenario, multiple threat missiles/multiple phases of flight/multiple AORs, represents the grim yet distinctly possible reality of multiple staggered launches emanating from two or more different AORs; the only conceivable case that is not related to one of these scenarios is one in which threat missiles are launched inside the national (NORTHCOM) AOR but not in any of the lower (i.e., more distant) COCOM AORs, such as an attack from barges or ships just a few nautical miles off either coast of our homeland.

3.2 The Simulation Results

Using the model depicted in Figure 1, we simulated all three scenarios. We implemented the passing of messages between the levels of command and observed the timing of message passing in 100 iterations. Our objective was to observe the automation of message passing and analyze the results in order to derive an evaluation of the rate of interception. In doing so, we implemented parameters that were used as metrics to facilitate the analysis of message passing. The parameters used include: TIME_TO_CONSIDER_INTEL, TIME_TO_PROCESS_NOGO, TIME_TO_EVALUATE_KILL_NO_KILL, TIME_TO_PAIR, PERCENT_CHANCE_OF_DETECTION, TIME_TO_DETECT, MAX_SALVO_SIZE, PERCENT_CHANCE_OF_KILL, TIME_TO_PROCESS_STATUS, and GLOBAL_SENSOR_TRACK_DELAY. Each iterative running of the OMNeT++ model yielded the results of the simulation as depicted in Figure 2. The window confirms the number of threat

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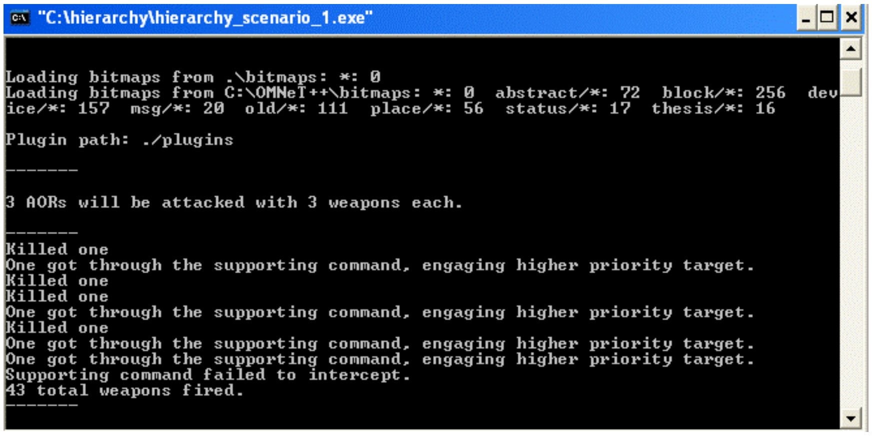
[1] A resource is considered "organic" by a commander if it is under his or her tactical control.

missiles and the number of AORs for each scenario. This information is followed by a sequence of narrative of the actions taken at successive levels of command as the missile interception is attempted through the phases of flight. Figure 2 is representative of the worst-case scenario involving multiple missiles from multiple AORs.



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Loading bitmaps from .\bitmaps: *: 0
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ice/*: 157  msg/*: 20  old/*: 111  place/*: 56  status/*: 17  thesis/*: 16

Plugin path: ./plugins

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3 AORs will be attacked with 3 weapons each.

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Killed one
One got through the supporting command, engaging higher priority target.
Killed one
Killed one
One got through the supporting command, engaging higher priority target.
Killed one
One got through the supporting command, engaging higher priority target.
One got through the supporting command, engaging higher priority target.
Supporting command failed to intercept.
43 total weapons fired.
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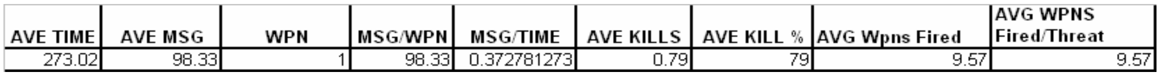
Figure 2. OMNeT++ Simulation Result.

The model was simulated 100 times for each of the three scenarios. The summary of the simulation results are shown below.

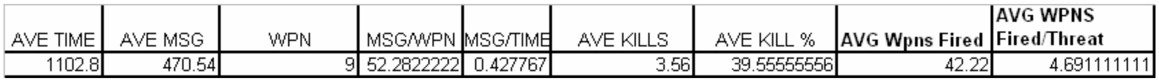


AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIME	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
273.02	98.33	1	98.33	0.372781273	0.79	79	9.57	9.57

Table 1. Single Missile, Single AOR summary results

AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIME	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
523.04	219.9	3	73.3	0.425064	1.91	63.66666667	22.86	7.62

Table 2. Multiple Missiles, Single AOR summary results



AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIME	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
1102.8	470.54	9	52.2822222	0.427767	3.56	39.55555556	42.22	4.691111111

Table 3. Multiple Missiles, Multiple AORs summary results

Remember that our simulation model was designed to capture the amount of time and number of messages required to process the average threat missile given these conditions. The atomic modules that make up these models have defined "behavior" or coded routines for handling each of the nine types of messages that they may encounter. Given that each of the module-types take the same action given the same inputs (i.e., messages), and the same random variables and constants are used (e.g., the chances for detection or kill and delays time for each message), we can compare them on equal footing for the number of messages and time used in the average case. Note that time and the number of messages are related, as more messages incur a bigger time delay for processing.

Figure 3 shows that, as one might expect, the number of messages that are passed increases with complexity. The number of messages exchanged between the commands rises steadily from approximately 100 messages in a single missile/single AOR scenario to over 450 messages in the multiple missile/multiple AOR scenario; this increase in message traffic will certainly be taxing to any network and might lead to complications and ultimately be culpable in decreasing the success rate as the scenario becomes more complex. However, we were surprised to find that the effect was the exact opposite when each level of command was closely scrutinized for the number of messages that were sent and received, as shown in Figure 4. On closer inspection, we discovered a simple explanation for the decreasing average number of messages per threat missile by each command as the complexity of the situation is compounded by greater numbers of missiles and AORs: as the threat missiles progress through the phases of flight, if an assigned weapon cannot engage and complete a successful prosecution, then the only message that the weapon sends is a single CAN'T CO to his higher command, as opposed to multiple messages relating the successful tracking and prosecution of the missile if the weapon had successfully engaged. Likewise, Figure 5 demonstrates that less time is spent per threat missile as more are added.

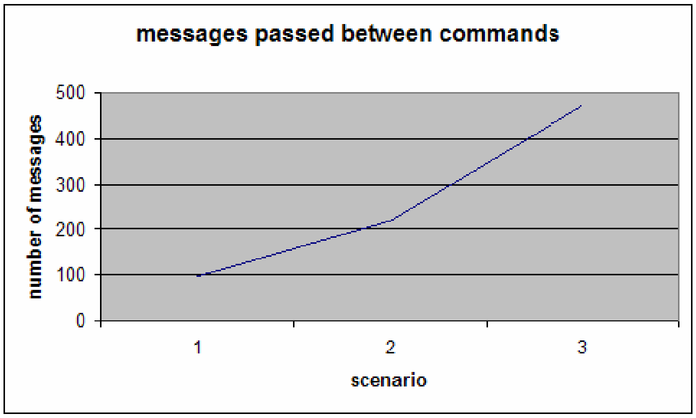


Figure 3. Messages Passed Between Commands

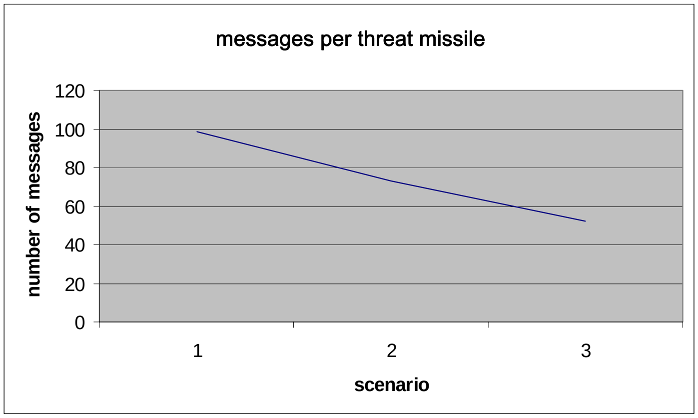


Figure 4. Messages per Threat Missile

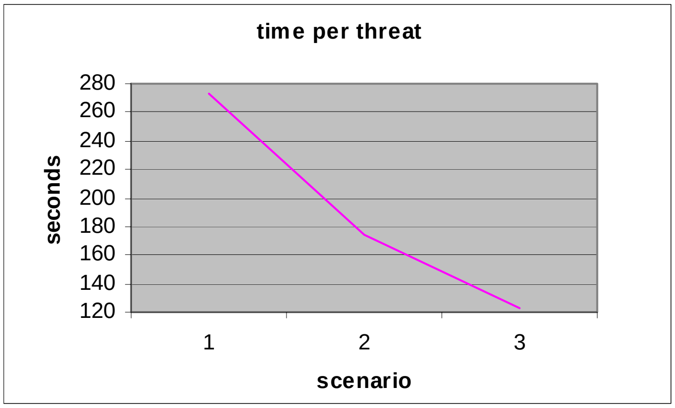


Figure 5. Processing Time per Threat Missile

This illustrates the fact that some reduction of the ratio of messages per threat missile and processing time per threat missile in the more complex scenarios can be attributed not only to the command structure, but to the simple fact that NORTHCOM has a limited number of resources, which become particularly strained when lower echelons hand off engagements simultaneously. We anticipate that this structure will be revealed as inefficient in terms of congestion due to duplicate message passing, some of which have associated delays, which, in reality, will further limit the number of opportunities for engagements.

In our model, since boost-phase engagements are limited to 120 seconds and engagement of any one threat cannot exceed 600 seconds total,[2] the number of interceptors fired per threat missile decreases with added complexity of the scenario, as noted in Figure 6. Again, this is not a metric in which we are specifically interested, but is a phenomenon we felt worth noting.

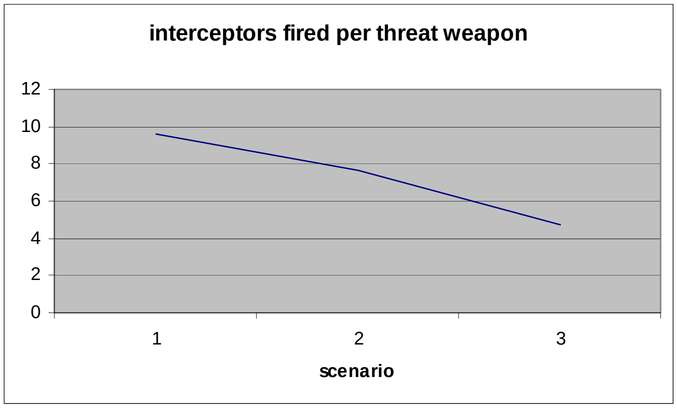


Figure 6. Interceptors Fired Per Threat Missile

3.3 Limitations of the existing C2 structure

Data from preliminary simulation runs show that the amount of messages will overload the network in anything more complex than a single missile/single AOR scenario. The significant increase in message congestion and decrease in processing time available for each threat in the

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[2] These values are points of reference rather than absolute.

current C2 structure correlate to the increase in the number of threat missiles and the number of launch-points. We observed this during Desert Storm, with the simultaneous launching of multiple SCUD missiles to different designated areas of operations of coalition forces. It is a fair assessment to declare that the current C2 architecture is not organizationally optimal in confronting varied scenarios that present greater challenges in terms in increasing numbers of factors, be it the missiles or the origination of the missiles.

4. Alternative BMD C2 Structures

In this section, we present two alternative BMD C2 structures in an attempt to streamline the chain of command in BMD.

4.1 Compressed C2 Structure

Figure 7 presents an OMNeT++ simulation of the model of a modified compressed C2 structure. Unlike the one proposed in [6], we only remove the supporting commander from the existing C2 structure and allow one global authority to direct the actions of regional COCOMs directly. Comparing Figure 7 to Figure 1, we can discern a distinct difference: the element Supporting_Command, representing STRATCOM, is deleted in Figure 7. Instead, the regional COCOMs, represented by AOR1, AOR2, and AOR3, are directly connected to the Global_Authority. We chose to leave the total number of weapons and sensors the same in order to avoid skewing the data; one could expect fewer messages if fewer units are participating; this explains why the global authority maintains two independent sensors.

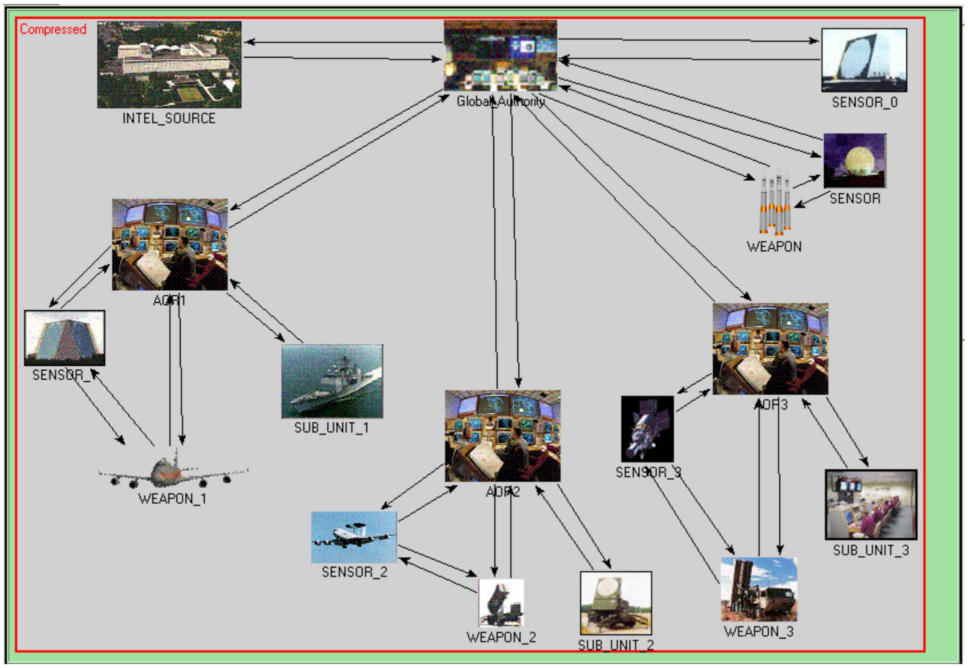

Figure 7. OMNeT++ Model of a Modified Compressed C2 Architecture

Without the extra supporting command, the global command now has additional duties which affect the message flow and algorithm of the model. Specifically, the global authority previously maintained the weapons fired count as a variable by tracking the number of engagement updates received from the supporting command. This was possible because each of these messages was sent from the AOR commanders to the supporting command and forwarded. In the case that the supporting command itself generated the engagement (a simulation of midcourse of terminal engagement in our model), a new engagement update was generated and forwarded to the global authority. With the removal of the supporting command, the global authority now has to participate in engagements as well as track those of lower echelons. This adds some responsibility and complexity to the role of this commander, whereas the previous model included a commander whose sole responsibility was to watch events unfold and intervene only when necessary.

4.2 Flattened C2 Structure

Figure 8 shows the OMNeT++ simulation model of a flattened C2 structure proposed by Weller et al., which attempts to improve the effectiveness and efficiency of the forces by "elimination of several links" along the chain of command, much like how the Special Operations Forces operated in Afghanistan without multiple layers of command above them. Under the flattened C2, the missile defense forces revolve around a central entity, namely the Global Authority with STRATCOM assuming this position. The Global Authority has at its disposal its own sensors and weapons, as well as a robust set of sub-units with inherent capabilities to launch interceptors.

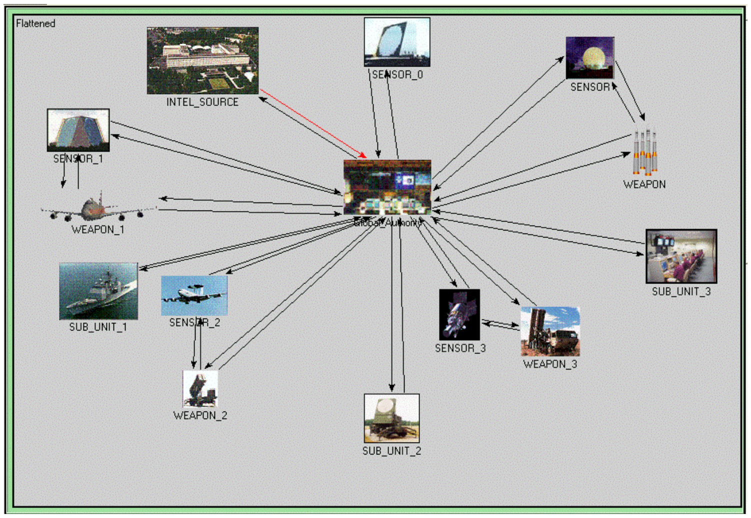

Figure 8. OMNeT++ Model of the Flattened C2 Architecture

5. Simulation Results of the alternative BMD C2 Structures

The experiments were conducted under the same conditions as the first model; simulations were conducted for 100 iterations under three scenarios (single missile/single AOR, multiple missile/single AOR, multiple missile/multiple AORs) for each of the two alterative models. The results were captured and displayed accordingly in Tables 4 through 9.

AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIME	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
257.3	84.52	1	84.52	0.342604838	0.83	83	9.1	9.1

Table 4. Single Missile, Single AOR summary results for the Compressed C2 Structure

AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIME	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
506.58	190.13	3	63.376667	0.379457147	2.05	68.33333333	20.75	6.916666667

Table 5. Multiple Missile, Single AOR summary results for the Compressed C2 Structure

AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIME	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
1089.2	427.13	9	47.458889	0.393033882	4.04	44.88888889	40.06	4.451111111

Table 6. Multiple Missile, Multiple AOR summary results for the Compressed C2 Structure

AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIME	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
249.56	77.6	1	77.6	0.313686451	0.86	86	9.14	9.14

Table 7. Single Missile, Single AOR summary results for the Flattened C2 Structure

AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIMI	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
554.06	186.43	3	62.1433333	0.337362	1.76	58.66666667	22.81	7.603333333

Table 8. Multiple Missile, Single AOR summary results for the Flattened C2 Structure

AVE TIME	AVE MSG	WPN	MSG/WPN	MSG/TIME	AVE KILLS	AVE KILL %	AVG Wpns Fired	AVG WPNS Fired/Threat
1101.21	387.55	9	43.0611111	0.352439	3.62	40.22222222	41.18	4.575555556

Table 9. Multiple Missile, Multiple AOR summary results for the Flattened C2 Structure

Figures 9-11 and Tables 10 show the effect of the two proposed C2 structures on the number of messages exchanged between the commands, the number of messages per threat missile processed by a command, the time spent per threat missile, and the number of interceptors fired per threat missile.

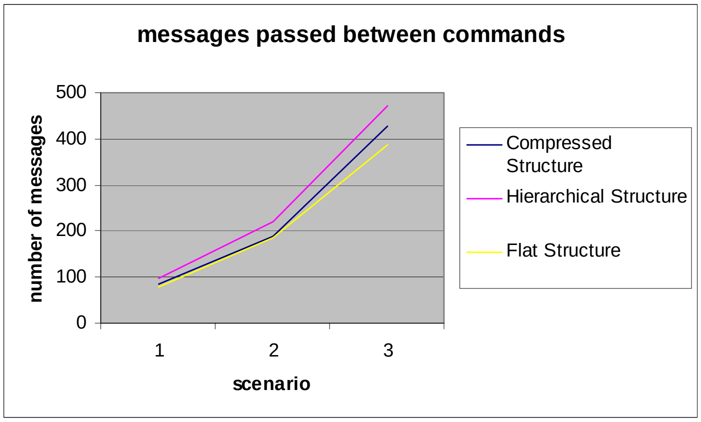

Figure 9. Comparison of Messages Passed Between Commands

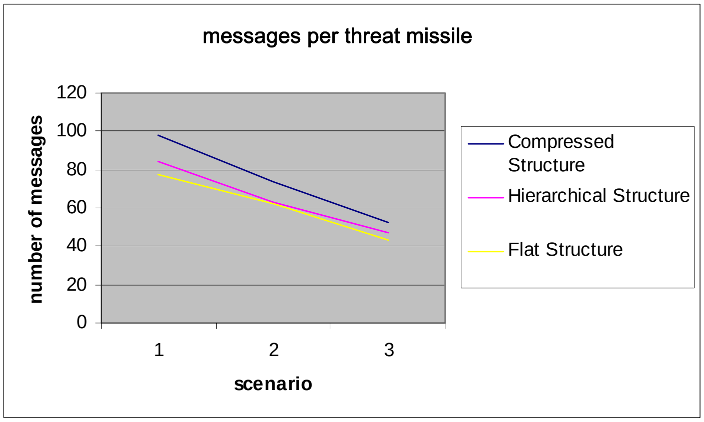

Figure 10. Comparison of Messages per Threat Missile

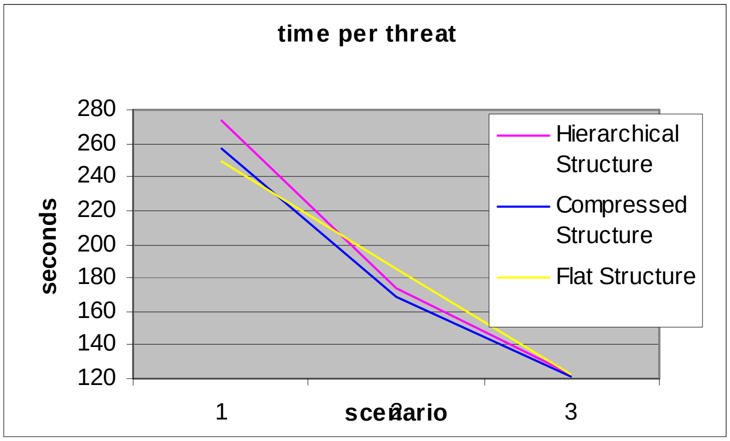

Figure 11. Comparison of Processing Time per Threat Missile

Interceptors Fired Per Threat Weapon			
	Scenario #1	Scenario #2	Scenario #3
Hierarchical Structure	9.57	7.62	4.69
Compressed Structure	9.1	6.91	4.45
Flat Structure	9.14	7.64	4.57

Table 10. Comparison of Interceptors Fired Per Threat Missile

As expected, the simulation data show that there is a general reduction of the number of messages exchanged between commands when middle layers are removed from the existing BMD C2 structure. The flattened model generates the least amount of message per threat missile in our model because it is evident that there are less entities for messages to be exchanged with, eliminating the requirement for status updates to higher echelons which consume more time and effort for those units at the bottom rung of the ladder. In fact, an entire type of message is eliminated. The "engagement status" message type never manifests itself under these conditions. This is another unexpected result which runs counter to our initial expectations and forces us to reconsider our list of "essential messages," since it has proven itself expendable in this case.

Figure 11 depicts a comparison of the average time per threat missile between the three models. For the trivial case (single missile/single AOR) the difference is not staggering, however, with greater numbers of missiles from different directions, the flattened model actually takes the longest to respond in the second scenario while it does about as well as the current C2 structure for the worst-case scenario. One could have hypothesized that the opposite of what we find in Figure 11 to be true, relying on the assumption that lesser number of entities will result in improved performance, as declared by Weller [5]. However, one should keep in mind that the centralized Global Authority in the flattened model has become the sole authority with the combined responsibilities once shared by the regional COCOMs and the higher levels of command. It must now generate the track data and armor the data with sufficient information to ensure that the data is good enough for the launching unit to rely on to execute its mission. In effect, the centralized entity has to handle all nine messages on its own, from cradle to grave, in order to provide the missile defense force the properly discriminated and absolutely unquestionable data. This creates a processing delay at the Global Authority level in the flattened model; the single C2BMC must now deal with having to track multiple targets as well as deal with additional, new data that it receives in order to create new tracks.

Although these results suggest that the flattened chain of command is not practical on the surface, this complication can be overcome by appropriate resource allocation to the principal commander. In [6], Weller *et al.* suggested that, “a centralized commander may have a better overall picture of the battlespace and be better equipped and staffed to most efficiently fight the battle.” Assuming that this commander could be provided with sufficient processing power to distribute delays across AORs, even if from afar, the limitation exposed in our model can be thus neutralized and the advantage of concurrent delays regained. Furthermore, such a structure may provide additional flexibility if resources from one AOR could be brought to bear on threats originating or heading for another (one of many possible scenarios not addressed in our modeling).

6. Conclusion

The implication of removing a layer of command from the C2 structure is that the overall performance of the structure in response to missile threats in various scenarios is relatively better than that of the current C2 architecture with a more complex hierarchical arrangement. The trend that was observed during the simulation of the current C2 structure was that as the scenario’s level of complexity increased, the C2 structure’s reactive ability to cope with the missiles degraded. The same inclination towards degraded performance due to greater complexity of the scenario permeated throughout the compressed model. One might have assumed that the removal of a layer of a hierarchy will have counter-balanced the complexity matter by cutting out formalities such as duplicate situational awareness messages being exchanged between hierarchies, thereby eliminating additional time required to conduct information exchange with higher headquarters; this is intuitively interpreted since most readers can relate to situations where conversation within a larger group of people is more intense and multifaceted, sometimes requiring multiple attempts at relaying the same information, than that of a smaller group of people where communication and thus the delivery of the essential points are much more effective and efficient. However, the OMNeT++ experiments proved otherwise.

It demonstrated that the removal of a layer intensified the effects of the fog of war and instead created an environment for reduced rate of success of interception. However, as pointed out in Weller's thesis [5], this fog of war can be lifted given the appropriate resource reallocation to the single centralized entity and that further modeling constituted from a foundation built on multiple C2BMCs at each level will yield different outcomes, specifically, one in which the flattened C2 structure is unanimously the winner.

More refined models are needed to fully understand the impact of different C2 structures on missile defense. Future modeling should include estimates for awaiting human decisions, should a semi-automated system be selected over a fully automated one. Our model does not represent delays for awaiting additional authority. Selection of the appropriate level of government to permit an engagement has been under discussion for some time, to include some proposals that such permission be granted before the engagement actually unfolds based on current threat levels or specific intelligence.

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