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THESIS

**LEVERAGING MANET AND MOBILE DEVICES IN
SHIP-TO-OBJECTIVE MANEUVER AND
EXPEDITIONARY MAGTF OPERATIONS**

by

Joshua C. Waddell

September 2014

Thesis Advisor:
Co-Advisor:

Alex Bordetsky
John Gibson

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**LEVERAGING MANET AND MOBILE DEVICES IN SHIP-TO-OBJECTIVE
MANEUVER AND EXPEDITIONARY MAGTF OPERATIONS**

Joshua C. Waddell
Captain, United States Marine Corps
B.A., Virginia Polytechnic Institute and State University, 2008

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requirements for the degree of

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**NAVAL POSTGRADUATE SCHOOL
September 2014**

Author: Joshua C. Waddell

Approved by: Dr. Alex Bordetsky
Thesis Advisor

John Gibson
Co-Advisor

Dr. Dan Boger
Chair, Department of Information Sciences

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ABSTRACT

This thesis examines the challenges, specifically in regard to tactical C2 in austere conditions, to the Enhanced MAGTF Operations (EMO) concepts being developed by the Marine Corps. EMO hinges on the ability of company landing teams (CLTs) to deploy from a seabase, conduct over-the-horizon insertion, and retain the data-driven C2 inherent in modern military operations, specifically with regard to warfighting functions of intelligence and supporting fires. This thesis leverages the capabilities of smartphones, mobile ad hoc networks (MANET), and long-haul data trunks to offer a conceptual solution set to these C2 challenges.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	anti-access/ area denial
AAR	after action review
AFATDS	advanced field artillery tactical data system
AO	area of operations
ANW2	adaptive networking wideband waveform
ASCM	anti-ship cruise missile
BGAN	broadband global access network
BLT	battalion landing team
C2	command and control
CDS	containerized delivery system
CLT	company landing team
CLIC	company-level intelligence cell
CLOC	company-level operations cell
COC	combat operations center
COIN	counterinsurgency
COP	common operational picture
COTS	commercial off-the-shelf
DTCS	distributed tactical communications system
DO	distributed operations
ECO	enhanced Company Operations
EMO	enhanced MAGTF Operations
FOB	forward operating base
FMV	full motion video
FST	fire support team
FST	full systems test
GOTS	government off-the-shelf
GPS	global positioning system
HFN	Hastily Formed Networks
HHQ	higher headquarters

ICCTRS	International Command and Control Research and Technology Symposium
ICA	integrated capabilities application
IED	improvised explosive device
IOC	Infantry Officer Course
IP	Internet Protocol
ISR	intelligence surveillance and reconnaissance
IT	information technology
JTAC	joint terminal air controller
JTRS	joint tactical radio system
LOE	limited objective experiment
LOS	line of sight
LZ	landing zone
MAGTF	Marine air ground task force
MANET	mobile ad-hoc network
MCSC	Marine Corps Systems Command
MCWL	Marine Corps Warfighting Laboratory
MEB	Marine expeditionary brigade
METN-CE	mobile expeditionary tactical network – CLOC enabler
ME-L	Marine expeditionary – light
MERS	Marine expeditionary rifle squad
MEU	Marine expeditionary unit
MRAP	mine resistant ambush protected
MUOS	multiple user objective system
NGO	non-governmental organization
NPS	naval postgraduate school
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OPFOR	Opposing force
OTH	over-the-horizon
PLI	position location information
PTT	push-to-talk

RCT	regimental combat team
RIMPAC	Rim of the Pacific
ROIP	radio over IP
SatCom	satellite communication
SPMAGTF	special purpose Marine air ground task force
TCM	tactical control measure
T/E	table of equipment
T/O	table of organization
UAV	unmanned aerial vehicle
USMC	United States Marine Corps
VHF	very high frequency
VPN	virtual Private Network

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I. INTRODUCTION

This research is in response to the changing nature of Marine Corps expeditionary operations. Specifically, it seeks to address areas for improvement in C2 and Intelligence collection during initial phases of expeditionary operations in austere environments with limited logistical footprint. This study seeks to leverage current IT solutions with modern communications architecture to provide a demonstrated proof-of-concept for intelligence collection in tandem with C2 functions in distributed operations.

My interest in this field of study stems from my personal experiences as a Marine Corps infantry officer. I had the pleasure of deploying twice to Helmand Province, Afghanistan in support of Operation Enduring Freedom (OEF) in 2010 and 2011–12. During both deployments I was struck by how command and control (C2) supportability was a major limiting factor that would drive operational planning. Our Marines are incredibly bright, talented, and very well equipped to handle any enemy threat. However, no modern conventional military unit is capable of operating without maintaining contact to a higher headquarters (HHQ) element, which coordinates higher-level functions of battlespace management such as air/artillery fire support, logistics, intelligence, and casualty evacuation. During both deployments our forces were arrayed in such a way that they pushed the limits of current C2 capability. As a Second Lieutenant in 2010, my primary communication method to my higher headquarters was the chat function on our Blue Force Tracker unit. A civilian satellite system, intended for troop morale usage, was the most reliable communication method to my commander, however we could never use it to discuss the more sensitive aspects of our operations as it was an unprotected system. As I was the officer in charge of a patrol base with 70+ Marines, four MRAP vehicles, a forward logistics point, and was simultaneously interfacing with the local police headquarters and district political headquarters, this C2 capabilities shortfall was a severe hindrance to our complex counter insurgency (COIN) mission. This was largely due to the 15+km of mountainous terrain separating my commander and me. Limited availability of satellite channels at the tactical level and no reliable relay systems created this C2 gap. Later, in 2011, while serving as a company executive officer in charge of

running the company combat operations center (COC; company-level C2 node), it came to my attention that our squads on the tactical edge using biometrics survey equipment had no capability of synchronizing with an accurate database of previously captured individuals. As there was no data link between the COC and the dispersed patrol bases, these squads would have to return to the main forward operating base (FOB) once a month to upload their data to our networked systems. We would then find that they had come across persons of interest in the course of their operations but had no way of knowing as their local databases were out of date. Additionally, any new intelligence or threat reporting had to be conveyed via voice communications or physical delivery of intelligence packets to the patrol bases. As we were engaged in a rapidly evolving counter-IED (improvised explosive device) and COIN fight, this slowed our ability to adapt to our dynamic environment. Contrasted against the computing power and information availability in the smartphone in the average American high school student's pocket, we began to question the effectiveness of our C2 capability as a 21st century fighting force.

A. PROBLEM STATEMENT

The functional requirements of C2 and intelligence collection in modern warfighting have outstripped the linear VHF-based tactical communications architecture currently in use by the Marine Air-Ground Task Force (MAGTF), particularly given the stresses of over-the-horizon (OTH) expeditionary operations. There is currently a lag between the deployment of frontline conventional troops and the establishment of a consolidated C2/Intelligence node on the battlefield in expeditionary operations. This study seeks a solution to eliminate that lag time and that further enhances the commander's situational awareness and decision-making process during this critical and chaotic initial phase of operations.

B. PURPOSE STATEMENT

The purpose of this study is to assess the feasibility of a system-of-systems approach to C2 and intelligence collection during the initial, austere, and expeditionary phases of operations undertaken by the MAGTF in combat and non-combat scenarios.

This study will seek to outline the advantages to the commander's decision-making process by allowing for a more distributed deployment of his forces through advanced radio technology, more accurate and robust initial intelligence reporting during the initial phases of operations, and an IP-based solution to allow reachback to higher headquarters, subject-matter experts, and trans-national organizations to deal with contingency situations outside the normal scope of operations of the traditional MAGTF. This study will provide a detailed performance analysis of current COTS and GOTS systems through field experimentation with specific focus on the tactical deployment formations of the MAGTF as identified through traditional doctrine and emerging techniques.

C. RESEARCH QUESTIONS AND HYPOTHESES

This document will seek to answer questions regarding potential solutions to this capabilities gap.

- Compare/contrast benefits of MANET solutions with existing programs of record for battlefield networking.
- How would MANET systems complement the traditional and emerging formations of the USMC MEU-Level MAGTF, specifically in the T/O and T/E of a CLT?
- What are the bandwidth capabilities and limitations of a combined MANET/SatCom system with only a man-portable equipment footprint?
- What potential benefits are there for having data connectivity on the tactical edge through the use of peripheral devices such as commercial smartphones and tablets?

Hypothesis: Using currently available COTS and GOTS technology, it is possible to create a “system of systems” which is able to provide and support a data-rich combat networking environment. This environment would provide on-demand services to units on the tactical edge while also providing operationally relevant data a higher information-processing node across significant geographical separation. This C2 architecture would be both reliable and sustainable in the confines of austere tactical operations.

D. RESEARCH METHODS

This research was primarily conducted in a field setting. It included participation in multiple field experiments with the Marine Corps Infantry Officer Course as well as Marine Corps Warfighting Laboratory. In these exercises the potential strengths and weaknesses of emerging C2 architectures were considered, use cases for the equipment itself evaluated. The observations made were then referenced back to the core planning documents of Expeditionary Force 21 (EF21) and the Marine Corps Vision and Strategy 2025. The research included field-testing of emerging radio technology that could allow for high data throughput in ground combat use cases. Finally, a conceptual architecture for Marine Corps C2, which incorporates the lessons learned from field experimentation and study, was developed.

E. POTENTIAL BENEFITS AND LIMITATIONS

Benefits: This study sought to provide a compelling alternative to the standard VHF communication framework currently in use by tactical units by demonstrating the value added by emerging COTS and GOTS systems through the ability to collect and distribute data at the tactical edge. The study also sought to show how the data transmission abilities in the current VHF family of tactical communication systems are inadequate for the complexities involved in intelligence fusion in the modern collection environment.

Limitations: All data transmissions were only testable with CSFC encryption and security. Further testing will need to be done with NSA-approved military level encryption protocols. Also, all field-testing with Marine units was dependent on availability and supportability for outside observers.

F. INITIAL FINDINGS

Through the literature review process and initial conversations with development agencies such as MCWL and IOC, it became readily apparent that these issues are at the forefront of the minds of leaders and planners for Marine Corps capabilities modernization. Examination of currently available COTS and GOTS systems indicates that the technology for the proposed solution sets is already available. The major question is then in regards to the best architecture to employ and what requirements drive that architecture's conceptual and hardware development and acquisition strategies.

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II. BACKGROUND

The Marine Corps of 2025 will fight and win our Nation's battles with multicapable MAGTFs, either from the sea or in sustained operations ashore. Our unique role as the Nation's force in readiness, along with our values, enduring ethos, and core competencies, will ensure we remain highly responsive to the needs of combatant commanders in an uncertain environment and against irregular threats. Our future Corps will be increasingly reliant on naval deployment, preventative in approach, leaner in equipment, versatile in capabilities, and innovative in mindset. In an evolving and complex world, we will excel as the Nation's expeditionary force of choice.

– Vision Statement, Marine Corps Vision & Strategy 2025 (USMC, 2007)

Following the gradual de-escalation of large-scale operations in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), the U.S. Marine Corps has begun to look to the future of the organization. The past 13 years of war have changed the way Marines have come to think about the deployment of conventional forces. The vision statement from the 2007 Vision & Strategy document (V&S), seen above, outlines some of the key requirements Marines can expect to see in the future. Taken at face value, this may seem like a generic re-branding of the Marine Corps Title 10 responsibilities. However, through the lens of the Global War on Terror and its follow-on contingency operations, this vision has heavier implications.

Fighting “from the sea” is no longer a reference to the linear, large-scale amphibious operations of Tarawa and Iwo Jima in the Second World War. In 2001, the 15th MEU made history by successfully conducting an amphibious assault at over 400 miles from the embarking fleet. This was the first conventional ground presence of the war, which had, until then, relied on dispersed Special Operations forces (USMC, 2013). This ushered in a new era of thought in terms of expeditionary maneuver. Constraints such as “naval deployment” are no longer as restrictive as they once were. With the current aviation support of the modernized amphibious fleet combined with the deep-striking potential of the MV-22 Osprey and J-35 Joint Strike Fighter, the

Expeditionary Strike Group (ESG) has gained an effective range once reserved for Carrier Strike Groups. Finally, the “irregular threats” referred to in the 2007 strategy document signifies continued requirement for advanced information processing and intelligence analysis incurred by counter-insurgency operations, humanitarian crises, and other non-traditional military actions.

A. RECENT PROBLEM SETS

As OIF has ended and OEF draws to a close, the current deployment patterns and formations of Marine Corps ground units do not resemble those of past conflicts. Battalions document instances where one platoon commander, typically responsible for 42 personnel and operating under the control of a company commander, would be responsible for over 160 multinational troops with seven static base positions disbursed over a wide area of operations (AO) (MCCLL, 2012, p. 8). Other units experienced rapidly changing mission sets and shifting AOs that required rapid re-deployment and flexible organization. This is often accomplished in coordination with multinational forces and with interagency cooperation (3d Battalion, 7th Marines, 2010). In the span of a single deployment, a single unit could experience non-kinetic counterinsurgency efforts and nation-building, while conducting fully kinetic clearing operations in a different AO the next month (3d Battalion, 7th Marines, 2010).

This trend is not exclusive to units deployed in support of OEF. Regimental Combat Teams (RCTs) deployed in support of OIF were eventually responsible for AOs such as AO Denver, a 30,000 square mile area in the Western Al Anbar Province of Iraq. In addition to the inherent requirements of coordinating combat and security operations, these units were responsible for numerous police and military transition teams spread throughout the battlespace. Logistically, RCTs were responsible for over \$440 Million in equipment and \$28 Million in engineering and construction contracts. The information requirements incurred from this expanded mission set far out-strip what was the traditional standard (RCT-2, 2008).

These advanced mission sets and developing trends in U.S. military deployments have led the Marine Corps to seek out a new paradigm for its ability to conduct

operations as the “Nation’s expeditionary force of choice”(USMC, 2007). The Marine Corps Warfighting Lab (MCWL) has begun to explore the implications of Distributed Operations (DO), which eventually birthed the Enhance MAGTF Operations (EMO) concept. In this framework a new vision for the most basic Marine Corps unit was born through the concept of Enhanced Company Operations (ECO). This conceptual framework examines the capabilities of an infantry company with additional organic headquarters support and firepower. ECO allows for the Marine Corps to deploy a lower-level maneuver unit as an economy of force measure to assert combat power over a larger battlespace (MCWL, 2010, pp. 3–6). Before this proposed methodology and its implications can be discussed, however, there must be a point of reference in current operations.

B. CURRENT MARINE CORPS TASK ORGANIZATION

The focus of EMO lies with the principal unit of a MEU: the infantry battalion. Figures 1–4 show the current task organization of the infantry battalion and its maneuver companies.

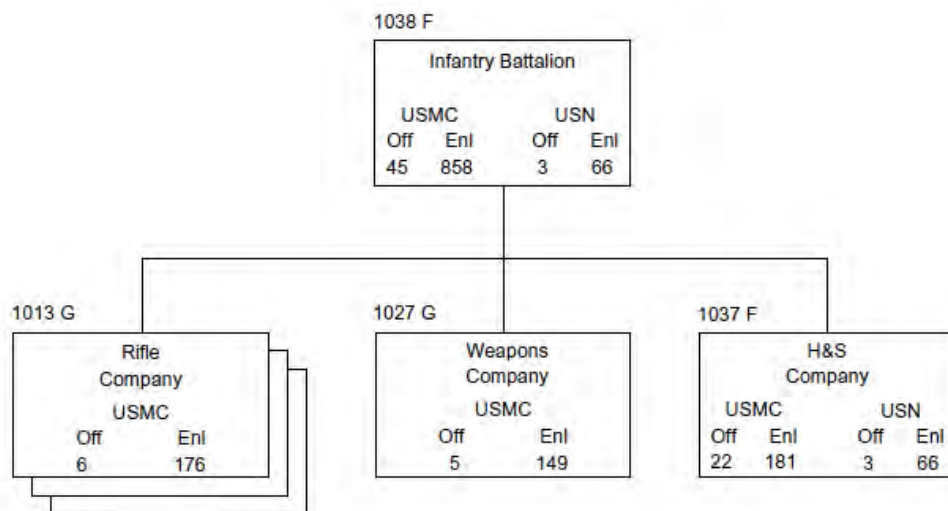


Figure 1. The Marine Corps Infantry Battalion (from USMC, 1998, pp. 4–7, 4–8)

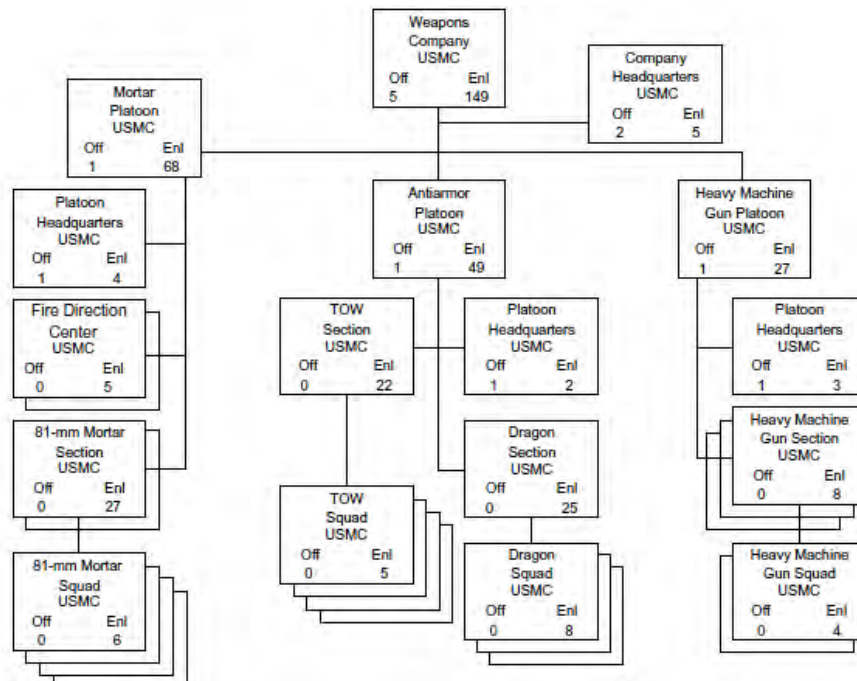


Figure 2. The Marine Corps Weapons Company
(from USMC, 1998, pp. 4-7, 4-8)

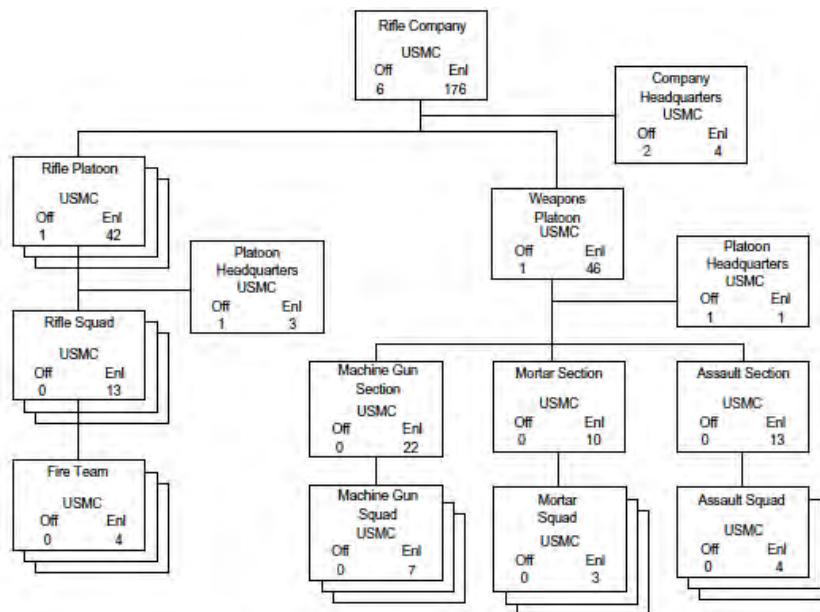


Figure 3. The Marine Corps Rifle Company
(from USMC, 1998, pp. 4-7, 4-8)

The nature of the above organization leaves the individual companies reliant on the battalion command structure to provide support in the form of heavy weapons allocation, indirect fire agencies, logistics support, and information/intelligence processing. The ECO construct under the EMO initiative by MCWL seeks to instead transform each individual company into a truly self-sustaining maneuver unit; with all the tools it would need to handle an expanded mission set, while deployed away from the MEU main body (MCWL, 2010, pp. 3–4).

While a series of ECO tables of organization have been evaluated, the trend has led to the below constructs at the battalion and company levels:

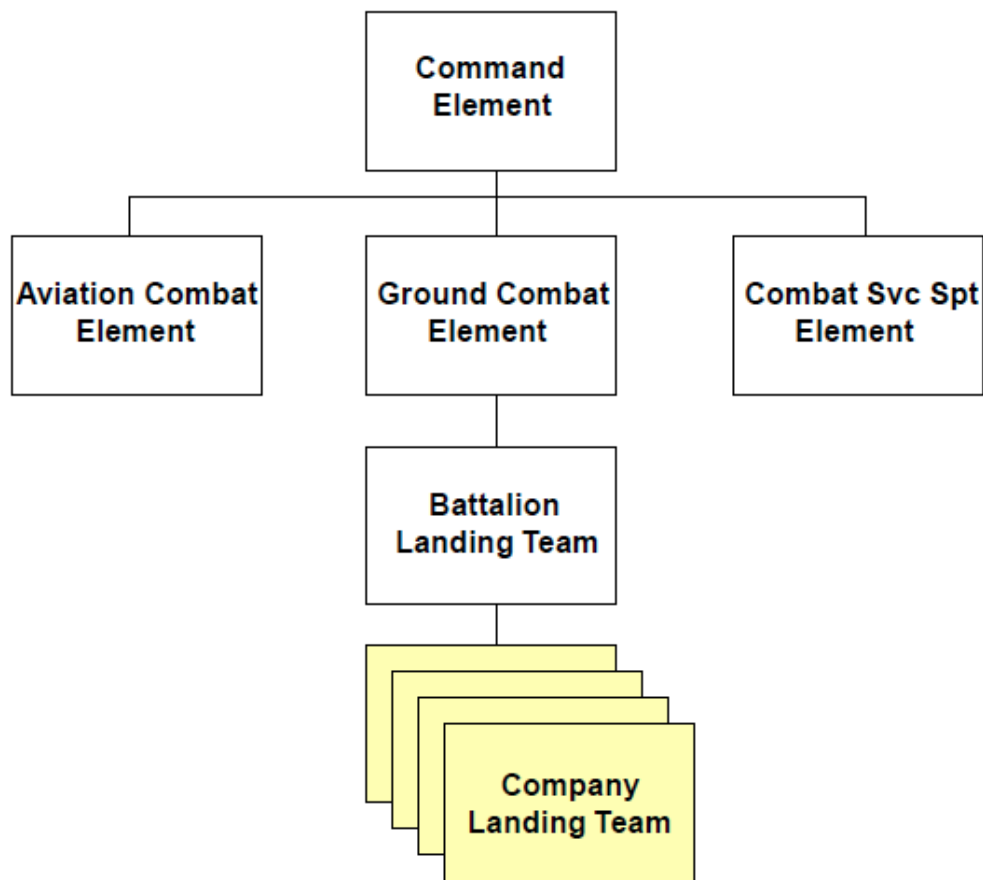


Figure 4. EMO T/O for MEU (from MCWL, 2009)

These company landing teams (CLTs) are the cornerstone of the emerging EMO concept. In order to tackle the more diverse mission sets in ECO, the table of organization for these units has been modified as follows (Figure 5).

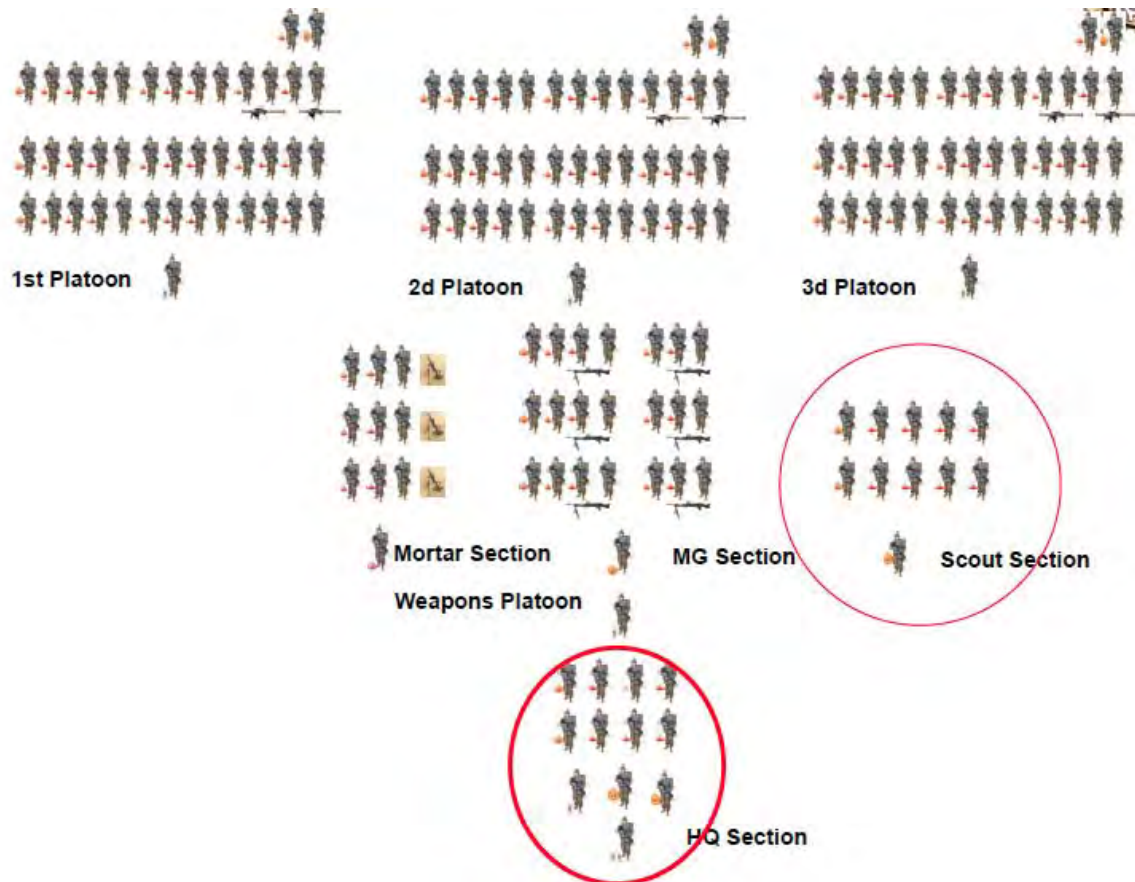


Figure 5. Proposed CLT T/O (after MCWL, 2009)

The principal changes in this T/O include the addition of a scout section and a much more robust headquarters element to include a logistics chief and intel/ops cells. Other MCWL experiments have also included additional indirect fires agencies and enablers. In the past years there have been live fire tests involving attaching a company fires support cell, to include an integrated fire direction center (FDC), to the headquarters of a CLT. Other experiments have gone so far as to attach an actual firing artillery battery of howitzers or 120mm expeditionary mortar systems directly to the CLT to exponentially enhance its combat power. It is also important to note here that the

effectiveness of these units was not negatively affected. Rather, the response times between contact reports and the complete processing of a fire mission were, on average, less than half that of the traditional schema of having the FDC at the battalion headquarters level (Finlay, O’Leary, Reid, Sullivan, & Talley, 2011, pp. 5–7).

C. IT IMPLICATIONS

The implications of this evolution in expeditionary warfare weigh heavily on the capabilities of the communications suite assigned to each CLT. Current experimentation involving an enhanced suite of equipment also includes a heavier footprint of equipment than is the current standard for an infantry company (MCWL, 2010). This is in direct conflict with the aim of the ECO initiative in that it interferes with the requirement of high mobility in these units (MCWL, 2012).

Additionally, the current suite of communications equipment lacks the inherent over the horizon (OTH) capability required by these emergent mission sets, while maintaining a mobile posture. Current COC gear sets lack the necessary radios to maintain a link (SatCom or other) while conducting dismounted movement (MCWL, 2011, pp. 39–41). As much of the emerging tactical concepts are developed for this new EMO model, it is important to remember that these units will typically be deployed from aviation assets and will not have the heavy vehicular lift capabilities that have become commonplace in OIF and OEF.

D. LITERATURE REVIEW

As stated earlier, the concept of this project was derived from the development of Enhanced MAGTF Operations (EMO) by MCWL. This is an ongoing study into the emerging capabilities of the modern Marine Corps in expeditionary, amphibious operations. One facet of this is described in the MCWL report on the EM Fires experiment in 2011 (Finley, O’Leary, Reid, Sullivan, & Talley, 2011). Here, the concept of the Company Landing Team (CLT), as opposed to the Battalion Landing Team (BLT), was tested in terms of C2 and fires coordination in conjunction with maneuver. The study showed impressive decreases in time required to process fire missions by supporting artillery and other agencies (Finley et al., 2011). This provides further support for the

evolution of the MAGTF toward more distributed operations. The study did not address communications architecture or intelligence collection in any detail, however.

The conference paper *On the Adaptation of Commercial Smartphones to Tactical Environments* details the utility of using the highly adaptable smartphone family of systems in tandem with multiple transmission solutions (Kaul, Makaya, Subir, Shur, & Samtani, 2011). Of particular interest was their focus on how smartphones could be used to co-opt an existing 3G (or higher) network through VPN-like solutions. They also provided rudimentary diagrams on how smartphones could be used in conjunction with 802.11 Wi-Fi clouds to network various tactical nodes. Data collection in the form of reports and images along with geographical location tags could be transmitted along these lines (Kaul et al., 2011).

The utility of ad-hoc wireless mesh networks were demonstrated in the NPS Katrina response team's after action report in 2005. This documents the deployment of the NPS HFN Lab's family of systems to austere conditions with recorded success in establishing a workable communications framework for the first-responder community (Bradford, Steckler, & Urrea, 2005). Although their success was hindered by lack of coordination between USGOV and NGO entities in that event, the actual hardware family was a demonstrable success as a rapidly deployable system.

The Marine Corps Center for Lessons Learned (MCCLL) database contains several reports referenced in this thesis from units recently deployed to OEF as well as recurring exercises such as Trident Warrior and RIMPAC. These help give background data and information on current families of solutions being employed to tackle parts of the problem statement in this research. MCCLL is also linked to the experiment reports conducted by the Marine Corps Warfighting Lab (MCWL). MCWL has a family of experiments that complements this research known as EMO Limited Objective Exercises.

There have also been several NPS theses in this subject field. Robert Gruber completed a detailed study of the propagation of wideband waveforms in shipboard and urban environments. He conducted field experimentation aboard large maritime prepositioning ships currently at long-term dock in San Francisco. He also conducted

urban experimentation aboard Camp Roberts and recorded his findings on radio propagation from differing angles, distances, and building materials (Gruber, 2011).

Joseph Rivera completed thesis work on the implications of MANET systems on the larger network management problems the Marine Corps could face. He tackles the questions of how to implement MANET solutions into the current architecture and what problems and subsequent modifications and tools could be employed in future network architectures. His research will be helpful in framing the more robust system this research proposes into the existing framework of Marine Corps networks, particularly in deployed environments (Rivera, 2012).

Another study, conducted by two more NPS students around the same time as the emerging EMO concept in 2007, details the future need for IP-based radios. It details interoperability problems facing the current family of systems with emerging technology. Also, it makes the case for 802.11 and 802.16 systems along with mesh networks in future operations. Ultimately, this thesis provides further illumination on the emerging requirement incurred by distributed operations (Craig & Tsirlis, 2007).

From a conceptual standpoint, the thesis by Major McHuen and Captain Price provides excellent historic perspective on the EMO concept and its implications for tactical communications. This thesis uses interoperability models in relation to the then-developing enhanced company operations (ECO) schema to determine gaps in existing technology. It then goes on to recommend future developing systems to address these gaps. The interesting concept here is, since it was written in 2009, it was authored at the time of transition from the distributed operations model to the current EMO and, specifically, the ECO models. Their conclusions are further support for this research in that they concluded that a tactical mesh network with voice and data operating at OSI layer 3 with IP-based connection to the Global Information Grid (GIG) is the course of action the Marine Corps should adopt (Price & McHuen, 2009). My proposed research addresses this requirement in light of emerging technologies aimed at fulfilling these requirements.

Colonel Goulding also supports this conceptual framework in his 2009 Marine Corps Gazette article. This is the initial public release documentation of the proposed changes to the infantry rifle company, the fundamental unit of the developing company landing team and the baseline of EMO. Col Goulding proposes a wholly new table of organization for the rifle company to include a distributed scout section and an enhanced headquarters element. The headquarters element would contain new units, such as the company level intelligence cell and the company level operations cell. Both of these subunits would be responsible for command and control, as well as information flow to units in the field and to higher headquarters. As such, their data requirements would be beyond what is currently standard in the present day operating forces. Even the platoons themselves, the functional subunits of the company, would be distributed over larger areas of operation than previously anticipated. Col Goulding makes the case that this new arrangement would require new ways of thinking about operations as well as new technologies to allow for complex operations such as this (Goulding, 2009).

Captain Puff also has published a thesis regarding the management of ad hoc network segments. His conclusions support the development of the system proposed by this research while also offering warnings as to avoiding information overload at the lower levels of the system. He proposes an 8th layer network management system to ensure the right nodes are transmitting the right information in near-real time to increase the value to the warfighter. His work specifically applies to the Trellisware radio suite, but the case could be made for a more generalizable network management system that could work on any family of MANET radios. His study also points out that the requirements of tactical operations will continue to have heterogeneous requirements in terms of technology required. Specifically, there is no golden fleece in this system creation and a combination of multiple technologies with a coherent network management system to monitor standards of data transmission is the way ahead (Puff, 2011).

E. METHODOLOGY

Over the course of my research I was able to work with both the Infantry Officer's course and Marine Corps Warfighting Laboratory as they explored ways of tackling these challenges. I was able to physically participate in multiple iterations of these experiments and was able to make some observations worth comparing and contrasting. Chapter III discusses the results.

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III. FRAMEWORKS AND ARCHITECTURES

This chapter explores the potential solution sets for EMO C2 currently proposed by the Marine Corps. The two principal organizations explored in the course of this research were the Marine Corps Warfighting Lab (MCWL) and the Infantry Officer's Course (IOC), along with their partnership with Marine Corps Systems Command (MCSC).

A. METRICS

The architectures discussed below were evaluated according to a set of common metrics. These metrics are by no means comprehensive, but instead focus on the operational viability of the systems proposed.

System Range—Each system must be able to operate at ranges that exceed the operational ranges of Anti-Access and Area Denial (A2/AD) systems employed by threat nations while also able to take advantage of the standoff provided by long range mobility assets, specifically, the MV-22 Osprey.

System Footprint—Each of the architectures was compared in terms of weight, packed space, and sustainability. These measures were compared against the operationally austere realities specified in Expeditionary Force 21. This addresses the architecture's ability to be sustained without the robust infrastructure enjoyed in the later stages of OIF and OEF.

Technical Capability—This metric is concerned with the data availability within the system itself. It was analyzed in terms of RF performance characteristics and data throughput.

Operational Capability—This is a cumulative metric that takes into account the previous measures of the system. Capability was analyzed in terms of potential for large scale deployment by a Battalion Landing Team (BLT) or greater in a crisis response situation or amphibious assault aimed at gaining access to a denied area.

Each metric was given a rating in terms of capability it brings to the warfighter. The ratings are:

Operationally Acceptable—The stated system and proposed architecture adequately answer the operational imperatives described in Marine Corps planning documents. This is a baseline, ready-to-deploy state that could offer basic functionality with little additional value added.

Operationally Unacceptable—The stated system and proposed architecture do not adequately answer the problem set stated by Marine Corps planning documents. Significant further work is required.

Emergent Capability—The stated system not only can stand alone as a potential answer to the problem set proposed in Marine Corps planning documents, but also provides additional capability that could further serve to enable tactical and operational maneuver in ways not previously directed by doctrine. The system has the potential to be at least a partial game-changer in the way the Marine Corps conducts its operations and provides additional vectors toward mission accomplishment.

B. INFANTRY OFFICER COURSE - TALON REACH

Beginning in 2013, the IOC staff began to explore the problem sets put forward by the Commandant's Marine Corps Vision and Strategy 2025 document. The director of Infantry Officer Course (IOC) recognized that his unit was uniquely positioned to conduct proof of concept experimentation due to his highly trained staff and steady supply of 60–90 infantry officers cycling through the training every 3.5–4 months. As part of the training's culmination exercise, IOC created a final event that would test the equipment and capabilities currently being fielded by the Marine Corps, and specifically MCSC. His students would form a provisional CLT and simulate a long-range crisis response mission, similar to those predicted by Vision and Strategy and EF21 (IOC, 2013). As of this document's writing, this exercise, known as Talon Reach, has gone through three iterations. As these exercises were evolutionary in nature, they were evaluated as a whole using the metrics above.

1. Talon Reach I - March 2013

This exercise was the first conducted by IOC for the express purpose of testing the concepts of EMO against the capabilities of the current C2 equipment set. The mission was to simulate a long-range raid taking place over 96-hours. The objective of this experiment was to test the CLT's ability to operate against an enemy that was equipped with stand-off A2/AD weapons such as the C-802 and C-803 anti-ship cruise missiles (ASCMs). To simulate the long-range requirement, the CLT launched from Quantico, Virginia, and travelled via MV-22 to its objective at Camp Blanding, Florida, a distance of about 500 miles. The distance was such that the Ospreys had to be refueled mid-air en route to and from the objective (IOC, 2013).

The main objectives of this experiment included validating the ability to conduct long-range C2 within an amphibious ship's operations center and to conduct local C2 as the CLT conducted distributed operations against multiple objectives. In order to simulate the long range C2, the CLT was required to maintain voice and data communications to a simulated headquarters element in Quantico as the CLT conducted operations in Florida. To test local C2, the two maneuver platoons operating in Florida were required to attack separate objectives while the CLT headquarters element maintained the ability to coordinate air support and tactical maneuver through timely and accurate local communication. During the initial landing and assault phase of this operation an aerial command node, in the form of a UH-1 Huey command variant, coordinated this C2 with a mission commander and his team in the back of the UH-1 overseeing the operation. This capability was only temporary and lasted only through the initial assault phase. Later, all voice and data communications had to be facilitated by the infantry units on the ground. To further make this experiment more realistic, IOC forced its CLT to operate against an opposing force (OPFOR) of about platoon strength. This OPFOR was given significant leeway to operate as they saw fit, bearing in mind historical precedents for near-peer adversary units. The specific model for operation was the 6–12 man, independently-operating squads with simple cell phone communication employed by Hezbollah in the 2006 action against Israel (IOC, 2013).

a. Equipment Set

In order to conduct this operation, the Marines of IOC were augmented with additional communications equipment not generally found in the average Marine Corps company. In order to facilitate the utilization of this new equipment, IOC placed its communications personnel, taken from the infantry-only main body, and put them through a 5-day intensive course on the new gear. Additionally, the IOC attached Marine Corps communications specialists to the CLT that would normally not be organic to ensure they had mitigated the risk of equipment failure due to human error (IOC, 2013). With this equipment and training, IOC had created an ideal scenario, which, in and of itself, is not completely realistic. However, for the proof of concept experiment, it was wholly appropriate. This equipment set included the following entities (see Figure 6).



Figure 6. Talon Reach I, March 2013 Gear Set (from IOC, 2013)

The PRC-117 was used as a UHF SatCom radio, which connected to the CF-19 as the primary terminal for sending and receiving data. PRC-152s were used as inter-platoon radios with PRC-117s using VHF frequencies to talk between distributed platoons. Both the PRC-117 and PRC-152 require line of sight (LOS) between radios in order to operate. The CLT also used a VideoScout (resembling a modified CF-19) to receive video signals from orbiting UAS systems, as well as video feeds from the Lightning Pods on Marine attack aircraft.

b. Architecture

Due to the reliance on LOS VHF legacy radios such as the PRC-117F and PRC-152 for communications within the CLT, there was little difference between the architecture here and that presented earlier in Chapter II regarding the architecture of present-day Marine Corps operations. The major difference is the presence of SatCom (albeit intermittent) between the CLT headquarters element and HHQ (Figure 7).

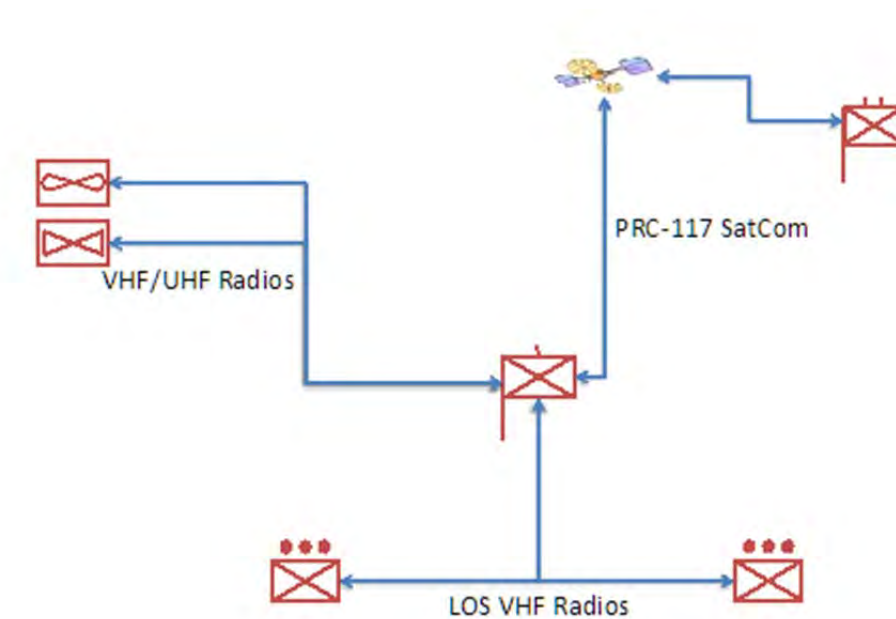


Figure 7. Talon Reach I, March 2013 Communications Architecture

As shown in the diagram above, the internal communications of the CLT is heavily reliant on LOS VHF communications. As such, the platoons in the CLT must operate at closer ranges than if they had their own separate long-range asset. This architecture offers no significant C2 advancement at the tactical level.

c. System Performance

Somewhat predictably, this assortment of equipment proved unreliable and impractical. The IOC After Action Review (AAR) bluntly states “all of the [CLT’s] communications gear seemed way too heavy, too expensive and arguably, for a concept such as the CLT, obsolete” (IOC, 2013). Each piece of gear was developed separately, and as such required complicated instructions and somewhat inventive connection methods to achieve a baseline operational capability.

Additionally, the system described above proved to be extremely inflexible and tactically cumbersome. The Enhanced Company Operations suite provided by SysCom for this experiment (CF-19, digital camera, and associated antennas and radios) weighed 43 lbs (Deane, 2013). All of that weight was required in order to establish a simple SatCom link back to Quantico and enable low-bandwidth data transfer. That is a significant investment in weight given that the individual Marines must carry all equipment for a mission set—Marines who are attempting to conduct a mission for which speed and flexibility are crucial to success. Also, the system incurs a significant amount of setup time and requires that the CLT’s C2 node remain static. This becomes a problem for a number of reasons. Primarily, this limits the flexibility of the patrol base, which is supposed to be able to break down and move on a moment’s notice. Additionally, while the patrol base is moving and the system is down, the CLT loses all connectivity to their higher headquarters. This presents a potentially dangerous situation where a unit could be in transit and come under attack en route. In this case, they would be forced to set up a system, which is difficult under the best of conditions, while under fire. To compound that, it is likely the headquarters and support units for that CLT would lack current awareness about the crisis situation until communications could be established.

Another critical shortfall in this system was the information blackout that occurs for the unit while in flight. Again, the purpose of this exercise was to simulate the likely scenario where a crisis response force is scrambled into the air for a multi-hour long flight that may even include aerial refueling. During this flight, the Marines inside the cargo bay of the Ospreys have no way of receiving situation updates or real time intelligence while in flight unless it is passed through the aircraft's voice radios, which then must be relayed by the pilots to the troop commanders. Despite the additional communication gear provided to the CLT in this exercise, they were unable to receive updates for the duration of their transit across nearly half the length of the United States' eastern seaboard. Their first update with on-site ISR and the C2 helicopter was when they were 10 minutes from the landing zone (LZ) (IOC, 2013). This does not allow for any effective in-stride planning or modifications given new and potentially life-saving information from reconnaissance forces on the objective or other ISR assets.

In contrast, despite the OPFOR being outnumbered by a 2:1 ratio, and without the maneuverability of MV-22s or drone surveillance assets, they were consistently able to conduct more efficient C2 and more flexible maneuver using commercially available smartphones and simple GPS-based location applications. Essentially, the most advanced C2 equipment IOC was capable of fielding was outpaced by a cell network and hardware with a much smaller footprint (IOC, 2013, pp. 3–4). In conversations with the IOC staff, it is apparent that this observation has led to a significant feeling of embarrassment and frustration in the equipment solution sets currently provided to Marines.

2. Talon Reach I - December 2013

As the follow-on exercise for the September iteration of Talon Reach I, and with a new wave of students and additional resources, IOC executed a second iteration of Talon Reach I to tackle a similar problem set as the original exercise. The December Talon Reach I also focused on the Marine Corps' capability to conduct crisis response at long range, however, it altered the scenario to make the execution more complex. Instead of being a 96-hour raid, this scenario closely resembles the sort of missions assigned to the new Marine Corps Special Purpose Marine Air Ground Task Forces (SPMAGTFs) in

Europe and Africa following the massacre in Benghazi, Libya in 2012. Specifically, this mission was to test a “CLT-like” unit’s ability to conduct a 1000-mile crisis response mission in one period of darkness (IOC, 2014).

The exercise began just before sunset with the CLT launching in MV-22 Ospreys from Twentynine Palms, California, to respond to a simulated threat on a U.S. embassy and its personnel over 1000 miles away in Ft. Hood, Texas. At 450 miles from the objective, the Ospreys were refueled mid-flight. The transit time to the objective lasted over four hours. During this time, the assault force was able to utilize their newly acquired ANW2 network through the use of the new PRC-117G and communicate via a chat application between aircraft. Once at the objective area, which was an urban training environment, the assault force was divided up into several distributed units with one section securing the notional U.S. Embassy and another fast-roping onto the roof of the notional ambassador’s house. Later, another force was sent to deal with an enemy force outside of the immediate urban center. Once all U.S. assets were secure, the CLT consolidated their forces and extracted via the same Ospreys on which they had arrived for the transit back to Twentynine Palms, all before the sunrise (IOC, 2014).

The exercise was a success in that it proved that Marines are capable of conducting long-range crisis response in a manner that could respond to future Benghazi-like situations. This was largely due to the addition of new C2 equipment.

a. Equipment Set

The major difference in terms of equipment for this exercise compared to the September iteration was IOC eschewing the bulky CF-19 Toughbooks, PRC-117Fs, and PRC-150s in favor of the smaller, more capable PRC-117G, the newly fielded Distributed Tactical Communications System (DTCS) radios, and Android tablets, as shown in Figure 8.



DTCS Radio



PRC-117G



Marine with Samsung Tablet

Figure 8. Talon Reach I Gear Set, December 2013 (from IOC, 2014)

The DTCS radio is essentially a satellite-based push-to-talk (PTT) radio. It operates by using the commercial Iridium satellite constellation. In conversation with Marines using the device, it is favored because when it is set up properly, it requires almost no training to employ. To the average user it is simply another “walkie talkie” style radio that simply works when VHF communications fail. In the IOC exercise, these devices became the primary voice C2 method to the HHQ element in Miramar, California, as well as the primary voice C2 internal to the CLT as it moved between its multiple objectives. Further, as the CLT units became more distributed, they faced the problem of losing voice communications with each of the sub-units as they maneuvered due to the legacy VHF, LoS communications equipment’s (PRC-152s) inability to provide the range or flexibility required by the mission. DTCS became the primary C2 net throughout the unit, and at one point it was the only way in which the command element was able to continue to process fire support missions by using the position location information (PLI) that is simultaneously broadcast during voice transmissions between DTCS radios (IOC, 2014).

Additionally, the PRC-117G's addition allowed the CLT to utilize the ANW2 data network. The technical aspects of this network are discussed later, but the major takeaway in this exercise was the highly acclaimed added capability of conducting text chat and limited data transfer between units while airborne. This begins to address the lack of situational awareness while in transit as discussed in the previous exercise as updates from the air crew could be pushed across the text chat network between separate elements of the assault force. The PRC-117G can also be used in simple VHF/UHF voice communications like legacy equipment as well as interface with UHF satellite communications using static, deployable antennas.

The Samsung Android OS tablets proved to be the greatest paradigm shifting equipment item in this experiment. Using these systems, in conjunction with some simple mapping and imagery and chat applications, Marines in the exercise assault force were able to greatly increase the situational awareness of the Marine leadership during this exercise. These tablets connected via an 802.11 Wi-Fi device attached to the PRC-117G, allowing the tablets to communicate on the ANW2 data network. This device uses Suite B encryption over its Wi-Fi link, requiring the PRC-117G to re-encrypt traffic to military standards prior to broadcast to another PRC-117G node. With the PRC-117Gs multicasting the ANW2 signal, each tablet was able to see information being shared between each PRC-117G. This, with the addition of simple applications, created a rudimentary collaborative information environment with shared data and awareness.

b. Architecture

Both the ANW2 network and the DTCS network were combined with the legacy NET-T network used in satellite communications between the MV-22s and their headquarters element. The PRC-117G radios are able to multicast their ANW2 signal so that each radio on that network will share the same situational awareness data. This is how the collaborative information environment was possible while the unit was in the air as it used multiple chat rooms to provide updates and refine planning (Figure 9).

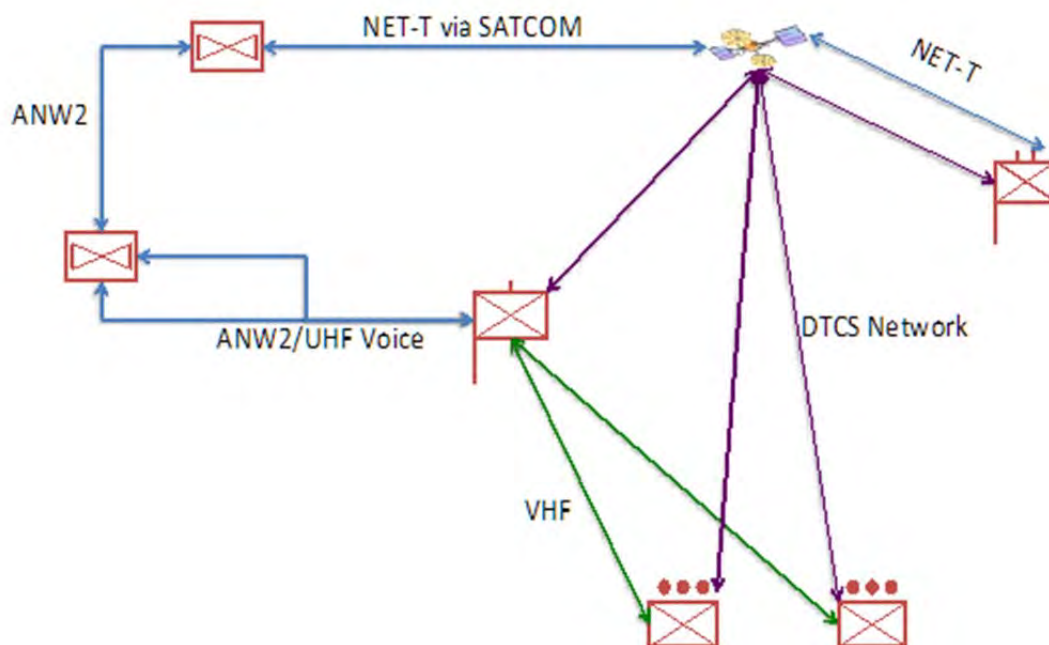


Figure 9. Talon Reach I, December 2013

In the absence of a C2 Osprey, which could relay the ANW2 signals, the DTCS network served as the backbone of internal voice communications, as well as long-range communications to HHQ.

c. *System Performance*

This new architecture begins to answer some of the problems put forward by the initial iterations of the Talon Reach exercise series and addresses necessary capabilities implied by EF21. The addition of peripheral devices at the tactical edge greatly increased the situational awareness of Marine leaders en route to their objective. Since each aircraft had at least one Marine leader with a tablet connected to the ANW2 data network, the old tradition of the assault force being “in the dark until the ramp drops” is beginning to fade away. It should be noted, however, that the limited bandwidth of the ANW2 waveform tends to be the main limiting factor. Technicians from MCWL claim that it stays around 40 kbps in terms of data transfer. This limits the CLT’s ability to fully integrate assets like full motion video (FMV) from ISR assets tasked against the objective, particularly while en route.

Additionally, while the addition of the PRC-117G was a great boost to the assault force, its limited numbers often left maneuver units reliant on their legacy VHF radios. This resulted in a potentially unsafe and tactically unsound situation when an enemy air defense threat was revealed during the course of the mission. Given the assault force's reliance on their air assets and operating so far from friendly lines, this asset received the highest priority for kinetic targeting. However, the Joint Terminal Air Controller (JTAC) assigned to the CLT headquarters element was unable to rapidly gain the necessary situational awareness in terms of friendly positions so that he could employ fire support safely and without the possibility of fratricide. This was due to lack of performance on the part of the legacy VHF communications that were the primary method of internal communication within the CLT. The CLT was able to rapidly flex its plan and instead used its DTCS radios and their associated PLI information to safely clear fire support (IOC, 2014). This demonstrates, however, the necessity for a local network that can support a data-rich environment and simultaneously update PLI, situational awareness, transmit coordinating instructions, and also retain simple voice communications. The fluid environment of crisis response requires that this network be fully functioning before the ramp of the Osprey ever touches down and must be robust enough to react to a rapidly changing battlefield.

3. Talon Reach II- March 2014

Leveraging the lessons learned from the previous exercise under Talon Reach I, IOC sought to further refine their employment of the ANW2 network with its associated PRC-117Gs and Android Tablets to create a more robust data network in a long range raid on a simulated enemy A2/AD asset, specifically a C-802 ASCM site located on San Clemente Island, California. To simulate launching from amphibious shipping, the mission was launched from Twentynine Palms, California, which essentially puts it as the mirror image of the ship locations represented in Figure 10. The primary objectives of this exercise were to further test the system's ability to maintain C2 while en route to the objective, to facilitate coordination of fire support assets before, during, and after debarkation of the assault force, and to test the system's ability to maintain connectivity

to the aerial assets and their associated C2 nodes on station during the assault once debarkation was complete.

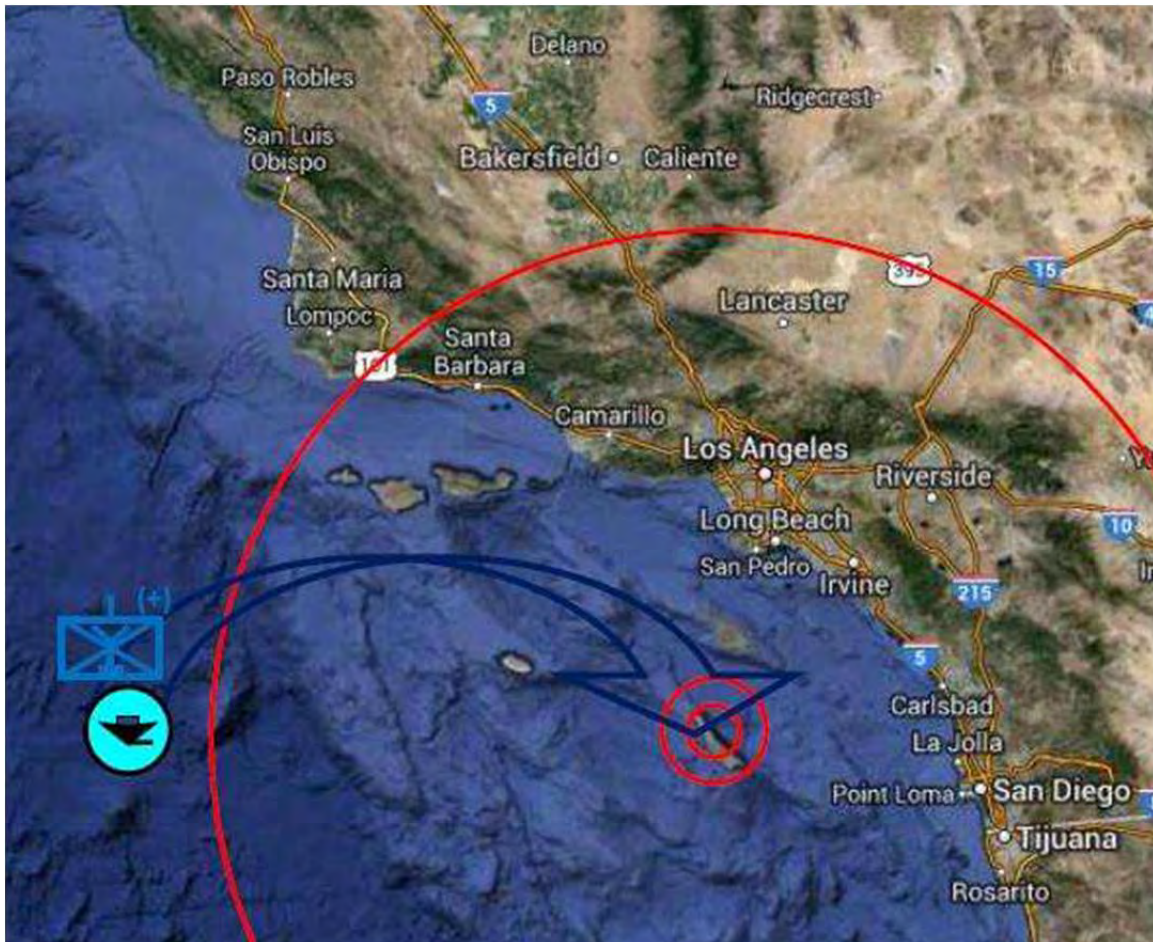


Figure 10. Representation of C-802 Threat on San Clemente Island
(from IOC, 2014)

Unique to this experiment was the employment of what is doctrinally referred to as a Fire Support Team [Airborne] (FST(A)). The FST(A) is a small cell of fire support subject matter experts combined with an infantry officer that provide the necessary coordination between artillery, naval gunfire assets, and close air support sorties while ensuring their usage is closely tied to the assault force mission commander's scheme of maneuver. This team remains airborne during the chaotic initial assault, often employing their fire support assets before the first transport aircraft disembarks the first wave of

Marines. For this exercise, the FST(A) was placed in a specially modified MV-22 Osprey that was configured to be a C2 variant. This Osprey housed two PRC-117G radios in the crew compartment and had additional cabling to provide easier access for the passengers to the aircraft's organic radio networks (IOC, 2014).

As for maneuver, the two platoons were disembarked at separate objectives about 3 km apart from each other and without line of sight between them, as shown in Figure 11.

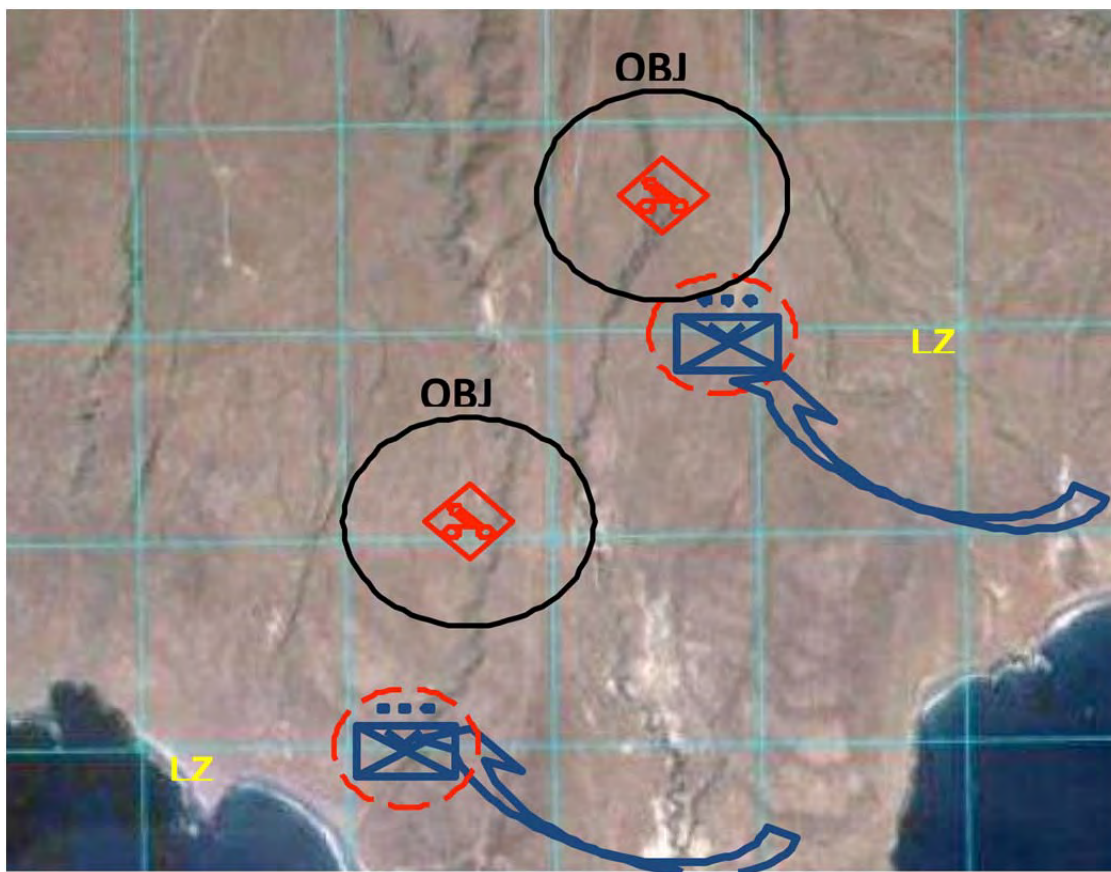


Figure 11. Talon Reach LZ Locations (from IOC, 2014)

Once the two platoons secured their individual objectives, they conducted link-up on higher ground, reorganized themselves, and began a 23 km (~14 mile) nighttime foot movement to their final objective, which in this exercise was an enemy airfield. In order to facilitate faster movement, the CLT employed hand-launched UAS in the form of the

Wasp UAV platform. This was used to scout ahead and allowed the CLT commander greater confidence in recognizing potential threats before his unit encountered them.

As in Talon Reach I, this operation took place during a single period of darkness. The initial assault took place at sunset, with the movement-to-contact the airfield taking the entire night. This again demonstrated the necessity for a network that provides key functionality prior to the first Marines debarking the transport aircraft.

a. Equipment

This exercise used largely the same equipment set as was used in the Ft Hood exercise in December 2013. They had, however, increased the number of PRC-117Gs and used the Wasp UAV. The CLT again used Samsung tablets with the Killswitch application and a simple chat window called CowChat (IOC, 2014). These applications also utilized the ANW2 network formed by the PRC-117Gs. The Wasp was unable to interface with this ANW2 network due to software compatibility issues, limiting the benefit to situational awareness to only those directly viewing the video feed from its associated laptop and control base station.

b. Architecture

The architecture of this network was very similar to that of the December iteration of Talon Reach I. Again, DTCS played a vital role in beyond line-of-sight communications. Its associated PLI information was also collected at the HHQ facility in Miramar, CA. Additionally, the FST(A) was able to use the aviation radios to conduct an aerial relay of information to HHQ during the initial assault. The major change was the more robust usage of the ANW2 network while in flight, as well as the inclusion of the FST(A) (see Figure 12). This FST(A) was able to receive targeting information via the Killswitch application on their tablets through the ANW2 network from the assault force. They could then use their internal radios to coordinate with outside assets, such as the gunship support and the advanced J-35 radar systems being tested in parallel with this exercise. Once the initial assault was complete, the FST(A) was disembarked and rejoined the CLT main body. At that point they were reliant on DTCS for long-range

communication to HHQ while they retained their ability to use the tablets on the ANW2 network for targeting.

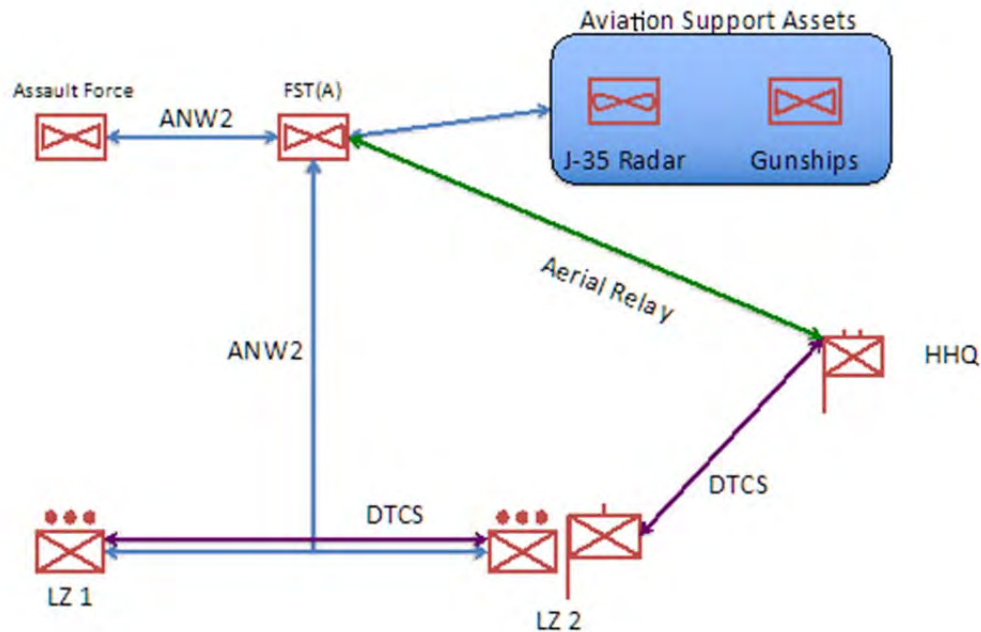


Figure 12. Talon Reach II Architecture

c. System Performance

A common thread of architecture and techniques, as well as equipment employment, emerges throughout the IOC Talon Reach experimentation campaign. In particular, the PRC-117G and its Wi-Fi transmitter, the Fortress system, and the associated tablets with their applications provided an impressive improvement in C2 capability at a small unit level. The 5–20 Watt power output of the portable PRC-117G allowed it to transmit over impressive distances when compared to legacy radio systems (Harris, 2014). The tablets and their applications greatly increased situational awareness both on the ground and in the air while in transit. However, the baseline capability of the ANW2 network was a limiting factor with respect to supported data richness. The bandwidth of the network during this exercise was limited at 5Mhz due to base restrictions. This resulted in the previously mentioned low throughput of 40kbps (max). This low data capability was successful in transmitting basic information, such as text

chat and PLI. However, this low rate precluded large file transfers such as high-resolution photography and FMV. It should be noted as well that all imagery and map files had to be pre-loaded on each tablet. The low data rates precluded retrieving map data from an off-site server. Also, due to equipment compatibility and availability, not all of the C2 nodes on the network were able to take full advantage of the system. That is to say, there was no C2 software that combined the PLI data from DTCS with the internal GPS of the tablets and PRC-117G radio nodes, nor the coordinating data being transmitted across the local ANW2 network in the field. This resulted in a lack of true end-to-end connectivity. However, in fairness to IOC, the inclusion of larger HHQ assets and more equipment would require a larger staff and more resources than are immediately available to that small unit. Again, the focus of this campaign of experimentation was to serve as a proof of concept and to provide realistic field-testing of unproven systems and concepts while also recording emergent techniques and procedures for expeditionary C2. For a larger scale test bed that could equate to the scale of a Battalion Landing Team (BLT) or higher-level unit, we must turn to the campaign of experimentation by the MCWL.

C. MCWL ECO AND EMO TEST BEDS

In response to the Commandant's planning guidance, the Marine Corps Warfighting Lab (MCWL) has undergone a series of experiments to test current capabilities and develop new techniques and technology in order to enable EMO. Their campaign of experimentation was born out of the previous campaign, which explored distributed operations, specifically, enabling this type of operation in areas such as Afghanistan's Helmand province, drawing from lessons learned in the Iraq war.

There are a few major differences between their experiments and those conducted by IOC. First, there is the matter of scale. IOC was focused on the CLT by itself; IOC was only concerned with proving functionality inside a low level unit. MCWL, however, has applied the same concepts on the scale of a battalion (reinforced) landing team (MCWL, 2009). Secondly, there is a fundamental difference in mentality as far as equipment footprint is concerned. The IOC experiments were solely focused on equipment that could be transported on the backs of Marines as part of an assault force.

MCWL explores options including internally transportable vehicles and externally hoisted heavy artillery pieces. These additions provide both enhanced functionality as well as additional requirements for C2 capabilities. Thirdly, there is a difference in the C2 equipment set being used. MCWL is exploring Ku- and Ka-band SatCom links as well as introducing MANET systems at the tactical edge, whereas IOC is focused on implementing more thoroughly vetted programs of record such as its PRC-117G.

Like the IOC campaign of experimentation, the MCWL campaign has been incremental in nature. It began under the title of Enhanced Company Operations (ECO) Limited Objective Experiments (LOEs) and has since evolved into Enhanced MAGTF Operations (EMO) LOEs.

1. ECO LOE 4

The ECO LOEs were focused on exploring technologies and techniques which would allow multiple CLTs to operate in a disbursed environment where each CLT was not necessarily directly mutually supporting, that is, not directly capable of offering fire support to their adjacent units and vice versa (MCWL, 2010, pp. 7–8). The objectives of this experiment included testing a new equipment set that would enhance the CLTs ability to coordinate between each other as well as an off-shore HHQ element. Another objective was to test the current architectures and techniques while adding the additional requirements of fire support coordination and control and logistical sustainment.

This experiment took place on the island of Oahu, Hawaii. There were two main objective areas, per the graphic in Figure 13. Golf Company, 2nd Battalion, 3d Marines (G/2/3) was selected as the experimental unit. Its three platoons were embarked in such a manner that the ranges between them locally and over the horizon to HHQ were beyond the capacity of current communications equipment (MCWL, 2010, pp. 21–28). Additionally, G/3 (third platoon) was given an attached artillery battery to provide local fire support for the CLT. This artillery integration at such a low unit level is not a doctrinal template for the Marines, and is a result of the Expeditionary MAGTF Fires (EM Fires) experiment conducted by 3d Battalion, 7th Marines in 2010, which will be discussed later (3d Battalion 7th Marines, 2010).

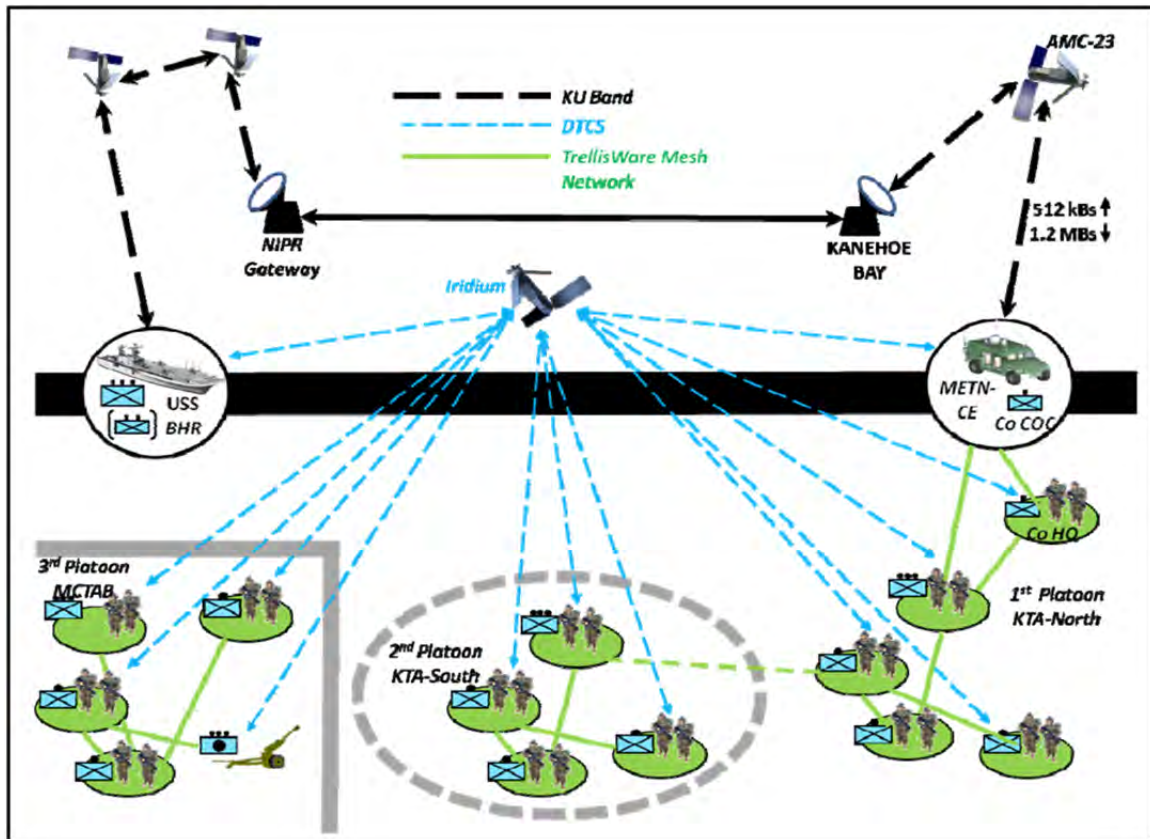


Figure 13. Force Layout for ECO LOE 4 Experimentation Unit
(from MCWL, 2010)

As seen in Figures 13 and 14, the force was divided up so that the force at KTA would provide organic fire support in the form of artillery to the other units maneuvering around the island. This artillery addition required the inclusion of its associated C2 node, the Fire Direction Center (FDC). This posed additional strain on the C2 architecture being used on the island. Once all forces were ashore, the experimental control division (EXCON) employed an OPFOR against Golf Company to stress test their C2 capabilities.



Figure 14. Force Layout in ECO LOE 4, KTA and MCTAB are Objective Locations (from MCWL, 2010)

a. *Equipment*

This experiment contained several different pieces of equipment from the suite used by IOC. The principal exception here was the widespread use of the DTCS radio (MCWL, 2010, p. 8). These DTCS radios were configured in such a way that had a more limited range than the versions later employed by IOC, with a maximum range of around 150 miles (MCWL, 2010, p. 8). However, they ended up forming the backbone of the distributed communications network.

MCWL also introduced a MANET for local networking in this experiment. In order to form this network, they employed the TrellisWare family of radios. Specifically,

they employed the TW-200. This radio was able to create a simultaneous voice and data network for use at the tactical edge of this operation (MCWL, 2010, p. 8).

Lastly, the major addition to this network was the introduction of the Mobile Expeditionary Tactical Network-CLOC Enabler (METN-CE). The METN-CE is a modified HMMWV (Figure 15). The vehicle contains all the communications equipment necessary to maintain the different networks in use by the unit, as well as a small laptop-based server and data management system for reachback to HHQ offshore. It uses a Ku-band SatCom data trunk for file transfer and is able to simultaneously monitor multiple DTCS networks (MCWL, 2010, p. 35).



Figure 15. METN-CE

It should be noted, however, that despite this experiment taking place in 2010, with a well-established commercial mobile device market, no smartphones or tablets were employed in conjunction with the experimental network. Rather, the CLT was forced to work on laptops, either aboard the METN-CE or with smaller, ruggedized laptops at the platoon-level (MCWL, 2010, p. 36). While not explicitly mentioned in the

report, the results of working with laptops at the tactical edge would almost certainly mirror IOC's experience in their original Talon Reach experiment in Florida.

b. Architecture

The operational layout of this exercise has some striking similarities to that used by the IOC team. Both templates call for a long range landing beyond the horizon from an offshore HHQ unit. Both templates also call for the internal units of the CLT to operate in a distributed manner, putting their units beyond line of sight. However, the communications architecture of the two experiments is fundamentally different. In the IOC experiment, the focus was on long-range Osprey raids. A key component of heliborne operations is the concept of redundancy. Aircraft can be lost prior to or during a landing due to equipment failure or hostile fire. Each component of the landing force must be able to achieve some level of basic functionality, independent of other landing units. For this reason, the IOC architecture ensured that each platoon in the CLT had virtually identical communications suites. However, in ECO LOE 4, MCWL opted to adopt an architecture that relies more on one central C2 node, the METN-CE. They adopted this architecture because of their stated requirements to transfer larger data files to and from the field unit, such as map overlays and imagery (MCWL, 2010, p. 35). MCWL cites the low data throughput rate of the DTCS (2.4 kbps) as the driving factor in adopting a Ku-band SatCom link. Current technology in use by MCWL requires this Ku system to be supported by a vehicle due to its increased data footprint.

Another principal difference in the C2 architecture is the introduction of a true MANET into the network. In the IOC experiments, only a few PRC-117Gs were fielded which could provide a distributed data network. With the introduction of the TrellisWare radios, this architecture evolves from a rudimentary network based on Routing Information Protocol (RIP) to a dynamic, self-healing, and algorithmically routed data environment with the added capability of providing PLI to network managers and enhancing situational awareness of friendly forces (MCWL, 2010, p. 34). For a diagram of this architecture, refer back to Figure 13.

c. System Performance

Like the IOC experiments, the MCWL 2010 LOE 4 proves that the types of operations listed in documents such as EF21 are technically feasible through a modernization of MAGTF C2 assets (MCWL, 2010, p. 10). The analysis report for this experiment largely lists its success as being due to the performance of the DTCS network. Heavy traffic congestion is cited as being the principal problem with this DTCS network; however, the observers conclude that this is more a result of a lack of adequate training on the new system rather than the fault of the hardware itself (MCWL, 2010, p. 10).

The inclusion of the TrellisWare radio systems seems to have drawn considerable excitement from the individual Marines in this experiment. Basic functionalities, such as range and voice quality, were a marked improvement over legacy equipment, which at the time were PRC-152s and PRC-117Fs. However, the analysis notes that the TrellisWare system is “more than just a radio,” despite its use as solely a voice communications asset (MCWL, 2010, p. 11). All data at the tactical edge, with the platoons and squads not co-located with the METN-CE, was forced to go through the DTCS system. This, combined with the noted lack of additional peripheral devices, left the Marines with no way with which to take full advantage of the significantly higher throughput of the TrellisWare radios, if only to use them to create a LAN.

The operational feasibility draws some concern as well. As stated, this architecture relies heavily on the vehicle-based METN-CE for network management and the sustainment of the data trunk. MCWL notes that the METN-CE would have lost its Ku-band link had it gone mobile during this operation (MCWL, 2010, p. 35). Combined with the platoons’ requirement to have an open laptop to sustain a data link rendered the CLT largely immobile. This is the major drawback between this experiment and those conducted by the IOC team. The IOC equipment suite was tailored to a rapidly moving force, able to respond to changing situations with much greater flexibility. While the MCWL architecture added significant long-range data capability in the form of its Ku-band link, the expense was flexibility. If the METN-CE was required to go mobile, then the whole unit would be reliant on the DTCS network.

2. MCWL RIMPAC 2014 Full System Test

As stated earlier, the 2010 ECO experimentation campaign was the culmination of the ECO program. That program would then give rise to the EMO program, which culminated with the 2014 LOE as part of Rim of the Pacific (RIMPAC) 2014 exercise. As this exercise was taking place at the time of this writing, its performance data was not currently available. However, I was able to observe the full systems test (FST) aboard Marine Corps Base Quantico prior to the equipment's deployment to Hawaii to participate in RIMPAC 2014.

As with LOE 4, this experiment largely focused on the Marines' capability to land and operate in a distributed manner while testing and evaluating the CLT concept as a whole. However, the EMO experiment was designed on a larger scale; instead of one CLT operating in a distributed manner, the MAGTF would deploy three CLTs comprised of Marines integrated with multinational forces. A single Marine company formed the backbone and C2 structure of the landing force, with each CLT containing one or two U.S. Marine platoons, partnered with two platoons from Canadian, Malaysian, Tongan, Australian, Indonesia, and New Zealand units (MCWL, 2014).

Each of these CLTs was expected to operate independently of others in its respective objective area. Unlike the previous ECO experiment, the direct augmentation with a full artillery battery was not anticipated. However, each CLT would be required to operate multiple Raven UAVs, manage a robust Combat Operations Center (COC), and coordinate airspace and fires deconfliction, as well as the enduring tasks of logistics and security. These tasks were expected to be considerably more difficult given the distributed nature of the operation, the multinational nature of the force, and the limited accessibility of the training areas in Hawaii where the experiment was to take place (MCWL, 2014). The CLT units would then be opposed by an OPFOR to stress-test the C2 architecture and the systems themselves.

a. Equipment

For this experiment, MCWL made a complete departure from existing C2 programs of record. The experimental force was not provided any legacy PRC-117, PRC-

152, or PRC-150 radio sets, as had previously been used by MCWL and IOC. Instead, the experiment relied heavily on software-defined equipment and IP-protocol driven communications methodologies (MCWL, 2014). The primary network for this experiment was implemented with the TrellisWare family of radios. This was augmented by newer, improved DTCS radios, as before. The major addition to this architecture, which seems to partially mimic that of LOE 4, is the added application layer, the Integrated Capabilities Application, in the data network and the inclusion of a new C2 node, the Marine Expeditionary – Light (ME-L), as shown in Figure 16.



Figure 16. ME-L; Front Tray Extended

The ME-L, is a compact Jeep-like vehicle that can be internally transported within a MV-22 Osprey. This vehicle is designed as an integrated communications node. Both DTCS and TrellisWare radios are integrated into its onboard systems, which allow the users to monitor multiple networks at once. Additionally, there is an onboard server that

manages the software application suites in use by the CLT as well as acting as a data and network management system (Figure 17). For this experiment, the CLTs were given an application suite known as the Integrated Capabilities Application (ICA), which comes in a laptop-based form as well as a mobile form for tablet users at the tactical edge. This ICA software serves to provide a common operational picture for units on the network, sharing information between units and providing information regarding the battlespace to the end user as well as HHQ. Additionally, units were also provided the Advanced Field Artillery Tactical Data System (AFATDS) software running on a ToughBook for their indirect fires control units. The TrellisWare radios serve to provide the physical and data link layers for these applications. These networks are then controlled by the ME-L, which controls the primary data connection to the offshore HHQ and logistics units.



Figure 17. ME-L Internal Servers and Network Management

Each ME-L uses a Ku SatCom dish to provide long-range backhaul and its onboard server controls this data flow. DTCS systems are also integrated but are largely considered a secondary connection for use in on-the-move scenarios since the Ku link cannot be sustained while the ME-L is mobile. Lastly, the airborne layer of this system was provided by the TrellisWare radios. They were simply programmed to operate on single UHF, single-hop channels much like legacy equipment (MCWL, 2014).

b. Architecture

Conceptually, the addition of the ME-L simplifies the C2 architecture for this experiment. Each CLT operates its own TrellisWare subnet, with the channel distribution behaving much the same way it would in legacy systems. Companies would have two command networks with each platoon having its own internal network. Being that these self-forming networks are provided by intelligent MANET radios, each network creates its own area of connectivity for peripheral devices to support the ICA suites. Concurrently, the DTCS network acts as a secondary voice communication method in long-range distributed operations situations or when the ME-L backhaul is down. Each unit is able to communicate with aviation assets since they have a channel on the TrellisWare that allows for simple UHF communication. This results in a relatively straightforward architecture in the physical domain of the network, as seen in Figure 18.

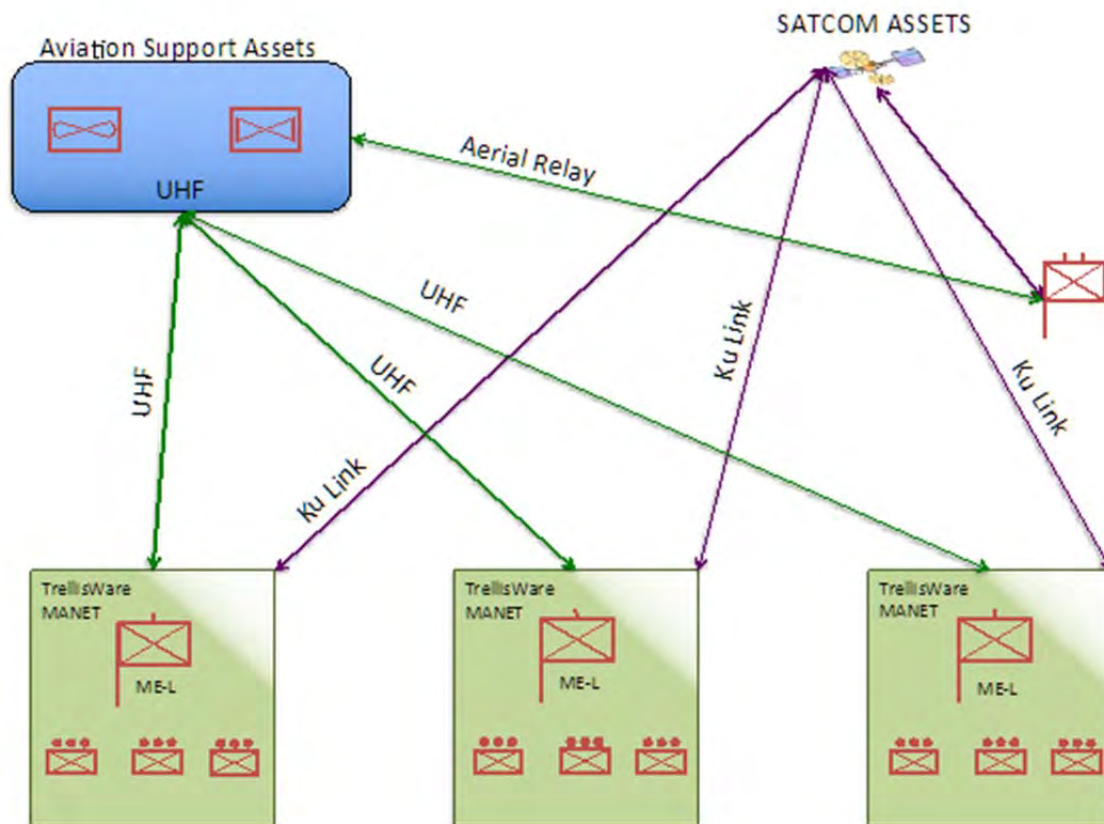


Figure 18. MCWL FST Architecture

However, the architecture becomes more complicated when viewed in the logical space. Each TrellisWare network must be configured with consideration for the distribution of nodes in the IP address space. This requires substantial setup and pre-programming on the part of communications specialists. The relatively low throughput of the Ku-Band SatCom system aboard the ME-L, in addition to the application layer requirements of the ICA, requires the ME-L to act as the control node for all traffic on the local network. It must both manage what is backhauled to the HHQ units as well as what data is available and shared among the subordinate TrellisWare data networks.

When multiplied by the scale of three CLTs and the additional logistical and operational control nodes present at the HHQ level and all associated application layer role names and connections, the architecture becomes much more complicated. As this IP-centric architecture is new to the Marine Corps, there are not standard ways of

assigning role names and IP space on a MAGTF scale with multiple landing teams. Policy and procedures are necessary to minimize confusion and mitigate human error.

c. System Performance

All observations regarding this potential solution set were taken at the time of the FST in March 2014. Further data is expected to become available following the completion of the RIMPAC 2014 exercise. However, there are a few items of note to be taken from the FST.

First, the data rates between the individual Trellisware radios far exceeds that of the ANW2 network and its associated PRC-117Gs in use by the IOC campaign of experimentation. Figure 19 is a throughput chart provided by MCWL following their FST.

	Unicast (Mbps)				Multi-hop / Multicast (Mbps)			
Voice Channels	1 Hop		2 Hop		Priority		Default	
	Max	Min	Max	Min	Max	Min	Max	Min
0	7.78	1.08	3.89	0.54	2.60	0.27	0.64	0.26
2	7.37	1.02	3.69	0.51	2.46	0.26	0.60	0.24
4	6.85	0.95	3.43	0.48	2.29	0.24	0.56	0.22
8	5.30	0.73	2.65	0.37	1.77	0.18	0.43	0.17
12	4.06	0.56	2.03	0.28	1.36	0.14	0.33	0.13
Link Quality = Blue					Bandwidth = 20MHz			

Figure 19. TrellisWare Data Rates for March 2014 MCWL FST
(from MCWL, 2014)

It is these higher data rates that enable a much more robust, data-rich operational C2 environment. This allows applications (i.e., AFATDS and ICA) to share a single data network and remain effective. However, the speed of the local MANET will continue to

be limited by the throughput of the Ku SatCom asset on the ME-L for data passed between HHQ and edge units. In the FST, this Ku system was able to handle 2 Mbps for throughput. This puts additional requirements on the local servers aboard the ME-L to prioritize data transmission and apportion the long-range backhaul between the applications on the network as well as voice channels.

Secondly, there have been some concerns with the ME-L itself. In conversation with Marines and engineers aboard MCWL, doubts were expressed about the vehicle's reliability as well as its general capabilities as an off-road vehicle. Anecdotal accounts cite the vehicle as having poor maneuverability and limited capacity in unimproved road environments, in addition to reliability issues. While this is understandable in a prototype, it does raise concerns as to the viability of a Jeep-like vehicle in extreme austere environments, such as unimproved mountainous terrain and jungles. The ME-L, in its current configuration, is the single point of failure for this architecture. This poses logistical as well as operational risk on the unit. Its maneuverability and survivability will limit the maneuverability of these small units if it is not redesigned to tackle the challenges of difficult infantry deployments, as taken from historical context.

D. FINAL SYSTEM EVALUATIONS

Each system, when compared using the metrics discussed earlier in this chapter, highlights its own advantages and disadvantages. Presented below is a short summary of my evaluation of each system with a short amplification as to the scoring. The reader should bear in mind that the standards for these evaluations are taken from the implications of the EF21 document and the emerging missions and areas of operation for the Marine Corps of the future.

1. Talon Reach

The Talon Reach campaign of experimentation combined the capabilities of the currently fielded Marine Corps' equipment set with some modest additions in order to achieve results in real-world scenarios. These scenarios are taken straight from the EF21 document in that they require the landing force to conduct network centric C2 in the austere littorals (real and simulated) in order to achieve objective success in a denied area

(USMC, 2014, pp. 6–9). While the CLT was able to achieve a measure of success, there were some artificialities built into the training evolution, largely due to support or equipment limitations. Namely, while the PRC-117G performed admirably when compared to its current generation peer radios, it alone is incapable of achieving the prescribed 65 nm range as per EF21. The system is capable of being retransmitted, however, this would require persistent aerial relay, or multiple terrestrial retransmission sites, rapidly increasing the support requirement for this system. The addition of the DTCS system may seem like an apparent solution, however, the DTCS data rates are inadequate to support a truly net-centric unit, as described by EF21. This lack of over-the-horizon data rich connectivity in support of user-oriented applications leaves this system largely lacking in the category of technical capability. This solution set’s major benefit, however, is its footprint. All systems in this suite of hardware could be carried by a lightweight, maneuverable assault force without the need for fixed sites or heavier ground vehicle support. This family of systems is a rough analog of current-generation systems and requires little form factor changes for the end users. Overall, while this is a positive step for Marine Corps C2, it is still inadequate to the requirements of expeditionary net-centric C2 requirements (Table 1).

Table 1. Talon Reach Rating

	Unacceptable	Acceptable	Emergent
System Range			
System Footprint			
Technical Capability			
Operational Capability			

2. MCWL LOE 4

The added resources of MCWL led to them being able to produce a more robust system, unconstrained by existing programs within the Marine Corps Table 2). The addition of the MANET in the form of TrelliWare radios provided a significant

terrestrial-based communications improvement, with each radio conducting intelligent OSI layer-2 forwarding and updating link statuses. The DTCS radios were again used to provide longer-range communications, and even limited text chat functionality with PLI inputs. However, the data rates available to the network through the employment of the higher-throughput TrellisWare radios were not employed. Instead, the network was treated like an intelligent voice-centric radio network. All major data backhaul was conducted with the use of the Ku-band satellite antenna mounted on their METN-CE vehicle. Individual data terminals came in the form of full laptop computers, vice smaller mobile devices. This greatly increased the footprint of the system and countermands the EF21 requirement for the CLT to be a lightweight and maneuverable force, capable of communications on-the-move (USMC, 2014, pp. 8, 35–36).

Table 2. MCWL LOE 4 Rating

	Unacceptable	Acceptable	Emergent
System Range			
System Footprint			
Technical Capability			
Operational Capability			

3. MCWL RIMPAC 2014 FST

The MCWL RIMPAC 2014 FST constitutes a massive leap forward in Marine Corps expeditionary C2. By taking full advantages of the TrellisWare MANET, tactical units are afforded a simultaneous voice and data network with a throughput rate that far exceeds the ANW2 systems currently in use. While company command posts were still afforded the computing power of laptops, the individual tactical units are provided with lighter tablets while still affording them enhanced battlefield situational awareness and greater accessibility to data than was previously possible. These peripheral devices feed into the larger battlefield network and provide the necessary inputs, in conjunction with PLI from the TrellisWare and DTCS radios themselves, for a comprehensive COP for

decision makers. Effective system range is enabled by the MANET locally as well as the links made available to the end user by bridging the MANET with the Ku SatCom link. However, the system's footprint still raises questions (Table 3). The viability of the current version of the ME-L and the operational implications of a single point of failure raise significant concerns.

Table 3. MCWL RIMPAC 2014 FST Rating

	Unacceptable	Acceptable	Emergent
System Range			
System Footprint			
Technical Capability			
Operational Capability			

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IV. PROPOSED ARCHITECTURE

Building on the advances of the MCWL and IOC campaigns of experimentation, this chapter seeks to propose another methodology and potential framework for achieving the objectives of expeditionary C2 for the Marine Corps. This chapter will focus on three key areas. First, it will address the implications for advances in MANET technology and its field-tested results. Additionally, it will explore the implications of moving Marine communications to an “all IP” solution. Secondly, this chapter will explore the potential equipment suites, which may address the problem of limiting the system’s footprint to what is physically transportable by individual Marines. Lastly, this chapter will seek to address an IP architecture, which would provide for scalability, flexibility, and redundancy.

A. “ALL IP” COMMUNICATIONS

Recognizing advances in communications technology, the DOD pursued a course of research and development to acquire a family of communications equipment that would be common among all the U.S. military branches. The project was named the Joint Tactical Radio System (JTRS). This acquisition project has largely been deemed an abject failure, incurring cost overruns and delays only to produce a final product with unacceptable reliability and capability (GAO, 2013, pp. 89–90).

This document will not seek to analyze the JTRS program, but rather offer another way forward to meet the operational requirements of the Marine Corps’ emerging CLT and EMO missions, as well as meeting the requirements of a jointly interoperable family of systems. Specifically, it should be noted that with the proliferation of software-defined radios, such as the PRC-117G and PRC-152A, an opportunity exists to move tactical communications to an “all IP” framework. By taking advantage of the processing power available in mobile radio units, all traffic could be reformatted into standardized IP packets. This could then take advantage of an already universal networking language, the underlying protocols of the Internet. This IP language is, by its very nature, highly interoperable. Combined with systems that can route and forward data such as the

MANET radios produced by companies such as TrellisWare and Persistent Systems, a true battlefield Internet becomes much more feasible. Voice data would be forwarded in much the same way as wire-based VoIP software currently operates, however, the experience for the end user would be largely unaffected. This, combined with some simple additions such as battlefield servers and routers, could create a truly interconnected environment where multiple systems in use by different units and services could communicate through shared IP protocols and tactical edge waveforms.

B. DATA CAPABILITY IN TACTICAL UNITS

To begin to evaluate the systems best suited for use on the tactical edge of C2, one must first have a strong foundation in the system's requirements, which must be grounded in field experimentation and drawn from lessons learned from previous conflicts and operations. While there was previously some debate about the need for data on the tactical edge, that is to say with squad level units, that debate has largely ended within the Marine Corps. Emerging reporting requirements and the added complexity of modern conflicts have led the Marine Expeditionary Rifle Squad working group to determine that the requirements for "real time transfer of data and [communications]" and "ability to maintain situational awareness to determine friend or foe" exist on the squad level (MERS, 2014).

C. REQUIREMENTS ANALYSIS

At the time of this document's writing, the Marine Corps is re-writing its material requirements to reflect these changes. However, through field observation and experimentation, several key requirements became evident. Between March and June 2014 I was able to participate in two field experiments and one laboratory experiment with IOC and MCWL, respectively. In November 2013, I took an opportunity to deploy communications equipment in support of the 3d Marine Expeditionary Brigade's disaster response and humanitarian assistance mission following the wake of destruction left by super-typhoon Haiyan (Waddell, 2014). These experiences, combined with personal experiences deployed as an infantry officer in the Sangin District of Afghanistan's Helmand province, allow for some contextual critical analysis of some key requirements

for Marine Corps expeditionary communication systems. These will be addressed first in terms of operational requirements, then in terms of potential material solutions.

Requirement 1: Scalable and survivable tactical voice communications network. This system must be able to operate both in rural, urban, shipboard, and tropical environments. This network cannot be dependent on singular nodes as they are vulnerable to targeting both with precision weaponry from peer opponents and techniques such as suicide and IED bombing from insurgent threats.

Requirement 2: Simultaneous transfer of voice and data down to the infantry squad level. As stated by the MERS working group, the requirement for data exists at the squad level. This system must be able to provide this capability without significant additional weight and support requirements on the individual warfighters.

Requirement 3: Long-haul voice/data communications to geographically disbursed units and headquarters nodes. This may come in the form of linking offshore headquarters elements to a CLT deployed over the horizon or, as in Iraq and Afghanistan, multiple units deployed over wide expanses of terrain. As with the local tactical network, this system must maintain survivability through decentralization and autonomous self-forming and self-healing.

Requirement 4: Interoperability. Modern military operations are, by their very nature, jointly executed between multiple services. While the Marine Corps may enjoy the benefits of fielding self-contained units, such as the CLT or MEB, at some point they will have to interface with their sister services. The communications system employed must be interoperable with the joint services as well as maintain options for coalition support.

Requirement 5: Information availability. The summary goal of this proposed C2 system is to provide the warfighters on the tactical edge an opportunity to find utility in information. If these edge units have access to the information made available through the military intelligence process they will find uses for it in new and inventive ways depending on the needs of the individual situation. This information should serve to increase situational awareness as well as provide planning tools and intelligence in an on-demand format, scalable to the needs of the individual warfighter.

D. ADVANTAGES OF HIGH THROUGHPUT MANET

Building on the work conducted by MCWL at RIMPAC 2014, I sought to test the higher throughput Persistent Systems MANET in a tactical environment. In June 2014, IOC again conducted a field experiment wherein they conducted another two-platoon CLT raid using MV-22 Ospreys for insertion. The two platoons were inserted separately and simultaneously on opposite sides of a simulated enemy controlled town. Once both platoons seized their individual objectives, they consolidated south of the town for a resupply drop from a C-130 cargo plane using a containerized delivery system (CDS) drop. The two platoons then formed into a movement-to-contact formation and proceeded to seek simulated enemy targets as they moved south under cover of night to seize an airfield approximately 19 km away (Figure 20).



Figure 20. Falcon Reach III Scheme of Maneuver

Prior to insertion, I had attached two Wave Relay MPU-4 MANET radios to instructors shadowing both the student platoons, while attaching one to myself as I travelled with one of the platoons. On my body armor I had also fixed a ruggedized flip-down case carrying a Samsung Galaxy S4 smartphone, which was attached to my MPU-4 (see Figure 21). The phone itself was loaded both with Wave Relay's proprietary node monitoring and management software as well as the DoD mobile application, Killswitch. I positioned myself on the flanks of the movement as we proceeded south. All three MPU-4 radios were configured according to the following specifications:

- Frequency: 2312 Mhz
- Bandwidth: 20 Mhz
- Link distance: 1.0 mile

Due to the tighter combat formation of the Marines as we moved south, my radio's position did not require any hops to complete a link to the two instructor radios. However, I was able to record throughput rates between 10 and 20 Mbps. My link distances were only between 500–900 meters due to my confined maneuverability on the live fire course. However, the data shows that advances in MANET technology allow for a local network capacity, which far outpaces the demonstrated ANW2 data rates using PRC-117G radios. These data rates are also beyond that observed by MCWL in their March 2014 field-testing.



Persistent Systems –
Wave Relay
MPU-4



Fold-Down Juggernaut Case
With Smartphone

Figure 21. Falcon III Gear Set Provided by NPS

This high throughput network, combined with the benefits of a self-healing MANET architecture, begins to address the requirements stated above. The MANET nature of the Wave Relay system provides the survivability and flexibility needed to meet Requirement 1. Since the network “self-heals” when nodes are added or lost, it remains viable in situations where individual radios may be disabled or destroyed. Additionally, each MPU-4 is roughly the same size as the current squad-level radio, the PRC-152A. In fact, each fielded MPU-4 was fitted to experiment participants using existing wearable cases for the PRC-152A.

Adding peripheral devices to the network begins to address Requirement 2. The smartphone adapter for the MPU-4 allowed me to access the data network provided by the Wave Relay MANET. As of firmware version 18.1.6 each Wave Relay radio is able to utilize up to 15 push-to-talk (PTT) voice channels per network. The bandwidth available on the network is apportioned to allow both application data and VoIP data to be transmitted simultaneously. The radios themselves are also usable as wireless access points where any 802.11 devices could interface with the MANET (Persistent Systems, 2014, pp. 52, 67–69).

E. LONG-HAUL C2

Due to the long-range and distributed nature of operations highlighted by the requirements of EMO, it is necessary to connect local networks to a second network specifically for this purpose. Since units could be several hundred miles away from their offshore HHQ nodes, LOS radios cannot be the only gear carried by the CLT. IOC and MCWL have both utilized satellite communications in order to bridge this gap. However, in the case of IOC, the data rate for the DTCS radios (2.4 kbps) used by their CLT are insufficient for media-rich data transfer (pictures and video). MCWL sought to address this challenge by utilizing a Ku-band SatCom dish. Their equipment was able to establish a link that provided approximately 2 Mbps throughput. While this material solution answers the requirement for a higher capacity backhaul method, the form factor of the SatCom node, being an entire vehicle, is ill-suited for the rugged terrain and limited logistical support infantry Marines can expect to face in scenarios such as those outlined in EF21 (USMC, 2014, pp. 9–10).

While present SatCom technology is unable to provide a man-portable, on-the-move solution capable of the required data throughput rates, there are some viable solutions to the problem. First, the utility of the PTT SatCom radio, in this case the DTCS, has already been demonstrated. This system was found to be extremely useful by both IOC and MCWL. This relatively simple piece of equipment could keep units connected while conducting complex maneuvers where no one unit is static. However, once that unit comes to a point where they are able to maintain a static position, for example in a platoon patrol base, they could deploy alternate, higher capacity linkages.

My 2014 ICCRTS paper describes how teams from the NPS' Hastily Formed Networks lab were able to travel around the post-typhoon disaster zone in the Philippines (Waddell, 2014). Taking only what equipment that could be carried in backpacks or in small transportable cases, each team was able to deploy small aperture Broadband Global Access Network (BGAN) systems and maintain connectivity to higher echelon HHQ units while being significantly geographically separated. While the throughput was still limited (around 200 Kbps), systems like these were capable of maintaining connectivity and providing access to applications such as Skype and e-mail. With improvements in

small aperture systems steadily entering the market, it is not difficult to conceive of a system, which could be acquired from a commercial vendor that could provide a gateway for a small unit to its higher headquarters. While this would not provide the throughput of an amplified dish on a vehicle, it would provide the connectivity required by front line units. Another emerging solution for high-throughput satellite terminals would be combining the recently launched O3b constellation with emerging technology in the form of flat panel, small-scale tracking-antennas from vendors such as Phasor Solutions (Waddell, 2014).

It is important to note that in my observation of the IOC raid exercises in Talon Reach I and II, there was not necessarily a requirement to access data from outside the local network at broadband speeds for most of the operation. Rather, the most used applications were simple chat windows and locally-stored map imagery with shared overlay data. The major drawbacks of their systems only became evident when they attempted to pass larger files, such as images of a damage assessment, to HHQ or adjacent units. These attempts were largely unsuccessful due to the low throughput on the ANW2 network and the lack of over the horizon data systems apart from their DTCS radios. The throughput issue is easily solvable using the MANET systems mentioned above. However, for broadband outside of the local network, a man-portable small aperture terminal such as the BGAN or similar system would prove adequate for the necessary task of maintaining a viable data link between higher headquarters and front-line units.

It is also important to note that SatCom is not necessarily the only solution for long-haul communication. In his NPS thesis, Major Jose Menjivar Captain Mark Simmons details how UAVs outfitted with MANET radios could interface with local MANETs and act as an aerial relay node (Menjivar, 2012). Using a link such as a UAV or a static point-to-point 802.16 antenna or tracking array, a MANET could expand beyond the local confines of the transmit power and line of sight limitations to smaller maneuver units. This could also serve to provide a means of redundancy should other systems such as DTCS or other SatCom assets fail.

F. FIELD DATA MANAGEMENT

As a result of the requirement for the two networks mentioned above, there remains the requirement of ensuring these networks are interconnected. That is to say, it must be feasible to support a scenario in which a squad of Marines is required to broadcast imagery or a document/form from their front line position, through the local MANET, and through the over-the-horizon backhaul system. Likewise, it should be feasible for an intelligence worker on an offshore amphibious ship to recognize that a squad is entering an area known to have a time-sensitive mission tasking on which they were not previously briefed, and transmit new orders and associated intelligence products to that unit.

The logical result of multiple battlefield data networks and local node management for MANET systems is the inclusion of a robust, field-hardened server/router system suitable for a battlefield. MCWL tackled this problem by integrating multiple laptop computers with routers on their METN-CE and ME-L vehicles. As previously stated, the requirements of CLT missions will not always allow for the inclusion of a vehicle asset, at least during the initial phases of an operation. It is conceivable, however, that with the advances in mobile computing a system could be devised that would allow a CLT unit to accomplish two critical tasks: providing local application data storage and support, as well as acting as the network manager for the CLT. Standard practice already includes carrying larger radio systems, such as the original PRC-117—roughly twice the size of the “G” version, which is more than enough “tactical real estate” to substitute with a man portable system that would accomplish the above requirements.

The primary function of this system would be to conduct network management. That is to say, it must first control gateway access outside the local MANET, as well as manage the traffic in and out of potentially multiple gateways (i.e., aerial relay and/or SatCom methods). Due to the throughput limitations of systems such as the BGAN, it is infeasible with present technology to allow every node on the MANET to access that data source. Instead, only specific application data such as PLI and simple overlay data for mapping and COP applications would be permitted, with larger files only passing through

on a mission-critical need basis. Instead, all other data requirements would be handled locally on its internal hard drives. This would allow the MANET users to take full advantage of the high throughput speeds of the local links to support faster data transfer and more bandwidth intensive applications such as video streaming without overwhelming the lower throughput of the over-the-horizon links. Higher volume data that is often static, such as high-resolution map imagery, media intensive intelligence reports, as well as data for the applications in use by lower-level peripheral devices, such as smartphones and tablets, could be stored on local drives and updated between missions. Should HHQ deem certain additional larger files necessary to mission success, these drives could be updated via their network management software, which would allocate all available throughput to the higher priority data. An additional function this system could provide is to make radio-over-IP (ROIP) possible between geographically dispersed units. At present, Persistent Systems has a software solution for cloud-based PTT radio, making ROIP accessible by any user with Internet or intranet access. This would alleviate the reliance on DTCS radios for over-the-horizon voice communications. These processes and others would largely run “in the background” with local users provided on-demand access to an information rich environment. A system like this would begin to address Requirement 5.

G. APPLICATION LAYER

A productive end user experience is the ultimate goal of this network. In order for a new system like this to be adopted it must both provide the same or better level of service as the systems currently in place as well as provide a significant advantage over those systems in terms of added capability. While software design is best suited to follow-on research, some observations from the IOC and MCWL experiments as well as reports from recently deployed combat units may prove relevant in perceiving the potential application layer of this system.

The first focus of this group of applications must be the COP software. This was, by far, the most used feature in the observed field experiments. For the IOC team, the DoD-developed software, Killswitch, was the primary tool. This software is a touch-

screen based application that provided the user with map imagery as well as planning tools, which could be collaboratively distributed among the network's users. I more often observed IOC students using their assigned tablets to conduct rapid "map-checks" where they were able to reference both traditional maps as well as aerial imagery of their surroundings and targets. Admittedly their allocated training time on the new software was limited, so use of higher order functionality was minimal. However, the ability to share route planning and other tools known as tactical control measures (TCMs) was extremely exciting to both the students and the more seasoned staff of combat experienced instructors.

The second tool that must be provided to front-line units is access to a file transfer system and shared database. Recent operations in Afghanistan and Iraq have noted the need for a shared information environment. In 2007–2008, Marine Regimental Combat Team (RCT) 2 noted a significant shortfall in the manner in which data was transferred between units. RCT-2 notes that information management was largely conducted by exchanging an actual external hard drive between units because the servers were not populated with the most relevant information to their current operations (RCT-2, 2008). More recently, in 2010 in Afghanistan, 1st Reconnaissance Battalion noted the importance of shared chat windows that allowed proactive coordination between geographically separated entities (1st Recon, 2010). This unit also noted the drastic increases in situation awareness provided to distributed units through the simple addition of the PRC-117G and its ability to connect units via ToughBook laptops to their HHQ (1st Recon, 2010). Another major unit in Afghanistan, the 7th Marine Regiment, noted in 2011 that there were issues with how local census data and biometrics were dispersed. They cited issues with their ability to populate a database with information gathered in the field, such as iris scans and fingerprints of individuals encountered by patrols. They recommended finding a way to more efficiently populate a shared database (7th Marine Regiment 2011). Other interviews with lower-level officers regarding their time in OEF cited inadequate automated COP assets and instances in which the best situational awareness tool was the nightly radio conference between company level staff, resulting in a decidedly analog shared information environment (MCCLL, 2011). These use cases,

combined with the imperatives highlighted by IOC and MCWL for the creation of a system that supports a shared information environment, make a compelling case for the fielding of peripheral devices capable of providing a COP as well as access to a common database.

H. ARCHITECTURE

The systems described above would force the Marine Corps to adopt a new communications architecture. However, this architecture would result in mostly transparent changes to the equipment footprint of the individual Marine. Squads would still be carrying a radio that would largely resemble what they have been previously using, the PRC-152. Their only addition would be a smartphone or similar peripheral device. Platoon leadership would only see the addition of DTCS radios, and the possible addition of a SatCom gateway device such as a BGAN, in place of their PRC-117. Company leadership would see the addition of DTCS radios, their gateway device, and the battlefield server system described above. The resultant architecture is depicted in Figure 22.

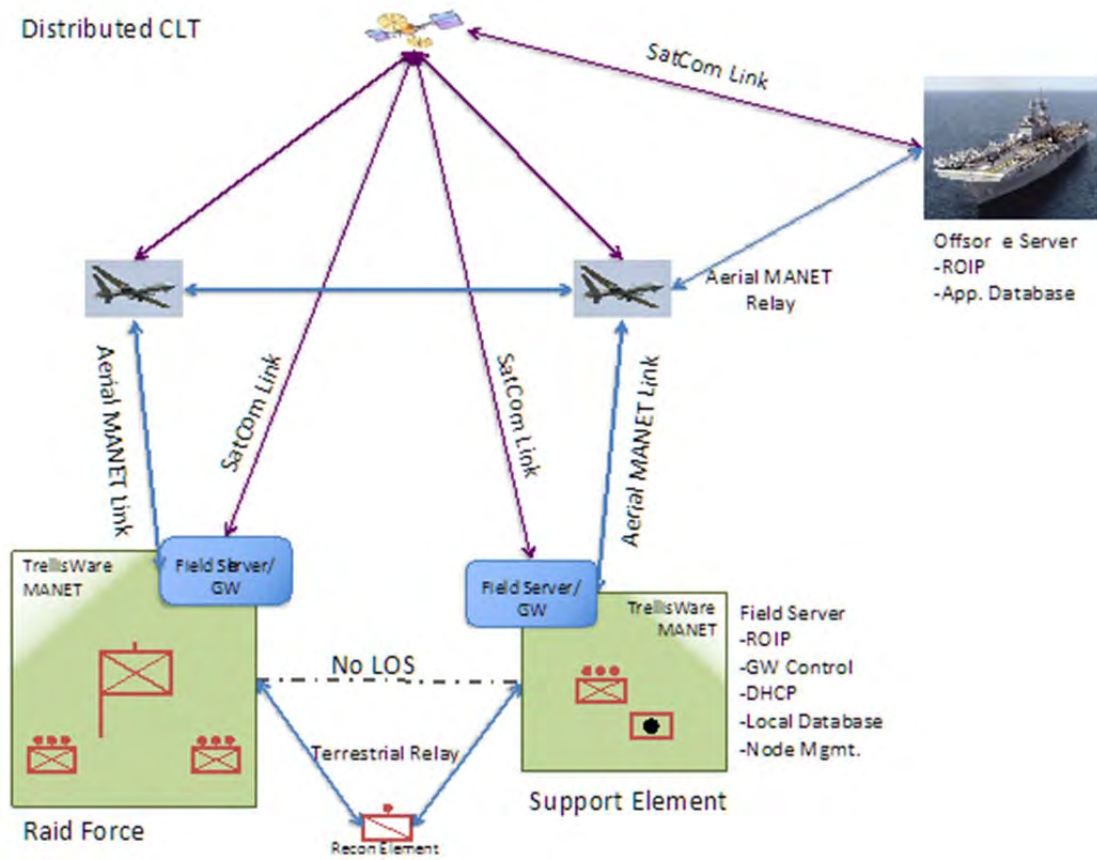


Figure 22. Proposed Architecture

This architecture is designed to provide survivability through diverse information paths. Each unit depicted has multiple methods for maintaining contact with their adjacent and supporting units. In the case of the support element, should they lose their SatCom gateway link, they have the option of terrestrial relay, aerial relay, or simple DTCS communications. This system also does not impose additional logistical burden on the deployed unit. There are no vehicles to refuel or larger power sources necessary to maintain this network.

As this chapter illustrates, the technology required to greatly increase operational capacity and capability is largely mature. Incremental action could be taken while still enjoying the benefits of the final proposed system, above. MANET radios, already being field tested by MCWL with fleet units, could be fielded as an alternative to the delinquent and deficient JTRS man-portable systems. Integration of these MANET systems could be

accomplished while the Marine Corps makes a material decision on what its COP mobile-application will officially be and what commercial SatCom services will be acquired for long-range data connectivity. Further research into the hardening of field servers and addition of battlefield application-layer service would need further development. This development, however, could be integrated quickly if the Marine Corps takes steps to upgrade their battlefield network infrastructure in the near-term, allowing it to enjoy the basic benefits it would offer while additional software is developed.

V. FINDINGS AND CONCLUSIONS

A. SUMMARY FINDINGS

The principal hypothesis underlying this research was determined to be correct. At the currently level of technological maturity it is absolutely possible to support a data-rich environment on the tactical edge of Marine Corps units while operating under the austere conditions outlined in EF21 and the Vision & Strategy 2025 document. By using Persistent Systems MPU-4 radios I was able to achieve data throughput rates of up to 20 Mbps across an infantry formation while conducting an attack. While in the Philippines, I observed the utility of portable, small aperture SatCom data terminals. Combined with intelligent, forward-deployed network control nodes and redundant push-to-talk SatCom systems like DTCS and MUOS, it is possible to create a highly survivable system of systems while also maintaining an expeditionary logistical footprint. This network is the enabler for putting smart devices in the hands of talented combat leaders on the tactical edge to enable a much more robust and responsive information environment than is currently available to today's warfighter.

It is worth noting that equipment like this has already been deployed in real world situations. In response to the 2010 Haiti earthquake the team from the NPS HFN Lab was able to use BGAN networks and wireless mesh networks to enable communication where no infrastructure currently existed (Nelson, Stamberger, & Steckler, 2011, p. 468). In the wake of Hurricane Sandy the New York City, the U.S. Coast Guard was able to rapidly deploy Wave Relay radios to enable communications throughput at around 65% of what they had available with fixed infrastructure that had had been damaged in the disaster (Robinson, 2013). This should be encouraging to military acquisition professionals in that many of the risks associated with technology development have been mitigated through years of successful deployments of these technologies within the civilian sector.

B. POTENTIAL FURTHER RESEARCH

Before the architecture advocated for in this document can be formally fielded, there must be additional research into a couple key areas to make this solution set feasible

for military use. First, research and development must be allocated to hardening the cybersecurity of this system. While each device mentioned in this document is capable of some form of encryption, it is incumbent upon acquisitions professionals to work with COTS and GOTS vendors to ensure devices meet the cryptological security needs of the modern cyber battlefield. There is an inherent vulnerability by creating an IP-based communications system that reaches between the lowest and most physically exposed locations on the battlefield and off-site headquarters servers. Additional research in trusted handheld computing technology and risk mitigation must be pursued.

Additionally, further research is needed in the development and acquisition of battlefield hardened network control nodes, such as those suggested in Chapter IV of this document. As computing power moves toward the tactical edge, the responsibility for node control will also move forward into the field. This is as much a hardware issue as it is a training issue. Our enlisted communications specialists must now also be trained on basic IP principals as well as radio wave propagation. Hardware and software acquisitions for this battlefield server and network management system must take advantage of advances in intuitive application interfaces that mirror the systems our Marines would use on a daily basis in the civilian world. Every effort must be made to introduce this piece of gear as not burdensome but as a useful addition to their equipment set. Research should also take place to determine the requirements on gateway control that will drive acquisition of satellite terminals as well as application layer data usage. It is important that these requirements be taken from field observation in realistic environments and use cases as was done in this document. From my observations, the most useful tools for individual tactical leaders were simple text messaging and chat programs as well as PLI and overlay sharing of COP programs with pre-loaded map data. Until our over-the-horizon communications equipment advances, acquisitions professionals should be wary of imposing additional requirements, such as full motion video streaming, from field units to HHQ. Local streaming can be done through MANET links to UAVs, but additional streams through SatCom assets have the potential to be burdensome on both the system's architecture as well as the individual Marine.

Another area of study to help drive requirements for further application layer acquisitions should be a measure of the utility of information to tactical leaders. There is a potential for information overload on the individual tactical decision maker. I observed this in the field experiments with IOC. Often, at the onset of a mission, leaders felt the need to always be plugged into their device, rather than directing their subordinate units and carrying out their primary mission. Behavioral research should be conducted to measure what the warfighter's informational dashboard should contain and which applications are assets and which applications have the potential to overwhelm him. Principal to this research should be a way in which to impose a system of checks and balances for higher-level leaders to avoid informational micromanagement. An example of this is in the full motion video argument posited above. While there may be use cases where decision makers must stream video to and from their HHQ or to subject matter experts, it may be unwieldy for tactical leaders to be forced to have a video feed to a higher-level officer to validate their decision-making in real time. Striking the balance of information utility and information overload must drive the requirements of both the system architecture as well as the doctrine and use cases of the new C2 system.

C. CONCLUSION

My research can confidently support my original hypothesis in that these capabilities are within the realm of the possible at the currently available levels of technological maturity. The pinnacle point I wish to convey is not the feasibility but the urgency of C2 modernization. At the time of this document's writing, permanently stationed Special Purpose MAGTFs are being positioned in Europe, the Persian Gulf and Southeast Asia. These units have been designated as primarily responsible for crisis response forces, largely growing out of the vulnerabilities demonstrated in the 2012 attack on the American Consulate in Benghazi, Libya. These units, along with the existing expeditionary presence of multiple forward-deployed MEUs around the world, are requiring Marines to return to their expeditionary roots rather than conducting steady state operations within established infrastructure as was done in the wars in Iraq and later-stage Afghanistan.

It is imperative that the Marine Corps, with its unique deployment challenges and mission sets, adopt an aggressive acquisitions strategy to modernize its expeditionary C2 capabilities. The functional requirements for data availability at the tactical edge will likely continue to grow, and the Marines must take steps to adopt a system of systems, which provides the services necessary for tactical and operational success while allowing for an upgradable and expandable architecture as technology continues to rapidly improve. Failing this, we may soon see our Marines, with the world's largest defense budget behind them, outpaced and outmaneuvered in the information environment of modern combat by small teams with smartphones, as IOC discovered in 2013 (IOC, 2013, pp. 3–4).

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