Space Situational Awareness using Market Based Agents

Christopher J. Sullivan, Edward Pier, Scott Gregory, Michael Bush
Oceanit, Oceanit Center, 828 Fort St. Mall, Suite 600, Honolulu, HI 96813

ABSTRACT

Space surveillance for the DoD is not limited to the Space Surveillance Network (SSN). Other DoD-owned assets have some existing capabilities for tasking but have no systematic way to work collaboratively with the SSN. These are run by diverse organizations including the Services, other defense and intelligence agencies and national laboratories. Beyond these organizations, academic and commercial entities have systems that possess SSA capability. Most all of these assets have some level of connectivity, security, and potential autonomy. Exploiting them in a mutually beneficial structure could provide a more comprehensive, efficient and cost effective solution for SSA. The collection of all potential assets, providers and consumers of SSA data comprises a market which is functionally illiquid. The development of a dynamic marketplace for SSA data could enable would-be providers the opportunity to sell data to SSA consumers for monetary or incentive based compensation. A well-conceived market architecture could drive down SSA data costs through increased supply and improve efficiency through increased competition. Oceanit will investigate market and market-agent architectures, protocols, standards, and incentives toward producing high-volume/low-cost SSA.

1. INTRODUCTION

Current Space Situational Awareness (SSA) is performed through pre-planned observations and rigid tasking with catalog maintenance as the focus. Not only is a person-in-the-loop required to examine objects that display unusual behaviors, resident space objects (RSOs) can be lost due to the interval between updates for any particular RSO's ephemeris. In addition, bad weather at telescope sites can prevent timely tracking of targets, as some are visible only from certain sites at certain times. SSA, as it is currently practiced, is geographically limited by borders and issues with dissemination of sensitive information. The Space Surveillance Telescope (SST) and the Space-based Space Surveillance (SBSS) satellite will be operating in the near future, significantly enhancing SSA. Both systems are expensive, being designed for specific missions and while enhancing current SSA will not achieve persistent and responsive observations. Space surveillance for the DoD is not limited to the Space Surveillance Network (SSN). Other DoD-owned assets have some existing capabilities for tasking but have no systematic way to work collaboratively with the SSN. These are run by diverse organizations including the Services, other defense and intelligence agencies and national laboratories. Beyond this, academic and commercial entities have systems that possess SSA capability. Most all of these assets have some level of connectivity, security, and potential autonomy; however exploiting them in a mutually beneficial structure would provide a more comprehensive, efficient and cost effective solution for SSA.

2. THE SSA MARKET

To satisfy SSA requirements, a scenario unconstrained by cost could be for the US to own and operate an extensive real-time network with a very large number of SSA sensors. The network could observe every orbital altitude in all areas of space without interruption and continuously track all known and unknown space objects. Coupled with this near-infinite number of sensors would be real-time data reduction and instantaneous distribution to end users. Unfortunately we are firmly rooted in fiscally constrained reality and this utopian scenario is beyond our reach.

Current architectures for SSA data collection have been constrained by the high cost and long lead times to acquire complex, technically advanced Government-owned systems and by the current limitations at the processing centers for SSA data that result in processing bottlenecks, making it virtually useless to collect additional data. At the same time, the number and complexity of on-orbit assets, the critical contributions these assets offer to tactical and strategic military operations, and the increasing number of sophisticated threats to these assets has made it necessary to pursue strategies that require significantly more frequent revisit rates, i.e., significantly more data. Acquisition programs are underway to remove the processing bottlenecks. Once these programs achieve their goals it will be not only useful but necessary to have a viable strategy to obtain massive amounts of SSA data at the lowest possible cost. Consider the information in Figure 1~~Figure 3~~ that was presented as part of a DARPA briefing titled "Space Domain Awareness (SDA)" at the 2011 Advanced Maui Optical and Space Surveillance (AMOS) conference.

DARPA Space Situational Awareness – in data space

	Current	Programmed	Threshold	Ideal
Number of Objects Tracked	20k	50-100k	100-500k	100-500k
Size Object	> 10 cm	> 5 cm	> 1 cm	> 1 cm
Orbital Vector Accuracy	~ 5 km	~1 km	250 m	10 m
Update Frequency (Active/Debris)	3 / 10 days	1.4 / 10 days	1.4 days	0.5 days
Collision Avoidance Warnings / Satellite	~10/year	~20-50/year	~1/year	~0.1/year
# Objects Characterized	1-10	1-10	10-100	100+
Threats Identified	No	No	Yes	Real-time
Change Detection	7-30 days	7-30 days	1-7 days	< 1 day
Dynamic Sensor Tasking	No	No	Yes	Yes
Rapid Object Characterization	No	No	Yes	Real-time
Positive Object Identification	Manual	Manual	Automated	Real-time
Number of Sensors	29	29	50-100	100-10,000
GB/Year of raw *usable* data	~1.5	~4.3	~9.8	~17.3

Threshold – Maintain awareness to identify potential threats to space capabilities.
Ideal – Provide real-time awareness of all threats to space capabilities.

12/29/2011 Distribution Statement "A" (Approved for Public Release, Distribution Unlimited). DISTAR case 18018. 7

Figure 1~~3~~. Slide from 2011 DARPA briefing: Space Situational Awareness - in data space. [1]

To perform to the level indicated in the columns labeled "Threshold" and "Ideal" requires high-rate sampling from frequent observations of the ever-increasing population of orbiting objects. Currently the US derives the majority of its actionable SSA information from the raw data collected by a relatively small number of Government-owned and operated sensors that participate in the Space Surveillance Network (SSN). At the same time, there are a variety of other sensors in operation throughout the world that are capable of contributing SSA data but have no systematic way to work collectively with the SSN. The application of economic theory and game theory in particular, as proposed in SSAMBA, promises to deliver significantly more data at significantly lower cost. The expectation is based on the application of mature economic theory to resource allocation over sets of competing customers and on one of the central tenets of economic theory – given proper conditions, a competitive market will produce an optimal distribution of goods at the lowest possible cost.

Currently, there is no marketplace for space surveillance data. This blocks would-be data suppliers from offering data products to the Government that would potentially be cost-competitive with existing Government-owned sources. If a marketplace can be created, with the correct incentives, protocols and regulations, then existing and potential sources for SSA data would have a medium through which data could be offered in exchange for some type of compensation. Furthermore, market forces could be designed such that costs for data are driven down through competition with existing and even future data sources. The very existence of the market would provide stimulus for would-be participants to develop more cost-efficient data sources such that market share could be captured. Careful consideration of existing and likely future data providers and potential incentives is required to frame market dynamics in a way that encourages the end result of many low-cost data sources.

One of the key synergies we can leverage to decrease the cost of obtaining a sufficient amount of relevant SSA data is to encourage a change in the landscape of current data suppliers and drastically unbalance the current market. By leveraging well-understood economic theories and fusing them with competitive gaming theory, we can upset the status quo and make an enormous, disruptive leap in SSA.

Relative to the discussion of SSAMBA, a *market* can be considered an economic system where a relatively fixed number of data consumers exchange financial funding for a relatively fixed amount of SSA data. In the current market, the need for timely and relevant SSA data (*demand*) actually exceeds the amount of relevant data provided by the SSN (*supply*). The market is *controlled*, meaning that the price for the SSA data is limited by the allocated funding and the accessible supply is fixed. Unfortunately, this leads to unchallenged ongoing operating expenses and operating inefficiencies that have no real likelihood of being improved.

A game-changing thrust towards a *free market* could be initiated by creating a means whereby more suppliers can participate in the market, creating an imbalance in the supply of relevant SSA data. In a free market, prices for commodities, in this case SSA data, would be determined by both supply and demand. Oceanit suggests that we break the current controlled market constraints and open the market up to a theoretically unlimited number of SSA data contributors. An increasing number of contributors to the SSN creates a disproportionate supply against the demand and causes competition in the marketplace. This competition leads to lower prices and effectively reduces the cost of gaining greater SSA. Furthermore, it provides motivation for SSA data providers to become increasingly efficient to ensure their survival in this Darwinian competition. Government assets would participate in the market as well, competing against a wider market to provide SSA data.

A free-market system does not come without its flaws. In this paradigm, it is possible that some higher priority observation requests (tasking) go unfulfilled because there are better prices to be scored on lower priority tasking requests. For this reason, there is a need to optimize the otherwise free market by applying some limited form of control.

The impact on military mission capabilities of the proposed development will be substantial. Capabilities will not be limited to those of existing SSN assets, but will expand to include infrared, daytime observations and emerging capabilities from Government, institutional and commercial entities. Instead of multi-year processes to develop Air Force owned assets for acquisition of particular data sets, requests for data can be generated and delivered to the network. Here bids to deliver this information will be made and then selected, based on price, quality and time of delivery. Within the proposed paradigm, a potential value proposition exists for unclassified, foreign and commercial sites. One of the unique problems of the current Space Surveillance Network (SSN) operations mode is that classified sites are required to contribute data to the SSN. This limits SSA data collection options to U.S. military bases. Unfortunately these are generally poor observation sites and lack geographic range to cover the entirety of LEO and GEO space. The proposed alternative would encourage the most cost-effective service solutions for SSA, allowing the use of optimal sites resulting in greater sensitivity and the geographic diversity needed to truly achieve global SSA. By using unclassified sites, commercially or institutionally owned across the globe, we have access to the range, variety, and density of observations really necessary to deliver near real-time persistent custody and global coverage.

3. AGENT BASED SIMULATIONS

In order to run simulations of the proposed market, Oceanit will be utilizing Agent-Based Modeling (ABM). ABM is a bottom-up approach to simulation that models interactions between autonomous agents based on agent-specific behavioral rules. These behavioral rules will be inferred from result of Market Parameterization. ABM is a more recent trend in financial market analysis and prediction that is replacing Dynamic Stochastic General Equilibrium (DSGE) modeling approaches and has been shown to more accurately describe financial market behavior. [2]

Traditional modeling uses a global description of the behavior of a system. The complexity of such models is limited by the complexity of this description. Agent-based models, on the other hand, break systems into a number of entities that follow rules governing how they interact with their fellow agents. The complexity of these models scales with the number of agents and even extremely simple rules can result in a rich variety of behavior.

Perhaps the best known example of an agent based model is the Game of Life [3]. In this model the agents are cells arranged in a grid, which can be either "alive" or "dead". They toggle between these states according to three simple rules involving the states of their neighbors. Although this behavior is tremendously simple viewed from the perspective of a single agent, the interactions between a large number of agents gives rise to infinite complexity that has spawned over 40 years of intense study.

By the 1990s the decrease in cost and the rise in power of off-the-shelf computing equipment made it possible to apply agent-based models to real-life systems. They have been used in a broad range of fields including biology, economics, psychology, computer science, engineering, fisheries, and business management [4].

Agent-based models are a natural fit for simulating the behavior of complex markets. Each agent represents a buyer or seller of some commodity and can be programmed with a set of rules to represent not only restrictions of production and consumption, but individual trading behavior. Each participant in the market can employ different strategies for maximizing their gain, and the types of agents can evolve depending on the effectiveness of these strategies. During the past decade such models have proven more accurate than traditional simulations that apply broad economic principles [5].

4. SSA MARKET-BASED AGENTS

Four general types of agents can be immediately identified to make up part of the multi-agent system that will together affect the network: Asset Agents, Broker Agents, User Agents and Other Agents. Asset Agents represent the array of available sensors such as GEODSS, SBSS, academic, commercial, etc. The main purpose of the asset agent is to collect information. They respond to requests from user agents and work with the broker agent to negotiate the best possible price. Broker Agents make trades necessary to eliminate inefficiencies and bring the market back into an optimal equilibrium and improve global utility. Asset agents act in their own best interest. When utilizing a dynamic market that allows assets to continuously bid until the market closes could potentially create an imbalance, Broker Agents could recognize this imbalance and buy and sell tasks until the market is once again in balance. User Agents are intelligent agents that represent customers interested in data from the sensor network. User agents request information from asset agents. As deemed necessary, other agents will be developed for roles required to run an efficient and productive market.

5. SSA MARKET OF AUTONOMOUS AGENTS

A realized SSA market of autonomous agents would enable real time buying and selling of SSA data services and would potentially expand the base of SSA data service providers. Agent software running on behalf of assets will autonomously decide to buy/sell based on predetermined market signals and philosophy. This expanded group of participants could include sensor systems that can provide data at a lower cost based on lower cost sensor systems, leveraged infrastructure or other factors. Expanding the pool of data providers would encourage lower cost technologies. Buyers of data would not only include the U.S. Government, but potentially also market participants that wish to acquire different data than their own assets can provide.

6. REFERENCES

1. Blake, T., *Space Domain Awareness (SDA)*, Presentation at AMOS Conference, 2011.
2. staff." Agents of Change," *The Economist*, July 22, 2010.
3. Gardner, Martin, *Mathematical Games – The fantastic combinations of John Conway's new solitaire game "life"*. 223. pp. 120-123, 2010.
4. Niazi, Muaz; Hussain, Amir, "Agent-based Computing from Multi-agent Systems to Agent-based Models: A Visual Survey" *Scientometrics* (Springer) Vol. 89, No. 2, 479-499, 2011.
5. Kim, J.H.; Shamsuddin, A.; Lim, K.P., "Stock return predictability and the adaptive markets hypothesis: Evidence from century-long U.S. Data*", Journal of Empirical Finance*, Vol. 18, No. 5, 868-879, 2011.