2010-06

Micro and pico satellites in maritime interdiction operations

Bordetsky, Alex; Mantzouris, Georgios

Proceedings 15th Command & Control Research & Technology Symposium, (ICCRTS '10) June 22-24, Santa Monica, CA, paper #179
http://hdl.handle.net/10945/35935

15th International Command & Control Research & Technology Symposium

Paper ID 179

Micro and Pico Satellites in

Maritime Interdiction Operations

Dr. Alex Bordetsky*

LCDR Georgios Mantzouris, Hellenic Navy (PhD Candidate)

Naval Postgraduate School

Track 2: Networks and Networking

* Point of contact

Dr. Alex Bordetsky

US Naval Postgraduate School
Graduate School of Operational & Information Sciences
Center for Network Innovation and Experimentation
589 Dyer Road, Room 225 Monterey, CA 93943
Tel: (831) 656-2287, Fax: (831) 656-3679, E-mail: abordets@nps.edu

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**
4. TITLE AND SUBTITLE **Micro and Pico Satellites in Maritime Interdiction Operations**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Center for Network Innovation and Experimentation,589 Dyer Road, Room 225,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **Proceedings of the 15th International Command and Control Research and Technology Symposium (ICCRTS ’10), Santa Monica, CA, June 22-24, 2010**		

14. ABSTRACT

In a complex maritime environment it is pivotal to localize, verify, search, track, and tag maritime assets that might travel through critical sea lines of communication while transferring sensitive cargo materials. In the emerging environment of network-controlled Maritime Interdiction Operations (MIO), tagging and tracking of hazardous non-proliferation materials that are transported by small craft around the world, remains one of the major technological and operational challenges. The emerging technology of Micro and Pico small satellites represents a unique tactical capability for extending small craft surveillance, by the introduction of a network into the low orbit, thereby maintaining ubiquitous situational awareness between the partners in the maritime patrol areas as well as remote expert and command centres around the globe. The goal of this paper is to explore how the unique capabilities of Cube and Tubesat small satellites could be applied to improve the MIO networking of tagging, tracking, and data sharing with remote expert sites. The Tactical Network Testbed (TNT) and innovative experimentation MIO process (TNT MIO) developed at the Naval Postgraduate School (Bordetsky and Netzer, 2009) in cooperation with Lawrence Livermore National Laboratory, USSOCOM, and other partners, represents the platform for the described study. In the paper we analyze capabilities and existing applications of small satellite technology to the maritime awareness tasks. Based on this analysis, we develop the set of Cube and Tube satellite integration experiments, enabling enhanced tagging, tracking, and global data sharing solutions for emerging network-controlled MIO scenarios. In the proposed field experiments, globally distributed players will be located by using Cube or Tube satellite capability. The experiment participants will evaluate the feasibility of applying Cube and Tube satellite data channels to the real-time sensor data sharing with the remote subject matter experts and associated constraints. All together the results of the proposed experiments would allow the development of a new concept of shared maritime interdiction operations based on the Nano and Pico satellite capabilities.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**28**	

TABLE OF CONTENTS

List of Figures

List of Tables

Abstract

In a complex maritime environment it is pivotal to localize, verify, search, track, and tag maritime assets that might travel through critical sea lines of communication while transferring sensitive cargo materials. In the emerging environment of network-controlled Maritime Interdiction Operations (MIO), tagging and tracking of hazardous non-proliferation materials that are transported by small craft around the world, remains one of the major technological and operational challenges.

The emerging technology of Micro and Pico small satellites represents a unique tactical capability for extending small craft surveillance, by the introduction of a network into the low orbit, thereby maintaining ubiquitous situational awareness between the partners in the maritime patrol areas as well as remote expert and command centres around the globe.

The goal of this paper is to explore how the unique capabilities of Cube and Tubesat small satellites could be applied to improve the MIO networking of tagging, tracking, and data sharing with remote expert sites.

The Tactical Network Testbed (TNT) and innovative experimentation MIO process (TNT MIO) developed at the Naval Postgraduate School (Bordetsky and Netzer, 2009) in cooperation with Lawrence Livermore National Laboratory, USSOCOM, and other partners, represents the platform for the described study.

In the paper we analyze capabilities and existing applications of small satellite technology to the maritime awareness tasks. Based on this analysis, we develop the set of Cube and Tube satellite integration experiments, enabling enhanced tagging, tracking, and global data sharing solutions for emerging network-controlled MIO scenarios.

In the proposed field experiments, globally distributed players will be located by using Cube or Tube satellite capability. The experiment participants will evaluate the feasibility of applying Cube and Tube satellite data channels to the real-time sensor data sharing with the remote subject matter experts and associated constraints. All together the results of the proposed experiments would allow the development of a new concept of shared maritime interdiction operations based on the Nano and Pico satellite capabilities.

1. Introduction

Maritime security has been a hot subject in the field of maritime arena. People and organizations from all over the world are trying to find methods and apply strategies that will enforce passive or sometimes active measures, in order to ensure maritime safety in both territorial and international waters. Countries, specifically in the Western world, have created internationally recognized organizations and signed worldwide accepted contracts and agreements, to utilize allied strategies to promote maritime security in a global level. Vigilance is a priority, especially when the sea lines of communication (SLOC) are the ways where terrorists use in order to transfer any type of Weapons of Mass Destruction, such as biological or radioactive materials. Therefore, the Naval Postgraduate School's CENETIX laboratory along with MIO Testbed, is attempting to explore solutions that are going to be pivotal for the global maritime security. In this paper we describe all the possible measures that we can apply through Pico satellite space based solutions in order to improve the reach-back capabilities of our collaborative systems and increase readiness when dealing with the transfer of Weapons of Mass Destruction.

The following analysis will be based on Pico satellite solutions that we can use in order to search, identify, track and tag hazardous materials that may cause a potential risk to maritime security. Maritime situational awareness is an issue that incurs a lot of dynamic discussions worldwide, but until recently there has been no specific resolutions that can be used in a real maritime warfare situation.

The experiments will start and end in the space domain due to the fact that space is by far the most efficient area to apply new technologies that need to be shared worldwide through operation centers. Micro, Nano and Pico satellite solutions will be reported as the primary means of applying reach-back technologies in the maritime domain (for example satellites with AIS systems), but at the end the Pico Tubesat satellite will be incorporated on scenarios that are applied in the maritime environment. Tubesat is a new and promising Pico-satellite solution through which we can transfer and share valuable information to ships or network centers. There are important restrictions and limitations, but all these will be assessed and there will be a final estimation on how easy, fast and cost-effective the use of the commercial and available Pico satellite is to the problem of tracking and tagging WMD materials through the sea lines worldwide. Through these series of space experiments with the Tubesat satellites, we would like to generate the capability of transferring information back and forth, from the scene of action to a central node, so as to provide a key solution to those who deal on a daily basis with maritime warfare and the need to search on board merchant vessels for the existence of illegal trafficking of Weapons of Mass Destruction. Tubesat will be a critical part in our MIO Testbed for conducting the experiments.

2. Conceptual Model of TubeSat Integration in MIO Testbed and Experiments

The Naval Postgraduate School is trying to apply innovative solutions to Maritime Interdiction Operations environment. Through CENETIX laboratory experiments and the assorted Testbeds which are located in United States as well as overseas, the ongoing research is focusing on covering areas that have not yet been administered in the scientific community. For that reason and sensing the need for technological improvement in the WMD Maritime Tracking Capability through space based applications, the team moves forward by applying innovative experiments which will hopefully provide solutions that will be used extensively in the real maritime arena.

It is inevitable that illegal WMD trafficking will continue to happen but if the illicit activity can be confined in specific areas of the world or if on the other hand the “good” guys can be identified, then we will create a plain picture in the maritime arena of where and when the sea lines of communication are safe. Thus, the primary goal is to armor our coastal waters and the populous, as well as bound the “bad” guys outside safety zones that will increase protection.

It is unrealistic to cover 100% the sea environment, or to know exactly when and where there is illegal WMD trafficking. One adequate solution that we may apply is to create check points outside ports or in areas of high shipping density. Using this method, we will have a greater possibility to maintain a clear picture of which merchant vessel is safe. To implement this idea and for the sake of our experiment we create these check points in the water and force all incoming or outgoing merchant traffic to pass through these points in order to be searched for the possession of illegal WMD/radioactive materials on board. This sensing procedure is being assisted by the Lawrence Livermore National Laboratory (LLNL), which has personnel with strong experience in the utilization of equipment such as radioactive sensors and devices that are sensing, identifying, tracking and tagging these types of materials.

The aforementioned cases have been already tested a couple of times but we have never used space based applications especially in the Pico Satellite level. In our experiment we will focus our attempts to transfer all the available data through the data channels that Tubesat Pico satellite will provide. Taking into account all the mission critical parameters and the operational characteristics of Pico satellites, we will try at the end to uncover unknown areas of application and find out if it is feasible to use Pico satellites in the WMD tracking procedures in the global maritime arena. Considering that similar applications (e.g. AIS or maritime tracking merchant vessels) are doable and implemented already in the daily life, such as the covering of the Norwegian fiords or the Canadian territorial waters, we are optimistic that our research application will be a full success.

No	Space Application	Satellite System (Micro / Pico)	Technology Gap
1.	Maritime Tracking	AISat, M3MSat (Micro)	NO
2.	Imaging	Ikonos, Spot, GeoEye (Micro)	NO
3.	Radar	SARSat	NO
4.	E/O – I/R	L band SARSat (Micro)	NO
5.	Maritime Communications	Inmarsat (Micro)	NO
6.	Maritime Positioning	GPS, Galileo (Micro)	NO
7.	Global Maritime Awareness	C Sigma Int' collaboration (Micro)	NO
8.	**WMD MIO Sensing**	**NPS Tubesat Pico satellite**	**YES**

Table 1: WMD MIO sensing is an application that has not yet been administered through Pico satellites. NPS is filling the technology gap by applying new research methods by using the Tubesat Pico satellite.

Although space applications and systems that deal with the maritime environment are numerous, previous research shows that there are not so many academic institutions or organizations utilizing WMD Sensing through space. It is clear from the above table that in spite the ongoing research in all the fields related with maritime applications there is a technological gap in the WMD area. It is primarily due to the fact that illegal trafficking of WMD materials has started to occupy the international community in the last years, even though this phenomenon has existed on a global level over the last century. Up to now, there were not any cost effective space solutions in order to implement this technology. Nowadays and with the advent of Pico Satellites, such as Tubesat, we are trying to send data regarding WMD back in MIO network operational centers and by analyzing this data we can provide fast and correct solutions to the people (e.g. Officers or Public Security Experts) that execute the boarding operations on board merchant vessels in real time timeframes. The Naval Postgraduate School is the first institution to deal with this critical subject and by using the Pico Satellite TUBESAT as an active part on the already applied MIO Testbed (Figure 1), we will try to overcome the obstacles and generate innovative and pioneering solutions for those that are dealing with WMD sensing in the maritime arena.

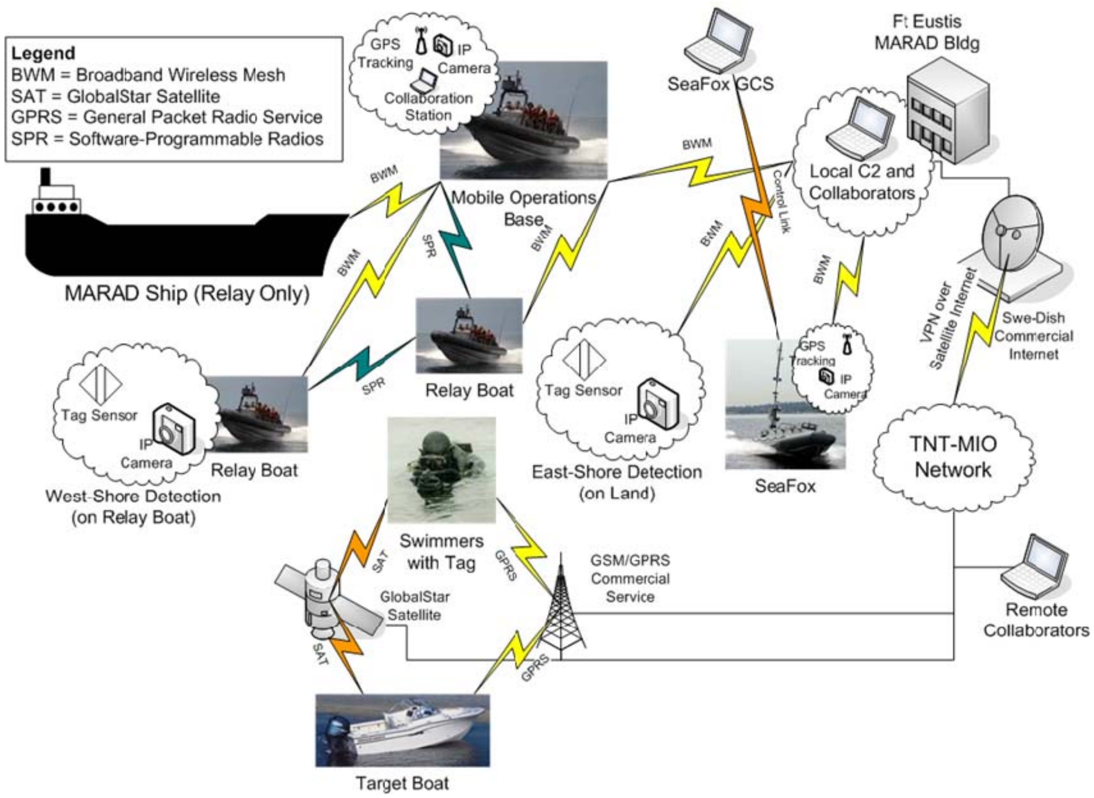

Figure 1: MIO Testbed configuration. Tubesat will be an active part of this Testbed trying to contribute precious data in the Network Operation Center regarding WMD in MIO.

We comprehend thoroughly that MIO is not an easy task, especially when the geographical differentiation has to do with multicultural environments as well as distances that are large enough to distort any kind of information. For that reason and in order to overcome these issues, we propose the use of space based MIO applications, through Pico satellites, which factors in the cost and also the accuracy of information that we may have at the end of the operation. Last but not least, we should keep in mind that MIO operations are difficult when we are dealing with the transportation of illegal Weapons of Mass Destruction, where a simple mistake can evolve to a huge crisis.

3. Small Satellites in MIO – Maritime Tasks

Regarding the Maritime Interdiction Operations (MIO), there are numerous reasons why we try to use these space based technologies instead of the traditional solutions. We are not going to analyze all the effects and parameters that a small satellite incorporates, but instead we are going to analyze and search what are the elements that are needed in order to integrate small satellites in MIO operations with respect to Weapons of Mass Destruction Trafficking specifically through the sea and land lines of communication.

Satellite Category	Net Weight	
Large	> 1000 kgr	
Medium	500 - 1000 kgr	
Mini	100 – 500 kgr	SMALL SATELLITES
Micro	10 -100 kgr	
Nano	1 – 10 kgr	
Pico	0.1 – 1 kgr	
Femto	< 100 gr	

Table 2: Categorization of Small Satellites in accordance with their net weight.

For revision purposes and taking into account that are different categorizations of satellites we need to specify that when we refer to small satellites we imply a bus that is less than 500 kgr in net weight. Table 1 summarizes the existing categories of satellites in the commercial space environment and shows explicitly what the weight differences in these categories are. In our research and experiments we are going to use the notion of Pico satellites, such as the Tubesat satellite bus which is less than a kilogram of net weight. Up to now there are no commercial Pico satellite buses in orbit that are able to reroute information from a maritime warfare operational area back to a network operation center.

Therefore, we conclude that for our research the type of parameters that are going to be utilized for our analysis are the so-called “Mission Critical Parameters”. We are listing hereunder the Mission Critical Parameters that a small satellite (a Micro or Nano or Pico satellite) must collect in order our operational mission to be antagonistic with respect to other already in existence.

“Mission Critical Parameters”:

- Satellite Operational Lifetime.
- Real or Near Real time Tracking Capabilities.
- Accuracy of Tracking.
- Available Data Transmission Techniques.
- Available Data Channels.
- Operating Principles of small satellites.
- Tactical Implications in MIO: Most of the times we do not consider the tactical requirements and discreteness of our mission. We usually take into account the strategic and operational MIO characteristics of a mission but we leave the tactical level solutions to be carried out from people that finally implement the research. This is a classic mistake and it usually creates insolvable problems. In this experiment we will try to reach the tactical level and find out solutions that will be able to apply in a maritime warfare environment operation, such as trying to send back information while being on board a merchant vessel, searching for illegal WMD materials and at the same time executing an “opposed boarding” mission. If we manage to provide solutions that will be useful also in extreme situations then we have accomplished our primary goal.

- MIO Scenarios implementation: In order to be realistic we need to think in reverse what MIO scenarios can be implemented with the small satellites usage. There are limitations in the application of this technology and it is a fact that with small satellites, especially with Micro and Pico ones, we cannot cover completely the whole maritime environment. Instead, it is our intent to create scenarios and maritime situational awareness tactics that can provide and cover all the critical characteristics needed in order to carry out an operation successfully.
- Video Capability.
- Reach Back Capability.
- Serve humanitarian missions: Finally and taking into serious consideration that MIO operations are followed or precede or being in conjunction with humanitarian operations numerous time, we shall mention critical parameters in accordance with the above mentioned theme. If our solutions cover at the same time a combined MIO – humanitarian operation, then it is for sure that we have outreached ourselves and provide guidance for every possible situation that can happen at sea.

4. Small Satellite Operational Characteristics

Moving forward and for the completeness of our work, it is necessary before we proceed, to mention all the Operational Characteristics that have to be taken care of in order to fulfill a MIO mission. Under the work “Operational” we mean primarily all these specific tasks that need to be satisfied in order our solutions at the end to be realistic. At this point we must study diligently all the details that will finally comprise parts of the MIO scenario. These details are sententiously considered below:

- Types of orbits that small satellites support, such as equatorial or polar ones.
- Available footprints.
- Segments that use and provide.
- Lifetime consideration.
- Time of Revisit.
- Services that is able to provide such as SMS / FAX / Teleconference – Video.
- Security that is being enabled.
- Available data rate.
- Probability to establish a call.

- Probability of maintaining a call for LEO – Small satellites.
- Back up satellites for service if needed.
- Ability for crosslink among satellites to transfer data on a near real time environment.
- Ability of global coverage.
- Available power throughput.
- Ability of the signal to penetrate through materials (such as through walls or inside a ship). How weak is the signal to be transmitted during wall networking.
- How the signal is transmitted through oceans and distant sea regions (coverage especially for MIO environment).
- Meteorological situation and how is it affecting the whole transmission operation in microsatellites.
- What is the more applicable solution for blue force (allies) and red force (enemies) tracking?
- Vertical / Horizontal accuracy of the system especially for cargo vessels between searching decks.
- What are the available clock accuracy and the mistakes that can occur if clock accuracy is low?
- Is there any small satellite (such as Tubesat) with some kind of on board processing and what are the advantages that a MIO operation can acquire if this exists?
- Is there any small satellite available with electric propulsion so as to maintain the accuracy or to serve any other usability purposes on orbit?
- Reorbiting a small satellite in order to tag and track the maritime asset. Is there any possibility of doing that?
- Examine if it possible to simulate the mission by using available software, such as STK, in order to understand explicitly, prior to launching, the capabilities and coverage areas that a Tubesat can provide and uncover maybe any grey areas that have not been considered but affect the mission at the end.
- What are the implications in MIO scenario if there are no terrestrial networks to support the whole mission?

5. Small Satellites in Maritime Situational Awareness

Satellites with Space Maritime Tracking Capability are a relatively new technology. The research was started by academic institutions and today is available commercially, primarily in the applications of space maritime tracking of merchant vessels around coastal waters and in the primary sea lines of communications (e.g. Gibraltar). In the next pages we present all the available commercial small satellite applications that are in orbit or under construction and in the near future they are going to be used for space maritime tracking. It turns out that there are not so many "people" around the world that are using or trying to apply this technology and even more we did not manage to find out any organizations or small satellite applications on orbit or under construction that are dealing with the tracking of merchant vessels that are maybe transferring or carrying illicit cargo, in our case WMD (radioactive or biological) materials. Then Naval Postgraduate School small satellite MIO Testbed/experiment is going to be a unique application on this subject area and we hope that at the end we will provide solutions that will be unrivalled throughout the world. Of course, all the above should happen with the use of Pico satellite technology which is in our case will be the Tubesat satellite.

a. Nanosatellite Tracking Ships (NTS), Canadian Nanospace eXperiment 6 (CanX-6) (University of Toronto – UTIAS - Space Flight Laboratory)[1]

The mission of this Cubesat is to provide secure space based AIS receiver and secure confidence in space-based ship tracking technology. The challenge is to detect AIS signals from space for global ship tracking and monitoring. It was launched on 28 April 2008[2].

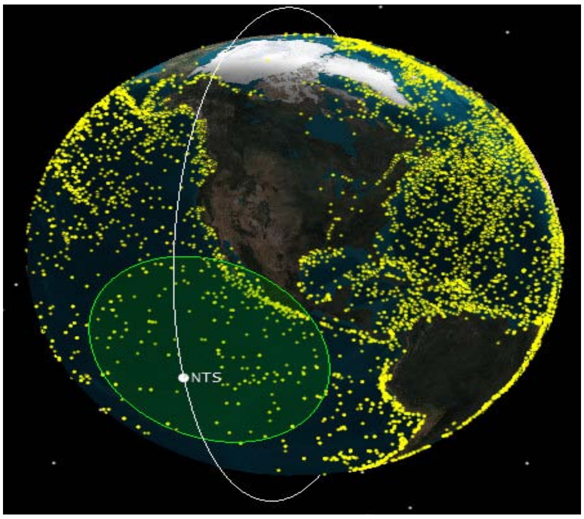

Figure 2: Illustration of the AIS messages recovered during the first six months of NTS operations. The high density of ships in the coastal regions can be seen clearly, as can the global shipping lanes. The footprint of the NTS satellite is also illustrated, showing the large area within the footprint of the COM DEV AIS receiver at any instant of time. (Courtesy: UTIAS)

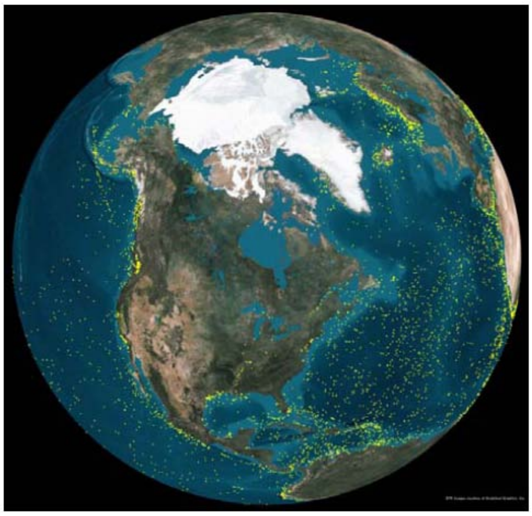

Figure 3: The Earth's shipping traffic density as it was acquired from the NTS Satellite on a specific day. Composite Image from NTS regarding maritime shipping. (Courtesy: UTIAS)

b. Maritime Monitoring and Messaging Satellite (M3MSat)

The Maritime Monitoring and Messaging Satellite (M3MSat) is the next miniature satellite from Canadian Space Agency. Its mission will be the Maritime surveillance that will enable an unprecedented global view of the world's shipping traffic. It will be in orbit by the end of 2010 and it will contribute to wide area surveillance coverage of maritime approaches to Canadian territorial waters, in the middle & outer zone coverage (50-1000 nm)[4].

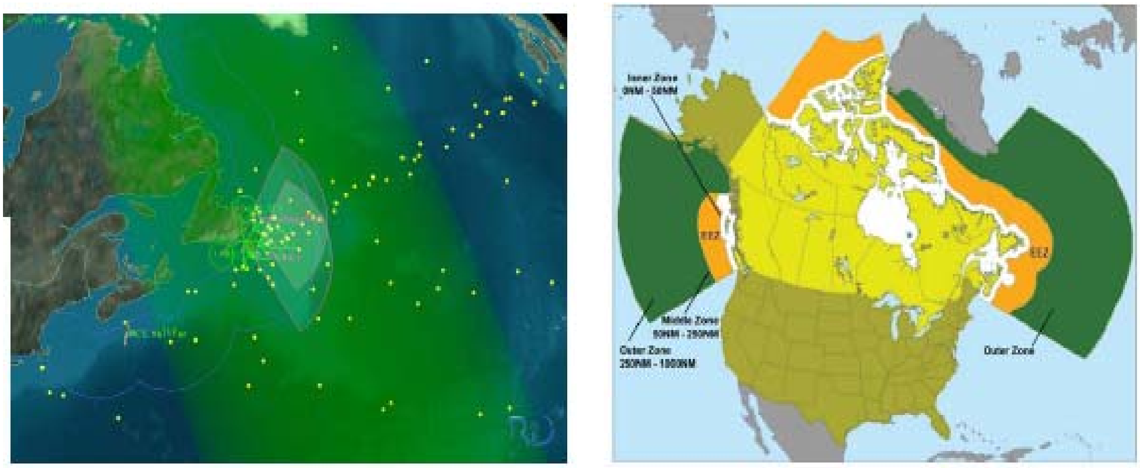

Figure 4: Coverage of M3MSat outside Canadian Territorial waters (courtesy UTIAS)

c. AISSat -1 Automatic Identification System Satellite[3]

AISSat can receive messages by a VHF receiver in space for wide area observation of maritime activity. Its mission focused on Norway's TTW, an area with long shorelines, large coastal waters and fishing grounds. This work is going to be executed by AISSat-1 during all 15 daily passes over Norwegian ocean areas.

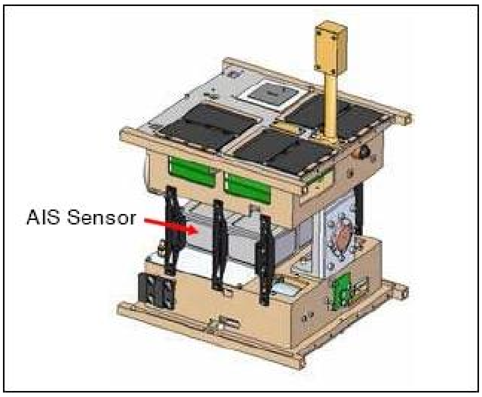

Figure 5: Internal structure of AISSat-1 (Courtesy AISSat)

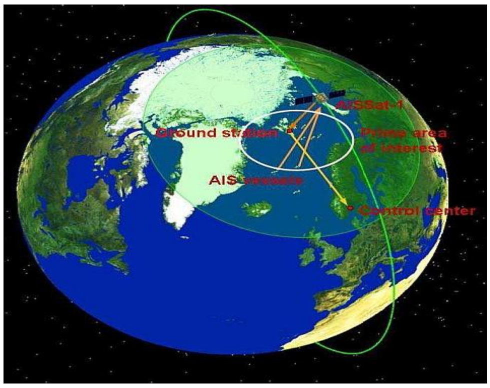

Figure 6: Coverage of AIS Sat outside Norwegian Territorial Waters (courtesy AISSat)

d. TACSAT-2: Maritime Surveillance Satellite for U.S. Coast Guard

The Coast Guard hopes to use the technology for its future nationwide automatic identification system (NAIS), which is the service's three-stage plan to extend its ability to track and identify vessels. The first stage will track ships near 55 critical ports and the second stage calls for AIS tracking as far out as 50 nautical miles. Satellites will be added in the final stage, and along with a network of offshore platforms and buoys, are expected to identify ships as far as 2,000 nautical miles. The system is expected to be operational in 2014[5][6].

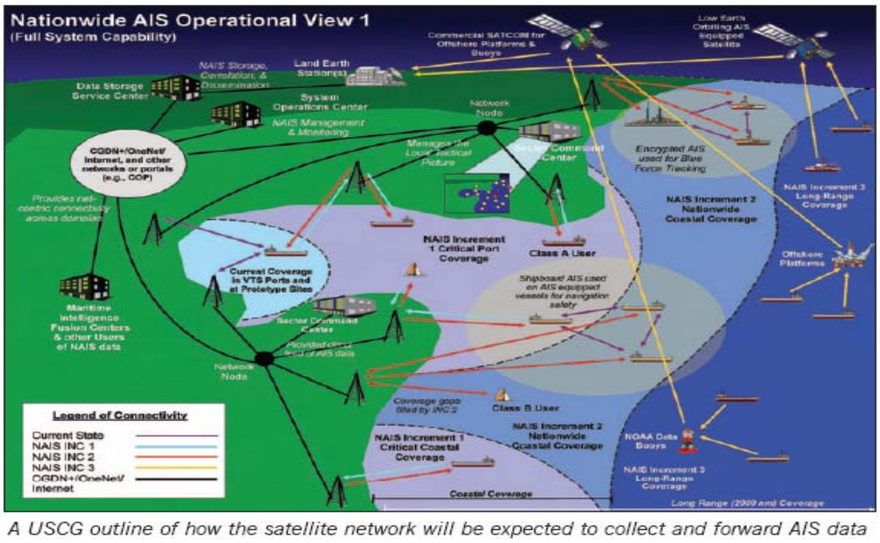

Figure 7: A USCG outline of how the satellite network will be expected to collect and forward AIS data.(courtesy TACSAT)[7]

e. ESA's Satellite Receiver for Worldwide Sea Tracking.

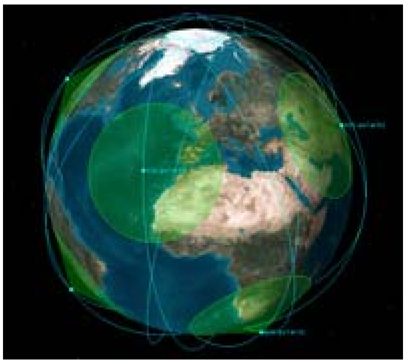

Figure 8: ESA's AIS signal detection from space (courtesy ESA)[8]

ESA, together with European industry, is developing a space-based system to monitor maritime traffic on a worldwide basis. Tens of thousands of ships are crossing the oceans at any one time but they could be tracked with a constellation of as few as five satellites, by using advanced signal receiver technology. Also this receiver will be used for Maritime Tracking and tracking and remove unexploded ordnance on land lines. During the tests ship's position was recorded within a certain time interval – three hours was a starting point and the probability of detection found to be around 85-90%[8].

f. Tubesat – Interorbital Company.

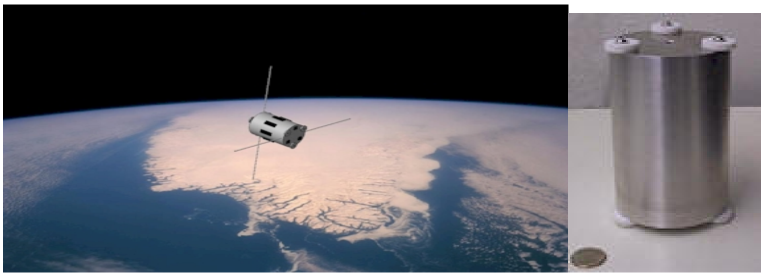

Figure 9: Tubesat Pico satellite pictures (courtesy Interorbital Company[9])

Tubesat is a new promising Pico Satellite. It is a standalone Pico-satellite with capability of earth from space video imaging with on board processing and with total mass of 0.75 kg. 0.2 kg of the total mass can be utilized for experiments (in our case MIO experiments). Tubesat is designed to operate for up to 3 months and from a 310 km orbit with an orbital longevity of three weeks to three months, depending on the solar weather (orbital decay satellite). The launch is executed from the spaceport of Tonga Island, which is ideally positioned for servicing both equatorial and polar orbits (figure 13). Total earth coverage will require approximately 4-6 Tubesat picosatellites.

Figure 10: The island of Tonga Spaceport where the Tubesat Pico satellite is going to be launched.(courtesy Interorbital)[9]

Finally, in the following table 3 we are showing explicitly that our experiments with Tubesat Pico satellites are covering an area where there is no ongoing research from any other institution that is dealing with maritime environment. NPS CENETIX Testbed is dealing with the WMD in MIO operations by implementing space based applications for only a small period of 3 months due to the orbital lifetime limitation (orbital decay parameter).

No	Space System	Category	Lifetime	Orbit	Mission
1.	NTS	Cube	2-3 years	LEO	**AIS** Maritime Tracking
2.	M3MSat	Cube	2-3 years	LEO	**AIS** Maritime Tracking
3.	AISSat-1	Micro	2-3 years	LEO	**AIS** Maritime Tracking
4.	TACSAT	Micro	2-3 years	LEO	**AIS** Maritime Tracking
5.	**Tubesat**	**Pico**	**3 months**	**LEO with** ***Orbital Decay***	**WMD in Maritime Interdiction Operations**

Table 3: Available small satellite systems with maritime tracking capability.

6. Tubesat Configuration for NPS Experiment

Following the above mentioned ideas and pursuing our innovative goals, we contacted Interorbital Company, which owns Tubesat satellites and discussed/designed with their personnel the generic frame of the mission.

Interorbital company is a new company that owns the Tubesat prototype Pico satellites. Discussing with its CEO, Mrs. Randa Milliron and the Interorbital team members, we decided at first point the different configuration possibilities that we are able to apply in our MIO mission / experiment and we concluded that we must execute the following steps:

(1). Three Tubesat Pico satellites will be purchased by NPS which will include materials, instructions, and polar orbital launch in Dec 2010 at Tonga Island. The satellites will be placed in Low – Earth polar orbit of 310 km and the satellite launch and release will be put into effect by ultra low cost rocket which is portable vehicle of 35’ weighing 18,000 lbs/ 9 tons (having also amphibious capability). The system itself has a capability of releasing at the same time 32 Tubesat and 28 Cube Set kits.

(2). Before the actual launch that is going to happen tentatively at December 2010, there will be suborbital test launches which will be held at the 2nd

(3). The suborbital test will happen at the altitude of 50,000 ft and will last approximately 2-3 minutes. The rocket will be on free fall. This is the net time that NPS will have to test communications of the Tubesat and solve other configuration problems that may arise at that time. At least three launches for testing will be placed before the actual launch to happen in December of 2010. This suborbital test is using a projectile type rocket that gives the opportunity to test all kinds of issues before the actual launch of the Pico Satellite.

(4). The preferred orbit will be calculated by using STK software which graphical user interface allows the user to build Pico satellite models even without propulsion elements. In our case the Tubesat will be placed into orbit and then an orbital decay element will play a major role in our Pico satellite orbit. However the actual orbit path of the Pico satellite will be calculated and the team will know exactly the actual path and the timeframe that will be allocated each time that this Pico satellite will travel from the same Earth point.

(5). It is preferable for the coverage of the whole Earth to use 4-6 Pico satellites using polar orbits, so as to increase the capability of having the satellite as much time available on top of the same point of Earth. In parallel we are trying to accommodate 24/7 communication coverage but it is obvious that there will be difficulties due to the orbital decay parameter. Ground stations can be anywhere overseas and at the same time in United States, such as in Naval Postgraduate School. The solution to this problem is going to happen after the calculation of the STK and the decision on the geographical position of the ground stations.

(6). The launch was decided to be at a winter timeframe where the Sun activity is less and so the orbital decay of the satellites will be less as well. This will increase the actual time that we are going to have our Pico satellites operational and active for our experimental mission.

(7). In the future we will consider of applying micro propulsion elements on Tubesat Pico satellites in order to make them stable on orbit and overcome the deficiency of orbital decay. At this point though and taking into account that we only apply the WMD sensing experiments on a pilot course it is adequate enough to use Pico satellites for only up to 3 months lifetime.

(8). The communication link that is going to be established with the Pico satellite will be in amateur radio band frequency 433 MHz or license free frequency of 902 to 928 MHz or 2.4 to 2.3825 GHz spread spectrum frequency. These link budgets parameters are going to be calculated, utilized and experimented by NPS team comms specialists Mike Clement and Jeff Vitalich.

(9). Considering the possibility that we would like to increase the number of revisit times and coverage periods we must go to a higher orbit. If we decide to do so, then we will have a huge benefit in revisit times and coverage (comparing to the case that we already mentioned above) but at the same time the cost will be significantly different. Then, the coverage time will be more than 3 months and this will depend on the choice of the orbital altitude.

7. WMD in MIO Scenarios

The Weapons of Mass Destruction Sensing in Maritime Interdiction Operations (WMD MIO) via the Pico Satellite Tubesat can be applied in different scenarios and operational environments. For simplicity, we are going to explore the most important of them that affect directly the merchant vessel traffic throughout the Seal Lines of Communications, but at the same time they are applicable in the maritime warfare. The main aspiration and pursuance is to keep illicit maritime traffic outside critical mission areas such as harbors, coastal areas, important territorial waters or even open sea areas that can be characterized as crucial for the completion of a mission. Additionally, if we have assigned naval warfare units to patrol specific areas with specialized personnel such as Boarding Teams, then we need to provide to those people as much info as we can in order to execute their missions successfully. The WMD MIO scenarios that we are going to be tested in our experiments are listed below:

- Coastal – Territorial Waters
- Harbor Entrance
- Riverine – Bay Area Traffic
- Open Sea Traffic

In each of the above cases we are going to apply collaborative elements to ensure that the situational awareness notion is able to be applied. Each time we will try to sense, through LLNL’s WMD sensors, materials that are going to be onboard the merchant vessels (simulated boats) and we will forward all the data to the main

Network Operation Center in CENETIX laboratory in Naval Postgraduate School, through our Pico Satellite. If we manage to maintain a clear and almost real time picture of the whole scenario then the results will be very valuable for moving forward in the future.

Before we proceed we need to answer an important question. What is the difference in the above mentioned scenarios regarding the use of the Pico satellite? The answer is not directly self evident, especially for someone without extensive knowledge of maritime interdiction operations. It would appear that there are few differences, but the element that distinguishes the scenarios from each other is the factor of time. Taking into account that searching a merchant vessel for illicit WMD materials with sensors is a time consuming procedure, it will be influential for the whole operation to investigate how the collaborative links work with regard to time allocation. If there is an incoming merchant vessel, moving towards a coastal area from the open sea environment, the searching procedure is not so imperative to happen in a very specific amount of time. The same applies in the open sea scenario, but in this case there is another important factor. Here, we are going to use network linking between a big ship (such as a frigate) and its own small boat and investigate how they can interconnect to the Pico satellite network and how the collaboration and sharing procedure is efficient. On the other hand, if we need check a ship in a harbor, where the maritime density is huge and the search procedures need to be fast in order not to bother the routine of the maritime traffic, then it seems that WMD sensing by using Pico satellites and fast collaborating networks is a challenge. It remains open to investigate if the link will respond as fast as we need in order not to create any additional maritime problems. Finally, in the harbor entrance scenario we have to pay attention not to congest the maritime traffic corridors, which drive ships in and out of the port. In this case we have to use our Pico satellite links in such a way that there is not going to be an increase in maritime traffic density the harbor entrance, situation that it is not desirable at all for numerous reasons which include also maritime safety and security parameters.

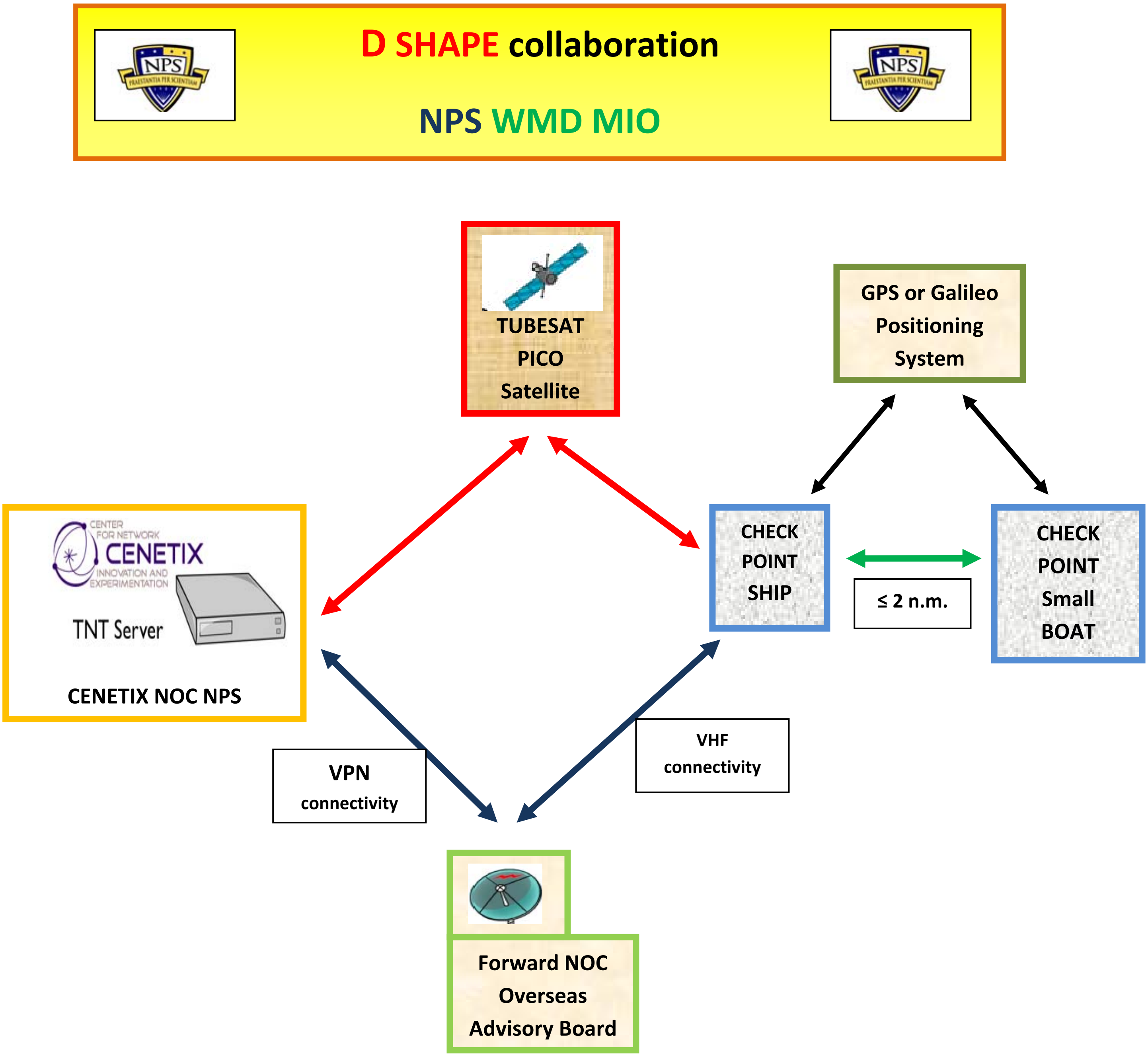

Figure 11: D – Shape collaboration scheme that is going to be implemented in NPS WMD MIO experiments with the use of Pico satellite Tubesat. This is a tentative connectivity scheme showing the flow of data through regular channels as well as through Pico satellite.

(1). 1st Scenario: Coastal – Territorial Waters

Sensing WMD illegal trafficking of materials that are a potential risk to a country's infrastructure or to public health, it is of utmost importance, especially in coastal areas and territorial waters. Of course, it is costly and inefficient to shield the whole shoreline with WMD check points but instead you can identify which are the most important land areas that are adjacent to the sea and armor them as much as possible. For example, there is no need to secure a shoreline that is connected to a huge tropical forest but it is critical to secure a sea area that is adjacent to a naval base or a big town. For these reasons we need to consider the Coastal – Territorial Waters entrance case in order to see how effective will be the collaboration tool and if the situational awareness model will work via the Pico Satellite. At the same time and taking into account the revisit times we need to clarify the disadvantages that will be created for the periods of time that there will be no communication coverage via the satellite. In this case we need to specify alternative communication paths that maybe have already been examined in previous MIO experiments such as VPN connectivity. At the end though, we must produce a clear picture on what are the factors that influence the operation in such a way that pico satellite networking collaboration is not efficient enough.

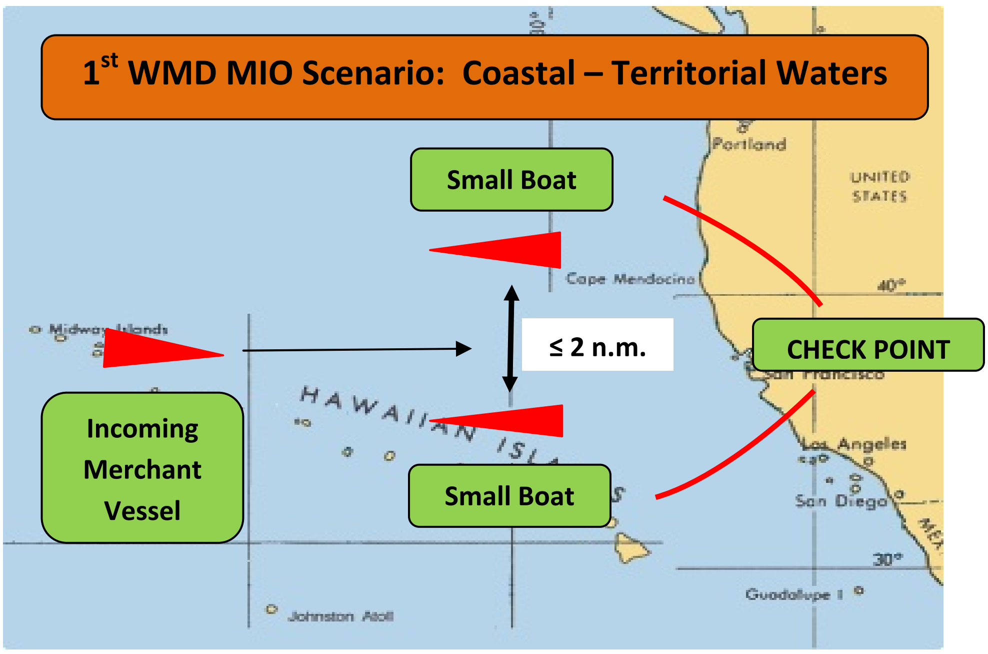

Figure 12: 1st WMD MIO Scenario regarding Coastal and Territorial Waters check points.

(2). 2nd Scenario: Harbor Entrance

The second scenario that needs to be executed is the installation of check points outside a harbor area. It is of utmost importance to implement search and tagging collaboration techniques outside major harbors in order to ensure that all incoming and outgoing merchant shipping traffic is clear and is not carrying any illicit WMD material. Is the Pico satellite network fast enough in order to share information among the boarding team personnel and the network operation centers in the land or they will be created traffic congestion and chaos? This question needs to be answered in order to investigate if our idea of using Pico satellites in WMD MIO operations is an efficient one.

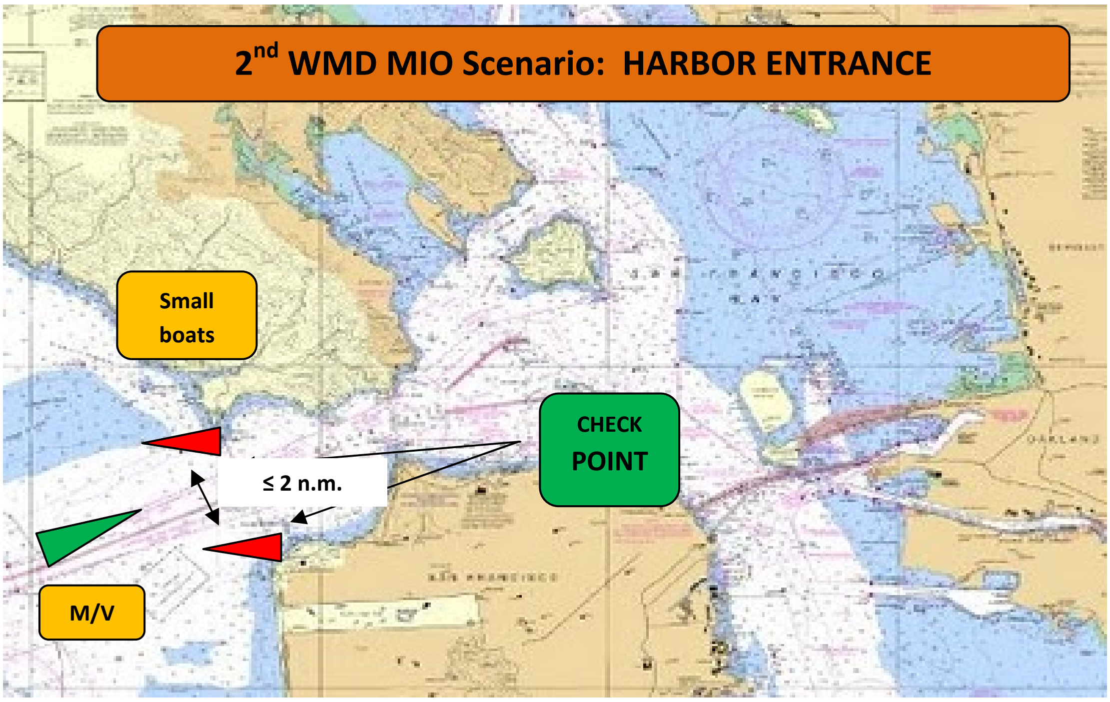

Figure 13: 2st WMD MIO Scenario regarding Harbor entrance check points.

(3). 3rd Scenario: Riverine – Bay Area Traffic

In the third case the situation is a little bit different. The check points are going to be placed inside the bay, which is like a Riverine area. The channel width is considered to be up to 2 nautical miles but if it is larger, then we can still implement our techniques but we need to use more than two small boats as check points (main difference from the 2nd Scenario). The operational MIO idea remains the same and our goal is still how to identify, search, track and tag an illicit cargo with WMD material inside a bay area, where the maritime traffic is much higher than the open sea and the time requirements are a lot tenser.

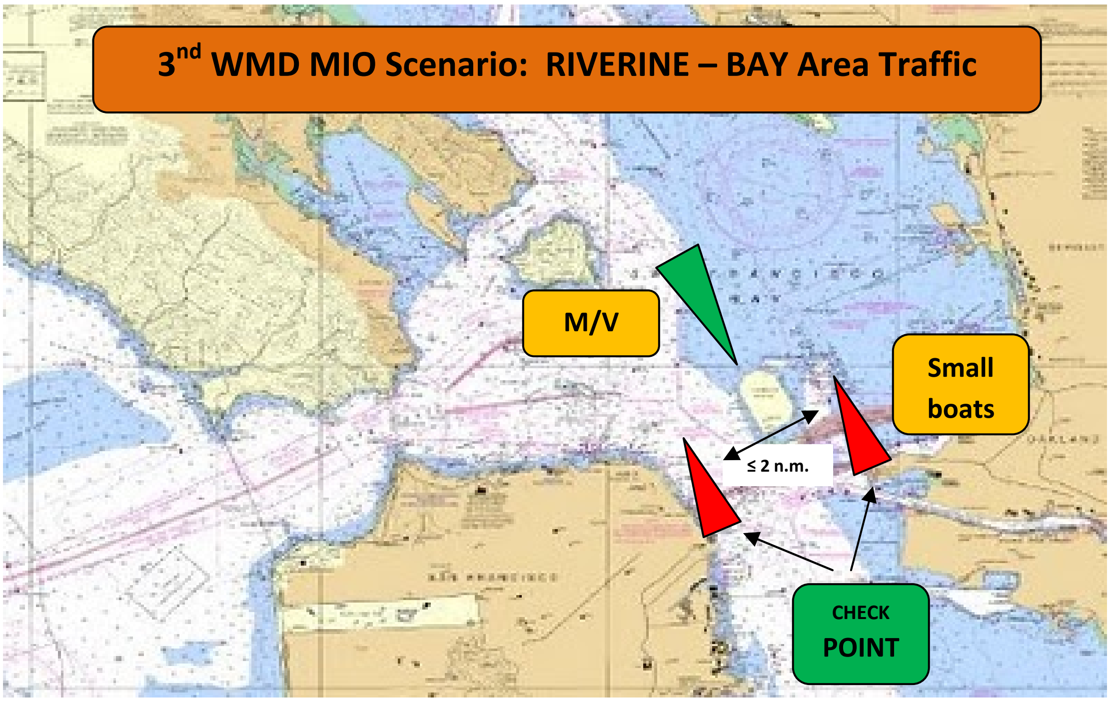

Figure 14: 3st WMD MIO Scenario regarding Riverine and Bay area traffic check points.

(4). 4th Scenario: Open Sea Traffic

Finally we need to apply our innovative ideas in the open sea merchant traffic. Let's assume that NATO or any other organization from US or European Union, has established an operational area outside a country, for example Iraq, in order to check all incoming and outgoing merchant vessels. Instead of using only small boats to interdict and check the incoming merchant vessels, we need now to use a larger naval unit, such as a frigate or destroyer, with satellite communications capability. This is because small boats have not the capability of operating at open seas and additionally their networking links can reach distances of no more than 7 n.m. However, the small boats to be used can be the boats of the frigate itself (for example a small Rigid Hull Inflatable Boat) and so with only one large unit you can apply the technology in the middle of the ocean, many miles away from the coastal or territorial waters.

The only requirement here that has to be created is a maritime traffic corridor through which all unexpected merchant vessels are going to pass through in order to proceed to further destinations. Thus, we have established an open sea check point away from coastal critical areas or harbors or even populated islands and generally land areas. Also another advantage is that there is not an issue of increased maritime density and more importantly if you still find something illegal it is in the open sea environment away from critical infrastructure.

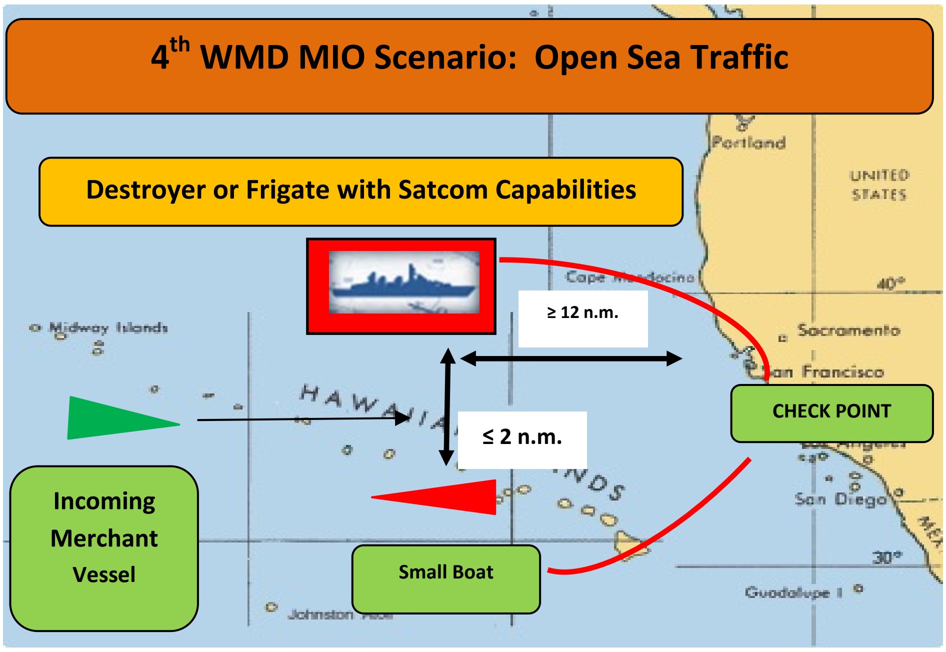

Figure 15: 4^st WMD MIO Scenario regarding Open Sea traffic check points.

8. Conclusions and Future Work

All the above mentioned actions and scenarios have to be tested in the three month timeframe that the Tubesat Picosatellite is going to stay in orbit. It is assumed that this timeframe is adequate enough in order to execute the WMD MIO experiments, implement the four scenarios and finally acquire important results.

The proliferation of WMD in Maritime Interdiction Operations through Picosatellites is an innovative and pioneering approach. Naval Postgraduate School along with CENETIX laboratory is implementing new technologies trying to fill the research gap that still exists in scientific community. It is a totally new and promising project and the usability of these data channels has not yet been assessed. The question addressed is whether the unique set of features of Micro and Pico satellites can be used beneficially in future implemented MIO scenarios in order to make identification, search, tracking and tagging of illicit WMD materials a procedure that we will be able to be executed in a fast and efficient way through Pico satellites.

9. References

1. "Nanosatellite Tracking Ships: Responsive, Seven-Month Nanosatellite Construction for a Rapid On-Orbit Automatic Identification System Experiment," Freddy M. Pranajaya and Robert E. Zee, Space Flight Laboratory, University of Toronto, Institute for Aerospace Studies, 7th Responsive Space Conference April 27–30, 2009 Los Angeles.
2. http://www.utias-sfl.net/nanosatellites/CanX6/
3. http://www.utias-sfl.net/nanosatellites/AISSat-1/
4. Torkild Eriksen, Gudrun Høye, Bjørn Narheim, Bente Jensløkken Meland, "Maritime traffic monitoring using a space-based AIS receiver," Acta Astronautica, Vol. 58, Issue 10, May 2006, pp. 537-549.
5. http://directory.eoportal.org
6. http://www.nasa.gov/mission_pages/tacsat-2/main/
7. "Satellite AIS from USCG" Article in Digital Ship Magazine, April 2007, pg 27.
8. http://www.esa.int/esaMI/Technology/SEMVDZ9NJTF_0.html
9. http://www.interorbital.com/TubeSat_1.htm