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ENHANCING MARITIME DOMAIN AWARENESS (MDA) THROUGH THE DEPLOYMENT OF INTELLIGENT AUTONOMOUS SYSTEMS (IAS) USING COMMERCIAL 5G TECHNOLOGY

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THESIS

ENHANCING MARITIME DOMAIN AWARENESS (MDA) THROUGH THE DEPLOYMENT OF INTELLIGENT AUTONOMOUS SYSTEMS (IAS) USING COMMERCIAL 5G TECHNOLOGY

by

Brian J. Caplan

June 2022

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13. ABSTRACT (maximum 200 words)

The United States Navy has been the dominate force of the sea in the last half century, but advancements in technology have given other nations the ability to narrow the gap and, in some cases, threaten U.S. superiority. The U.S. Navy, Marine Corps, and the Coast Guard are the triad forces for maritime domain protection. One area of potential vulnerability is in the littoral environment. However, emerging commercial technologies, like 5G, can expand the footprint of systems and capabilities within that environment for naval services to utilize. The private sector already has the lead in developing 5G state-of-the-art resources, which has enabled manned and unmanned systems to accomplish more tasks. One long-standing obstacle for the naval services to implement commercially available systems was the Department of Defense's desire to be the owner and operator of any systems it employed. One benefit of utilizing existing commercial systems in naval operations would be to enhance capabilities without developing a completely new system. This thesis explores current and projected abilities of a commercial 5G technology for employment by U.S. naval services. Testing of 5G millimeter wave was conducted for this research. This thesis also examines a theorized new system that integrates commercial systems to satisfy naval requirements.

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ENHANCING MARITIME DOMAIN AWARENESS (MDA) THROUGH THE DEPLOYMENT OF INTELLIGENT AUTONOMOUS SYSTEMS (IAS) USING COMMERCIAL 5G TECHNOLOGY

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ABSTRACT

The United States Navy has been the dominate force of the sea in the last half century, but advancements in technology have given other nations the ability to narrow the gap and, in some cases, threaten U.S. superiority. The U.S. Navy, Marine Corps, and the Coast Guard are the triad forces for maritime domain protection. One area of potential vulnerability is in the littoral environment. However, emerging commercial technologies, like 5G, can expand the footprint of systems and capabilities within that environment for naval services to utilize. The private sector already has the lead in developing 5G state-of-the-art resources, which has enabled manned and unmanned systems to accomplish more tasks. One long-standing obstacle for the naval services to implement commercially available systems was the Department of Defense's desire to be the owner and operator of any systems it employed. One benefit of utilizing existing commercial systems in naval operations would be to enhance capabilities without developing a completely new system. This thesis explores current and projected abilities of a commercial 5G technology for employment by U.S. naval services. Testing of 5G millimeter wave was conducted for this research. This thesis also examines a theorized new system that integrates commercial systems to satisfy naval requirements.

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LIST OF ACRONYMS AND ABBREVIATIONS

3GPP	3rd Generation Partnership Project
5G	fifth generation
AI	artificial intelligence
AIS	automatic identification system
CNO	Chief of Naval Operations
CONOPS	concept of operations
COTS	commercial off-the-shelf
CRADA	Cooperative Research and Development Agreement
dBm	decibel milliwatts
DOD	Department of Defense
DMO	Distributed Maritime Operations
eMBB	Enhanced Massive Broadband
EMCON	emissions control
FCC	Federal Communications Commission
FR	frequency range
HART	Highway Addressable Remote Transducer Protocol
HP	Hewlett Packard
IAS	intelligent autonomous system
IoT	Internet of Things
ISP	internet service provider
ISR	intelligence surveillance reconnaissance
ITU	International Telecommunication Union
JADC2	Joint All-Domain Command and Control
JIFX	Joint Interagency Field Experimentation
LEO	low earth orbit
LOE	lines of effort
MDA	maritime domain awareness
MDAS	maritime domain awareness system
MEC	Multi-access Edge Computing
MIMO	Multiple-Input Multiple-Output

ML	machine learning
mMTC	Massive Machine Type Communication
mmW	millimeter wave
ms	millisecond
NH	night hawk
NIC	network interface card
NOC	network operation center
NPS	Naval Postgraduate School
OPT	Ocean Power Technologies
OV	operational viewpoint
PCaS	Pier Connectivity as a Service
PTO	power take off
QOS	Quality of Service
RAN	radio access network
SLAMR	Sea Land Air Military Research
SOS	system of systems
TRL	Technology Readiness Level
UAV	uncrewed aerial vehicle
UE	user equipment
URLLC	Ultra-Reliable Low Latency Communication
U.S.	United States
USCG	United States Coast Guard
USV	uncrewed surface vehicle
UUV	uncrewed undersea vehicle
VPN	virtual private network
WI-FI	Wireless Fidelity
WP	wave point

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I. INTRODUCTION

Telecommunications technologies are advancing faster than the United States (U.S.) military can test and evaluate for operational use. One of the constant buzzwords traveling throughout the Department of Defense (DOD) is "5G," a fifth-generation cellular technology many believe may be employed to enhance national security. 5G technologies can be developed and operated within the DOD services, but previous acquisition and policy have slowed opportunities for implementation. The commercial sector is not confined by these same policies or restrictions. The expertise and experience collected in the commercial sector enables them to construct and test the latest technology at a faster pace, making technology readily available for the DOD to take advantage of. One area where the DOD can use 5G is in the littorals.

The United States has been the predominant force of the sea in the last half century but with advancements in technology, adversary nations have attained great strides to expand their reach, threatening U.S. dominance. In the *Design for Maritime Superiority*, The Chief of Naval Operations (CNO) reflects on the fact that it has been "decades since we last competed for sea control, sea lines of communication, access to world markets, and diplomatic partnerships" (Chief of Naval Operations, 2018). Publication 3–32 describes the "maritime domain as the oceans, seas, bays, estuaries, islands, coastal areas, and the airspace above these, including the littorals" (Joint Chiefs of Staff, 2013, p. viii). With the Navy, Marine Corps, and the Coast Guard's increased responsibility in near shore areas of the maritime domain, the littorals have been recognized as an area lacking appropriate attention and resources. This is a problem because naval services are challenged to monitor and detect credible threats in contested environments without new funding to develop new tactics, techniques, and procedures to counter potential threats. Utilizing 5G next generation telecommunications should enable increased range and data throughput, with low latency rates, thereby increasing maritime domain awareness (MDA) capabilities for naval operations.

The purpose of this research was to begin the exploration of 5G capabilities in the littoral environment and theorize a concept of operations (CONOPs) with various commercial intelligent autonomous systems (IAS) that can leverage a secure 5G system of systems (SOS) network to respond to the growing competitor capabilities and threats in that arena. This potential game changer can alleviate the naval services mindset of building and maintaining independent 5G systems by leveraging existing commercial infrastructure depending on the mission requirements. The DOD can potentially save money, time, and resources by pivoting to this new way of enhanced MDA in the littorals.

The research questions this study targeted were:

- How might 5G interconnected commercial systems in a littoral environment impact maritime domain awareness for various mission sets?
- How might naval services benefit from a system of systems 5G commercial concept?
- Can this framework be deployed globally?
- What are the requirements and conditions needed for the naval services to utilize a commercial 5G framework?

Through the guidance of these questions, insight on the challenges posed by the littoral environment were surfaced and the means by which a 5G enabled IAS system can bridge the gaps with possible solutions was explored.

A. THESIS BREAKDOWN

Chapter II: Literature Review

Chapter II provides a policy overview of the DOD including limitations for current and future technological advancements and how 5G can create opportunities from a commercial aspect. This chapter closes with an overview of the main thrust for this thesis describing the ability to expand a secure 5G network in the littorals and incorporating private sector solutions that support intelligent autonomous systems to potentially support maritime domain awareness.

Chapter III: Methodology and System Description

Chapter III illustrates the initial design of using AT&T's new 5G millimeter wave (mmW) tower on the Naval Postgraduate School (NPS) Sea Land Air Military Research (SLAMR) facility with a variety of user equipment to establish throughput numbers at various locations to help facilitate a baseline as testing increases out into the littorals. This chapter also brings together a CONOP breaking down different systems from an industry consortium that can be applied to a SOS 5G concept.

Chapter IV: Test Results and Service Applicability

Chapter IV depicts the results for the different applied tests conducted at the SLAMR facility. Details on how advanced technology can be applied to enhance the naval services to increase situation awareness and provide improved decision making to the warfighter are also included.

Chapter V: Conclusion and Future Research

Chapter V encapsulates the production of this thesis, analyzes the capability of the CONOP for naval services to leverage commercial secure maritime 5G as an alternative to developing and owning their own 5G network architecture. The inclusion of recommendations for future work to move from a CONOP to a proof of concept are also within this chapter. Furthermore, other potential technological research projects within the DOD are also discussed which briefly depicts the direction the DOD is progressing towards.

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II. LITERATURE REVIEW

A. NECESSITY OF U.S. SEA POWER

The topic of this thesis is driven by changing trends in military strategy. This literature review consists of several policy documents that necessitate a revision in military operations and standards. These policies lay the foundational understanding of the direction and future goals of the Department of Defense. Their importance and relevance to this study are apparent by their intention to guide military mindset, state applicable objectives and achieve a result within the spectrum of the topic of utilizing 5G and commercial partnerships. The DOD document *Advantage at Sea* provides the overview of reasoning for the necessity of U.S. sea power. The protection of the nation and other U.S. interests, as well as the prosperity of the nation has a high dependence on the sea (Berger, Gilday, & Karl, 2020). The sea enables a natural barricade for homeland security. Military strategies and objectives are geared for protection and ensuring liberty and peace. In addition to the protection the sea facilitates, it is also an important lifeline to the rest of the world, connecting nations and enhancing life through commerce (Berger et al., 2020).

> The oceans connect global markets, provide essential resources, and link societies together. By value, 90 percent of global trade travels by sea, facilitating $5.4 trillion of U.S. annual commerce and supporting 31 million American jobs. Undersea cables transmit 95 percent of international communications and roughly $10 trillion in financial transactions each day. For decades, the free and open international order has produced shared security and prosperity throughout the world. (Berger et al., 2020, p. 3)

The sea has always been a vital asset for the strength of nations from both military and prosperity perspectives (Berger et al., 2020). If a conflict arises, the advantage of superior sea power and control of the seas will aid in denying and defeating rival forces and securing the nation. The maritime domain is especially susceptible to smaller, more frequent incidents that can lead to long-term advantages for our rivals (Berger et al., 2020).

Berger, Gilday & Karl (2020) place heavy emphasis on the threats that China and Russia pose. Although China's military workforce vastly out numbers the U.S., their forces are focused primarily on the Western Pacific. Whereas U.S. forces are staged throughout the world to enable rapid deployment. However, the rapid growth and modernization of its military and the country's capability to produce naval ships has diminished the advantage that the U.S. once held over them. Russia also continues to modernize their forces with the intent to disrupt international order. Both China and Russia's progressive development challenges the abilities of U.S. sea power and threaten the current world order (Berger et al., 2020).

To address this growing threat new technologies and practices must be incorporated into standard military procedures (Berger et al., 2020). The adaptation to use "artificial intelligence, autonomy, additive manufacturing, quantum computing, and new communications and energy technologies could each, individually, generate enormous disruptive change" (Berger et al., 2020, p. 5). Militaries that incorporate these new technologies will hold an advantage over those that lack the ability to progress. In addition to implementing new technologies, the methods themselves need to be devised in a manner that obtains the most benefit from this change. The network of partnerships the U.S. has built needs to be strengthened against competition and threats. Capabilities and manpower of combined forces need to be able to integrate and work in tandem seamlessly for maximum efficiency. To accomplish this, training, educating, and practicing together will allow common understanding to bridge gaps between services and other partners. "We are an integral part of the Joint Force and work closely with allies, partners, and other government agencies" (Berger et al., 2020, p. 8). The network of partnerships and alliances that the U.S. has established increases the force and capabilities that help to protect and control the maritime domain (Berger et al., 2020).

The Office of the Secretary of Defense also alludes to the erosion of U.S. advantage in the 2018 *National Defense Strategy*. This document informs the public that the U.S. military advantages are being challenged not only in the sea domain but in every domain: air, land, space and cyberspace included (Office of Secretary of Defense, 2018). It supports *Advantage at Sea* by stating the most prominent rival to U.S. democratic values, China and Russia, continue to push the boundaries of the current capabilities and status of the U.S. in attempts to dominate us. The U.S. is no longer an invincible power as it once was considered and has become a constant target to many attacks. These attacks come in more forms besides military conflict or physical attacks. With the advancement of technology cyber-attacks are also a growing challenge that scales from personal to governmental damage, causing ripples within our society. The inability to adjust to the advancements of technology and the capabilities that adversaries are gaining will result in the decline of U.S. global influence and prosperity. The 2018 *National Defense Strategy* calls for the leveraging of opportunities and talent beyond U.S. military resources. The contributions of "multilateral organizations, non-governmental organizations, corporations, and strategic influencers provide opportunities for collaboration and partnership" (Office of Secretary of Defense, 2018, p. 3). The recognition of what the civilian workforce can contribute is also denoted in the *National Defense Strategy*.

> A modern, agile, information-advantaged department requires a motivated, diverse, and highly skilled civilian workforce. We will emphasize new skills and complement our current workforce with information experts, data scientists, computer programmers, and basic science researchers and engineers – to use information, not simply manage it. The department will also continue to explore streamlined, non-traditional pathways to bring critical skills into service, expanding access to outside expertise, and devising new public-private partnerships to work with small companies, start-ups, and universities. (Office of Secretary of Defense, 2018, p. 8)

Furthermore, the Defense Secretary includes the investment in autonomous systems in military operations to provide capabilities at a rapid rate to regain U.S. competitive advantage (Office of Secretary of Defense, 2018). Together, the *Advantage at Sea*, devised by the CNO, the Commandant of the Marine Corps and the Commandant of the Coast Guard, and the 2018 *National Defense Strategy* provide an overall depiction of the importance of how crucial controlling the maritime domain, and sea power, is to the prosperity of the U.S.

B. REDESIGN OF TACTICS

While the *Advantage at Sea* and the 2018 *National Defense Strategy* provided the overview understanding on the necessity for sea power, the Navy's, *A Design for Maintaining Maritime Superiority*, Version 2.0 is an updated approach to how the Navy plans to accomplish the objectives discussed in the prior two documents, mainly regaining dominance of the sea. It is a continuation of the 1.0 Version and is used to validate its assumptions and describe future actions. Each course of plan is meant to satisfy the mission,

> Our Navy will protect America from attack, promote American prosperity and preserve America's strategic influence. U.S. naval operations—from the seafloor to space, from the blue water to the littorals, and in the information domain—will deter aggression and enable resolution of crises on terms acceptable to the United States and our allies and partners. (Chief of Naval Operations, 2018, p. 1)

This document also emphasizes the threats that China and Russia create for the United States (Chief of Naval Operations, 2018). Their growing ability to challenge the U.S., and those allied and partnered by principles, leads the nation into a vulnerable state. As our adversaries develop alternate methods to exploit U.S. weaknesses through technological advancements, the nation will have to stay ahead of their progression and find other ways to create advantages. Version 2.0 lays out an agenda that drives new processes and strengthening assets that will enable the Department of the Navy to regain the competitive advantage and secure the lead in sea power. The guidance of four core attributes: Integrity, accountability, initiative, and toughness will ensure that each updated criteria meets the standards of the Navy in reaching overall goals. The four values are incorporated within the strategies for operational direction within four Lines of Effort (LOE) to increase progress to seize an uncontested lead once again. LOEs are designated by blue, green, gold and purple, and engage one of three themes. These themes are focused on, strength and agility in the maritime domain, new and innovation technology application to operations and information systems to decentralized operations (Chief of Naval Operations, 2018).

LOE Blue, focuses on the need to improve our naval forces power within the maritime domain and its capability to reach beyond by employing nine objectives to accomplish this task (Chief of Naval Operations, 2018). These nine objectives include:

- Readiness of USS Columbia
- Operational capability of Second Fleet
- Revitalization of warfighting culture through thorough evaluation

- Data-driven decisions at all levels
- Dynamic force employment to gain advantage
- Further development of the Distributed Maritime Operations (DMO) concept
- Sustain strategically staged logistics globally
- Reinforce mission command culture
- Utilize the diversity and talents of the Naval force.

LOE Green, focuses on results that lead to superiority through seven aspects (Chief of Naval Operations, 2018).

- Acquisition of platforms and payloads through contracts and developments through 2030
- Synergy of doctrine and application
- DMO support through operational architecture to deliver information throughout the naval force
- Upgrade Plan-Brief-Execute-Debrief to Plan, Practice, Perform, Progress and Promulgate cycle
- AI/ML algorithms to enhance training and decisions
- Maximize additive manufacturing
- Expand Live, Virtual, and Constructive training.

LOE Gold, focuses on the full circle support of service members (Chief of Naval Operations, 2018). Support such as:

- Constant improvements of military personnel management
- Real world scenario training for effective combat readiness

- Ease of access to personnel systems
- Centralized support detachments
- Efficiently utilize Navy Reservists
- Promote leadership development among enlisted
- Intertwine civilian workforce
- Effectively support sailors' families to lessen the worry placed on sailors from familial responsibilities.

LOE Purple, focuses on expanding the strengthening the network of partners (Chief of Naval Operations, 2018). This LOE is particularly relevant to this thesis because of the Navy's desire to use industry leaders to gain advantage over U.S. rivals. The six objectives in LOE Purple include:

- Strengthening naval integration into the Joint Force
- Work in concert with other branches of the government
- Increase diplomatic role
- Leverage partnerships with industry talents and leaders
- Include cooperation with academic and research institutes to stay abreast of changes
- Stabilize relations with partnering nations.

The literature that this thesis is built on concerns the incorporation of technology advances that are being developed and tested though commercial companies. The strive for utilizing skills and knowledge from the civilian workforce allows the military to bridge gaps within their ability and takes advantage of the progress developed within the private sector.

C. LITTORAL CONCERNS

The combined documents of *Advantage at Sea*, the *National Defense Strategy* (2018) and *A Design for Maintaining Maritime Superiority*, give a broad overview of the declining status of U.S. sea superiority as well as the plan to address it. However, the *Littoral Operations in a Contested Environment* presents a micro look into the battlespace of littorals, the area of focus within this thesis. A collaborative effort was made to devise a plan to integrate Sailors and Marines to protect, engage and maintain control of littoral environments at home and abroad. The Littorals are included within the maritime domain as defined in the Joint Intelligence Preparation of the Operational Environment (Department of Defense, 2009 & Neller & Richards, 2017). Two sections encompass the littorals, the sea-to-shore and shore-to-inland as far inward as operations from the sea can support or defend (Department of Defense, 2009 & Neller & Richards, 2017). Within the two sections, five dimensions are further defined: (1) seaward; (2) landward; (3) airspace above; (4) cyberspace; and (5) the electromagnetic spectrum (Neller & Richardson, 2017). Each requires an orchestration of operations to cohesively create a barrier or eject adversaries from the littorals. Capabilities of militaries, friendly or adversary, can far exceed the immediate area of the offshore and shoreline location. Therefore, it is necessary to define an operational area into a battlespace domain to produce tactics that successfully address threats and protect assets (Neller & Richardson, 2017).

Neller and Richardson (2017) indicated growing concerns of increased sea and land-based threats by state and non-state agents. As the capabilities of adversaries' advance, a concern of our future ability to control the littorals increases. There are nations that are implementing more aggressive force against regional neighbors as a means of gaining control over territory, littorals can be used as an access point. Within the littorals, Navy and Marine Corps forces operate individually and are not intertwined as a cohesive force. This division within operations weakens effectiveness and does not allow forces to build on each other's strengths. In addition, naval forces should be able to effectively operate at sea and ashore. Neller and Richardson (2017) referred to Dr. Milan Vego who stated, "the main prerequisites for success in littoral warfare are suitable and diverse platforms, weapons, and sensors; robust command organization; close cooperation among friendly forces; air superiority; well-developed theory; and sound doctrine" (Vego, 2015, p. 16). defining the elements which need to be improved to maintain U.S. advantage. The desired end state is the steadfast denial of capabilities of U.S. forces to protect littorals and employ operations when facing threats from the sea (Neller & Richardson, 2017).

D. TECHNOLOGICAL UNDERSTANDING

The collection of these literature materials, so far, provides the foundational understanding of the overall problem addressed in this thesis, diminishing U.S. sea superiority. The subsequent literature review addresses the following research questions: How might 5G interconnected commercial systems in a littoral environment impact MDA for various mission sets. Can this framework be deployed globally? These answers impact the necessary understanding of the 5G technological aspects of future suggestions.

To enhance the capabilities of U.S. and allied forces within the littorals advances in technology must be harnessed to build a thorough design that will ensure protection and control of the littoral environment. Myhre, Orten and Peterson (2020) describe in *Potential benefits of 5G Communication for autonomous ships* the abilities that 5G have over 4G and how its potential can provide new capabilities for military operations. 4G runs on a network that equally distributes processing power amongst users routing through one particular Radio Access Network (RAN). This means that the Quality of Service (QoS) is dependent on the number of users utilizing the same network. If the network is crowded and must equally distribute capabilities, then the ability of that network is slowed as a result of too much tasking within one frequency. In addition to the restricted abilities that 4G is burdened with, its edge computing centralized core networks are not appropriate for maritime applications. There are two reasons it is deemed inappropriate. First, sensitive data does not remain under the control of the data owner when it is transmitted from the RAN to the core network, making it vulnerable. The second reason, core network routing requires an additional process, and the drawback is the latency incorporated with this process. 4G and previous cellular technology focused on mobile broadband communications, while Wireless HART (Highway Addressable Remote Transducer Protocol) was utilized for industrial automation applications (Myhre, Orten, & Petersen, 2020). The basic components in a network are the User Equipment (UE), the RAN, and the Core Network shown in Figure 1.

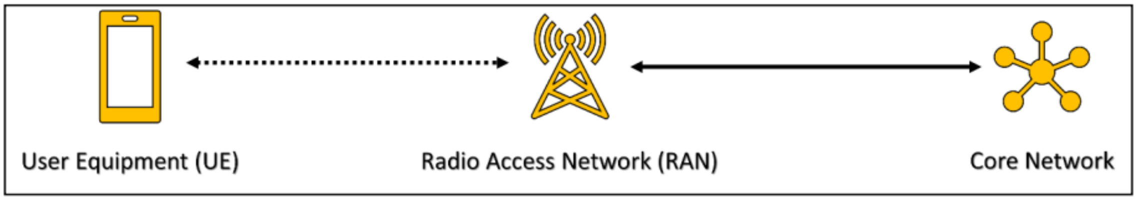

Figure 1. Components of a Mobile Network. Source: Myhre et al. (2020).

In 2015 the International Telecommunication Union (ITU) announced their vision to move towards the future and expand the capabilities of mobile communication systems allowing for greater capabilities and new opportunities (Myhre et al., 2020). Opportunities in industrial manufacturing, remote work, automation in smart grids and even transportation were included as examples of possibilities. However, 4G does not possess the capability to incorporate these ideas, therefore 5G is the mobile network concept that was utilized to satisfy these more robust needs. It's potential to deliver reliable high-capacity, low-latency sensor communication enables the application of autonomous vehicles and increase communication functions in the maritime domain (Myhre et al., 2020).

Myhre et al. (2020) describe how greater demands are needed for delivering these new capabilities. ITU addresses these requirements to meet the three categories: Enhanced massive broadband (eMBB) in Table 1, Massive machine type communication (mMTC) in Table 2, and Ultra-reliable low latency communication (URLLC) in Table 3 (Myhre et al., 2020). The separation of frequency range (FR) is pertinent because it is not possible to achieve all capabilities simultaneously. Mobile broadband for consumers and businesses will utilize eMBB, which accesses multi-media content, services, and data at a higher speed than 4G (Myhre et al., 2020).

Table 1. Requirements for eMBB. Source: Myhre et al.(2020, p. 3).

Key capability	Target value
Peak data rate	20 Gbit/s downlink 10 Gbit/s uplink
Peak spectral efficiency	30 bit/s/Hz downlink 15 bit/s/Hz uplink
User experienced data rate	100 Mbit/s downlink 50 Mbit/s uplink
Area traffic capacity	10 Mbit/s/m2
Latency	4 ms
Mobility	Up to 500 km/h
Mobility interruption time	0 ms

To support the Internet of Things (IoT) “which can be defined as a network of physical objects which communicate and collaborate to generate and share information” (Myhre et al., 2020, p. 4), e.g., smart devices, a second frequency requirement is used and listed in Table 2.

Table 2. Requirements for mMTC. Source: Myhre et al. (2020, p. 4).

Key capability	Target value
Connection density	10^6 devices per km^2

The third category produces the fastest, most reliable communication for use relating to large scale and complex tasks within industry fields. URLLC requirements are high-reliability, low-latency, and high-availability. Technical requirements for frequency are listed in Table 3.

Table 3. Requirements for URLLC. Source: Myhre et al. (2020, p. 4).

Key capability	Target value
Latency	1 ms
Mobility interruption time	0 ms
Reliability	99.99%

The three frequency categories were designed to fulfill the needs of different application requirements grouping tasks into specific needs (Myhre et al., 2020). To accomplish this segregation 5G will incorporate a set of novelties which previous network generations were incapable of doing (Myhre et al., 2020).

Due to the scope of 5G and the manner behind utilizing it, a set of four novelties are also incorporated to support the complexity of its application (Myhre et al., 2020). The first is *Network Slicing* depicted in Figure 2, previous mobile communication networks operated under a shared concept as previously indicated. Latency was dependent on the number of users operating within the same vicinity of the network regardless of application. Network slicing takes the idea of a one lane access for all traffic and dividing it into multiple lanes which are designated for specific traffic types. Slices of the network can also be reserved to guarantee communication performance thereby ensuring that critical applications retain a high QoS (Myhre et al., 2020).

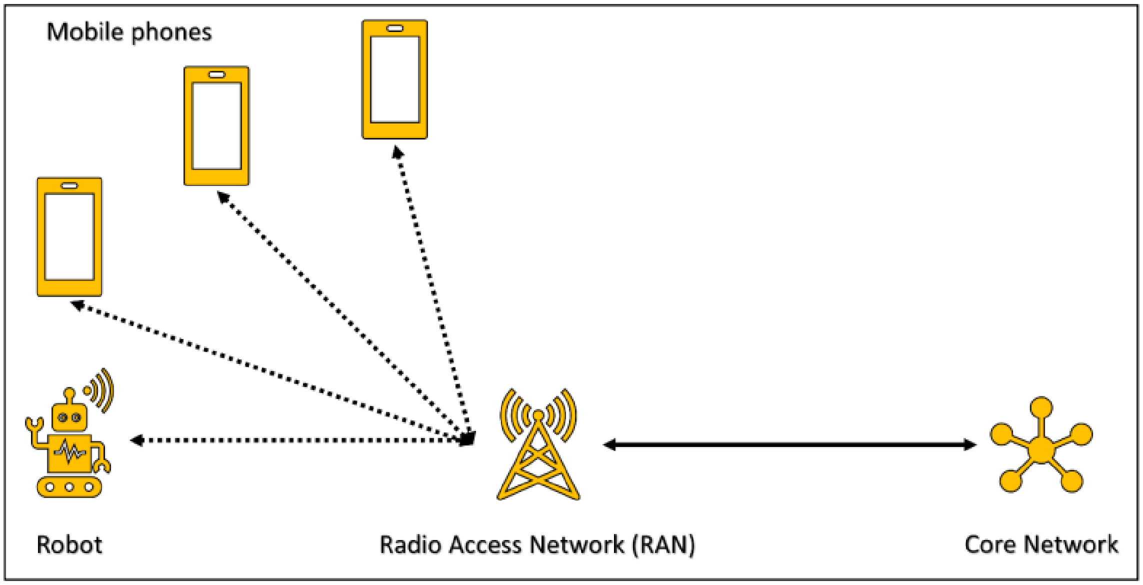

Figure 2. Network Slicing. Source: Myhre et al. (2020).

Network Slicing is beneficial to maritime operations because of the ability to retain a frequency ensuring its reliability for the more complex applications that are critical to success (Myhre et al., 2020). All communication networks are regulated by national authorities. The U.S. is regulated under the Federal Communications Commission (FCC). Telecommunication operators purchase licenses through the FCC to utilize frequency bands. When multiple operators use the same frequency, sub-bands are created to prevent interference between operators. However, "ITU has recommended that 5G should allow for specific frequencies to be reserved for local, geographically limited, frequency allocations" (Myhre et al., 2020, p. 6). Private frequencies enable operators utilizing 5G for robust operations to purchase frequencies and employ private networks to maximize operations.

In addition, previous network generations pushed data to a centralized core network before distributing to an end user. However, 5G *Edge Computing*, decentralizes this process and incorporates a local core network that computes and delivers data closer to the end user (Myhre et al., 2020). By decentralizing computing, sensitive data is less vulnerable through the centralized core network and reduces the latency experienced by routing data through it. Edge Computing is beneficial to maritime operations because of the need for real-time information for decision making and protection of sensitive information (Myhre et al., 2020).

The last novelty of 5G is radio communication and signal processing (Myhre et al., 2020). Error correcting coding is utilized in congested areas of communication or those areas that have electromagnetic interference. This coding permits high-capacity communications, low-transmit communications and low-power consumption, elements that are beneficial for industrial applications. Furthermore, signal processing can be accomplished through support of many antennas. This increases capacity, reliability and enables the ability to direct radio propagation. 5G's capabilities and benefits allow innovators to discover improved methods to secure the littorals and strengthening the U.S. sea power.

> The ongoing digitalization of the maritime industry opens new opportunities for products, applications, and services, but the full potential can only be gained if an efficient, flexible, and secure communication network for exchange of various types of data is in place. (Myhre et al., 2020, p. 7)

By understanding the capabilities and nuances of 5G Myhre et al. (2020) were able to conceptualize a ship-to-shore communication in their research. This concept indicates that the benefits of 5G, increased data communication and reliable transmissions, can enable remote operated unmanned and autonomous ship operations. However, the maximum range of these operations is dependent on the location of the RAN. Therefore, this option is only feasible for ships operating in the coastal waters of the littorals or waterways within range of a RAN as illustrated in Figure 3 (Myhre et al., 2020).

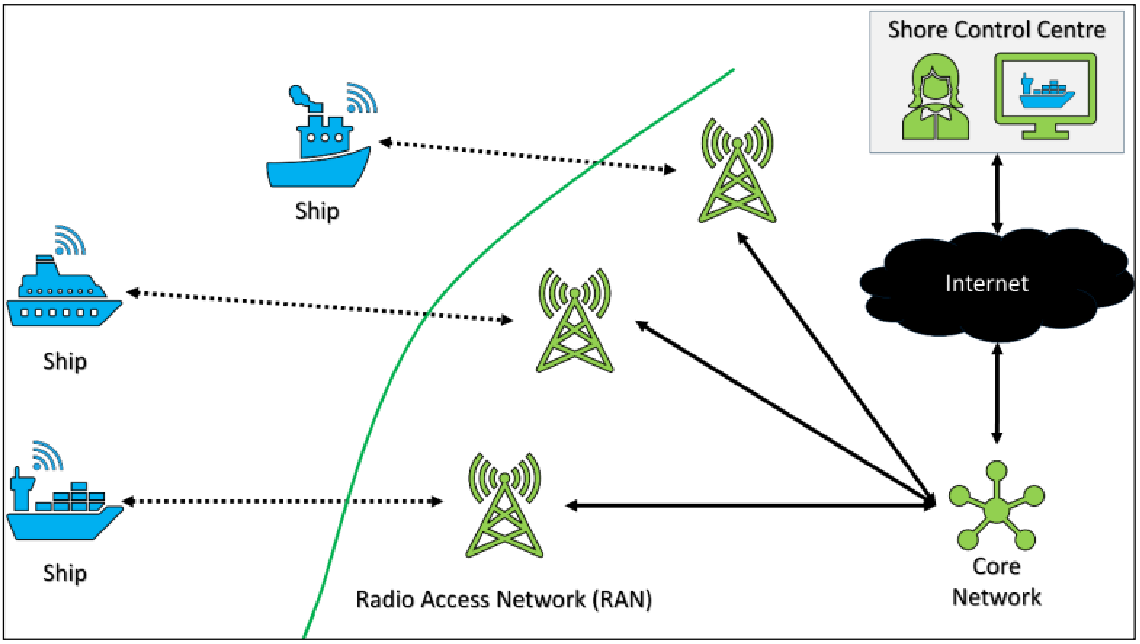

Figure 3. Ship-to-shore Communication. Source: Myhre et al. (2020).

The second concept shown in Figure 4 of ship-to-ship communication enables ships within proximity of one another to use the 5G network located onboard a ship to be the floating RAN on the water (Myhre et al., 2020). This concept is a segway to OPT's feasibility study for a buoy hub within the littoral environment. The network ship must be equipped with a RAN on deck and a core network which is connected to the bridge's systems. This infrastructure creates a private 5G network and enables other ships to tap into its system to gain 5G capabilities. The ability for a ship to house a 5G network extends the distance that these capabilities can be used since a ship is not limited to the confines of land (Myhre et al., 2020). The research and concepts described by Myhre et. al. (2020) in *Potential Benefits of 5G Communication for autonomous ships* look into the research questions: How might naval services benefit from a system of systems 5G commercial concept and what are the requirements and conditions needed for the naval services to utilize a commercial 5G framework?

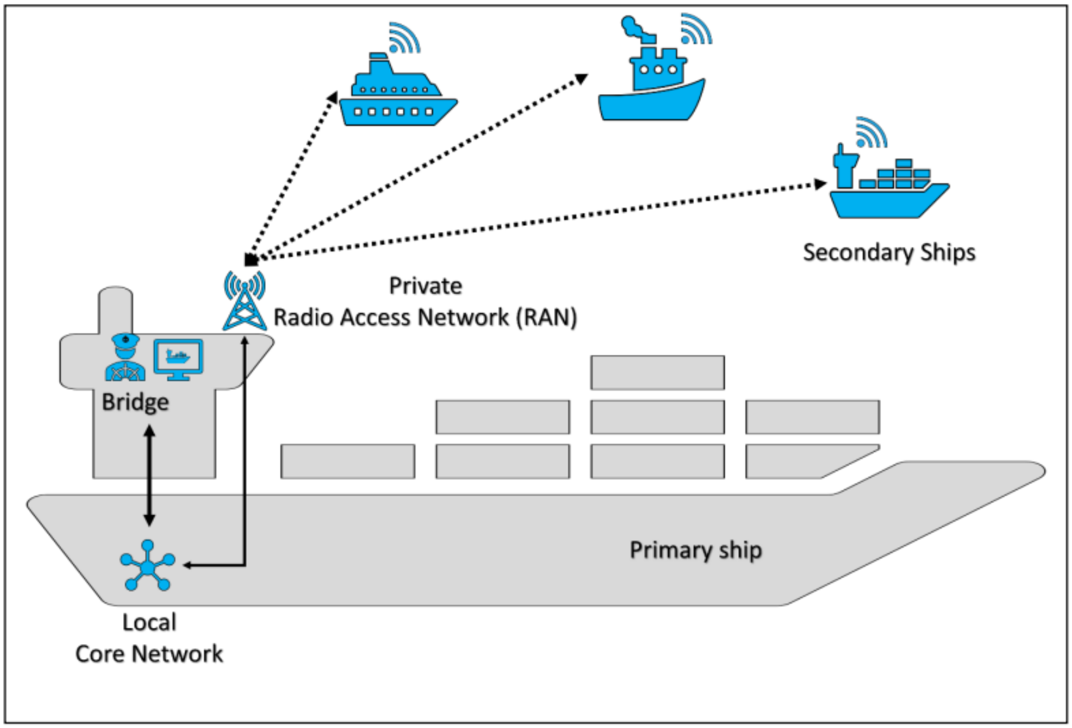

Figure 4. Ship-to-ship Communications. Source: Myhre et al. (2020).

The final literature review on *Ocean Power Technologies Feasibility Study: Sustainably Powered PB3 PowerBuoy Resident 5G Communications Hub for Autonomous Uncrewed Vehicles*, offers movement towards a solution of declining sea capabilities. Utilizing 5G next generation telecommunications to increase range and data throughput with low latency rates has the potential to increase MDA capabilities for naval operations. In the DOD's effort to collaborate with educational institutes to research and regain U.S. competitive advantage NPS created the SLAMR initiative. While the SLAMR facility, which will test applications for military use, is located adjacent to NPS in Monterey, California, the system overall can transfer to any offshore location (Ocean Power Technologies, 2021).

This study evaluates the potential to deploy an OPT PB3 PowerBuoy as a communications hub for Uncrewed Aerial Vehicle (UAV), Uncrewed Surface Vehicle (USV), and Uncrewed Undersea Vehicle's (UUV) in an MDA system. Technical aspects of this concept have been validated to meet the requirements of commercial host AT&T

communications equipment to successfully accomplish maritime awareness objectives. As the success of OPT's Maritime Domain Awareness System (MDAS) has proven possible in its early stages with AT&T communications, it will be referred to as their baseline solution for littoral environment coverage. OPT's study (2021) has indicated that 5G services can be extended further offshore by an antenna platform and power source located within the PB3 PowerBuoy. This capability enables greater span of control in the littoral environment. Moreover, multiple OPT PB3 PowerBuoys can be installed in one geographical area to increase an area of coverage. PB3 generates its own power, can sustain the integration of multiple vehicle communication payloads and be utilized as a recharging dock for UUVs. In locations that do not possess the wave activity necessary to generate power OPT can produce hybrid PowerBuoys that include a battery to sustain power. Additionally, operating capabilities and costs are estimated significantly better than that of satellite communications (Ocean Power Technologies, 2021).

III. METHODOLOGY AND SYSTEM DESCRIPTION

A. BACKGROUND

Following the literature review this chapter focuses on a preliminary concept of operations (CONOPs) for naval services, particularly the U.S. Navy. The intention is to leverage 5G commercial capabilities in the littorals for maritime domain awareness (MDA) by extending service from a buoy. This theoretical CONOPs uses commercial off the shelf (COTS) intelligent autonomous systems (IAS) from the private sector to form a system of systems (SOS) to support MDA. Additionally, this chapter will demonstrate the 5G RAN aspect of the CONOPs.

In 2020 Naval Postgraduate School (NPS) established a Navy Cooperative Research and Development Agreement (CRADA) which is a public/private academic contracting vehicle with AT&T Mobility, LLC in support of a highly secure tactical maritime 5G cellular mobile communication service (Naval Postgraduate School and AT&T Mobility, LLC, 2020). Through this partnership, the vision to explore innovative possibilities through 5G communications is created. Maritime shipping, oil and gas industry, recreational boating, homeland security, as well as other potential areas can benefit from 5G technology, limiting threats to the U.S. and Allied partners (Naval Postgraduate School and AT&T Mobility, LLC, 2020). Besides the CRADA, an active industry consortium was developed with additional private sector companies to expand the concept of leveraging 5G capabilities in the littoral environment. These companies include Ocean Power Technologies, Aerovironment Inc., Kaman, Ocean Aero, Nauticus Robotics, and TMGcore. These commercial companies provide expertise in autonomous systems in UAVs, USVs, and UUVs, edge computing and ocean power that can enhance Navy operations. This operational viewpoint (OV-1) in Figure 5 depicts the conceptual scenario and what each company can contribute to support the efforts against national security threats in the littoral environment.

B. CONCEPT OF OPERATIONS

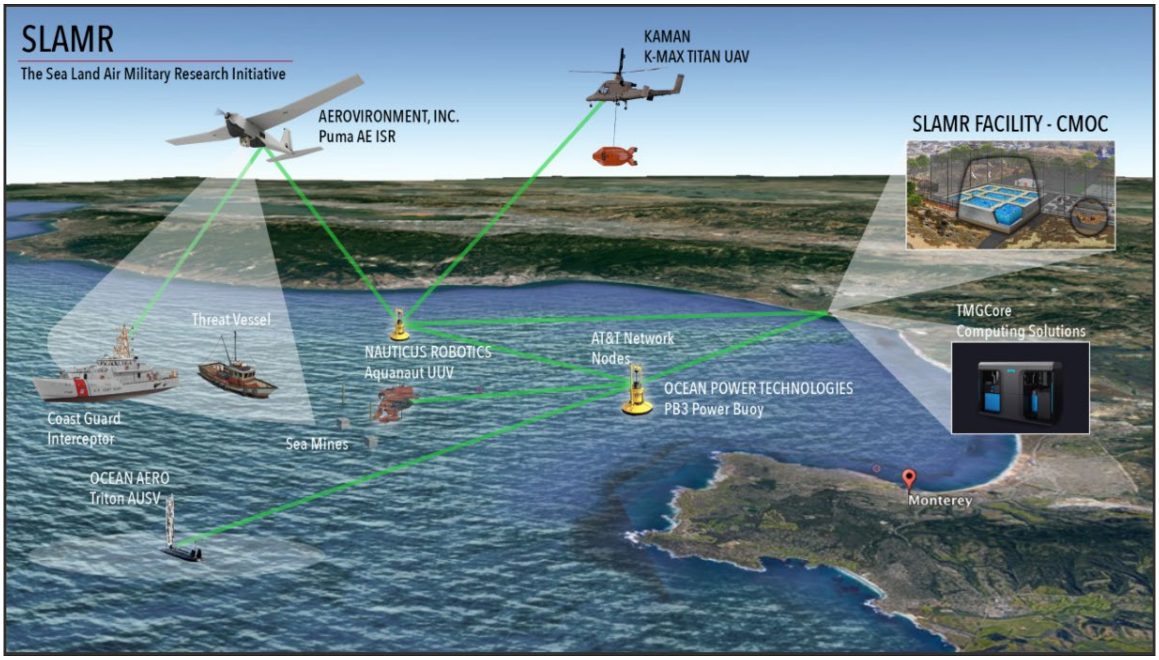

Figure 5. OV-1 for ACET / NPS SLAMR Networked UxV System. Source: Ocean Power Technologies (2021).

C. COMMERCIAL NETWORK

There are many commercial network providers that offer 5G services such as AT&T, Verizon, and T-Mobile. The CRADA allows AT&T to establish a highly secure tactical maritime 5G cellular mobile communication service at the SLAMR facility that extends to the NPS campus (Naval Postgraduate School and AT&T Mobility, LLC, 2020). While the CRADA is Navy focused to support MDA, there are potential uses for commercial shipping, USCG, oil and gas industry, and recreational boaters (Naval Postgraduate School and AT&T Mobility, LLC, 2020). AT&T is one of the leaders in wireless telecommunications in the U.S. Their developments and innovations can be employed to extend coverage throughout the littoral environment. To-date, voice, video, and data services, for military or commercial use are limited in the littorals (Naval Postgraduate School and AT&T Mobility, LLC, 2020). As part of the CRADA, AT&T constructed a 50-foot millimeter wave (mmW) antenna cell tower on the NPS SLAMR facility that will be leveraged for experimental use ashore as shown in Figures 6 and 7. AT&T 5G Sub-6 equipment will also be used on the OPT buoy as the network transport from sea-to-naval ship or sea-to-shore.

Figure 6. AT&T 5G 50-ft Millimeter Wave Tower. Source: LCDR Caplan iPhone (2022).

Figure 7. AT&T 5G 50-ft Millimeter Wave Tower. Source: LCDR Caplan iPhone (2022).

1. Sub-6 5G

5G frequency is split into two main types in the frequency spectrum: Sub-6 and mmW. Sub-6 supports FR below 6GHz. 4G, 3G, and 2G operate in this spectrum which is already cluttered with devices (Martonik, 2021). Upgrades to network infrastructure simply requires equipment updates to existing towers since 4G technology is still applicable. However, while users expect 5G capabilities on devices it remains operating under the many limitations that 4G networks are built on. The issue is that Sub-6 networks aren't significantly increasing the end user performance compared to 4G networks. The Sub-6 5G networks provide merely a slightly faster experience than 4G networks (Martonik, 2021). One area Sub-6 will be able to take advantage of is in the mid band FR of 2GHz to 6GHz where 4G networks typically haven't operated (Martonik, 2021). This space allows for increased speeds with better range and fewer base stations as well as object avoidance due to the unused spectrum.

2. Millimeter Wave 5G

This bandwidth delivers the most capabilities for 5G, with FR between 30GHz and 300GHz (Martonik, 2021). While the FCC has started auctioning off frequencies up to 48GHz, most commercial carriers are operating in the 30GHz to 40GHz range (Martonik, 2021). This new network stands alone apart from 4G and requires new infrastructure, however updating the infrastructure requires a lengthy process to accomplish nationwide compared to Sub-6 5G. This technology is designed to provide higher data speeds and decrease latency. Gigabytes per second download speeds, one millisecond latency, and real time communications between devices, vehicles, and autonomous systems, are all centered on mmW capabilities (Martonik, 2021). A challenge carriers like AT&T, Verizon, and T-Mobile are facing, relate to higher frequencies which travel a shorter distance and would increase the number of towers or cell sites to cover an area. Additionally, any object can disrupt performance. For example, buildings, vehicles, cars, etc., so it is imperative to install an abundance of towers to support mmW coverage (Martonik, 2021). Direction sensitivity between the UE and the antenna can also affect the 5G outcome. However, when a device does receive 5G+ (AT&T) signal the performance is unmatched. Additionally, there can be multiple UEs connected to a single network without any degradation of service. Having the ability to leverage both 5G Sub-6, for consistency and coverage, and mmW, for speed and density will enhance the ability to tackle any situation (Martonik, 2021). This makes it important to understand the desired mission situation to leverage the appropriate 5G technology.

D. TEST DESIGN

The SLAMR initiative supports the NPS facility and students as well as industry partners for research and development. The theoretical concepts depicted above (figure 5) will start with the operational capability of AT&T's 5G mmW tower. This 50ft cell tower provides the capability to test signal strength at different ranges, speed from end user devices, and data throughput. The initial testing established a local footprint to determine these capabilities. To collect this information the following equipment was used; NETGEAR MR 5100 Night Hawk (WIFI connection to the 5G tower), Samsung Galaxy

Tab S7, and a Samsung S21 5G phone, all provided by AT&T. Other devices used to support testing were an iPhone 7, Hewlett Packard Notebook, and OOKLA speed test application that was downloaded on UE devices. Figures 8–13 illustrate the characteristics of each device to establish a baseline to assist with the results.

1. MR5100 – Night Hawk 5G Hotspot Pro

Figure 8. AT&T Netgear Night Hawk Mobile 5G Hotspot Pro (MR5100). Source: NETGEAR (2022).

- Supports mmW and Sub 6GHz
- Max throughput: 1.2Gbps on 5GHz
- Max Theoretical Downlink Speed: Ethernet 1 Gbps. Wi-Fi: 802.11ax 1.2Gbps
- Ethernet port for point-to-point or hub
- Secure control access with password-protected Wi-Fi and VPN passthrough

- Supports 32 devices
- Firmware Version: NTGX55_12.04.10.01 (NETGEAR, 2022)

2. **Samsung Galaxy Tablet S7**

Figure 9. Samsung Galaxy Tablet S7. Source: Samsung (2022).

- OS: Android 10
- Chipset: Qualcomm SM8250 Snapdragon 865 5G+
- WLAN: Supports Wi-Fi 802.11 a/b/g/n/ac/6
- Latest firmware and software updates (Samsung, 2022)

3. Samsung Galaxy S21 5G

Figure 10. Samsung Galaxy S21 5G. Source: Samsung (2022).

- OS: Android 11
- Supports 5G sub6 / mmW
- Wi-Fi 802.11 a/b/g/n/ac/ax 2.4G+5GHz
- Supports up to 1.2Gbps Download and Upload
- Latest firmware and software updates (Samsung, 2022)

4. iPhone 7 (Verizon Carrier)

Figure 11. iPhone 7. Source: Apple (2022).

- Model: A1660 / Not 5G capable
- Software Version: 15.2.1
- Supports 802.11 ac Wi-Fi with MIMO
- Latest firmware and software updates (Apple, 2022)

5. HP Notebook

Figure 12. HP Notebook 15-ay078nr. Source: Hewlett-Packard (2022).

- Model 15-ay078nr (energy star)
- Intel Core i7-6500U
- OS: Windows 10 Home 64
- Wi-Fi: 802.11 b/g/n
- Network interface: Integrated 10/100 Base-T ethernet LAN
- Latest firmware and software updates (Hewlett-Packard, 2022)

6. OOKLA (Speed test) Application

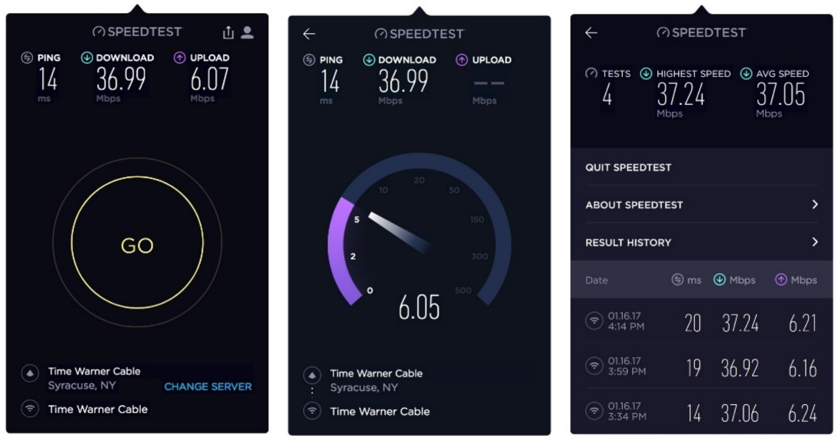

Figure 13. OOKLA Application. Source: OOKLA (2022).

- Installed on all devices via app store
- Server: Walnut Creek, CA
- Version: 1.15.163.0 (OOKLA, 2022)

Testing was conducted in three phases. Using Google Maps to print out the SLAMR facility footprint the aim was to establish different look angles to the 5G mmW tower and document different range points using the AT&T Galaxy S21 phone by accessing the phone's built-in signal strength feature to connect to the tower. Access to AT&T capability through the call feature *#*#4636#*#* was inputted. This can be accomplished on any AT&T end user device. The next menu lists three options, Phone Information was selected, then locate Signal Strength. This feature will display in negative decibel milliwatts (dBm). The lower the negative number the stronger the strength of signal to the tower. At each waypoint (WP) selected, the procedure consisted of a wait between 2–3 minutes before collecting the signal strength to allow for a stable and accurate reading. A total of 9 WPs were randomly selected and documented for this part of the testing. While there are two distinctions within 5G technology: Sub-6 and mmW, this test focused on mmW. When the UE connects to 5G it is locking on to one of these 5G network frequencies. To visually verify which network frequency range the AT&T device is connected to either a 5G (Sub-6) or 5G+ (mmW) symbol will appear on the top part of the device.

Phase two included taking the Night Hawk (NH) in conjunction with marking signal strength at each WP and seeing if the NH would connect via 5G+ to the tower. This was critical to measure high throughput and low latency with end user devices. The NH enables secure means of communication to the tower as the NH is password protected for authorized devices only. Once the NH had established 5G+ connection the next phase was to connect different end user devices to the NH via Wi-Fi or connected via a tethered to the 5G+ tower.

Phase three connected the different end user devices described above and by accessing the installed application OOKLA, conduct 3 speed tests at 5-minute intervals using a selected app server and documented the download and upload Mbps to analyze the findings. Additionally, ping tests (latency) in milliseconds (ms) was collected from each device. Collecting ping data at each WP provides reaction time of the communication connectivity using mmW.

This test ashore provides key aspects to better understand 5G mmW capabilities and the end user devices that enable best results. By focusing from the shoreline, it provides easier means to troubleshoot making the appropriate adjustments to coordinate with the subject matter experts as required. Additionally, this test offers a baseline as testing matures away from the 50-ft tower into the bay area where possible challenges will increase connecting to the mmW tower. Figure 14 depicts the location of the mmW AT&T tower and the 9 WPs latitude and longitude.

Figure 14. Overhead Picture of the SLAMR Facility in Monterey, CA. Source: Google Maps (2022).

E. TEST LIMITATIONS

While this CONOP is still in the developmental stages some testing was conducted to gain a sense of range and throughput limitations using the AT&T 5G+ tower. It is important to document the test limitations to provide a clear understanding of the data gathered within set environments. All testing was constrained to inside the SLAMR perimeter and just outside the fence line closest to the ocean due to the fact that only one (of three) sectors of the 5G+ tower was authorized to be energized for use because of NPS requirements. Having only one sector of three available activated means the connection range is isolated and can't be utilized to the maximum 360-degree extent possible. Other factors to consider include the type of user equipment used during the data collection. To maximize the full arsenal of mmW capabilities each piece of equipment needs to be able to support such factors. Testing will show what this looks like using capable and non-capable mmW equipment. Additionally, since the CRADA is between NPS and AT&T to utilize the mmW tower, an AT&T device would need to be used either connecting directly to the tower or through a Wi-Fi device, for instance a NH.

Another limitation to testing is the novelty of the 5G mmW tower and still learning the technical aspects that the tower presents in the Monterey area. While testing was conducted for security reasons there isn't any archived data that can be referred to, to compare throughput and range as this testing infrastructure is being used. These tests are the initial steps necessary to begin testing of the PB3 PowerBuoy and its capabilities.

F. COMMUNICATION HUB

1. Ocean Power Technologies (OPT) PB3 PowerBuoy

OPT previously tested the PB3 PowerBuoy off the coast of New Jersey. The PB3 PowerBuoy is at technology readiness level (TRL) 9, the highest evaluation by the DOD indicating the maturity of a technology or invention. To receive a TRL-9 designation denotes the actual system has been tested during mission operations. The PB3 is an autonomous wave-energy convertor that generates electricity through the power take off (PTO) system that is then stored within the onboard batteries (Ocean Power Technologies, 2021). The Spar, which is the main component, houses the PTO that attaches to the surface float. The PB3 offers an energy storage system, real-time onsite data collection, processing, and two-way communication in a max sea state of 5. OPT offers a variety of options depending on the requirements. One of the options supports Maritime Domain Awareness System (MDAS) through autonomous and sustainable offshore continuous monitoring systems. This foundational setup incorporates radar, camera, and automatic identification system (AIS) an automatic tracking system, to provide real-time monitoring information to command-and-control center either on or offshore. A successful use case in the North Sea involving Premier Oil was conducted from August 2019 through March 2020 (Ocean Power Technologies, 2021). Figures 15 and 16 show component locations on the PB3 power buoy.

Figure 15. OPT PB3 PowerBuoy. Source: Ocean Power Technologies (2021).

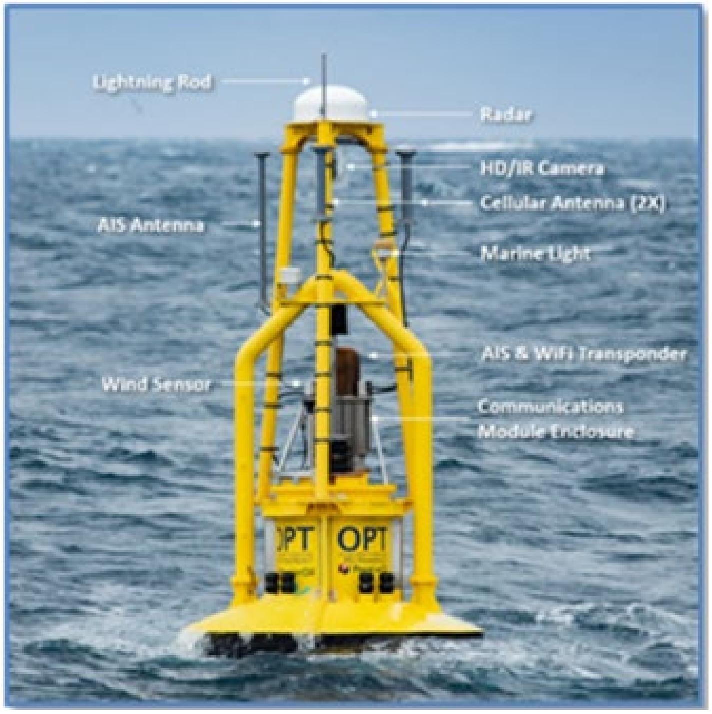

Figure 16. OPT Maritime Domain Awareness System. Source: Ocean Power Technologies (2021).

a. Specifications for the Use Case

- Radar
- HD camera with thermal imaging
- AIS transponder
- Water to Shore Communications
- Near range Wi-Fi
- Independent Satellite tracker
- Marine navigation light

The experiment identified targets via radar or AIS within the designated monitoring zone by the camera's ability to automatically lock onto the target (Ocean Power

Technologies, 2021). If a vessel's AIS is off, the radar system will lock on to the vessel once in range and use its camera to visually identify the questionable vessel.

Where OPT's PB3 can play a pivotal role in this CONOP is by housing AT&T's 5G communication equipment providing a durable antenna platform and energy source to support the various IAS that can pass through, and download collected information to be relayed back to a command-and-control network operation center (NOC). OPT's PB3 allows for substantial development options in bandwidth and lowered operational costs compared to other communication means (such as satellite) to operate a collection of unmanned systems. Additionally, this mixture can decrease the naval service footprint presence around operation improving warfighter safety and cost to operate other manned platforms to complete the same mission requirement.

G. COMMERCIAL UNCREWED SYSTEMS

The companies below are part of the active SLAMR Industry Consortium that has the theoretical capability to support the SOS MDA represented in the OV-1 concept in the littorals (Figure 5). The aim is to provide some background of each system that can support interconnection through the OPT/AT&T buoy system back to a RAN ashore or to a NOC or equivalent.

1. Ocean Aero Triton

According to Ocean Aero, Triton shown in Figure 17 specializes in autonomous underwater and surface vehicle (AUSV) that can sail on the surface and dive below the ocean's surface (Ocean Aero, 2022). It's ability to generate power from the wind and sun makes it ideal to support a vast amount of mission requirements. The modular architecture allows for custom payloads or prebuilt off the shelf packages. It is constructed and operated in the U.S making the acquisition process and security for DOD use ideal. The ability for the Triton to collect data above and below the surface and relay that information from anywhere at any time enhances the MDA capability.

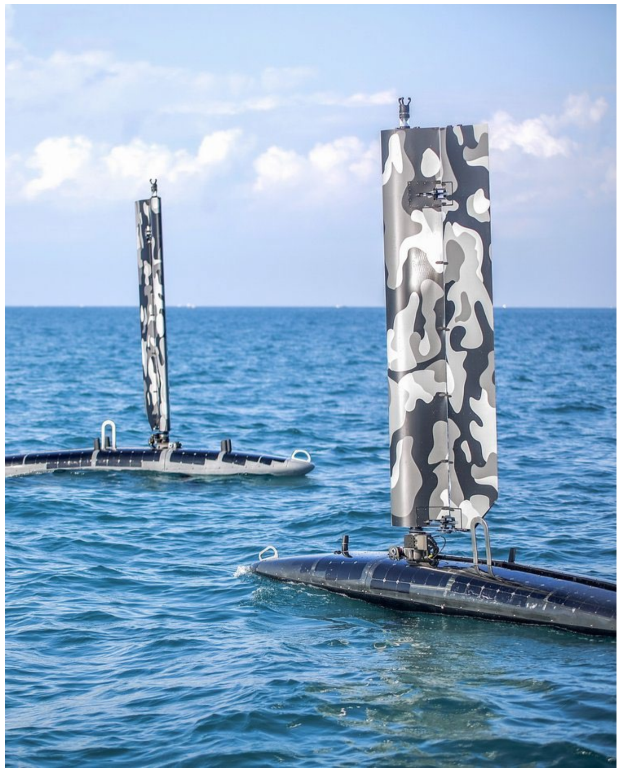

Figure 17. Ocean Aero Triton. Source: Ocean Aero (2022).

a. *Triton Advantages*

- Launch and recovery from land or sea within minutes
- Stealth: low radar and visual signature, with the ability to deep dive to avoid detection and evade threats
- Cost effective over traditional Naval ships
- Integrate and operate with other systems

The Triton has the ability to be outfitted with high resolution video line scanners, combined thermal imagery, solid state radars, passive mini-towed arrays, side-scan and gap-filler sonars to support intelligence, surveillance, and reconnaissance (ISR), Mine Countermeasures, and Anti-Submarine Warfare (Ocean Aero, 2022). Additional advantages are Triton’s solution for ocean surveillance and monitoring that can strengthen Monitoring, Control and Surveillance capabilities. Payloads, including visual and IR cameras, acoustic arrays, salinity, temperature, wind speed and direction, and bathymetry sensors can provide the intelligence, communication, cooperation, and coordination required to surveil the ocean safely and effectively (Ocean Aero, 2022).

b. Triton Specifications

- Max Submergence Depth: 100m/328ft
- Max Surface Speed: 5 knots
- Max Subsurface Speed: 2 knots
- Battery power: 4kWh
- Solar Collection: 200W
- Comms: Iridium, Wi-Fi, 900Mhz, Mesh
- Payload: 50lb body, 25lb Keel, 8lb wing
- Surface Endurance: 3+ months
- Subsurface Endurance: 5+ days (min power) (Ocean Aero, 2022)

2. Nauticus Robotics

According to Nauticus Robotics (2022) the Aquanaut depicted in Figure 18 is an unmanned underwater vehicle (UUV). It can transform itself from a submarine designed for long-distance cruising into a half-humanoid robot. Complex manipulation tasks at depths up to 3,000 meters can be carried out without the need for support vessels (Ackerman, 2018). The traditional remotely operated vehicle requires supported resources to fulfil the operation, but the Aquanaut can be launch from a boat or released from an autonomous helicopter. It can inspect subsea oil and gas infrastructure, mine detection, operating valves, and using tools. The Aquanaut operates completely untethered and communicates acoustically through the water, a new concept in the UUV industry (Nauticus Robotics, 2022). This feature can become a significant advantage in the event of a degraded communication environment.

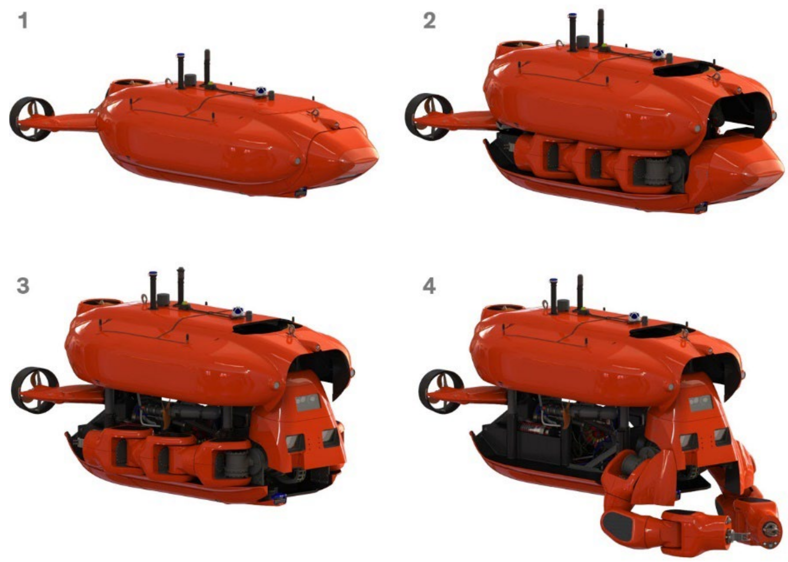

Figure 18. Aquanaut, the Shapeshifting Subsea Autonomous Robot. Source: Nauticus Robotics (2022).

a. *Nauticus Specifications*

- Vehicle Size:
  - Length: 174.3 inches / 244 inches w/arms extended
  - Width: 70 inches
  - Height: 60.8 inches
- Vehicle Weight: 7408 pounds / 8488 pounds (extended range)
- Depth Rating: 3000 meters
- Cruising Speed: 3 knots / Max speed: 6 knots
- Max range: 75 miles / 137 miles (extended range)
- Endurance: 116 hours / 175 hours (extended range in 1-knot current)
- Battery Capacity: 67.4 kilowatt hours / 101.1 KWh (extended range)

- Payload Capacity: 200 pounds

b. Manipulator Specifications

- Reach: 73 inches
- Lift Capacity: 779 pounds (max) / 90 pounds (full extension)
- Gripper Force: 1000 pounds (minimum)
- Gripper Rotation: 360 degrees continuous

c. Sensing Packages

- Multiple packages to include Navigation, Acoustic Communications, Survey and Mapping, Pipeline inspection, and Subsea Integrity. (Nauticus Robotics, 2022)

3. AeroVironment PUMA 3AE

AeroVironment (2022) indicates the Puma 3AE in Figure 19 as a system that has been battlefield tested. It provides vital ISR resources across all conditions for operational success. Its ability for plug and play interoperable components add to the warfighter's capabilities to successfully achieve success in various missions. As an unmanned aircraft system (UAS) the Puma features a reinforced airframe that can support various payloads and third-party applications, making this UAV multi-mission capable. The ability to launch by hand, bungee, rail, or vehicle gives the maximum flexibility for day, night, and low light operations. Additionally, the Puma's improved digital data link supports increased frequencies with AES-256-bit encryption strengthening security communications (AeroVironment, 2022).

Figure 19. Puma 3 AE. Source: AeroVironment (2022).

a. Specifications

- Link range: 20km, 60 km with LRTA
- Wingspan: 9.2ft / Length: 4.6ft / Weight: 15.4 lbs
- Endurance: 2.5 hrs with Mantis i45
- Payloads:
    - Mantis i45: Dual 15 MP EO/IR
    - Mantis i45 N: Dual LWIR/5 MP low Light
- Total Payload Capacity: 4 lbs
- Speed: Cruise: 49 km/hrs (26 kts), Dash: 76 km/h (41 kts)
- Operating Altitude: 300–500 ft (91-152 m) AGL, typical Max. launch 10K ft (3,048 m) MSL
- Recovery Method: Autonomous or manual precision deep-stall landing (AeroVironment, 2022)

4. Kaman K-MAX Titan

According to Kaman (2022), Titan illustrated in Figure 20 is the first, heavy lift unmanned helicopter to be produced globally. The 4,500+ lbs. payload capacity provides the reliability and flexibility in various conditions increasing the Titan's ability to sustain operations. With a heavy emphasis on COTS technology, Titan's affordability ties into the DOD's goal of interoperability (Kaman, 2022).

Figure 20. Kaman K Max Titan Heavy Lift. Source: Kaman (2022).

H. COMPUTING THE DATA

1. TMGcore

TMGcore (2022) provides high-performance computing solutions and manufactures commercial grade hardware specializing in liquid immersion cooling technology. This capability can support a variety of industries in the government and commercial sector like telecommunications. The importance of data within the government is being collected at exponential rates for national security, intelligence, and disaster relief. TMGcore offers OTTO™ shown in Figure 21 which provides real-time data collecting and delivery to process, store, and analyze these volumes of data. TMGcore is part of the backhaul once the information passes through the RAN to increase naval service decision making (TMGcore, 2022).

Figure 21. EdgeBox 4.5 Source: TMGcore (2022).

I. SUMMARY

Through these system descriptions an understanding of how each system can contribute to the SLAMR OV-1 CONOP can showcase a thorough net of protection and defense in MDA. The commercial IAS has the ability to create an SOS concept utilizing a 5G network mounted on a commercial buoy extending the range from shore to the littorals. This CONOP enables the naval service to support MDA from the air, surface, and subsurface mission requirements from farther distances from land at faster and more reliable speeds. This theoretical notion has the ability to deploy globally by leveraging the assets listed above to complete various mission criteria.

IV. TEST RESULTS AND SERVICE APPLICABILITY

A. SLAMR SECURE 5G MMW OUTCOME

The objective of this research was to collect a variety of data through different end user devices, at various WPs to better determine the initial capabilities of 5G mmW. Furthermore, it can provide the DOD agencies alternative options with using commercial technology that can satisfy DOD requirements. Naval services, operating in the littorals, can establish a 5G SOS environment with already developed technology created by the commercial industry.

The tables recorded in this section outline the results of the testing, with a few parameters impacting all tests. These included the OOKLA server in Walnut Creek, CA, which was automatically selected when the application launched at the SLAMR site. Server verification was made each time the application was launched and throughout the test to ensure consistency was established. The OOKLA application showed the Walnut Creek server 90 miles from the SLAMR installation that was utilized. A manual server selection of Cruzio in Santa Cruz, CA which is the closest at 28 miles from SLAMR revealed poor test results when comparing the first four WPs. Allowing the application to auto select the server to receive best results was determined from this. Additionally, the built-in antenna on the NH (Cat5 connection side) always pointed to the 5G tower as it established the strongest connection possible. The final implemented standard was a 3–5 minute wait time at each WP before testing was conducted. This allowed for stabilization of the connection between all systems to get the most accurate reading. A 5-minute wait time between each OOKLA speed test recording was established at three different times to maintain uniformity. From this analysis, the aim was to describe how the CONOP could benefit from the 5G technology to support DOD operations.

1. Samsung Galaxy Tab S7

Table 4 depicts results collected on February 16th, 2022, using the Samsung Galaxy Tab S7 to the 5G+ AT&T tower using the OOKLA speed test application. What is evident to note is the download speed in gigabytes per second at each of the WPs (Figure 14) when using a 5G+ connection from end user to RAN system.

Table 4. Samsung Galaxy Tab S7 Speed Test Results

Location/ distance from tower	Download Speed (Mbps)	Upload Speed (Mbps)	Time Intervals (5min)
WP1 / 97ft	1,289	50.3	1130am
	1,285	75.4	1135
	1,184	71.6	1140
WP2 / 318ft	1,286	77.4	1145
	1,325	78.1	1150
	1,216	77.5	1155
WP3 / 386ft	1,208	41.7	1200pm
	1,210	60.3	1205
	1,274	80.9	1210
WP4 / 285ft	1,180	15	1215
	1,197	17.7	1220
	1,260	68.9	1225

2. iPhone 7 (4G LTE)

Table 5 depicts results collected on February 16th, 2022, using an iPhone 7 (4G LTE) through Wi-Fi NH MR5100 5G+ to the mmW AT&T tower using the OOKLA speed test application. The aim was to show the difference in download and upload speeds using a non 5G capable device. While the NH enhanced the throughput capability it was hindered by the end user device's limitations on the older non 5G components. The download results show a significant decrease compared to a 5G+ end user device.

Table 5. iPhone 7 (4G LTE) Speed Test Results

Location/distance from tower	Download Speed (Mbps)	Upload Speed (Mbps)	Time Intervals (5min)
WP1 / 97ft	563	85.2	1000am
	564	99.6	1005
	557	109	1010
WP2 / 318ft	365	157	1020
	414	147	1025
	296	156	1030
WP3 / 386ft	522	67.9	1035
	258	52.1	1040
	257	61.7	1045
WP4 / 285ft	513	59.1	1050
	497	22.7	1055
	526	72.9	1100

3. WP Signal Strength Markings

After the first day of testing at the four WPs, testing was expanded to outside the perimeter as well to include signal strength at all nine locations. Table 6 shows each WP to the mmW tower to indicate signal strength communications. Results collected on Feb 17, 2022, using Samsung Galaxy S21 5G+ model phone through built in application as it automatically adjusted signal strength as device moved in correlation to mmW tower. Also, signal strength will fluctuate as the tower needs to balance the device load. Consideration of the fact that the low number of devices connecting to the AT&T 5G tower contributed to the excellent signal strength at each of the WPs. The lower the negative number the stronger the connection signal. Before collecting any data, a minimum of 5 minutes was observed to allow the signal to stabilize for best results. While each of the WPs showed strong signals at WP 6 and 8 (Figure 14) showed the highest negative number due to poor look angle to the tower.

Table 6. WP Signal Strength in dBm

WP1	-62
WP2	-67
WP3	-68
WP4	-68
WP5	-67
WP6	-76
WP7	-72
WP8	-80
WP9	-65

4. HP Laptop Wi-Fi to NH

Table 7 results were collected on Feb 17, 2022, using an HP laptop connecting via Wi-Fi to MR5100 NH to the mmW AT&T tower using OOKLA speed test application. The laptop's wireless component limited the capability to access 5G speeds due to the age of the device off the shelf.

Table 7. HP Laptop Wi-Fi Speed Test Results

Location/distance from tower	Download Speed (Mbps)	Upload Speed (Mbps)	Time Intervals (5min)
WP1 / 97ft	31.06	5.54	1245pm
	30.92	27.85	1250
	31.39	6.38	1255
WP2 / 318ft	30.29	29.48	1300
	19.48	16.26	1305
	27.73	29.33	1310
WP3 / 386ft	38.94	35.40	1315
	38.27	36.85	1320
	37.22	20.26	1325
WP4 / 285ft	25.74	36.06	1330
	36.40	34.82	1335
	40.16	34.26	1340

5. HP Laptop Cat5 to NH

Additional testing with the laptop revealed another limitation when connecting directly to the NH via Cat5 cable. The network interface card (NIC) is only outfitted with 10/100 BASE-T ethernet. This means that the NIC cannot achieve download speeds greater than 100 megabytes per second. Table 8 confirms this for all 9 WPs on May 9th, 2022, using an HP laptop physically connected to MR5100 (5G+) via Cat5 to mmW tower using OOKLA speed test application. The asterisk on WP 6 (Table 8) indicates no mmW connection received due to the drop in elevation and the inability to see the tower from its look angle position within the 5-minute duration.

Table 8. HP Laptop Cat5 Speed Test Results

Location / distance from tower	Download Speed (Mbps)	Upload Speed (Mbps)	Time Intervals (5min)
WP1 / 97ft	93.28	11.62	0900am
	93.33	33.64	0905
	93.46	33.72	0910
WP2 / 318ft	93.44	13.40	0915
	93.42	22.20	0920
	93.66	39.13	0925
WP3 / 386ft	93.45	14.31	0930
	93.40	11.62	0935
	93.20	69.39	0940
WP4 / 285ft	93.24	20.64	0945
	93.35	100.30	0950
	93.43	101.12	0955
WP5 / 409ft	93.39	32.10	1000
	9370	27.09	1005
	93.58	100.05	1010
WP6* / 503ft	No data available		1015
WP7 / 543ft	93.75	91.37	1020
	93.58	92.95	1025
	85.78	85.82	1030
WP8 / 585ft	93.48	103.4	1100
	93.57	106.55	1105
	93.46	103.27	1110
WP9 / 305ft	93.4	96.91	1115
	93.36	101.96	1120
	93.75	103.99	1125

6. Samsung Galaxy S21 5G+

Table 9 represents test results collected on May 11, 2022, using Samsung Galaxy S21 5G+ connected to the mmW AT&T tower through cellular service using OOKLA speed test application. Again, WP 6 wasn't able to establish 5G+ connection to record any valuable data in the allotted five minutes. A direct connection between the device and the mmW tower produced speeds listed below.

Table 9. Samsung Galaxy S215G+ Speed Test Results

Location / distance from tower	Download Speed (Mbps)	Upload Speed (Mbps)	Time Intervals (5min)
WP1 / 97ft	1,008	15.2	1000am
	799	44.8	1005
	808	33.4	1010
WP2 / 318ft	937	89.4	1015
	972	22.3	1020
	957	90.8	1025
WP3 / 386ft	976	29.9	1030
	1,022	95	1035
	980	95.9	1040
WP4 / 285ft	1,220	103	1045
	929	101	1050
	918	99	1100
WP5 / 409ft	1,086	85	1105
	1,132	190	1110
	1,143	134	1115
WP6* / 503ft	No data available		1120
WP7 / 543ft	1,154	127	1125
	1,148	112	1130
	1,200	102	1135
WP8 / 585ft	1,198	99	1140
	1,066	98.3	1150
	1,200	243	1155
WP9 / 305ft	979	88	1200pm
	989	84.3	1205
	1,006	80.3	1210

7. Samsung Galaxy S21 Wi-Fi to NH

Table 10 highlights test results collected on May 11th, 2022, using Samsung Galaxy S21 5G+ connected via Wi-Fi to the NH to mmW tower using OOKLA speed test application. The additional piece of equipment (NH) in between the end user device and the tower decreased the download speed limiting the full capability of the connectivity path. This is due to the NM component capability and overhead requirements.

Table 10. Samsung Galaxy S21 Wi-Fi to NH Speed Test Results

Location / distance from tower	Download Speed (Mbps)	Upload Speed (Mbps)	Time Intervals (5min)
WP1 / 97ft	549	45	1000am
	548	13	1005
	582	13.6	1010
WP2 / 318ft	755	50.8	1015
	689	45.6	1020
	685	12.2	1025
WP3 / 386ft	779	31.3	1030
	714	5.82	1035
	863	10.3	1040
WP4 / 285ft	672	2.37	1045
	766	10.9	1050
	741	4.95	1100
WP5 / 409ft	858	141	1105
	891	38.6	1110
	888	31.2	1115
WP6* / 503ft	No available data		1120
WP7 / 543ft	793	30.2	1125
	795	5.97	1130
	761	2.33	1135
WP8 / 585ft	852	10.89	1140
	725	10.6	1150
	754	10.1	1155
WP9 / 305ft	701	8.2	1200pm
	816	34.3	1205
	829	11.5	1210

B. KEY OBSERVATIONS OF SLAMR 5G MMW TOWER

After testing was concluded there were several observations evident which enabled access to 5G mmW services on the SLAMR installation. First, the UE needs to be 5G mmW capable and in the footprint of the tower's cellular or Wi-Fi range. Since the tower is owned and operated by AT&T, the device connecting to the tower must be AT&T compatible either directly from end user device or through some type of medium, for example the NH to the tower. The end user device needs to be provisioned to support the mmW service plan. In some cases when there is a 5G Sub-6 tower in the area the end user device doesn't automatically shift connection to the 5G mmW. In this case the best option is to navigate to airplane mode and select off and then on to force the 5G mmW connection. On AT&T devices a 5G+ will appear on the top of the screen. Additionally, browsing the internet or playing music may be required to activate mmW service. This is due to the way cellular providers like AT&T configure service plans. If users aren't producing enough processing requirements for mmW, there is no need to waste data on user service plan.

C. SUMMARY OF RESULTS

1. Speed Test Considerations

Speed test applications are an important tool to understand the speed from a device all the way to the selected test server that reflects the internet service provider (ISP). It is also critical to know factors that can impact the speed test. As the results indicate, devices (computers, phones, tablets, mobile hotspot, etc.) can produce Wi-Fi and cellular capability differences. Another factor is that speed test servers can generate various outcomes. As mentioned above, trying out a variety of servers can help create an overall picture but through this testing it appeared the application always selected the best available speed test server automatically to produce the best result. Lastly, there are many speed testing services available, each providing different capabilities so its possible results will not look the same. For this testing, OOKLA was chosen because the major ISPs use it as their troubleshooting tool.

OOKLA measures real-time network connection, which is why results vary depending on network congestion and available bandwidth (SPEEDTEST, 2022). Also, if the device is on Wi-Fi for one test and physical connection on another test the speeds will be different as components are different. The significant variation in Wi-Fi and cellular communication quality can trigger devices to produce slower test results as indicated during this study.

Another feature with OOKLA, besides providing download and upload information, is ping (latency). Throughout the different testing, pings ranged from 4 to 32 milliseconds (ms) with the lower pings representing the total path using 5G mmW equipment. These low ms pings at the higher transfer speeds enable quicker dissemination of data to be collected and analyzed for naval service decision making.

2. Testing Assessment

This assessment confirmed that 5G technology can provide significant throughput versus 4G technology when 5G capable equipment is used in the communication path. The latency results were within the optimum range in a single end user device set up in a 5G mmW configuration. While ranges maxed out at 585 ft, signal strength and connectivity remained at optimal levels within the mmW environment. Non 5G capable devices that are interjected into the connection path have diminished throughput and latency, degrading the effectiveness of the data flow. Per the CRADA, AT&T is responsible for adjustments on AT&T equipment if errors or issues are presented. During the initial testing with NH, data was not displaying anticipated results. Through prior lab testing AT&T engineers determined a standard of results, the deviation from field testing led engineers to change settings in the mobile application. The updated NH application was downloaded from the app store and configuration changes produced results within projected expectations. These changes did not affect the off the shelf capability that DOD seeks to incorporate.

Further testing to analyze the effects on throughput and latency while multiple devices simultaneously utilize the network will need to be conducted at each WP (Figure 14). This will depict a more accurate assessment of the mmW capability since a test in this manner will display a true indication of capabilities for load balance between the variety of 5G devices. Determining the threshold of the 5G mmW environment will dictate how many components a 5G system of systems can utilize to support operations in the littorals.

Additionally, the ability to stop transmission from the 5G mmW tower will need further consideration. The Navy considers this as setting emissions control (EMCON) conditions. EMCON is defined as "selective and controlled use of electromagnetic, acoustic, or other emitters to optimize command and control capabilities while minimizing, for operations security: a) detection by enemy sensors; b) mutual interference among friendly systems and/or; c) enemy interference with the ability to execute a military deception plan" (Joint Chiefs of Staff, 2016, p. 79). There are four primary conditions (Tektronix, 2018):

- **Delta** (lowest), used during normal operations with no emissions constraints.
- **Charlie**, allow ships to radiate and transmit from mission-essential equipment and sensors, but requires sensors unique to that type of vessel be shut down in order to prevent adversaries from identifying the class of ship.
- **Bravo**, further limits the ship's electronic emissions, but still allows for communication and data transfer with others.
- **Alpha,** (most restrictive) when an operation requires complete silence. No emissions or radiations from any sensor are permitted.

It is critical for AT&T to incorporate naval service EMCON requirements with the ability to adhere to EMCON levels on the mmW tower. AT&T can leverage quarterly Joint Interagency Field Experimentation (JIFX) events to test solutions for different EMCON conditions to simulate restricted emissions or radiations against adversaries during real world operations.

> The JIFX program exists to provide an opportunity for NPS faculty, students, private companies, and academia to demonstrate and evaluate new technologies related to the Department of the Navy and the Department of Defense research in an operational field environment, and also to provide the operational community the opportunity to experiment with these technologies to better understand the capabilities that they may represent. (Naval Postgraduate School, 2022)

After this initial testing, the next phase of testing should be 5G Sub-6 ashore utilizing the same process. Then perform testing from the water in Monterey Bay using different 5G end user equipment aboard a boat to the SLAMR mmW tower and Sub-6 antenna on the NPS campus. These tests will help determine possible OPT PB3 buoy positioning with AT&T 5G equipment to conduct further testing in demonstrating the CONOPs (Figure 5).

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V. CONCLUSIONS AND FUTURE RESEARCH

A. SUMMARY

This thesis sought to analyze the incorporation of possible technological abilities to address the shift of the numerous strategies and policies from the DOD. Particularly, within the littorals where they have limited capability, the naval services must modernize their approach to support and defend this area. The aim was to highlight how the private sector can provide vital improvements through 5G in MDA by IAS for the DOD services to present a strategic advantage against our adversaries. By leveraging the private sector, technological transitions can be streamlined within the DOD to demonstrate the art of the possible. Utilizing experts in diverse fields to develop a CONOP for a 5G SOS demonstrates what future possibilities are available to protect national security interests. While this thesis stems from a theoretical concept, the path to proof of concept begins with the CRADA and active consortium of the private industry. The use case ashore completed for this thesis is the initial data collection which builds an illustration of faster, superior mobility rates that 5G technology can provide the naval services.

B. CONCLUSIONS

As technology advances, researching viable options to incorporate those advances are key. Not all technology brings benefits that suit military application. In determining whether 5G can provide specific impacts to a focused objective several questions were developed to guide research. Weakened littoral defense and 5G possibilities prompted considerations of *How might 5G interconnected commercial systems in a littoral environment impact maritime domain awareness for various mission sets? And how might naval services benefit from a system of systems 5G commercial concept?*

A complete evaluation of interconnected commercial systems was not fully tested as part of this thesis. While the initial phase of testing did indicate the advantages of 5G, several other conditions are required to be tested before a comprehensive conclusion can be confirmed. The theoretical concept of coordinated commercial air, surface, and subsurface IAS under a 5G SOS environment can be tested once the foundational setup of

5G is established. Although each system mentioned in the commercial uncrewed system section has been tested individually, concurrent application of multiple systems must be tested to evaluate this capability. The PB3 buoy from OPT is in the final stages to mount AT&T 5G technology to extend the range in the littorals. Testing of AT&T's mmW showed promising results using mmW end user devices. If the assumption with respect to the IAS as end devices with 5G capability and power sustainability on the PB3 then inserting this SOS environment can impact MDA for delivering naval service mission sets.

In addition to determining the feasibility of 5G in the littoral environment the notion for deployment abroad was considered since military operations also occur outside of our borders, this led to *Can this framework be deployed globally?* In theory this concept can be deployed globally as shown in OPT's feasibility report. Wave activity is necessary for self-powered buoys, but stagnant water could also feature a buoy with a battery indicating that the buoy can be placed in any body of water. Frequency accessibility is also necessary, while we may be given permissions by host countries, authorization is still required. Delivering and maintaining the buoy are also considerations in determining global deployability. After consideration of these factors the theory of being globally deployable is justified.

As this is the initial phase of testing 5G, it is premature to corroborate the theoretical CONOP. However, research does show promising indications thus far. At this point the question *what are the requirements and conditions needed for the naval services to utilize a commercial 5G framework,* cannot be fully explained beyond the theoretical examples in the literature review without proper testing to determine limitations and necessary conditions.

C. FUTURE RESEARCH

The littorals will continue to be a national security interest within the U.S and its coalition partners as adversaries continue to present a viable threat. As technology improves, so do capabilities and threats. Continual research to better understand the benefits and limitations of technology are needed to counter the growing threat of our adversaries in the MDA environment. The private sector pursues innovation to progress, therefore will continue to lead the way in IAS and the DOD would gain greater capabilities quicker through such partnerships. The topics defined below are not all-encompassing but provide additional importance in driving towards MDA in the littorals for the naval services and allied partners.

1. Expand Communications

The CONOP utilizes telecommunication provider AT&T to extend communication capability within the SOS construct. Testing was confined to cellular capabilities and therefore restrictions apply if cellular service is interrupted. Although latency is affected and does not support the real-time data collection desired by 5G testing, satellite solutions incorporated into the loop should be conducted as a back-up access to the AT&T backbone. Hence a recommendation to include satellites in low earth orbit (LEO) should be considered to support littoral MDA. Recent advancements in technology surrounding LEO have made enormous strides providing global communication coverage. Incorporating satellite communications from LEO within the OV-1 (Figure 5) should be explored as a secondary support due to its closest distance to earth's surface.

2. Security Considerations

This thesis did not cover security considerations in 5G. Naturally as technology improves so do security methods, however, a national security level of protection is not commonly implemented in commercial products. Having a SOS introduces security risks to the overall structure of the design and needs to be thoroughly tested to substantiate its capability to ensure national security. Various IoT coexisting under a 5G umbrella requires the ability to communicate to enhance the effectiveness of the operation, establishing common policy and protocols which can be applied using the 3rd Generation Partnership Project (3GPP) foundation will ensure efficacy. The 3GPP is the backbone of telecommunications standards for global specifications. The 3GPP's Organizational Partners are a collective of seven organizations that "cover cellular telecommunications technologies, including radio access, core network and service capabilities, which provide a complete system description for mobile telecommunications" (3GPP, 2022, p. 1).

Aligning the procedures of 3GPP and incorporating security features amongst the SOS should be evaluated and tested to identify vulnerabilities.

3. 5G Policy within Naval Services

While this CONOP can be deployed globally as indicated in this thesis, to sustain a global mobility concept, additional testing is recommended on U.S. Navy ships as the RAN. Policies and training which would affect military operations should be included when 5G wireless communications are being used on the ship. Such policies should include applications, equipment, and compartmentalization on where wireless is authorized.

D. SUPPORTING 5G NAVY PROJECTS

Hughes Network Systems collaborate with Dish Networks and obtain an $18 million agreement to implement a detached 5G network at Naval Air Station Whidbey Island (Abarinova, 2022). The goal is to provide secure 5G to operations, maintenance, and flight traffic management through low-band, mid-band, and millimeter wave (Abarinova, 2022). The uses of an open RAN will provide flexibility and allow continuous satellite communication in LEO and geostationary orbit (Abarinova, 2022).

In February of this year AT&T reported seeing progress in the Navy’s 5G smart warehouse experiment by demonstrating data throughput speeds greater than 4 Gbps with less than 10ms of latency (Strout, AT&T sees progress in Navy's 5G smart warehouse experiment, 2022). This initiative is part of the greater DOD’s $600 million investment plan in testing and experimentation with 5G networks on military installations. The goal is to enable transshipment, inventory tracking and other logistics operations by connecting video cameras, autonomous robots, augmented reality systems and IoT devices through the 5G network (Strout, AT&T sees progress in Navy's 5G smart warehouse experiment, 2022).

AT&T was also the lead in testing 5G pier connectivity as a service (PCaS) on both coasts for 30-day prototyping at British Aerospace shipyard San Diego and Norfolk Naval shipyard (AT&T, 2020). This PCaS included commercial core Multi-access Edge Computing (MEC), 5G mmW and Wi-Fi wireless connection between a ship and the network operation center using secured IPSEC tunneling through a TACLANE (AT&T, 2020). These 5G Navy examples show the importance and dedication DOD has in investing and leveraging the commercial industry to improve operations and increase capabilities. The incorporation of 5G for littoral MDA is part of this overhaul throughout the DOD.

E. NAVY PROJECT OVERMATCH

The Navy is focused on Project Overmatch, which is intended to find a common network and communication approach for naval integration. With the increase threat from our competitors this concept is crucial to protect the U.S. and U.S. interests. While the details of Project Overmatch have been contained in hopes to maintain a low profile to U.S adversaries, what the Navy aims to accomplish is the ability to connect weapons and sensors building a tactical data network. The Navy's primary objective is on strengthening their abilities in the maritime domain. Prolonged downtime for constant upgrades to ships in the fleet is detrimental to U.S. naval strength. Additionally, staggering ship improvements causes ships to be on different networks which is a disadvantage to cohesive operations. The OV-1 concept (Figure 5) can support the ideals of the Navy's Project Overmatch by incorporating a SOS environment to accomplish their intention.

In fiscal year 2022 the Navy received $73 million to begin the process of Project Overmatch and seeks to increase the asking price to $195 million in fiscal year 2023 (Strout, Navy dramatically increases funding for secretive Project Overmatch, 2022). Rear Adm. Doug Small, Commander of Naval Information Warfare Systems Command stated at the West 2022 conference, "We are bringing the best of world-class commercial technologies, how the best companies in the world deliver capability to their users, and we're just bringing that into the Navy and doing it at speed and scale" (Strout, Navy dramatically increases funding for secretive Project Overmatch, 2022, p. 1). The CNO (Adm. Mike Gilday) signed two memos in October of 2020 with one stating "Our unmanned developmental efforts require increased urgency and coherency with each other and from their manned teammates." (Eckstein, 2020, p. 1). In the same article Dorothy Engelhardt, director of unmanned systems for the Deputy Assistant Secretary of the Navy for Ships was quoted saying "the vision is, when I say the words distributed maritime operations, we mean that, and you should let your imagination run with that. How do I have a fleet of manned assets under the sea, on the sea and in the air collaborating and working with unmanned assets in the fight." (Eckstein, 2020, p. 1) These two quotes from the CNO and Ms. Engelhardt show the importance of commercial secure 5G support in the littorals. However, it is also relevant from a joint perspective, not just within the other DOD services but ally partners as well. Ms. Engelhardt mentions working with allied forces and how the network can be utilized by feeding information to unmanned systems or applying the data they're collecting to support the mission (Eckstein, 2020).

The DOD is integrating this revision throughout all services, like the Navy's Project Overmatch, each defense service has a project that supports DOD's Joint All-Domain Command and Control (JADC2) which seeks to connect any sensor, any system, at any time, to any place. In March 2022 the DOD published a summary of the JADC2 strategy outlining the vision and importance of the Joint Force across all warfighting domains (Department of Defense, 2022). Within this summary are six guiding principles to unify LOE across all departments which include (Department of Defense, 2022):

- Information Sharing capability improvements are designed and scaled at the enterprise level.
- Joint Force C2 improvements employ layered security features.
- JADC2 data fabric consists of efficient, evolvable, and broadly applicable common data standards and architectures.
- Joint Forces C2 must be resilient in degraded and contested electromagnetic environments.
- Department development and implementation processes must be unified to deliver more effective cross-domain capability options.
- Department development and implementation processes must execute at faster speeds.

Understanding the big picture, and how 5G can contribute to the DOD's vision for joint interoperability, the Navy can align their Project Overmatch. 5G is forecasted to enable the connectivity between all defense services, collaborating and exchanging data, in JADC2 to enhance the ability for decision making from headquarters to the tactical level.

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