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GomX-1: A Nano-satellite Mission to Demonstrate Improved Situational Awareness for Air Traffic Control

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ABSTRACT

Since the launch of the first Cubesats in 2003 significant resources are now being invested worldwide in developing technologies and capabilities that allows nano-satellites to perform more meaningful missions in space. In November 2012 GomSpace will launch the GomX-1 nano-satellite, which features a payload capable of tracking from space trans-oceanic flights by reception of the Automatic Dependent Surveillance-Broadcast (ADS-B) signal emitted by the aircraft. The future potential uses for space based ADS-B are many and range from the optimization of air space procedures based on statistical data from a few nano-satellites to an operational real-time system for operational air traffic management. The GomX-1 mission will be the first ADS-B demonstration from space.

INTRODUCTION

Since the launch of the first cubesats in 2003 significant resources are now being invested worldwide in developing technologies and capabilities that allows nano-satellites to perform more meaningful functions in space other than being a great educational resource for young engineers. On this basis we are now starting to see very interesting science and technology demonstration missions based on nano-satellite platforms being launched.

The growth in the number and maturity of nano-satellite projects is well documented[1] and a recent forecast prepared by SpaceWorks Commercial[2] show evidence that the number of missions will continue to grow rapidly.

In the coming years we expect that commercial applications of nano-satellites will follow where niches can be found that can be well served by nano-satellites, but are too expensive to address with traditional satellite systems.

In November 2012 GomSpace will launch the GomX-1 nano-satellite, which features a payload capable of tracking from space trans-oceanic flights by reception of the Automatic Dependent Surveillance-Broadcast (ADS-B) signal emitted by the aircraft. The ADS-B signal is in use today for air traffic control in areas covered by terrestrial based receivers, but is currently not of use over the oceans due to its limited range. The GomX-1 satellite with its sensitive Software Defined Radio (SDR) payload will be the first demonstration that the ADS-B signals can be received from space and utilized to provide increased global situational awareness for key stakeholders in air traffic control.

The future potential uses for space based ADS-B are many and range from the optimization of air space procedures based on statistical data from a few nano-satellites to an operational real-time system (utilizing geo-stationary satellites for data relay) of 40-70 active nano-satellites. One application of a fully deployed constellation could be the reduction of required separation of trans-oceanic flight allowing up to, in theory, 16 times as many aircraft on the most fuel-efficient routes.

The GomX-1 satellite is essentially a two unit Cubesat built from commercially available standard subsystems and with a custom designed payload consisting of a deployable helical antenna, a fine-tuned and extremely sensitive radio front-end and an in-space reconfigurable FPGA hosting dedicated algorithms for decoding ADS-B signals in space.

The paper describes the rationale for a global air traffic surveillance capability based on space based ADS-B monitoring and its potential applications and expected impacts on the economy and passenger safety. Further, the GomX-1 nano-satellite platform is described together with an overview the design of the dedicated payload and the approach for system evaluation.

SPACE BASED ADS-B

The Automatic Dependent Surveillance – Broadcast (ADS-B) signal consists of a periodically transmitted set of data packages, which are broadcasted using the aircrafts Mode-S transponder at 1090 MHz, and which provides information key data such as aircraft ID, position, altitude and intent.

The signal is received by terrestrial ground stations and used in operational air traffic control in the same manner as information from air surveillance radars; in fact, traditional radars are now being out phased and replaced with ADS-B receivers, which provide a reduced maintenance cost to operators.

The ADS-B system is today standard equipment on new commercial aircraft and it is estimated that 70% of the current fleet is equipped. Recent decisions taken by the various aviation authorities such as EUROCONTROL and FAA means that ADS-B will become mandatory equipment on all high performance aircraft from 2015 and 2020, respectively.

The ADS-B system is designed to provide a range of 80 NM meaning e.g. that oceanic coverage is very limited and it is also expensive to cover large land areas with poor infrastructure using terrestrial receiving stations.

Nano-satellite Space Based ADS-B Concepts

Space Based ADS-B is the idea to place sensitive receivers on board satellite in (low earth) orbit, which can receive ADS-B packages and relay these to the relevant stakeholders.

We are working on two concepts for utilizing nano-satellites to provide space based ADS-B service; See Figure 1.

Off-line data: A small fleet of satellites (3-6) sampling the airspaces and providing information for mainly statistical processing off-line. The data is downlinked with delay when passing by one or more ground stations.

On-line data: A larger fleet (40-70) of satellites is connected to the air traffic control infrastructure via geostationary data relay satellites in near real-time. This could be realized using e.g. the SB-SAT for the Inmarsat BGAN network, which is in development[3].

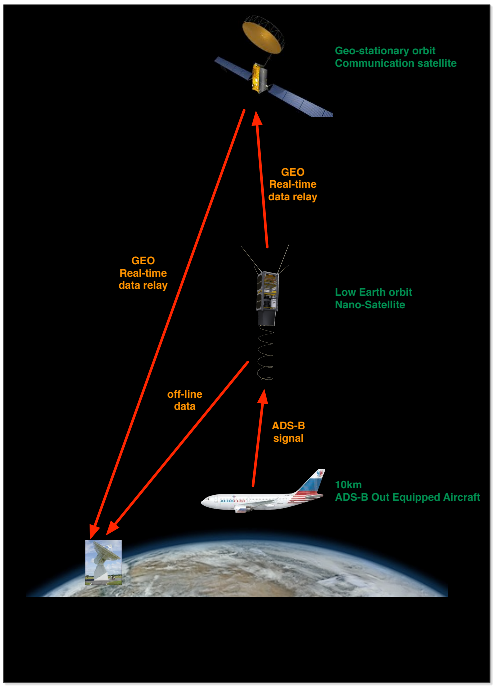

Figure 1: Space Based ADS-B Concepts

Business Case

While certainly an interesting idea, Space Based ADS-B needs to bring economical benefits to the table to be viable and worthy of investment.

For the off-line concept, which is only a modest investment, value can be generated by analyzing past data providing proof-of-flight information as sampled by the satellites. This information can be used for e.g.:

- Improvement in en-route charging calculations increasing yield 1-2% over charges calculated from posted flight plans.
- Second source on plane routes and prior locations as an input to national security intelligence gathering.

- Improvement of oceanic air space operating procedures based on usage patterns documented by Space Based ADS-B to increase air space efficiency.

Clearly, as the number of satellites in the constellation increases, the better a service can be provided. For the on-line concept, requiring significant investment, offering global full-time situational awareness of the air traffic situation, additional uses cases are possible:

- Application to search and rescue situations allowing the position of air crafts in distress to be reported immediately, unlike e.g. the situation with the crashed Air France flight AF447 in 2009 for which the crash position was not known – in fact it was only when the air craft did not show up in Paris much later that air traffic controller became worried.

- Operational air traffic control in which air traffic controller directly manages flights based on Space Based ADS-B in areas that are today not covered by radar or ADS-B. This will allow significant reduction in the inter air craft spacing and provides benefits in terms of reduced fuel consumption (and emissions), reduced flight time and greater air space capacity. To be of full value, however, a robust radio link must be available to the cockpit for the air traffic controller to interact with the pilot.

We estimate that the potential benefits to the air traffic sector from a fully deployed Space Based ADS-B infrastructure with global coverage are on the order of one Billion US dollars, with a large share of that value potentially being generated over the North-Atlantic area.

Nav Canada who are a strong proponent of ADS-B technology are investing heavily in increasing the coverage of their terrestrial ADS-B network in the Hudson Bay area and in south Greenland – an area that sees a lot of the trans-Atlantic traffic to and from Europe. They estimate that their investments in this geographical area will bring about fuel cost saving of $187 million USD annually[4].

Wider Interest

Certainly given the potential of Space Based ADS-B, the topic has generated significant interest among key stakeholders in the air traffic management industry and a number of studies have been initiated.

The perhaps most interesting announcement has been by Iridium who are looking to bring Space Based ADS-B on to their Iridium NEXT constellation as hosted payloads[5] – to be operational in 2017. While such a move makes a lot of sense given the already planned constellation, the schedule is not leaving much room for risk mitigation concerning the unproven technology in space and as of this writing it is still unclear if in fact the Iridium NEXT constellation will feature space based ADS-B.

GomX-1 mission

The GomX-1 mission to be launched in November 2012 will be the first to fly an ADS-B receiver in space and will therefore play a major role in risk mitigation (technology and businesswise) for the whole application area.

The mission is experimental in nature with the following mission objectives relating to ADS-B:

- To be the first demonstration of space based ADS-B.

- To validate and refine the established link and signal environment models, including characterization of signal collision in congested air spaces.

- To characterize and optimize different algorithmic approaches for decoding received data with a low SNR.

- To perform evaluation of potential performance of space based ADS-B with relevant stakeholders in the loop.

The mission will launch on a Dnepr launch vehicle in the fall of 2012 together with a large number (20+) of small satellites sharing the launch opportunity. The orbit will be a 720km polar orbit (near SSO).

Figure 2: The Dnepr Launch Vehicle

The project is managed by GomSpace, who are in charge of launch procurement, bus design, operations & lead payload development. Aalborg University in Denmark contributes to the payload design with focus on implementation of software defined radio techniques for data decoding. Finally, DSE Airport Solutions are in charge of developing software for in-orbit performance evaluation.

GOMX-1 COTS BUS

The external configuration of the GomX-1 satellite can be seen in Figure 3 below.

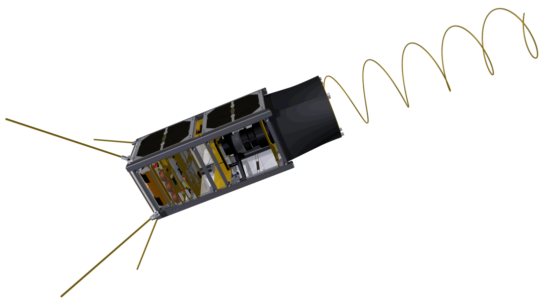

Figure 3: Mission Bus Configuration

The satellite is a 2 unit Cubesat with deployable UHF antennas for tele-commanding and telemetry, and a deployable helical antenna for reception of the ADS-B signal.

The payload antenna will be Nadir pointing at all times, with pointing being handled by the autonomous 3-axis attitude control systems that is based on magnetic actuation and attitude estimation using an Unscented Kalman Filter with inputs from sun-sensors, a magnetometer, and rate-gyros.

The platform elements of the bus are taken from GomSpace's standard portfolio of products for Cubesat and Nano-sats. See Figure 4 for an overview of the GomSpace standard integrated stack. The camera is an additional payload flown on the mission with no specific relevance to the main mission.

At first glance the top-level bus architecture is not that different to that of AAU-Cubesat launched in 2003[6], but a lot has been learned since then and these valuable lessons learned from the early Cubesat days have been vigorously integrated into the subsystem and system design.

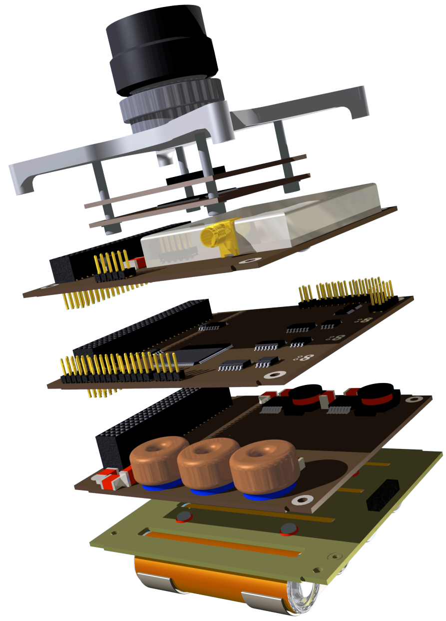

Figure 4: Standard Integrated stack

The Cubesat Space Protocol

A key distinguishing feature of the architecture is the use of the Cubesat Space Protocol (CSP) – a service oriented network protocol implemented on all the subsystems and extending transparently across the space link to the ground segment.

CSP is developed in collaboration between Aalborg University and GomSpace and is available as open source[7].

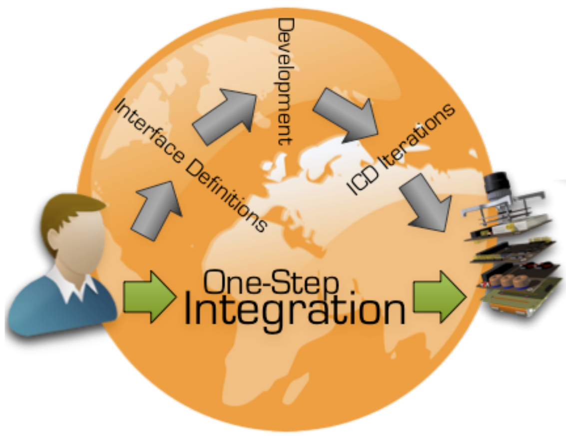

Figure 5: Integration with CSP

This "mission internet" provided by CSP, and the design philosophy behind it, makes it very easy to integrate and test systems – we call the process "One-Step Integration" and offers much more flexibility than a typical star-topology with the On-board computer in the middle as the facilitator of all communication.

With CSP all subsystems are autonomous nodes that can access and command resources available on the network. Further "virtual subsystems" exists such as e.g. the system wide logging service that is a software task on the on-board computer with its own network address.

ADS-B RECEIVER PAYLOAD

A top-level block diagram of the ADS-B receiver payload is provided in Figure 6 below.

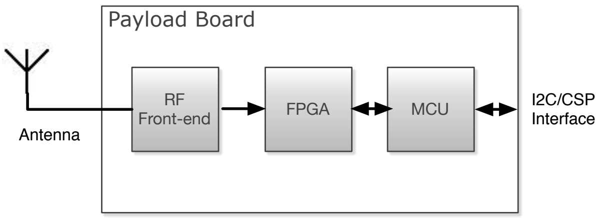

Figure 6: Payload block diagram

The antenna is the deployable helical antenna depicted on Figure 3, which provides 10 dB of gain at 1090 MHz.

The RF front-end provides amplification and initial down-conversion of the signal. To compensate for the increased path-loss due to the receiver location in space in contrast to the 80 NM nominal range of the system, the RF Front End has carefully been designed to provide the required sensitivity to be able to decode the signal.

The FPGA samples the down-converted signals and run the decoding algorithms. The FPGA can be reconfigured with new bit-code during the mission and this feature will be used to improve operational performance of the payload during the mission based on the feedback gained from operating it in space.

The FPGA transfers decoded packages to the Micro-controller unit that stores the data in a (in memory) database that can be queried over the CSP network providing wide opportunities to extract ADS-B data and meta-data on system performance.

ADS-B Signal Structure

The ADS-B message consists of a preamble and a data block. The preamble makes it possible to synchronize the local clock to the ADS-B message, since it is received non-coherently. The preamble is 8 us (micro second) long and consists of four pulses at specific times. The preamble is followed by the data block, which consists of 112 bits. The data block contains information about the aircraft like the unique aircraft ID, call sign, position, velocity etc. In Figure 7 the form of a ADS-B message is shown. It is seen that each bit in the data block is 1 us long giving a symbol rate of 1 MHz.

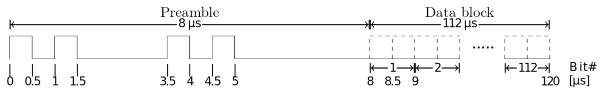

Figure 7: ADS-B Signal Structure

The ADS-B message is binary pulse position modulated (BPPM) onto a carrier wave, which has a frequency of 1090 MHz. The carrier frequency is in the L-band, which is used for aeronautical radio navigation and is allowed to deviate with +/- 1 MHz.

With BPPM there exists two symbols "1" and "0". With BPPM "1'" is defined as the transition from high to low, and "0" is defined as the transition from low to high. In Figure 8 (A) the two symbol waveforms are illustrated and in Figure 8 (B) an example of a short BPPM sequence is given. Because there are only two symbols in BPPM the symbol rate is equal to the bit rate. When transmitting the message the BPPM signal is multiplied with the carrier wave, this way of transmitting is also called "on-off keying" where the carrier wave is turned on or off depending on the symbol.

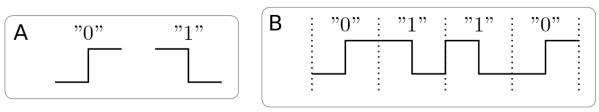

Figure 8: BPPM Sequences

Decoder Example

Figure 9 illustrates one of the decoder architectures that have been tested in the project, namely the correlation-based one, where both the synchronization and decoding rely on (low complexity) correlations techniques.

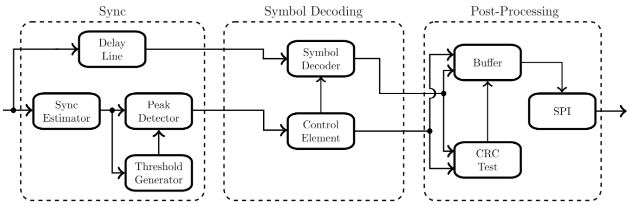

Figure 9: Example Decoder Architecture

Figure 10 shows the maximum and minimum altitude observed in distance bins of 10 km for a set of receivers evaluated against each other; BSDA is the architecture presented before (in two variants) vs. two commercially available products (commercial 1 and commercial 2).

The black line indicates the distance to the horizon seen from the antenna. As can be seen the proposed receiver has a higher sensitivity than the ones it is compared against.

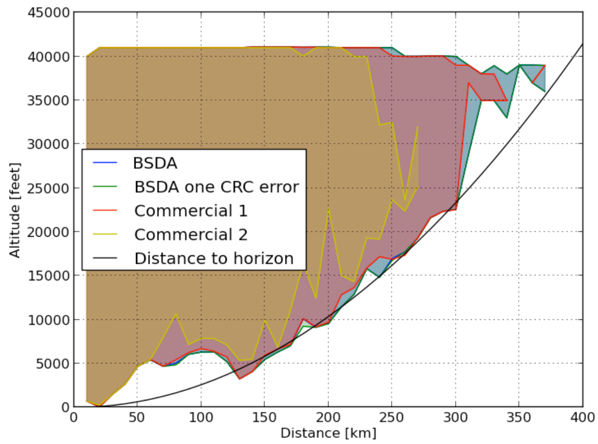

Figure 10: Example Performance Evaluation

The presented test-setup is a test case for ground based comparative testing of decoding performance and should and the range is not indicative of the reception range in space with the specialized antenna and front-end.

Sensitivity measurements of the antenna and front-end systems have verified adequate performance for space based ADS-B reception.

OPERATIONAL EVALUATION

Data will be downlinked to the primary ground station in Denmark on every pass of the satellite. In order to evaluate the performance of Space Based ADS-B data, it will be systematically correlated with information obtained from ground based radars and ADS-B receiving stations bordering the north-Atlantic oceanic area.

DSE Airport Solutions will perform this correlation in the existing SERIS tool, which is a product for archiving, visualizing and processing flight data from multiple data sources.

SERIS has been used within some EUROCONTROL countries for the past 10 years for en-route charging.

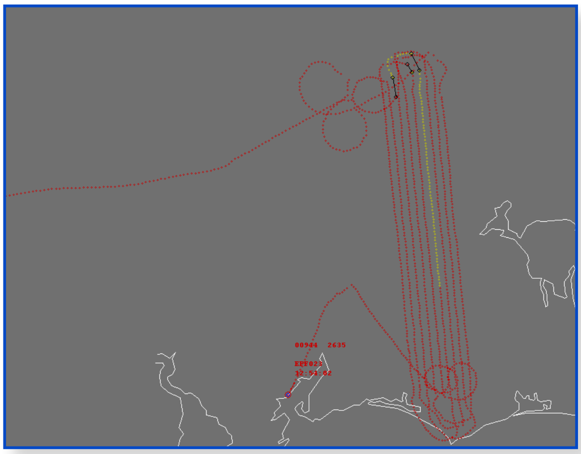

Figure 11: Example trajectory Analysis in SERIS for a search-and-rescue operation

SERIS has been extended with functions explicitly to report the quality of service provided by Space Based ADS-B compared to other sources and to visualize flights path as reported by Space Based ADS-B vs. other sources.

One of the key functions of SERIS is the ability to batch process all available data for a given geographic region and calculate the en-route charges due to the relevant air service provider. By conducting this analysis with and without the Space Based ADS-B data source enabled, the economic value for improving en-route charging yield can be evaluated very accurately as part of the GomX-1 mission.

Stakeholders in the air traffic control community are invited to review the results and provide feedback on the potential adoption of Space Based ADS-B as a source of flight information to be used operationally in the future.

CONCLUSION

The GomX-1 mission will be the first demonstration of Space Based ADS-B an open up an exciting new application area for small satellites.

The project is a clear example of how the innovation brought about by the "attack of the Cubesats" is starting to provide results other than education and with perspective of providing services that are relevant outside the space community.

Acknowledgments

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