Journal of Naval Science and Engineering
2012, Vol.8 , No.2, pp. 1-30

MICRO AND PICO SATELLITES IN MARITIME SECURITY OPERATIONS

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Abstract

This paper examines the use of micro and pico satellites in the maritime interdiction and maritime security operations. It is providing the operational background of the above mentioned areas of operations and it is trying to interconnect the micro and pico satellite technology to the use of it by field officers on the move. After a brief literature survey in the area – where there are not currently many candidates – there is an analysis for operational micro and pico satellite characteristics as well as vulnerabilities of those for Low Earth Orbits. Additionally real scenario implementation has been run and simulated results provide facts for the conduction of those space operations in the maritime security arena. Finally, there is an initial cost benefit analysis and an analysis of how these very small satellite structures can be better utilized in the future with the use of micro thrusters. An in depth analysis of the current technology in the area has been performed.

Keywords: Micro satellites, Pico satellites, Space Maritime Security Operations, Micro propulsion, Vulnerabilities

1. INTRODUCTION

Micro and Pico satellites are small space assets that have been around for decades. Sputnik, the first ever satellite to fly was considered to be a microsatellite since its weight and characteristics were similar to the ones designed for today's operational environment. These small devices have been considered part of our space lives for years but nobody until now has ever thought if we can use these devices in order to minimize the cost of global maritime security operations. It is imperative in the middle of one of the most severe economic crisis that the world has ever sensed, to reinvigorate all the ideas that deal with space operations, but from a cost effectiveness perspective. Solutions that have been proved successful but require high costs in order to be implemented in space are no longer solutions and no one consider them as being viable. On the other side, solutions that prove cost effectiveness and the cost benefit analysis rates on a very low scale are being analyzed as appropriate for implementing them into our operational environment. In older times everybody was thinking of the smart ideas not including though in the analysis the cost as one of the most important factors. Today, smart idea is considered the one that can fill the operational gaps, but with very little amount of money. This is the modern challenge for the governments, academic institutions, organizations and in this direction the scientific community has turned with all its power and effort.

Following the above mentioned principles and believing that there is still room for great advancements and improvement in the areas of micro, pico and femto satellites applications to the maritime environment, we are going to analyze in the following paragraphs how these types of very small devices can add significantly to the maritime security operations area and most importantly that with these little space "toys" we can sustain effectively an operation, such as counter piracy or to help counter any other type of maritime terrorism operation. Of course there are limitations and restrictions and the research is still ongoing. Through this research though we are hoping to investigate and propose solutions that are going to minimize the cost to the lowest allowed for space operations and in the range of some thousands of dollars, which is an exceedingly crazy figure for today's missions.

2. OPERATIONAL BACKGROUND

It has been traditionally proven that surveillance in real time framework and parameters in the maritime environment attracts the most interest from communities when an operation is being planned on the strategic or operational level. The command and control procedures and command schemes needs to succeed in order for the operation to be executed in a smooth way. At the same time efforts have been made throughout the last decades to minimize assorted costs and make the intelligence command and control designs affordable and robust.

In maritime operations the factors that affect the conduction of a mission are so many that sometimes the planners follow only the most important ones without caring about the side effects. It is imperative for a successful and cost effective operation to take into account all parameters that will finally lead us to the desired result. Maritime environment is an area where real time intelligence support is of primary importance especially, when advising from ashore fusion centres is needed and must be implemented.

Contemporary maritime security operations are covering a full range of different missions starting from countering piracy to countering transportation of illegal goods, as well as human trafficking and embargo situations. All these operations cannot be followed or covered with one intelligence acquisition scheme and usually different applications and technological frameworks are being utilized in order to effectively support them. A real time information infrastructure that will cover all of the aforementioned operations and combine them in one and cost effective intelligence scheme is still absent from today's operational and tactical maritime environment. Addressing this problem we may encounter many obstacles but at the same time it is worth pursuing a solution like this, since if it at the end we succeed, then we will have merged the cost effectiveness with the real time operational requirements covering almost all aspects of maritime security operations.

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 100 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 micro, nano and pico satellites, with net weight near or less than a kilogram. Up to now there are no commercial very small satellite buses in orbit (in the range of 1 kgr) that are able to reroute information from a maritime warfare operational area back to a network operation center.

Satellite Category	Net Weight
Large	> 1000 kgr
Medium	500 - 1000 kgr
Mini	100 – 500 kgr
Micro (Cubesat)	**10 -100 kgr**
Nano (Cubesat)	**1 – 10 kgr**
Pico (Tubesat)	**0.1 – 1 kgr**
Femto (?)	**< 100 gr**

Table 1: Categorization of Small Satellites in accordance with their net weight.

3. SMALL SATELLITES IN MARITIME SITUATIONAL AWARENESS – BRIEF LITERATURE SURVEY

Satellites with Space Maritime Tracking Capability have been around not for many years. The research started from academic institutions and today is available commercially primarily in the applications of space maritime tracking of merchant vessels around coastal waters in the primary sea lines of communications (e.g. Gibraltar). In the following pages we present some of 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 up 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 or supporting critical maritime security missions. Also and up to now the applications are exceeding the acceptable costs for this research which is some thousands of euros.

a. Nanosatellite Tracking Ships (NTS), Canadian Nanospace eXperiment 6 (CanX-6) (University of Toronto – UTIAS - Space Flight Laboratory)[1,2].

The mission of this cubesat (type of microsatellite in rectangle size) 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[1].

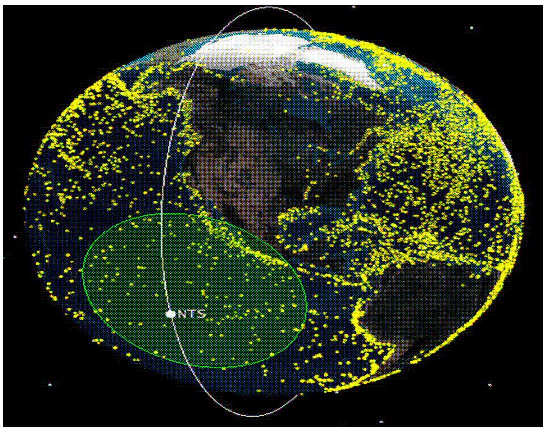


Figure 1: Illustration of the AIS messages recovered during the first six months of NTS operations. The high density of ships in the coastal regions can be seen clearly, as can the global shipping lanes. The footprint of the NTS satellite is also illustrated, showing the large area within the footprint of the AIS receiver at any instant of time.(Courtesy: UTIAS[3])

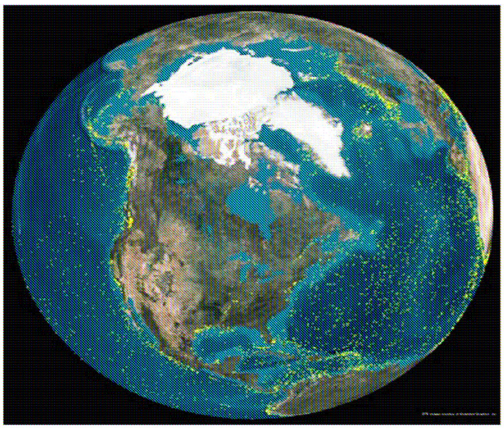


Figure 2: The Earth's shipping traffic density as it was acquired from the NTS Satellite on a specific day. Composite Image from NTS regarding maritime shipping.
(Courtesy: UTIAS[3])

b. Maritime Monitoring and Messaging Satellite (M3MSat)[25]

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 was planned to 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].

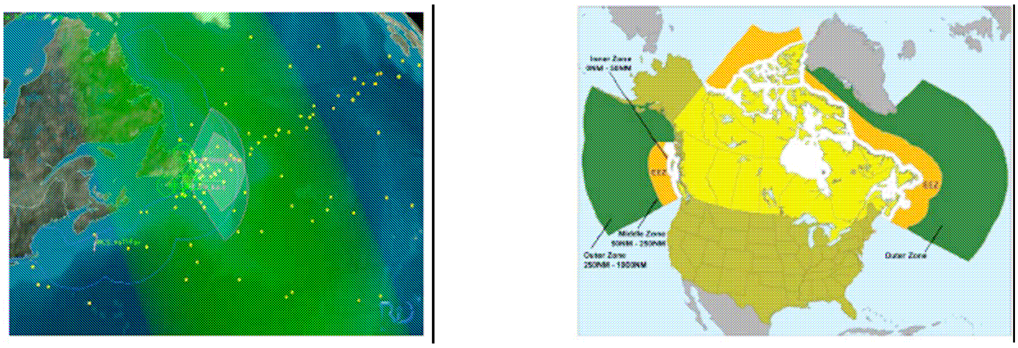


Figure 3: Coverage of M3MSat outside Canadian Territorial waters (courtesy UTIA[2])

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

AISSat can receive messages by a VHF receiver in space for wide area observation of maritime activity. Its mission focused on Norway's TTW (territorial waters), 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.

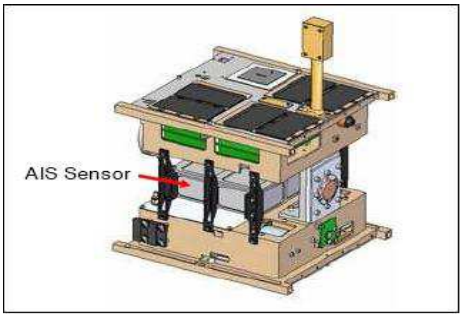


Figure 4: Internal structure of AISSat-1 (Courtesy AISSat)

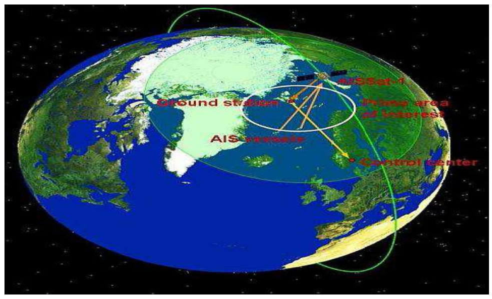
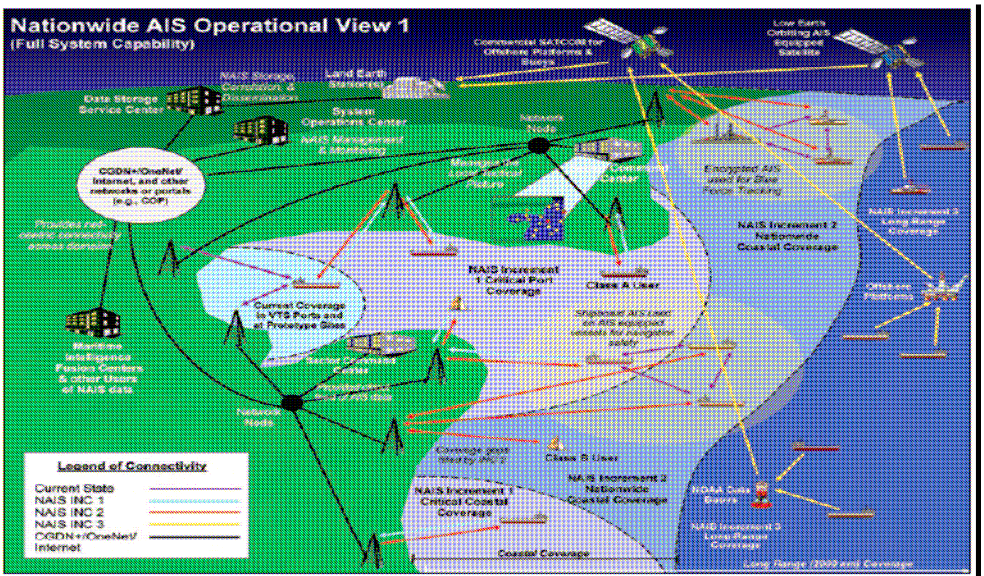


Figure 5: Coverage of AIS Sat outside Norwegian Territorial Waters (courtesy AISSat)

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

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].



A USCG outline of how the satellite network will be expected to collect and forward AIS data

Figure 6: A USCG outline of how the satellite network will be expected to collect and forward AIS data.(courtesy TACSAT[5])

4. PICO-SATELLITE APPROACH – STATE OF THE ART REVIEW

In this short reference we are trying to propose to international maritime community a small but smart satellite command and control system that will be effectively used from every platform and will convey all information from the area of operation to a fusion centre ashore minimizing the assorted costs and giving to interested community (e.g. a country, a non-governmental organization, an international organization) the desired effect, which is intelligence superiority and dominance over a specified area of interest. This system needs to be cost effective in such a way that by comparing it with systems that are now in use will give 50% more surveillance capabilities and it will be at least 50% financially more effective from any other asset in use. This should be our initial goal, yet very difficult to accomplish.

Our attempt is to use the inner space area (very low earth orbits) for implementing such a solution by incorporating very small satellite technologies in order to drive us to the required solution. The pathway to this end result and goal is not easy, needless to say that at the same time during an era of global economic crisis it is imperative for us to prove to international maritime community that a very small satellite system can be a viable solution and decrease the amount of spending money daily in operations. By accomplishing all of the above a new business model should arise with less personnel capacity to be used in maritime security operations than it is used today, such as the participation of military personnel on board military ships on very long sea tours in the high risk areas of operation (e.g. Gulf of Aden).

In this case and being more specific we propose the so called nano or pico satellite system which usually refers to a standalone satellite bus with weight smaller than 1 kgr, capability of earth from space video imaging and simple on board processing. Flying on very low earth orbits, near the outer atmosphere at around 300 to 400 kilometres from earth’s surface, these toys can convey viable information to any fusion centre ashore or to vessels underway by using basic communication schemes that are not subaltern from any other modern communication application used in space. If we are able to have up to 1.5 Mbps bandwidth and at the same time capability of transferring audio, data and even video (current level of technology) at all times through satellite passes, then we would definitely say that this application is worth mentioning and being researched. A system like this (standalone pico-satellite), which is flying at so low orbital paths can communicate on earth and transfer information covering 12 to 15 % of daily time (around 1.5 to 2 hours). Also using more than one small satellite, let's say a cluster of a dozen of those we cover almost the whole daily timeframe on top the area of our operations, leaving the only thing still to consider the cost. But the cost for a small nano or pico satellite is not high. With less than few thousands of dollars (all inclusive) you can have one of those little "toys" flying over the earth for the duration of your operation and as the technology now stands with maximum satellite lifetime to reach three to four months. Therefore the situation now is that this system can stay up only for a mission oriented operation with a timeframe of three to four months (orbital decay parameters are being implemented). Still we do not have the capability of applying micro propulsion systems on board, but it is a fact that for sure is going to happen in the near future. With the application of small but effective microwave electrothermal thrusters these satellites will have the capability of increasing their flying lifetime over the earth for almost 7 years or so and they will provide us with services that current satellites are providing with very high costs including maintenance and flight sustainment. To sum up and set the technological limit we should say that although the concepts of nano and pico satellites have been experimented with for over two decades now, stable and successful designs in the 1 kg class area are so rare, that are virtually non-existent. The design and manufacture of very small satellites is not simply a matter of miniaturization, but as the experience has proven, several technical hurdles such as space qualification of materials and systems, power system design, and orbital control and ground control assume enormous significance in the design process[32]. The solution though to the application of a nano or pico satellite to a real operation is now closer to reality than ever before.

Comparing the figures, we can say that if you have a small cluster of picosatellites (let's consider tentatively six of those) and each one of them costs around 10.000€, then with 50.000€ you can have adequate coverage of an area of operations 24/7 and at the same time the amount of money you have spent for the next seven years or so is nothing to be compared with the one being spend today. Imagine that a medium size ship (e.g. corvette or frigate) costs thousands of euros per day (usually more than 30000€ or even more - approximate figure) containing the amount of money that is being spend for oil, maintenance, salaries of personnel and other side costs. Additionally this operational planning (with surface ships) does not give you the capability of covering a vast or even a large sea area, since a ship is deemed to be positioned on the surface of the earth and the capability of providing accurate info is limited to some decades of miles. With small nano or picosatellites the coverage is complete (day and night) and the cost will be approximately 150 to 200 € per day, which compared to the amount of money that a ship is spending per day to the high risk area is nothing. The difference in cost is very large and the advantages are at the same time innumerable. In maritime security situations like illegal trafficking of goods, embargo operations, counter piracy operations, human trafficking, slave trade, illegal fishery, illegal environmental pollution, drug trafficking and other illegal activities that may happen in the maritime environment we need robust surveillance or real time intelligence support and the proposed system can help confront them efficiently. It is our belief that any conventional or unconventional illegal activity in the maritime domain can be diminished effectively with the use of these small technological assets. It is not an exaggeration to say that by applying this technology we could search and cover the critical maritime environment areas throughout the world's Sea Lines of Communications with relative easiness and primarily with the use of few national or international assets. The only thing that needs to be done is for the academic society to undertake the risk, make relevant research and combine the effective, efficient and affordable parameters into one small pico-satellite device (research is currently ongoing). The creation of a really miniaturized plasma propulsion thruster (in the range of some grams) is a part of this solution of the problem helping to extend the life of the pico-satellite from months to years. Also miniaturized cameras or any other commercial sensor could be used to increase the operational effectiveness of the satellite itself with less additional cost. If these could happen then a breakthrough to the international maritime industry and community worldwide would occur. The will is here. It only remains to be executed through well formed combined academic and industrial initiatives.

The above mentioned potential solution could be a saviour and having a major operational impact for a number of different actors that make their living in the maritime environment (e.g. merchant mariners). Let’s consider a merchant marine company that needs fast, reliable and cost effective intelligence data in order to transit the Gulf of Aden or an area where piracy is the main problem. The pico-satellite conveys the real time data information from the area of operation to the fusion centre or to the merchant vessel itself. By this way, all info is relayed to the merchant vessel, prior to their transit of the area of elevated risk. The pico-satellites could transfer 24/7 real time information (data, images) to the merchant vessel. Therefore the captain of the ship knows well in advance what is happening around his ship in a vast area and that gives him the capability of taking fast and proactive active or passive measures in order to tackle any illegal action towards his ship.

On another potential risky area, like human trafficking, a realistic example is that we may need to verify if small vessels transiting near the shore are conveying illegally people from one country to another (transferring illegal immigrants). The above mentioned standalone maritime surveillance system could be used and provide 24/7 real time images to a command and control centre helping to cease this problem or at least arrest the illegal conveyers on the act.

It may seem futuristic or utopian that a very low cost solution from space could solve so many problems happening every day in the maritime environment. It is not though difficult to apply such a solution but of course political and legal wills will remain critical factors. Covering with images an area on top of a country has legal limitations in the international community and this is something that needs to be examined before proceeding to the execution level. It is worthy though to undertake such an endeavour and find solutions that will help humanity to stop the emerging problems that occur in the maritime environment and impede the safety of transportation via the navigation lines.

5. VULNERABILITIES OF MICROSATELLITES IN VERY LEO

Living on Earth is not always easy to understand the mechanisms that take place every day in the inner space region. It is not an exaggeration to say that space is not an empty environment. There are so many things that take place every second that it would be truth to say, we may not even know the exact composition of Earth's inner space region. Generally though, the region that circles around the Earth is called magnetosphere and is the origin that creates and alters the environmental characteristics in our near Earth environment. In the following pages we describe briefly some of the magnetosphere's parts and characteristics in order to comprehend how space environment can affect microsatellites flying in very low earth orbits (orbits among 300-5000 km), when travelling through these areas.

The Earth's magnetosphere can be defined by the area of space around Earth that is controlled by the Earth's Magnetic Field. The space enclosed by the magnetosphere is not empty but filled with trapped particles, mainly ions, protons and electrons. The magnetic forces are much stronger than gravity. The real shape of the boundary of magnetosphere, the magnetopause, is strongly modified by the solar wind. The distance of the magnetopause is on the side facing the Sun 10-12 Re (earth radii), over the poles 15 Re and on the night side the tail reaches past several 100 Re. There exists also a neutral gas envelope of the Earth, the Geocorona that extends from 4-5 Re. A satellite in LEO will thus be exposed to trapped particles only during certain portions of the orbit. These are the polar horns (electrons below 1000 km, electrons and protons above that altitude) and the South Atlantic Anomaly (protons and electrons at all altitudes)[6].

Giving an example to visualize the overall effects let's consider a spacecraft launched from Kourou. It will first pass through a zone with a large flux of energetic trapped protons when being injected into geostationary transfer orbit. This must be taken into account when designing on board electronics which may be sensitive to Single Event Effects produced from protons. Of course we must have in mind that infrequently we can face extreme proton or electron events in the Earth's radiation belts that can affect any space system dramatically with energies much greater than the common ones. Other areas in which LEO micro-spacecraft will be affected are the Van Allen Radiation zones. Some risky issues that we always have to have in mind are how electrons and protons in Van Allen radiation belts affect the survivability of satellites when they are passing through that zones, what are the major risk areas inside Van Allen belts, especially in polar horns where distance to earth is near enough and what are the implications on satellite's body from the atomic oxygen in north pole (aurora borealis). Additionally, what is the density of atmosphere near the mirror points of trapped particles and what are the affections (if there are any) by this dense magnetosphere region on satellite's orbit. Another important effect is how the 11 or 22 year solar cycle can affect the magnetosphere of earth and as an aftermath ionizing procedure in Low earth orbits. What are the vulnerabilities that a LEO satellite can withstand from ionizing particles coming from earth's ionosphere and how heavy ions in low earth orbit affect satellites material (aluminum, titanium etc) and are these capable of doing a catastrophic damage on satellite's bus? Also, what are the material thicknesses in accordance with orbit we have to use in order to avoid particle penetration procedures and finally charging of satellite? Finally what are the effects of Solar U.V. into low earth orbit through ionization of magnetosphere and density of trapped particles and which is the low earth orbit that have the slightest vulnerability on magnetosphere's particles? How deep dielectric charging can affect a satellite? In low earth orbits there is an antiproton radiation belt. Is it a strong enough to destroy our satellite and how can possibly do that? [7] Therefore the above mentioning facts are only few of those that we have to take into account in order to design a microsatellite mission aiming to support maritime security operations. A satellite orbiting in Low Earth Orbits and close to the equator (300 km) is passing through a very low radiation environment. A satellite in LEO with inclination of 45º has to overcome the effects of South Atlantic Anomaly. The incoming radiation is cumulative as it passes through the South Atlantic Anomaly (SAA) region. That is to say the more frequent the satellite passes through the SAA region the more is the effect of the radiation that is going to encounter. Another effect that a LEO satellite has to overcome is the polar horns, if it is orbiting in a polar orbit. In this specific polar regions we have concentration of high energy charged particles until Earth's Surface. Heavier ions as He, C, N, O, Ne can not affect satellites electronic systems, but can have effect in charging of a satellite. Monatomic Oxygen is the only charged particle that can have severe effect on low Earth Orbiting satellites. In 200 km it has a density of 109 atoms / cm3 and in 800 km it is less than 105 atoms / cm3. The speed that these charged particles have can reach 7 km/sec with energies up to 5 KeV. The results that can have on a satellite if there is a contact is primarily material erosion (very low though for aluminium, but high on Arg). Also there is oxidization of the metals and the connections on the electronic circuits. The effect on cameras or mirrors that are used on board a satellite can set aside. It is a given fact that electrons up to 7 MeV in Van Allen Radiation Zones and protons up to 600 MeV have major impact on satellite's electronics. They can also penetrate the surface of a satellite but only travelling short distances not having the capability to affect the satellite's operation [8]. Aluminum shielding of more than 0.3 mm is used extensively for satellites that are travelling through radiation zones, such as Van Allen Radiation Zones. For a satellite in LEO the charged particles that we have to take seriously into account and can affect our mission are energetic protons with energies more than 50 MeV in the inner radiation belt and energetic electrons with energies up to 1 MeV in the outer radiation belt. Finally, solar protons (from solar flares) are another charged particle that can have serious effect in our mission. A LEO micro satellite is exposed to radiation from galactic cosmic rays when it is orbiting near the poles. It is not affected from galactic cosmic rays when is near the equator. Protons in LEO orbits are having energies ranging among 150 – 250 MeV. Future technologies recommend the usage of polymers in new micro satellite missions. For our mission though we use simple aluminium materials (space certified) and remains in an true flight mission to verify if the mission is being affected by radiation during the passes of the micro satellite through the high risk radiation areas.

6. MICRO - PICO SATELLITE OPERATIONAL CHARACTERISTICS

In the following paragraph a short list of operational characteristics of micro and pico satellites are being reported in order a more digestive and detailed comprehension of the system to be fed to the reader. All these characteristics may seem highly tactical or operational, but if one analyzes the effects that are going to affect the execution of operations then the results can be considered highly operational or even strategic. Therefore, some of the most important characteristics are provision of fine resolution images from the area of operations, real time transfer of information to merchant mariners / vessels of interest for the existence of suspect peripheral traffic, real or near real time tracking capability depending on the selection of orbital parameters and the area of operation and audio - voice and video communication to a fusion center ashore for the specified window that a satellite is passing on top of the area (on the move networking capability). Also feasibility of a two way communication implementing reachback techniques and coverage of a vast geographical sea area by providing partial or total situational awareness based on the number of satellites to be used. Finally, lifetime consideration (1 to 3 months depending on solar weather for our case) is another critical factor and if this research successfully increase micro and pico satellites lifetime to more than a year then this system will definitely have a strategic effect on the execution of maritime security[29].

Figure 7: An indicative commercial pico-satellite system under consideration for design. The system (satellite) is called Tubesat and is deemed to undertake all maritime security missions for very low cost. Many universities, academic institutions and organizations have already register for participation to the project hoping of minimizing cost in space on a logarithmic scale (courtesy Interorbital Company [8])

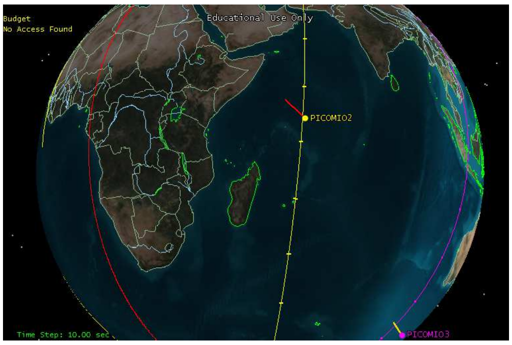


Figure 8: A pico-satellite is passing over the area of maritime operations in the Somali Basin, sending data to a merchant vessel that is underway transiting the high risk area. The available timeframe for communication is 7 minutes four times per day increasing the total communication time to 120 minutes. This time is more than enough for feeding the Captain of a maritime vessel with valuable information supporting his proactive actions towards a maritime illegal act situation that may occur [9,10].

Delays can and do occur but the benefits of providing the afloat officer with rapid, reliable, efficient communications with the fusion center and the technical experts directly, are clear. The team is safer and more efficient at adjudicating the situation. It is obvious that by giving to the afloat officer the capability of communicating directly with experts ashore is of critical importance and with the use of micro and pico satellites over the operational area we will have this capability in place by using command and control networks that will link the action area officer, the tactical afloat command and the fusion center as well. This is one approach will finally provide effectiveness and efficiency to the completion of the overall operational mission. This approach is nowadays a need. To sum up though the operational part one has to have in his mind the following attributes of the micro and pico satellite system.

The approximate total time that we have during a whole day to communicate through a system that has four satellites (the cost will be around 50000 € approximately) is 120 minutes (2 hours during the day). Therefore the total gap time between satellite passes during one day is approximately 22 hours. However with this amount of timeframe we have the capability to exchange the needed information with a merchant vessel underway and feed the important information required for a safe and secure transit from a high risk area. Modern maritime threats, as they appear on the international scene today, do not require 24/7 hours of communication with fusion centers ashore but only a logical timeframe sufficient to transfer critical information back and forth and secure future courses of action [9].

For the purposes of our research, we've conducted simulation runs using the Satellite Tool Kit modeling software and in the following tables we illustrate the modeling results. As we can see on table 2 in a day time frame we have approximately four micro satellite passes. On the abs Time column we report the results indicating between which time the satellite is on top of the ground station having connectivity. This duration varies from 9 to 2 minutes depending on the orbital characteristics and the ground station position each time. Therefore the microsatellite is available for this amount of time to be used each time and as we can see from the time intervals between satellites we have to wait approximately from 40 minutes to two hours in order to see the satellite again. This amount of interval is not much taking into account that a merchant vessel can only progress in this timeframe only a few miles ahead (speed of a vessel at sea 10-15 knots). So with this speed a vessel has only progressed 40 miles ahead the maximum until the satellite passes again on top of it giving the capability for communication again. The same situation applies to any vessel at sea and also for all types of vessels participating in maritime security operations (e.g. military vessels such as frigates). Finally and if we sum up all the passes and the available communicative timeframe we found that in each day a satellite will pass on top of our ground station (in this case a merchant vessel) almost 17 times with total timeframe available for communication to reach 111 minutes per day. This amount of time is more than adequate if we want to support the maritime security operation with critical information relevant to maritime terrorism, piracy etc.

Passes / Satellite	**Abs Time** (GMT)	**Duration** (min)
4	From 05:09:41 to 05:18:35 From 06:43:08 to 06:47:11 From 16:14:30 to 16:20:26 From 17:44:02 to 17:52:40	9 4 6 8
Total passes per day: 15		**Total min per day: 113**
4	From 03:56:26 to 03:58:52 From 05:23:18 to 05:32:17 From 16:27:31 to 16:35:02 From 17:58:00 to 18:05:53	2 9 7 7
Total passes per day: 17		**Total min per day: 111**

Table 2: STK modeling results from a microsatellite mission. Report of results pertaining to a whole day communication windows with the available micro space asset [9].

On the following table 3 we report time gaps among satellite passes. As we can see these gaps ranging from 1 hour and 10 minutes to 2 hours and 40 minutes for the designed scenario, giving us the overall impression that every 1 and a half hour approximately a satellite connectivity scheme can be applied among a vessel at sea and a ground station. This amount of time is adequate and not impede the flow of critical information from an ashore center to the maritime assets underway. The overall gap of communication for the whole day is 22.5 hours. That evidently means the available time we have for effective communication is 1.5 hours per day splitted approximately in 7 minutes frames.

Start Time of Pass	**End Time of Pass**	**Gaps among passes**
00:33:12	00:38:50	1 h 10 min
01:51:42	02:00:08	1 h 22 min
03:22:56	03:29:33	1 h 40 min

05:09:41	05:18:35	1 h 25 min
06:43:08	06:47:11	1 h 02 min
17:44:02	17:52:40	2 h 30 min
20:22:44	20:31:42	2 h 41 min
23:12:53	23:21:50	-
≈ Total Gap Time in one day		22 , 5 hours

Table 3: Total gap timeframe in one day using a microsatellite. The total time available for communication is almost 1.5 hour [9].

In the analysis we applied also to our simulation four and six micro satellites in order to record the differences in results and eventually in the available communication availability. The results clearly illustrate that by adding two more satellites the total daily time coverage is being increased by 3 - 4 % which is approximately 1 hour and 20 minutes more per day.

Dates in June 2011	**4 Micro Satellites** Daily % time covered	**6 Micro Satellites** Daily % time covered
4	7.00	11.32
5	7.17	11.84
6	8.10	11.81
7	7.92	11.66
8	7.96	11.66
9	7.77	10.14
10	7.23	10.15
11	7.52	11.51
12	7.62	11.67

Table 4: Daily Percent Time Covered with the use of 4 and 6 microsatellites [9]

After running the model (incorporating relevant orbital decay characteristics) we acquire the following results. The microsatellites will remain on orbit for a little over a month, ranging from 30 to 33 days. This scheme of available orbital timeframe is such, because currently there is no propulsion available for satellites ranging in weights less than 2 kgrs. That is why the satellite remains on orbit only through physical / natural procedures and is being severely affected by solar and radiation activity. That is why there is a proportional decay usually in month's timeframe.

Micro Satellite	**Date** (June 2011)	**Time** (GMT)	**Orbits** (in one month)	**Lifetime** (in days)
Micro 1	4	07:39:32	527	33
Micro 2	3	19:28:47	528	32
Micro 3	2	05:54:02	503	31
Micro 4	2	07:29:36	504	30

Table 5: Results for the lifetime of microsatellites. Satellites without propulsion schemes will stay in orbit a little bit more than 30 days [9].

Research is ongoing to understand and investigate though the possibilities of applying micro propulsion to these micro satellite buses and increase their lifetime from one month to at least one year. As we can see in the following figures and based on extensive analysis and state of the art review that we have done for all available electric micro propulsion systems, candidates are in the range of very few watts providing thrust of only very few mN. Currently there are only eight universities and organizations that are dealing with this kind of research and these initiatives are depicted in the following figures. The best available figure is coming from the University of Kyoto (Japan) where they have reported microwave electrothermal thruster capability by using power of 3.1 Watt and providing thrust for the satellite of 4.3 mN. This figure can be considered to be applied on a micro and pico (but not femto) satellite bus and sustain orbital path for over a year. As it is proven from the last figure, the microwave electrothermal thrusters (MET) are the most capable machines currently being considered for application to microsatellite buses. The cost is not serious but not minimal and the cost benefit analysis of these systems is still under research, in order to decide if they apply to real satellite missions.

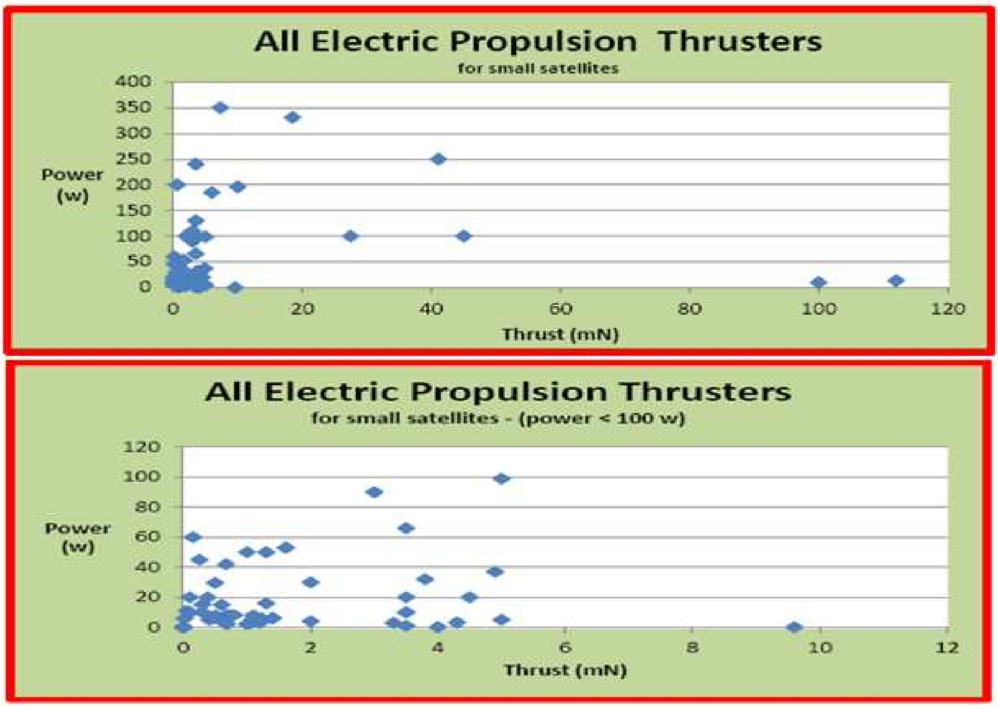
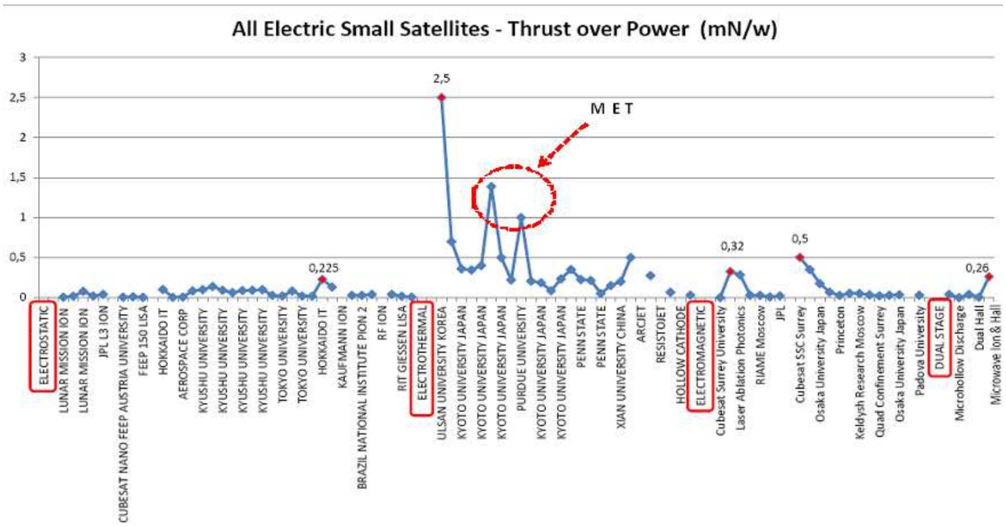


Figure 9: State of the art review of all electric propulsion thrusters available today. Results of the above mentioned graphs are being reported for thrusters available for small satellite buses (upper graph). On the below graph there is a more clear depiction of the available small satellite thrusters with power levels less than 100 W and thrust lower of 10 mN. These figures indicate solutions that can be applied (under certain circumstances) to micro and pico satellite solutions.

micro / nano / pico - Microwave Electrothermal Thruster (MET) Comparisons											
No	Power W	Thrust mN	Isp sec	Thruster Efficiency %	Propellant	Propellant flow rate sccm	Weight kgr	Frequency GHz	Flown in space?	Date	Institution
1.	3	↑ 1.8 - 5.6%	N/A	N/A	Ar			4	No	2011	Kyoto[22]
2.	6	↑ 2.8 - 12.3%	N/A	N/A	Ar			4	No		
3.	3	1.08	62	10	Ar	60 magnet		4	No		
4.	3	1.03	59	9.2	Ar	60 no magnet		4	No		
5.	6	1.23	70	6.8	Ar	60 magnet		4	No		
6.	6	1.11	64	5.6	Ar	60 no magnet		4	No		
7.	6	0.51	250	10.1	He	2-70		4	No		Kyoto[21]
8.	6	0.51	375	10.1	H_2	2-70		4	No		
9.	6	0.2 - 1.4	50 – 80	2 – 12	Ar + 5% N_2 and H_2	10-60		4	No	2009	Kyoto[20]
10.	6	1.4	80	8.7	A r + 5% N_2 and H_2	60		2, 4	No	2008	Kyoto[18]
11.	With 4 GHz, plasma is little affected, with 10 GHz and shorter chamber, improve of thrust performance									2007	Kyoto[17]
12.	3	1.2	66	12	Ar			4	No		Kyoto[16]
13.	6	1.4	79	8.7	Ar			4	No		
14.	6	1.4	80	8.7	Ar + 5% N_2 and H_2	10-60		4	No	2008	Kyoto[19]
15.	10	2.5-3.5	130-180			2 mg/s		1-25	No	2006	Kyoto[14]
16.	5	1.1	73	4.2	Ar	10-50		4	No		Kyoto[15]
17.	4	2	136	12	Ar	1.5 mg/sec		4	No	2005	Kyoto[148]
18.	3.1	4.3	320		Ar	280		4	No	2004	Kyoto[13]
19.	100	3-6	30-80	50-78	He, N_2, Ammonia	2-20 mg/sec			No	2004	Penn State[42]
20.	20	0.2-4.5	169-197		He	2.15 mg/sec		14.5	No	2007	Penn State[8]
21.	200		321-434	6.9-75	Ammonia & Hydrazine		<1	8	No	2010	Penn State[118]
22.	100-250	15-90	190-315		N_2H_3			8	No	2011	Penn State[154]
23.	2.94				He			30	No	2011	Penn State[181]
24.	100-300	20-120	450-650	34-50	He	4.09-6.14 mg/s			No	2008	Xian[35]
25.	70	15	340		He				No		
26.	120	$25.5x10^{6}$	5758	61.3	N_2H_4	4.4 mg/sec	1.5		No	2011	Xian[152]
27.	1-5	2.5-3.5	130-180		Xe, Ar	80			No	2011	Korea Ulsan University[162]
28.	150	40-75	70-200		He & N_2O	0.025 mg/sec		7.5	No	2004	Princeton[69]

**Categorization in accordance with Institution and Date of application*

Figure 10: Representing all different organizations that are currently undergo research towards the micro propulsion areas. The best available figure (red indication on above table) is coming from the University of Kyoto (2012) with power as less al 3.1 W and produced thrust of 4.3 mN. This is the best overall figure up to now for a micro propulsion thruster (Microwave Electrothermal Thruster – MET) that can be applied on a micro satellite bus. The below table is also indicating the same results but reporting those in Thrust / Power ratio, a figure that is extensively used in industry when referring to micro propulsion thruster performances.



Overall though, the modeling results clearly demonstrate that having six micro or pico satellites in polar orbit would provide an operationally effective communication window, as big as three hours per day, depending on the configuration of the satellites. However, based on the described modeling results for four microsatellites, we are going to have almost 2 and a half hours availability of communication, which is also enough time for applying reachback methods in operational use to our maritime security missions. The field officers (e.g. Captains of vessels) need this capability in order to enhance their mission success and safeguard their tasks. The above studied / proposed microsatellite based networking model contributes directly to the emerging concept of Space Operations to Counter Maritime Terrorism (Fig. 11) by populating the “funnel” part of the diagram. This diagram has been created solely for the purpose of this research and is a prototype.

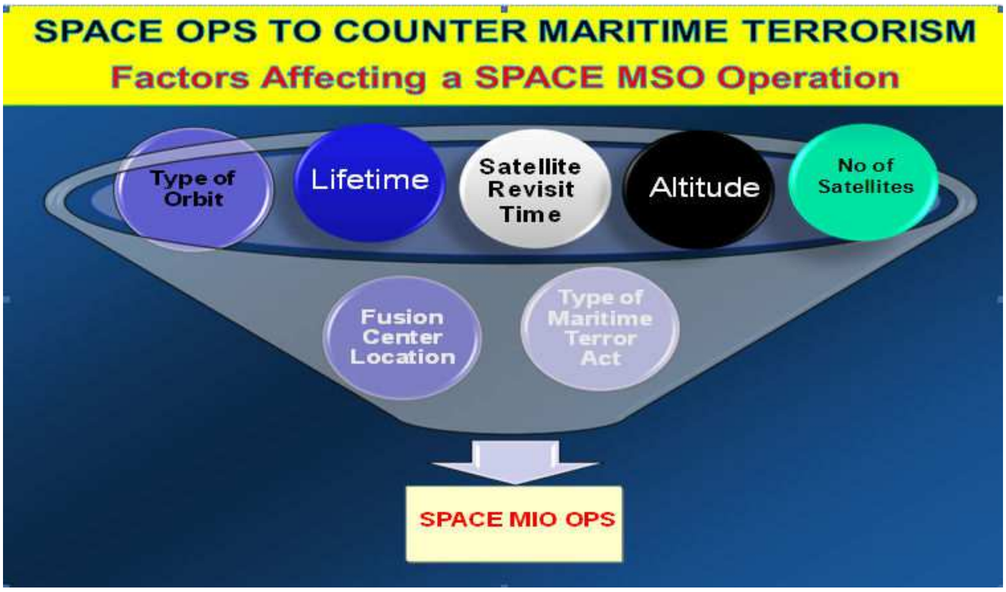


Figure 11: Concept of Space Operations executed for supporting Maritime Security activities

7. CONCLUSIONS – FUTURE

The above short but concrete analysis tried to provide to the potential reader an alternative way of how in the future maritime security operations can be supported and executed with alternative cost effective ways. It is yet to be proven that solutions like micro and pico-satellites will succeed in the years to come and having in mind the advent of microsatellites (space assets less than 100 kg) two decades ago, where it seemed unreal that solutions like those could place themselves in a way that would change absolutely the daily operational world, then is more than evident that nano or pico satellites solutions will ameliorate our world towards cost. Future is not very far and the technology has proven numerous times that can provide solutions better that those we can imagine. It is only a matter of willingness, persistence and hard work that will lead us to another more cost effective future environment. Cost – benefit analysis of the above proposed pico-satellite system is under stuffing and is in the process of being executed in order to acquire the first primitive results on how we can implement solutions like the one above in the maritime daily business without affecting the operational environment's key factors. It is our firm belief though that this analysis and approaches will change dramatically the way of executing maritime security operations. The operational needs will seek demanding solutions and technology will provide them. It remains though unclear how these solutions will affect our world, which to us seems a sure aftereffect and outcome by minimizing the cost, giving us more possibilities to survive in a harsh global economic environment. For us future is the past and the "real future" is our ideas that are waiting to come and enlighten our endeavors towards perfection in the small satellite arena.

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**All of the above mentioned literature (from 11 to 46) has been reviewed in order for the writer to acquire all the knowledge that would help him to extent the ideas towards a micro and pico satellite model. If a referenced citation is not mentioned in the paper that means no specific parts were taken directly into this paper, but only notions of it were studied and considered.*