LtCol Jim Shoemaker, USAF
Program Manager, Tactical Technology Office
DARPA Space Activities

Space Situational Awareness and Mission Protection

Once our access to space is ensured, the next logical question is: How do we ensure our ability to operate in space? As a context to consider operations in space, I suggest we consider freedom of navigation of the seas, because operations on the seas are conceptually very similar to operations in space.

The seas are a vast area, but as the famous naval strategist Admiral Mahan pointed out, ships from every nation naturally cluster in sea lanes of communication. Similarly, in the much larger ocean of space, satellites from every nation naturally cluster in preferred orbits: low Earth orbits (LEO) for weather and reconnaissance, middle Earth orbit (MEO) for navigation, and geosynchronous orbit (GEO) for communications.

Just as sea lanes are littered with icebergs, shipwrecks, and other hazards to navigation, these preferred orbits are littered with spent rockets, dead satellites, and thousands of other bits of debris that are hazards to space operations. Just as hazards to sea navigation can endanger US commercial and military operations, hazards on orbit, accidental or intentional, can threaten US operations in space. US National Space Policy recognizes that mastering space is as essential to national and economic security as our mastery of the seas. At the same time, any vulnerability in space could prove as essential to that same security.

So how do we provide ensured operations in space? Space situational awareness means knowing the location of every object orbiting the earth, active or inactive, big or small; and knowing why it is there, what it is doing now, and what we think it will be doing in the future. By charting and tracking all the potential hazards to navigation, space situational awareness enables the US to avoid the hazards and assures safe operations in space.

Another means for achieving ensured operations in space is space mission protection, creating a space force that is robust against attack. A space force that is robust against attack represents a stabilizing deterrent because adversaries will not threaten our space assets if they know our space force can withstand the attack. This robustness can be achieved in many ways: using satellite constellations that can be rapidly reconstituted, flexible architectures for servicing satellites on orbit, or distributing satellite functionality from one large platform onto many smaller platforms.

What are the challenges involved in space situational awareness and space mission protection, and how is DARPA addressing these challenges? I'd love to tell you that DARPA already conquered these challenges, but so far we've only scratched the surface. That's why we're interested in listening to your ideas.

First, consider space situational awareness (SSA). Right now, the United States uses a tasked based tracking strategy for keeping tabs on objects in space, which I think of as point and check. Instead of searching the entire sky, point and check means that you look only where I tell you to point, and I tell you to point only where I expect something to show up. Then you check a box to verify that something was there. How do I know where to tell you to point? I have a cheat sheet, the catalog of known space objects that's maintained by US Space Command.

Most of the time, I'm really just verifying a checklist. A few times a month something new gets launched, and my cheat sheet won't help me, so I have to worry about updating it. Even then, launches are announced so far in advance that I can devote my space surveillance network to getting a good catalog entry, and then it's back to putting Xs in the checklist.

Point and check works okay if you're concerned with a relatively small number, hundreds, of fairly large objects, which don't deviate from their normal orbits very often or very quickly, and if only a small number of new objects show up every month, namely, the way things are today. As the space environment becomes increasingly more complex and cluttered; however, point and check falls short, and the safe operation of both manned space operations and high-value satellites will be challenged.

Many of my colleagues at DARPA aren't helping the situation. Steve Walker is a spontaneous kind of guy. If he decides to launch something, he would like to be able to launch it tomorrow. Owen Brown doesn't like big satellites. He wants to break them up into itty-bitty pieces so I have dozens of to track instead of just one. Each of those itty-bitty pieces looks a lot like orbital debris, so I have to start doing a really good job of tracking all the orbital debris in addition to the satellites. And I've been working on ways to refuel satellites so they can maneuver whenever they want, which means you can say goodbye to reliable orbit predictions.

If we used our current SSA capabilities to keep track of all my friends, we'd end up with a lot of enigmas, unidentified orbiting objects, that don't match any entry in the catalog. When the stork surprises you with a little enigma, boy does it get your attention. Your new number one priority suddenly becomes trying to figure out what the heck that thing is, in addition to keeping track of everything else up there, so say goodbye to evenings out.

Since we're concentrating on catalog entries, what's worse is that we would most likely not find the vast majority of these new objects; which means you'd be adding an unknown risk of failure every time you launch. Navigating an aircraft carrier through the Straits of Hormuz would be an entirely different proposition if you knew that a coral reef could popup overnight anywhere in your path.

The only way to keep up with this exponentially increasing number of space objects is to move away from tasked-tracking and develop systems that can perform synoptic, or broad area searches. We then need to augment this synoptic search capability with exquisite characterization and continuous track, so that when we discover something new and potentially hazardous, we can tell if it's friend, foe, or foreign object debris (FOD).

The current suite of SSA sensors performs reasonably well for LEO, so DARPA is focusing on MEO and GEO. In LEO, radar is used for search, and telescopes are used for characterization, much as you would expect. Beyond LEO, the situation is reversed, because the great distances mean that reflected radar signals are weak and require long integration times, making them unsuitable for rapid search. Unlike objects in LEO, high-orbit objects are almost always illuminated by the sun, making them observable from ground-based optical systems (as long as the telescope is in the dark), which makes a telescope the preferred choice for synoptic search.

Our objective for ground-based telescopes is clear. We need the ability to search rapidly, at high orbits, for small objects that might pose a hazard, accidental or deliberate, to our own satellites. Why is this so difficult? We need a telescope with significantly greater sensitivity than our current systems to detect the increasingly smaller satellites that are being deployed. We need a telescope that can perform rapid, broad area searches to be able to react to objects that suddenly appear.

This means we need a telescope with a very large field of view, very short focal length, and a mount that produces a very short step and settle time so we don't lose time waiting for the telescope to stop vibrating every time we repoint it. The optics have to be precise enough to provide undistorted data so that processing software can keep track of the thousands of detected objects without getting them confused. All this requires major progress in developing curved focal plane arrays, which are crucial to building a compact, rapidly steer-able, wide field-of-view telescope. Once we are able to bring all these elements all together, we'll have the Space Surveillance Telescope (SST), and the capability to conduct unprecedented high sensitivity searches of the GEO belt.

Space Surveillance Telescope

Characterizing objects at GEO using optical techniques is extremely challenging, even for DARPA. Assuming perfect diffraction-limited image fidelity, an optical system would require an aperture diameter well over 100 meters. Novel techniques using many small telescopes arranged over a large area have been suggested; however, using radar is a more straightforward approach. While radar requires very high power to obtain measurable signals at GEO, for characterization purposes, long dwell times are acceptable; which means that much of the required signal strength can be accumulated through coherent integration.

Nevertheless, to achieve such exquisite characterization, radar technology must be simultaneously pushed in several areas. Transmitters must be able to generate very high power millimeter wave pulses over a very wide frequency range, requiring advances in millimeter-wave power generation, as well as power and frequency combining. The antenna must be able to focus the transmitted energy into an extremely tight beam and direct the pulses onto a very small target at extreme distances. This requires a large (40-meter class) dish antenna with a 100-micron surface tolerance and sufficient rigidity to be able to also track fast-moving LEO satellites. In addition, the low noise millimeter wave receiver must receive very faint radar echoes and separate them from always-present background noise. All this is what we're trying to achieve in the Deep View program.

Of course, no matter how good a ground-based telescope you build, there will always be times when your telescope is in daylight or under clouds, giving you gaps in your coverage. We're looking at a space-based system to augment ground-based SSA. This space-based system would fill in the gaps when the ground-based telescope is unavailable, and more importantly, enable continuous tracking of suspicious objects. Though capable of performing synoptic search, these space-based assets would focus on cued tracking and characterization of those pesky enigmas.

Space Situational Awareness and Mission Protection

This space-based gap filler could also monitor "keep-out zones" in the immediate proximity of our satellites, where intrusion would signal likely trouble ahead. We might also want to validate the concept of a host vehicle inspector, a nanosat carried by a host satellite, able to be released to inspect its host to assist in anomaly resolution, such as an incompletely deployed solar array. These are some of the ideas we're exploring on a new program called Spectator. We're not exactly sure what Spectator should be, and we welcome your input in defining the program.

Beyond DARPA's current development efforts, future SSA capabilities will also require major improvements in data processing and command and control. We must be able to collect, sort, and identify literally tens of thousands of space objects, and be able to expeditiously advise our national decision makers when we believe one of our critical space systems is at risk. Without a new strategy for data processing, we will quickly be inundated and overwhelmed by an avalanche of uninterpretable data.

Space mission protection: How can we achieve robustness against attack? One option is to distribute satellite functionality from one large satellite to a number of microsats. The distributed satellite concept of F6 provides significant robustness against attack. The distributed satellite concept would provide other advantages as well, such as graceful degradation and the ability to be easily reconstituted with Falcon launches because you'd only have to replace parts of satellites.

To realize the advantages of a distributed satellite means overcoming a new set of challenges, especially in the areas of in collaborative operations and distributed apertures. Being able to maneuver a satellite is obvious to avoiding hazards. Right now, fuel is a life limiting commodity for a satellite, so the process of deciding to maneuver is painful and filled with hand wringing and gnashing of teeth. If we could refuel the satellite, using say, Orbital Express, the decision to maneuver becomes practical. You just do it. There are a plethora of potential approaches to provide space mission protection; so many that we cannot define as clear a path as I did for SSA. We're still looking for a lot of good ideas for space mission protection, so we can winnow them down to a few great ideas.

DARPA's goal is quite simple, freedom of operations in space, to guarantee our policymakers that our space capabilities will be available anytime, all the time.