20th ICCRTS

Paper ID: 067

Exploring the Application of Pico-Satellites for Maritime Security

Topic 4: Experimentation, Metrics, and Analysis

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Abstract

Pico satellites (PicoSats) are small size short lived satellites that operate at a low earth orbit. They can carry various payloads such as imagery sensors, Automatic Identification Systems (AIS) and communications. Interest in PicoSats is rising given their relative low cost of production and operation, relative ease of engineering and available wide range of off-the-shelf equipment. Therefore various applications for PicoSats are being explored, including security and defence.

This work explores the application of PicoSats - as a low-cost effective system - to assist maritime security operations, including surveillance, anti-piracy and search and rescue operations.

We plan a set of experiments that will resort to the Greek PicoSat Lambdasat to demonstrate the capability to generate situational awareness (via the AIS receiver that tracks all the vessels inside its footprint around the globe) and exchange messages (e.g., piracy alert) between ground stations (located in Greece and in the U.S.A.) and vessels at the Mediterranean Sea. We describe our work in planning and designing the experiments, including installation of a ground station at the University of Aegean, Athens. With our experiments, we will demonstrate the PicoSat ability to create shared situational awareness and increase mission efficiency, that is, improve maritime security. Our experiments are planned for the mid of 2015.

1 Introduction - The Operational Maritime Dimension

Contemporary maritime security operations cover a full range of different missions. As outlined in the European Union Maritime Security Strategy [1], adopted in June 2014, they encompass protection of critical maritime infrastructure (e.g., ports and port facilities, off-shore installations, energy supply by the sea, underwater pipelines), preservation of freedom of navigation (including security of crew and passengers against piracy) and prevention and countering cross-border illegal activities (such as human trafficking and illegal transportation of dangerous materials and substances).

In order to be effective, modern maritime security operations require a variety of different applications, multiple information sources and technological frameworks. In addition, a real-time infrastructure allowing to combine them into cost effective intelligence schemes would dramatically decrease response time and, as a result, increase mission efficiency. However, such infrastructure is still absent from today's operational and tactical maritime environment.

Maritime security missions cover a vast environment where satellites play an important role in exchanging information and contributing to the creation of shared situational awareness between force's elements. Satellites can provide important capabilities supporting Command and Control (C2) including imagery, surveillance and communications services, the latter also enabling bi-directional information exchange with military and civilian entities (e.g., commercial ships).

This paper is part of a work that explores the application of small satellites, also called PicoSats or CubeSats, to assist security maritime operations, including surveillance, anti-piracy and search and rescue operations. Interest in PicoSats is rising given their relative low cost (development, launch and operation), relative ease of engineering and available wide range of off-the-shelf equipment [2].

In our work, we will conduct experiments that resort to the Lambdasat PicoSat, being one of the main objectives the transmission and dissemination of information globally between ground stations and ships.

This paper is structured as follows: we present our reasoning on the relevance of PicoSats for purposes of maritime security; then we describe the Lambdasat, a recently deployed PicoSat that we will use for our experiments on maritime security; then we describe our work related with maritime experiments based on PicoSats and we finalise by presenting the way ahead.

2 Pico-satellites for Maritime Security

We propose to the international maritime community the application of PicoSats supported by command and control systems that can (1) effectively be used by a variety of platforms, (2) convey information over distant areas (e.g., from fusion centres ashore to ships) and (3) decrease operation costs (expenditure in maritime operations and communications).

A PicoSat [3] refers to a small size satellite system weighting less than 1Kg capable to carry a variety of payloads such as imagery sensors, communications and on-board processing. Flying on very low earth orbits near the outer atmosphere (between 300 and 400 Km from the Earth's surface), PicoSats can convey information to fusion centres ashore and vessels at sea using communications technologies that are not subaltern from any other modern communication application used in space. As an example, we outline the work of the European Space Agency's experimental small satellite OPS-SAT that incorporates an experimental miniature high rate X-band transmitter to provide variable rate downlink at up to 50 Mbps [2]. This high data rate allows deploying applications that require high-definition imagery, high-definition video and exchange of large volumes of data.

A stand alone PicoSat can communicate and transfer information with a ground station over 12 to 15 % of daily time (that is, 1.5 to 2 hours) [3,4,5]. However, a cluster comprising a dozen of PicoSats would almost provide coverage over the 24 hours of a day.

Another important aspect to consider is the PicoSat's lifetime that reaches three to four months [3], meaning they operate over the duration of a short mission. Promising on-going research is suggesting micro propulsion systems - such as small and effective microwave electrothermal thrusters [6] - on board PicoSats to increase of their lifetime for about 7 years. If such is achieved, PicoSats will provide us with services at a fraction of the cost offered by current satellites.

The design and manufacture of PicoSats is not simply a matter of miniaturisation. As 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 relevance in the design process.

Regarding costs, a small cluster of PicoSats (let's assume 6), each costing 10K€, would require 60K€ and would result in a coverage time of 12 hours per day [7], which is adequate for most missions. Assuming a longevity of 4 months, this cluster cost would be about 500€ per day[1]. This is an insignificant cost when comparing with the costs of operating a medium size ship (e.g. corvette or frigate) which is around 100K€ per day (approximate figure that includes costs with fuel, maintenance and staff salaries). Additionally, PicoSats brings significant added value to a ship's commander since their wide observation capability greatly extends the ship's surface visibility (limited to a few dozens of miles) and their communications enable data exchange, intelligence support and force coordination globally.

It is our belief that the effectiveness of maritime security missions can be greatly increased with the use of these small technological assets. It is not an exaggeration to say that by applying this technology we could 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. As the technology evolves, PicoSats economic prospects also improve and their deployment for purposes of supporting maritime operations get closer to reality [8-14].

To explain the PicoSat's usefulness for maritime security, we now present three simple examples.

Example 1: Merchant marine company planning transit over the Gulf of Aden

Consider a merchant marine company that needs fast, reliable and cost effective intelligence data in order to safely plan transit over the Gulf of Aden, an area where piracy is the main problem. Prior to its transit, the merchant company planner **obtains direct live real-time observation data from the PicoSat pertaining to the area of interest**. Furthermore, **via the PicoSat, the company receives messages (e.g., piracy alerts) relayed from a remote fusion centre (ashore)**. The planner identifies areas of greater risk and plans the safer routes to take (and when).

Example 2: Merchant marine vessel transiting over the Gulf of Aden

A vessel is transiting over the Gulf of Aden, an area where piracy attacks have been reported. **Via the PicoSat, the vessel commander receives a piracy alert, with indication of the likely location of pirates**. The commander requests and **receives observation data from the PicoSat pertaining the area of interest**, identifies suspicious activity and opts for a safer route.

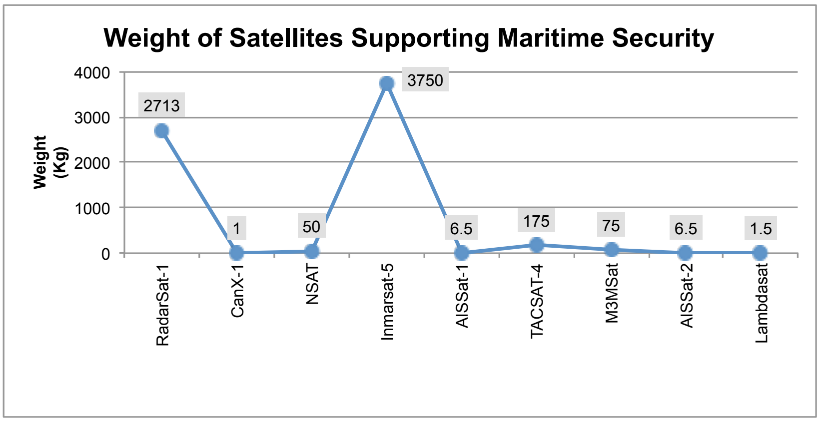
Example 3: Combating human trafficking

Human trafficking occurs frequently in the Mediterranean Sea, where small vessels illegally transport people into Europe. **Using the observation capabilities of the PicoSat, remote command and control centres monitor the Mediterranean Sea** detecting suspicious activity and deploying, where needed, naval means to assist victims and arrest criminals.

It is relevant to point out that the use of satellites for maritime security is not a new field. Figure 1,

[1]If a longevity of 7 years is obtained, costs would be, in practice, negligible

presents a list of satellites that support maritime security operations, where it is indicated their launch date and weight. It can be seen that the first satellite to deal with Maritime Security was RadarSat-1 with more than 2000Kg (launched in 2000) and two recently launched satellites (AISSat-2 and Lambdasat) are below 7 Kg. As explained later, the Lambdasat is especially relevant for this work for we'll resort to its services to conduct our experiments.



Name	Launch Date	Weight (Kgr)	Power (W)
RadarSat-1	1995	2713	2100
CanX-1	2003	1	2
NSAT	2005	50	107
Inmarsat-5	2005	3750	15000
AISSat-1	2010	6,5	0.967
TACSAT-4	2011	175	700
M3MSat	2011	75	70
AISSat-2	2013	6,5	1
Lambdasat	2015	1,5	1,5

Figure 1 - Weight of Satellites Supporting Maritime Security

To understand in more detail the relevance of PicoSats in support of maritime operations we describe next their operational capabilities.

PicoSat Operational Capabilities

PicoSats can carry a variety of payloads, including communications, observation sensors (e.g., high definition cameras) and maritime sensors (e.g., AIS). Some of the most important characteristics [3,7] are:

- Provision of fine resolution images from the area of operations.
- Monitor maritime traffic using on-board AIS.
- Real time transfer of information to merchant mariners for the existence of suspect peripheral traffic.
- Real-time or near-real-time Tracking Capability depending on the selection of orbital parameters and the area of operation.
- Voice (audio) and video communication to a fusion centre ashore when a satellite is passing over the area (on-the-move networking capability).
- Feasibility of a two way communication implementing reachback techniques.
- Cover a vast geographical sea area and provide partial or total situational awareness based on the number of satellites to be used.
- Lifetime consideration: three to four months depending on solar weather. If increased to more than a year then this system will definitely have a strategic effect on the execution of missions.

Albeit these characteristics are highly tactical or operational, if one analyses the effects over the execution of operations, then, the results are of strategic importance. Later in this paper (see Section 3) we will mention strategic objectives of such a small low cost system to the global maritime community.

Next we present the Lambdasat and its relevance for our work.

3 The Lambdasat small satellite

Lambdasat (Λ-sat) is a Greek small satellite with a 1U dimension[2]. It was built by the Lambda Team, an international group of Greek scientists and students based in Silicon Valley (San Jose), CA, USA [15]. The Λ-sat has deployable solar arrays, which unfold to a 3U envelope for increased power. The Λ-sat will demonstrate the following Scientific, Commercial, Technology and Educational mission objectives [15]:

- (Scientific) First of-its kind space qualification of the nanotechnology material "Graphene" and its direct exposure to solar radiation and extreme space environments.
- (Commercial) Flight demonstration of a communications platform that monitors, with real-time positioning, Hellenic merchant ships for maritime security. It aims to mitigate risk to Hellenic ships and their crews from piracies at sea.
- (Technology) Space qualification of innovative advanced three-fault tolerant spacecraft hardware
- (Educational) Address Science Technology Engineering and Math (STEM) educational objectives

The Λ-sat was launched on board of Cygnus CRS-2 to the International Space Station to be deployed from the Japanese airlock and was deployed on 4 March 2015.

Figure 2 presents an illustration of the Λ-sat (from [15]).

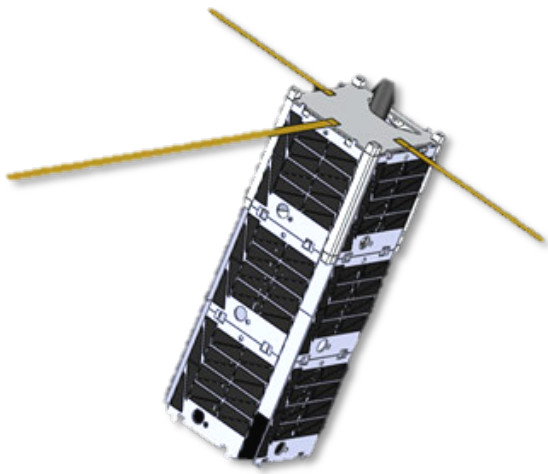


Figure 2 - Lambdasat picosatellite (Courtesy Lambda Team)

Λ-sat carries several technologies to assist a variety of experiments, including:

- Equipment to measure the radiation effects on graphene material in real environment in Low Earth Orbit (LEO) courtesy of Columbia University [15].
- Experimental AIS (Automatic Identification System) receiver for tracking all the vessels inside its footprint around the globe.
- For communications, it has an Iridium Short Burst Data (SBD) modem that makes use of the Iridium constellation.
- In addition, it has one UHF transmitter and one UHF receiver that will supplement the satellite communications uplinks and downlinks.

The above mentioned electronics are integrated and operated by one power system and a main computer that have been designed and built for Λ-sat.

[2] 1U (one unit) corresponds to a standard 10x10x10cm cube.

The Λ-sat technical specifications are the following:

- **Orbital characteristics**:
  - Perigee 420 km (260 mi)
  - Apogee 426 km (265 mi)
  - Orbital inclination 51.65 degrees
  - Average speed 7.66 km/sec (27,600 km/h; 17,100 mph)
  - Orbital period 92.89 minutes
  - Orbital decay 2 km/month
- **Footprint** : 800 to 1000 km
- **Passes per day**: 3 to 5 times from same point
- **Time per pass**: 1 to 8 minutes depending on inclination
- **Period**: ~ 1.5 hours
- **Lifetime**: 9 to 12 months
- **Weight**: 1 Kg
- **Communications**:
  - Downlink Frequency: 437.462 MHz 1200 bps AFSK (UHF)
  - Uplink Frequency: 434 MHz 9600 bps GFSK (UHF)
  - AIS Receiver: 161.975 MHz VHF
  - Transmission Power: 0 to 1Watt (adjustable)

  Λ-sat uses the Stensat Radio Beacon, a small FM transmitter capable of generating AX.25 unnumbered Information (UI) packets at 1200 bps AFSK and 9600 bps FSK. The 9600 bps FSK signal is compatible with G3RUH modulation.

The University of the Aegean (UoA) is the designer for space maritime security operations and risk assessment methods / analysis through the Λ-sat [15]. Specifically, the strategic and operational objectives of the satellite with respect to maritime security are as follows:

Strategic Objectives

- Evaluate the use of nano and pico satellites to maritime security
- Provide deterrence to maritime terrorism in the global commons
- Provide Merchant Mariners with low cost near real time operational support during their transiting through high risk areas.

Operational Objectives

- Experiment AIS implementation to maritime security operations
- Support counter piracy – armed robbery operations through various methods of communication to merchant mariners (e.g., text, audio and video)
- Create Merchant Marine Risk Assessment Indexes - Methodologies to effectively counter piracy – armed robbery through space micro assets (such as Lambdasat)
- Operational support to armed guards on board the merchant vessel on a near real time frame
- Conduct feasibility studies and implement a cost benefit analysis for inserting PicoSats in the maritime security arena
- Utilise a ground station in Greece (at UoA facilities)
- Conduct Studies for Measures of Effectiveness (MoEs), Measures of Performance (MoPs) and Risk Assessment
- Exchange data from the satellite ground stations to Merchant vessels transiting through the High Risk Area

- Measure the operational effectiveness to support counter piracy – armed robbery in high risk areas (post orbit)
- Measure Risk Assessment factors change with the use of picosats for Merchant Mariners transiting high risk areas (post orbit)

Λ-sat is capable to assist maritime security operations through the use of space AIS system as well as the exchange of messages within the available footprint of the satellite. As part of our work, we will use to Λ-sat for the transmission and dissemination of information globally between fusion centres ashore (monitoring piracy activity and assessing risks) and ships.

Next, we describe our experimentation work using Λ-sat.

4 Maritime Security Experiments with Lambdasat

We plan a set of experiments resorting to capabilities provided by the Λ-sat to demonstrate the PicoSats capabilities to support maritime security operations. More specifically, we will cover the following operational capabilities (see full list in Section 2):

- Monitor maritime traffic using on-board AIS.
- Real time transfer of information to merchant mariners for the existence of suspect peripheral traffic.
- Voice (audio) and video communication to a fusion centre ashore for the specified window that a satellite is passing on top of the area (on-the-move networking capability).
- Feasibility of a two way communication implementing reach back techniques.
- Cover a vast geographical sea area and provide partial situational awareness.
- Lifetime consideration: three to four months.

We will use two ground stations for the exchange of messages with Λ-sat: the first is located at the UoA (Athens, Greece) and the second at the San Jose State University (SJSU) (USA). A high-level view of the system is depicted in Figure 3.

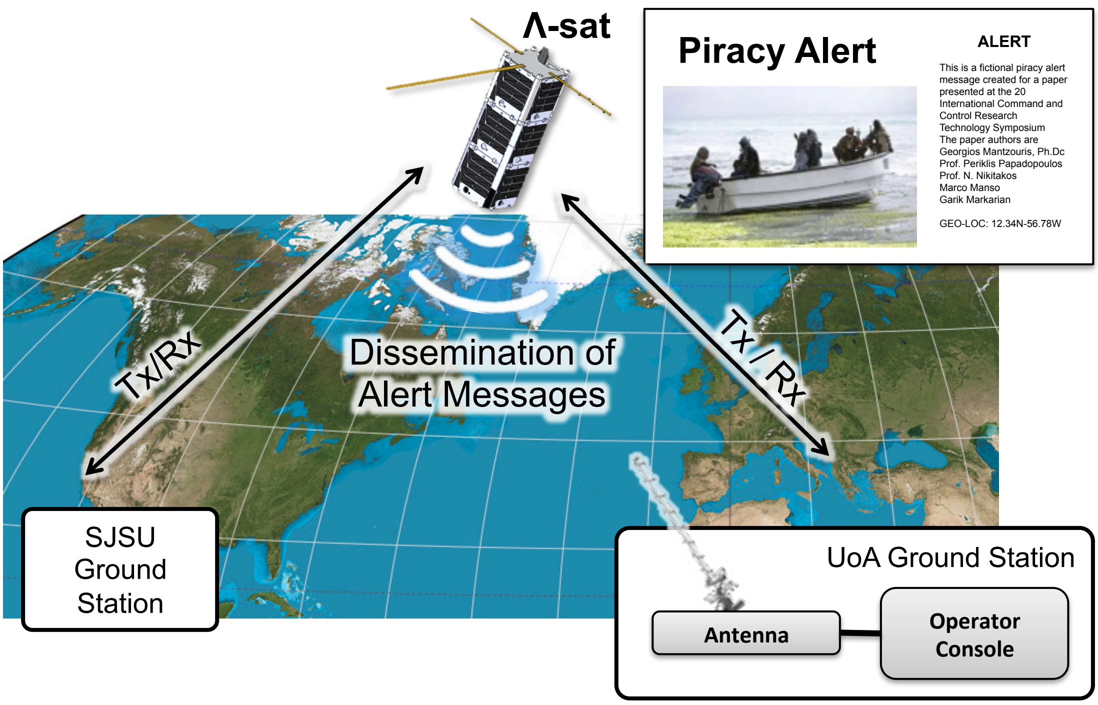
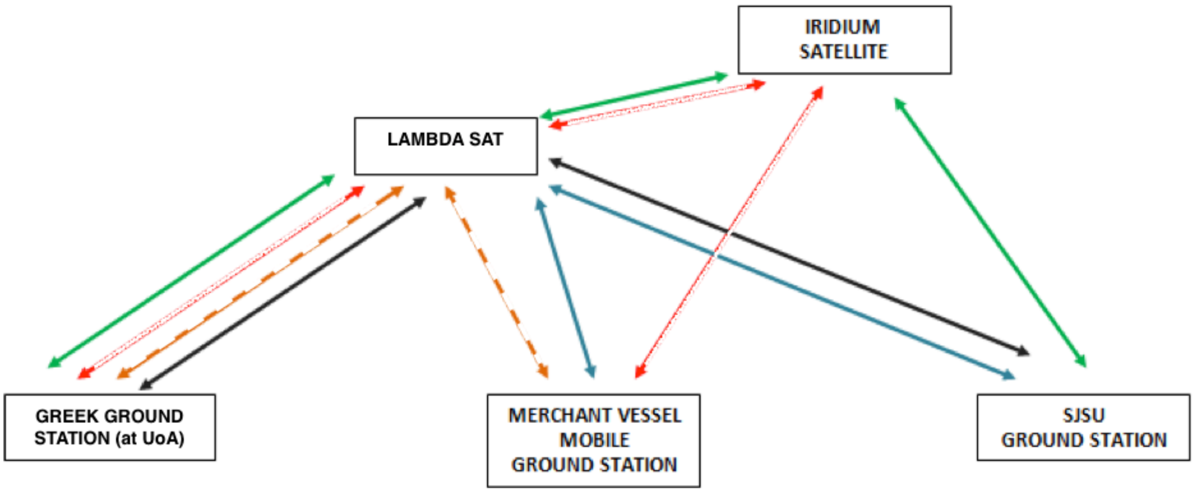


Figure 3 - High-level View of use of the Lambdasat for Maritime Security Experiments

The experiments comprise the following main elements:

- **Lambdasat** described in (Section 3).
- **Greek Ground Station** at UoA that will be used to exchange (upload and download) maritime security related messages with the Lambdasat (e.g., piracy alerts to be disseminated to vessels).
- **San Jose State University Ground Station** that will be used to exchange information between the Lambdasat and the Iridium satellites.
- **Merchant Vessels** operating at the Mediterranean Sea that will be able to receive messages from Lambdasat (e.g., piracy alerts) and send alerts (e.g., help request) to the Lambdasat (that will be relayed to the Greek and SJSU ground stations).
- **Iridium satellites** that will be used to relay messages from/to Lambdasat when necessary.

The information flows between the above main elements are depicted in Figure 4.



No	COLOR CODE	Communication Path
1.		GREEK MOBILE – LAMDA SAT – MERCHANT VESSEL
2.		GREEK MOBILE – LAMDA SAT – IRIDIUM SATELLITE – SJSU GROUND
3.		GREEK MOBILE – LAMDA SAT – IRIDIUM SATELLITE – MERCHANT VESSEL
4.		SJSU GROUND – LAMDA SAT – MERCHANT VESSEL
5.		GREEK MOBILE – LAMDA SAT – SJSU GROUND

Figure 4- Communications Flow

Both the Greek and SJSU ground stations can upload messages to and receive messages from Λ-sat. Piracy status and alert messages will be uploaded to the Λ-sat and the Λ-sat will disseminate the messages to any receiver below (on land or on sea).

The SJSU ground station has the additional capability to communicate with Iridium satellites, thus being able to receive (and send) messages relayed by the Λ-sat Iridium modem.

Merchant vessels, equipped with a mobile ground station, will be able to receive messages from the Λ-sat (e.g., piracy alerts) and will be able to send messages to the Λ-sat (e.g., help request).

The above setting demonstrates the PicoSat's capability to interconnect distant actors - located in Greece, USA and vessels over the Mediterranean Sea - and the generation of situational awareness (piracy risk assessment) among them.

UoA Ground Station

To conduct these experiments we have built a ground station located at the University of Aegean, Athens, capable to receive/send messages from/to Λ-sat (and PicoSats in general).

The ground station has been implemented using the equipment listed in Table 1. The total cost of the Ground station was below 5K€ including set up and computers.

No	Equipment	Cost (€)
1.	Kenwood TS-2000 - HF/VHF/UHF All Mode Transceiver	1835
2.	Power Supply	169
3.	Cross Yagi multiple (42 elements) antenna UHF 70cm (430 - 440MHz)	300
4.	Phasing Harness – cross polarization	180
5.	30 meters ECOFLEX 15 low loss coaxial cable	100
6.	N type connectors	50
7.	YAESU G5500 rotor with Az – El	800
8.	Wire for Rotor cabling	30
9.	Support mast for the antenna	100
10.	Tracking satellite software	50
11.	Rotor Software Interface	150

Table 1 - Equipment used for the implementation of the Ground Station

In Figure 5 we present photos of the ground station. The bottom left part of the figure show real time tracking of a PicoSat. The bottom right part shows the UHF Cross Yagi antenna (18.9 dB) with the auto Az-El rotor and harness.

Figure 5 - Ground Station at the University of the Aegean

The ground station also includes a VHF antenna for communication with picosats that are sending and receiving VHF messages, like AisSat1 and 2 via AIS messages configuration. The UoA ground station is capable of receiving information from those satellites and it is under the scope of our research to receive and analyse messages from satellites using VHF frequencies and support maritime security operations.

Both antennas are depicted in the bottom right photo of Figure 5. Finally it is worth mentioning that a mast preamplifier is going to be mounted to the whole communication system in order to increase the effectiveness of the signal reception by approximately 34 dB. In this way, even weak signals in the presence of noise can be received and decoded in the Ground Station.

5 Next steps

Our experiments will be conducted in the mid of 2015, where we will demonstrate the PicoSat ability to exchange maritime security related messages between distant ground stations (taking role of fusion centres ashore) and vessels at the Mediterranean Sea to measure the operational effectiveness to support e.g., counter piracy in high risk areas.

If successful, our results will demonstrate that a relatively low-cost real-time infrastructure can be built and combined with existing means to obtain effective intelligence schemes, create shared situational awareness and increase mission efficiency, that is, improve maritime security and C2 capabilities.

In addition to a better understanding of the role and importance of PicoSats in support of maritime operations, the results of our analysis will be used to prepare a second generation of a PicoSat constellation that will be more sophisticated and provide full tactical support to maritime security applications. Integration with existing earth observation services, such as the European COPERNICUS [16], which provides products resulting from its marine environment monitoring service free of charge to registered users, will be also explored.

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