TACSAT-2: PATHFINDER FOR A CLOSE SPACE SUPPORT ASSET

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ABSTRACT

With the launch of TacSat-2, the Operationally Responsive Space (ORS) community had its first on-orbit asset and opportunity to prove or disprove the premise that small, inexpensive, and quickly constructed spacecraft could perform useful operational missions when needed and for as long as needed. All of the components of the complex TacSat-2 system had to work together to answer the basic questions, "In a crisis, can a lab-developed spacecraft and ground architecture competently perform the mission of systems that cost twenty times the price and take four times as long to develop? Moreover, can this system actually improve on the responsiveness of National Systems to a certain set of underserved Operational customers?"

Figure 1. TacSat-2

When all was said and done, TacSat-2 was a spacecraft that had to: 1) Carry thirteen tactical and scientific payloads to orbit, many of which doubled as essential, non-redundant subsystems; 2) Launch from an unproven launch base on a last minute "replacement" launch vehicle; and 3) Fulfill about 140 on-orbit mission requirements. It had tactical sensors, two unproven communication links, numerous next-generation single-string components (e.g., high-efficiency propulsion system, thin-film solar arrays, low-power versatile star camera), and autonomous software to make the system more friendly and familiar to Tactical, rather than Spacecraft Operators.

However, the mission was as much about the implementation as it was about the components. TacSat-2 was designed for and employed with a different concept of operations (CONOPS) than traditional National Operational Assets. It was designed to be the first-ever Close Space Support platform and operated in a manner more analogous to Close Air Support aircraft than to traditional spacecraft. Therefore, the primary objective of the TacSat-2 mission was to use the TacSat-2 system to identify those parts of the spacecraft, ground system, and CONOPS that make it effective and suitable for a Tactical Operator employing it as a Close Space Support asset.

The TacSat-2 story was truly a story of survival in the low-budget, high-expectation spacecraft world. The mission successes were significant and ground-breaking, but they were, almost without exception, compromised successes. Most importantly, you will see an asset that was unquestionably both effective and suitable for military operators, but only worth the investment if current responsiveness deficiencies drive leadership towards a solution where Close Space Support platforms are a pursued alternative.

This paper will present the objective positive and negative results of the TacSat-2 system's space/ground components and CONOPS and will use these results to project the complexion of an OpSat-X that could best fulfill the role of a Close Space Support platform directly employed by a front-line tactical operator to responsively return a product that meets an immediate need.

1. What is Close Space Support?

Before introducing the new concept of Close Space Support, it is helpful to familiarize ourselves with the model for this mission – Close Air Support or CAS. CAS is defined as air action by fixed or rotary winged aircraft against hostile targets that are in close proximity to friendly forces, and which requires detailed integration of each air mission with fire and movement of these forces[1].

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With the launch of TacSat-2, the Operationally Responsive Space (ORS) community had its first onorbit asset and opportunity to prove or disprove the premise that small, inexpensive, and quickly constructed spacecraft could perform useful operational missions when needed and for as long as needed. All of the components of the complex TacSat-2 system had to work together to answer the basic questions, In a crisis, can a lab-developed spacecraft and ground architecture competently perform the mission of systems that cost twenty times the price and take four times as long to develop? Moreover, can this system actually improve on the responsiveness of National Systems to a certain set of underserved Operational customers? When all was said and done, TacSat-2 was a spacecraft that had to: 1) Carry thirteen tactical and scientific payloads to orbit, many of which doubled as essential, non-redundant subsystems; 2) Launch from an unproven launch base on a last minute replacement launch vehicle; and 3) Fulfill about 140 on-orbit mission requirements. It had tactical sensors, two unproven communication links, numerous next-generation singlestring components (e.g., high-efficiency propulsion system, thin-film solar arrays, low-power versatile star camera), and autonomous software to make the system more friendly and familiar to Tactical, rather than Spacecraft Operators. However, the mission was as much about the implementation as it was about the components. TacSat-2 was designed for and employed with a different concept of operations (CONOPS) than traditional National Operational Assets. It was designed to be the first-ever Close Space Support platform and operated in a manner more analogous to Close Air Support aircraft than to traditional spacecraft. Therefore, the primary objective of the TacSat-2 mission was to use the TacSat-2 system to identify those parts of the spacecraft, ground system, and CONOPS that make it effective and suitable for a Tactical Operator employing it as a Close Space Support asset. The TacSat-2 story was truly a story of survival in the low-budget, high-expectation spacecraft world. The mission successes were significant and groundbreaking, but they were, almost without exception, compromised successes. Most importantly, you will see an asset that was unquestionably both effective and suitable for military operators, but only worth the investment if current responsiveness deficiencies drive leadership towards a solution where Close Space Support platforms are a pursued alternative. This paper will present the objective positive and negative results of the TacSat-2 systems space/ground components and CONOPS and will use these results to project the complexion of an OpSat-X that could best fulfill the role of a Close Space Support platform directly employed by a front-line tactical operator to responsively return a product that meets an immediate need.

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Figure 2. AC-130H, a close air support vehicle

The determining factor for CAS is detailed integration, not proximity, because the targets in CAS missions fall out of the events that occur during mission execution. It is this undefined and dynamic nature of CAS missions that makes it essential for the "supported" troop (i.e., the person with real-time superior situational awareness and in immediate need for support) to have direct control over the supporting asset. This is contrary to more strategic aircraft missions, such as interdiction, where the target is established well in advance of the beginning of the mission and the mission timeline is static and predictable.

Since spacecraft orbit the earth, it seems reasonable to view them as strategic assets. As a result, space assets have always been employed strategically. However, as it becomes possible to build smaller, less expensive spacecraft and we establish an in-theatre infrastructure to connect the tactical warfighter to the global information grid (GIG), it may become sensible to define a more tactical implementation of space assets. This is the implementation we call Close Space Support.

Close Space Support is a new way to employ spacecraft designed for the tactical warfighter. It is the use of a space borne asset against targets which are sufficiently near the supported force or sufficiently dynamic as to require detailed integration or coordination of the supporting action with the fire, movement, or other actions of the supported force.

2. Why use Close Space Support?

It is not straightforward to extrapolate the CAS mission to spacecraft. Spacecraft will always orbit the earth and there will always be the temptation to optimize their usage in theatres around the world. However, as developers seek to drive down the size and cost of spacecraft, they implicitly impose resource constraints on the resulting vehicles and drive down the "mission usable time". For instance, TacSat-2 class vehicles, seeking to remain below 400 kg to take advantage of inexpensive launch opportunities, can only carry a single battery and limited capability unarticulated solar arrays. This constraint forces them to spend significant time in an orientation where their arrays are tracking the sun – an orientation incompatible with imaging operations. Additionally, due to the mass and resulting power constraints, a TacSat-2 class vehicle will carry a single tactical sensor to orbit with limited aperture. For TacSat-2's visible imager to be effective, the spacecraft had to be passing overhead the target, within a twenty degree slant angle, during daylight hours. Therefore, while the spacecraft always remains in orbit, the amount of time that it is in orbit and able to perform its primary mission function is severely limited.

However, these constraints, rather than rendering the vehicle ineffective, can be seen as driving it to be effective for a specific kind of customer in a specific kind of mission. If you restrict its employment to a single tactical theatre, you can perform maintenance (e.g., battery charging) activities during other parts of the orbit and tailor the orbit and mission profile to provide maximum useable time over that target tactical theatre. In this way, you can retain the benefits of a more capable system, as long as you only exploit those benefits sparingly.

It helps to think of this type of a "tactical" spacecraft as a high-altitude Unmanned Aerial Vehicle (UAV), particularly when extrapolating its use to Close Space Support missions. Only recently has the DoD began to entertain the use of UAVs to perform missions that require in depth situational awareness and detailed interaction with the on-site tactical warfighter. Additionally, the trend is for the tactical warfighter to directly command less complex UAVs in less complex missions to eliminate the time lag and remove the uncertainty associated with a third-person controlling agency. Why have we chosen to make this giant leap?

First, and most importantly, UAVs elimininate the risk of losing a pilot to enemy action. Second, UAV and sensor technology has improved sufficiently to allow them to perform their missions at higher altitude than in the past, making them less vulnerable to enemy action. Finally, long-haul communication bandwidth has increased sufficiently that remote real-time situational awareness can support the dynamic activities associated with CAS missions within acceptable risk levels to the ground warfighter. Therefore, while we have not yet achieved the ability to remotely execute CAS missions with the same effectiveness as we could with our traditional implementation, we have achieved a capability that is sufficient for many CAS missions with acceptably increased risk to the ground troops and significantly decreased risk to the airborne personnel (if any) and assets.

A space vehicle provides several advantages over a high altitude aerial vehicle. Unlike aerial vehicles, space vehicles have no airspace restrictions and are not

vulnerable to ground attacks. A single space vehicle can collect data over much larger area than a high altitude aerial vehicle. It is also more difficult for an adversary to know they are being spied upon using a space vehicle than a ground vehicle.

As an illustration of how Close Space Support could have affected the outcome of an actual operation, consider the highly documented extraction of US troops from Mogadishu, Somalia in 1993. This operation found US troops severely undermanned in the middle of the densely populated Somali capital city of Mogadishu. Their urban surrounding implied restricted long-range vision and limited situational awareness, particularly as it applied to the whereabouts of multiple bands of armed mobs roaming the streets. Moreover, the skies above the city were not safe for available airborne assets, so they could not gain situational awareness sufficient for a safe egress using their normal means.

These troops needed two things: 1) An understanding of all the routes from their current location to the target "safe" location; and 2) Sufficient situational awareness to know which route would give them the best chance of reaching their "safe" location safely. Projecting this scenario to today's capabilities, a commercially available GPS receiver with mapping software overlay could easily fulfill the requirements for need #1. GPS, therefore, along with satellite communications, are probably the most successful implementations of spacecraft in Close Support Roles to date.

However, while GPS could identify the full set of routes to a "safe" location, the situation was very dynamic, changing on tactical timelines, so the lowest risk route to that "safe" location required additional information. Now consider another step forward in time to where the capability exists for a GPS satellite to communicate with a tactical imaging satellite and convey the message that, in addition to identifying routes between current and "safe" locations, it needed current imagery of those routes. If the imaging satellite then had the capability to relay its imagery through the GPS satellite to the GPS receiver where it would be overlayed with the directional information, the ground troops would have everything they need to safely egress Mogadishu.

3. Building a Close Space Support Satellite using TacSat-2 Lessons Learned

TacSat-2 is probably the only satellite ever designed with a Close Space Support mission in mind. However, TacSat-2 was far from a pure Operationally Responsive Space (ORS) or Close Space Support platform. Due to multiple political, financial, and schedule constraints, TacSat-2 was a spacecraft that had to carry thirteen payloads to orbit (many of which doubled as essential, non-redundant subsystems) and fulfill about 140 on-orbit mission requirements, both tactical and scientific. It had two tactical sensors, two innovative new communication links, experimental solar arrays, star cameras, and propulsion systems, as well as payloads designed to answer basic scientific questions, such as how atmospheric density and RF signal interference fluctuates with local and remote environmental conditions. Moreover, it had to accomplish its mission on a shoestring budget and under the severe schedule pressure inherent laboratory efforts.

However, despite the diverse objectives and constraints, TacSat-2 was a fairly good first incarnation of a Close Space Support platform and the lessons learned during development and the Military Utility Assessment (MUA) Exercises were extremely valuable in defining a follow-on architecture that could serve the tactical warfighter in an operational setting.

First, many of the design characteristics that made TacSat-2 less effective for the Strategic Operational Community made it more attractive as a CSS asset:

- Small budget and short development timeline
    - Not enough time or money to make something that is very reliable, very capable, and very appropriate for a wide range of potential customers
        - Forced to tailor orbit, spacecraft, and ground architecture to a targeted set of users performing a single mission.
        - Inexpensive enough to be considered a "disposable" asset specifically designed to serve the urgent needs of a single tactical customer in a single tactical theatre.
    - Not enough money to build a ground architecture that with non-COTS equipment and software that would support the very protected data associated with strategic missions.
        - Forced to use PCs with standard SW packages and the internet. Coincidentally, these are the same tools the tactical warfighter has at his fingertips (via laptops or smart phones in modern urban theatres and front-line troops don't have the capacity to carry additional mission-specific equipment or learn complex new tasking or satellite control systems.
        - Architecture is suitable only for data that might have high classification, but won't retain

that classification over an extended period of time due to the transient nature of its usefulness. Fortunately, this is exactly the kind of data a warfighter would need in a Close Space Support mission.

In order to assess the military utility of TacSat-2, the platform was exercised in four events. Two of the events, Talisman Sabre and Valiant Shield, were National Exercises picked by the Assessment Team as part of the MUA. Because they were National Exercises, the TacSat-2 concept of operations was tailored to support the larger Exercise objectives and the platform was operated in a manner that was a combination of the traditional space asset tasking process and a more streamlined process that took advantage of a subset of TacSat-2's web-based tools and onboard Autonomy. These events were excellent opportunities to put TacSat-2 data products (e.g., imagery) in front of Operational Warfighters for a quality and usefulness assessment. Unfortunately, the primary purpose of these Exercises was to achieve certification for a Unit's primary mission and it was therefore difficult to get the participants to use the fully envisioned TacSat-2 capabilities and Close Space Support concept of operations, which was drastically different from what is currently being exercised in the field.

In addition to the two official MUA events, TacSat-2 was evaluated in two in-house Exercises, Lost Kitten / Cat Nab, a Joint US/UK/Canadian Exercise. The benefit of these events is that they were specifically designed to utilize the on-orbit asset and its supporting ground system in the Close Space Support manner for which it was designed.

3.1. Talisman Sabre

Talisman Saber is the name of the major Australian-US bilateral biennial exercise. Tacsat 2 participated in the 2007 military exercise and was considered an intelligence asset for the exercise. The area of intelligence interest was comprised of the fictional geography developed by the Scenario Working Group. This scenario had multiple end users that requested all their tasking to one group that used several sensors including Tacsat 2 to provide the end users the end item products. The group forwarded the Tacsat 2 tasking to the Tacsat 2 Mission operations center where taskings were uploaded to the spacecraft

- Lessons Learned from Talisman Sabre
    - Web-based tasking and data distribution is a highly valued enabler for streamlined access to space assets, but security of information is essential and non-negotiable for the current strategic implementation of spacecraft. Exercise personnel insisted on a conversion from encrypted internet to SIPRNet TacSat-2 tasking and data distribution architecture. This conversion, while successful, came too near the beginning of the exercise to allow CONOPS rehearsal and any effective results.
    - Sensors that work day and night are much better suited for Close Space Support. The Talisman Sabre exercise occurred during a time when TacSat-2 flew over the theater at night. This rendered TacSat-2 imager ineffective, but TIE data was recorded during the event. If the user absolutely needs a day only sensor such as an imager, using a constellation of satellites in low earth orbit or placing the satellite in an optimal orbit will help.

3.2. Valiant Shield

Valiant Shield 2007 was a PACOM-sponsored exercise focused on integrated Joint training among U.S. military forces, enabling real-world proficiency in sustaining Joint forces in detecting, locating, tracking, and engaging units at sea, in the air, on land, and cyberspace in response to a range of mission areas. The Exercise brought together approximately 22,000 U.S. troops representing the Navy, Air force, Army, and Marines. TacSat-2 was considered an intelligence asset for the exercise. The area of intelligence interest was comprised of the fictional geography [2].
Valiant Shield was a sequence of events with various services acting independently. Unlike the Talisman Saber exercise that TacSat-2 participated in June 2007, the TacSat-2 members were able to pre-plan data requests prior to the Valiant Shield exercise. This scenario had multiple end users that requested all their tasking to one group that used several sensors including Tacsat 2 to provide the end users the end item products. The group forwarded the Tacsat 2 tasking to the Tacsat 2 Mission operations center where taskings were uploaded to the spacecraft

- Lessons Learned from Valiant Shield
    - Provide example of data output to the end user so the user knows what to expect. During initial phases of Valiant Shield we discovered that the end user liked to see the images in NITF format instead of the JPG format. Similar issues were discovered with ELINT data.

- Time from product request to receipt must be very short to make spacecraft useful for tactical operations. This time turned out to take too long in Valiant shield because there were two groups of people that were required to authorize the task before it gets uploaded to spacecraft. The first group receives task requests from all end users and prioritizes the tasks. The second group reviews the list of tasks and removes tasks the system will be incapable of doing for power or memory reasons. Both of these processes were manual and could be automated.
- For a visible imager sensor, need a multiple ball constellation and ability to accurately predict cloud cover to drastically increase the time of usefulness over target area. Alternatively, develop a day/night/all-weather sensor with a wide FOV, tailor the orbit, and engineer methods to minimize the amount of time required to maintain spacecraft health (e.g., body-mounted or articulated solar arrays; three-axis thrusters; etc.) to provide maximum useful collection time overhead the tactical theater.
- Use a fast attitude control system to allow multiple narrow field of view sensor collects over a single theater. There were multiple tasks over a single theater during valiant shield and talisman saber. The spacecraft could not slew fast enough to image all the targets. More robust attitude control system would have allowed more imaging opportunities.
- Using data compression to minimize bandwidth. Images can be compressed over 1400% with minimal visible losses. Reducing data reduces link budgets allowing for lower power consumption components on ground and space to transfer the data. For Tacsat 2, this would have also reduced the downlink time from 12 hours to the first contact after image (less than 3 hours).
- Decouple ground contact time lag by having an instant link (such as through a geo satellite) to s/v. There were cases where the spacecraft's last imaging opportunity was 1.5 hours from current time, the next scheduled AFSCN contact was 2.5 hours away, the target went into nightfall, and orbit did not cross over the target for 18 more hours, and the next ground contact was 3 hours later meaning the user got his data 21 hours later when he could have gotten the data in as little as 1.5 hours from now
- Make the tasking system web based to decouple a ground station/system from end user. Having a web based system similar to an airline flight booking system not only allows the user access to the vehicle from anywhere in the world, it also eliminates the need for a user to carry his own unique satellite communication system.
- Have a method to tag data with specific user request to decouple multiple users. During talisman saber and valiant shield multiple sensor collects were uploaded to the spacecraft, to further complicate the situation, some data was downloaded in pieces. This resulted in a lot of work correlating data to the end user. OpSat-X space-ground architecture should correlate the data in a seamless fashion to minimize amount of time end user spends to use the system.
- Have a priority scheme to decouple user requests and provide feedback to user the status of his/her request. The first day of Talisman saber, the Mission Operations Center (MOC) received 87 tasks for the spacecraft. The spacecraft can realistically do ~6 tasks per day over the theater. Develop an adjudication process analogous to the daily Aircraft Tasking Order (ATO) process used by aircraft. On a daily basis, identify the available space resources/capabilities and anticipated tactical needs and assign the resources to the tactical warfighter in support of their activities during that time.
- Minimizing number of servers on ground between end user and spacecraft. During Valiant shield, a 3rd party server went down, and there was no 24 hour support for that server which disabled the entire system until the server was back online
- Allow spacecraft to autonomously adjudicate task requests. This would mean user 1 sends a low priority request to image target 1. this is followed by user 2 sending a high priority request to image target 2 at the same time as target 1 imaging is to take place. The spacecraft images target 2 and images target 1 next time it is flying over the area. This capability of Tacsat-2 was not used during any of the exercises, however it was proven.

- Creating a direct access to spacecraft via UHF or secure World Wide Web.

3.3. Lost Kitten / Cat Nab

Lost Kitten and Cat Nab were AFRL developed and executed Exercises developed to practice a tactical imaging CONOPS in 2 parts[4]:

1) Rapid development and execution of Imaging Plan for multiple targets in a single AOR by the Mission Planning and Operations Teams

2) Real-time direct commanding of the on-orbit asset via satellite internet from a remote location.

They were reviewed by personnel at Special Operations Command, as well as local personnel who have had recently participated in combat operations and assessed to be "realistic".

In a fictional scenario for part one (Lost Kitten), a CIA Agent has been kidnapped while in Africa on a mission. The US identified six potential locations in which he may be held captive. Current imagery of the locations is desired prior to anticipated enemy action to relocate him.

In part two (Cat Nab), the agent's location is being tracked by in-theater personnel. They follow him to a remote location and are told to directly command TacSat-2 to collect imagery of his location so friendly forces can plan an appropriate course of action.

- Lessons Learned from Lost Kitten and Cat Nab
  - Revisit rate for a single ball imaging spacecraft overhead a single theater is insufficient to gather imagery data over multiple targets on a tactical timeline.
  - Tactical warfighter doesn't need insight into spacecraft operation as much as they need a simple interface that works on existing equipment with existing software (e.g., a PC with Windows.) The tasking and data distribution interfaces should be designed with sites like Expedia in mind. Expedia users don't need to see what the site/spacecraft is doing to fulfill their request get their results, they just need to be able to competently use it with no training and have confidence that it will return them a product that best meets their needs.
  - Data that is important to the Tactical Warfighter doesn't need to be protected at high classification levels because the time during which the data will be exploitable is limited to the short time of the operation. Put the tasking and data distribution system on the encrypted internet, rather than higher classification webs that require specific hardware and software packages. Many more Tactical Operators will have much higher bandwidth access to internet than more secure webs.
  - Maximize off-Nadir data collection capabilities. There were several flyovers of targets where the satellite would have been able to collect data, however the imager is a line scan array and data collects >40 deg off nadir are impossible for the tacsat 2 imager due to distortion.
  - Use arrays that independently tracked sun. Tacsat 2 had fixed solar arrays, this coupled any image collect with power generation. There were several passes where imaging was impossible due to power reasons.
  - Use Omni directional antennas and if necessary, steerable antennas for downlink. Tacsat 2's high rate download antennas were fixed to the spacecraft and had to be pointed to the ground station due to their limited field of view, this coupled with a slow attitude control system meant very few opportunities of instantly down linking high rate data after an image collect.
  - Use dedicated ground links. The high speed downlink ground system was being shared with several programs and many different personnel during exercise. Reconfiguring settings of the component during different modes of operation proved to be very complicated.
  - Time stamp recorded data. The Tacsat 2 ground operator needed to know the start and stop memory address of each image to download. This meant the satellite had to contact ground between images. This coupled image collects with AFSCN ground contacts which occurred on average once every three hours. Decoupling image collects with AFSCN contacts would have allowed the spacecraft to take more images.
  - Minimize required data for downloading by geolocating data. Tacsat 2 has a default 1 second image setting which creates a

7kmx 7km image. The warfighter may only need a small section of the image (1kmX1km). Creating a spacecraft that can point accurately enough and a ground system that can choose to download only part of the image data could shrink the data download size by 98%. This will allow future satellites to have turnaround times of 3 hours instead of 12-24 hours using AFSCN.

- Provide GMT time in ground system web page. Spacecraft operates in GMT time a warfighter uses local time, having GMT time displayed on the web pages would ease use
- Provide feedback on Pre-Contact completion. A pop-up, or something similar, should indicate the pass plan is ready for execution.
- Provide user a time when data will be available. There needs to be some automated feedback on when the image will be taken and when to expect the image data to be available.
- Accept MGRS input coordinates as well as latitude and longitude. MGRS coordinates are universally used and understood by tactical troops and more accurate over short distances.
- Allow the Tactical Team to determine the coordinates of a target from a map. The current input for image target is lat/lon the ground user may find it easier to point on a map instead of determining target's lat/lon
- Minimize steps to command spacecraft. The Tactical Team assessed that the process to create and execute an image tasking has far too many steps. After the planning, the execution should be automatically scheduled for execution.

4. Concept of Operations of OpSat-X using Tacsat 2 lessons learned

We begin this section using the same the highly documented extraction of US troops from Mogadishu, Somalia in 1993 discussed earlier. This time these troops have access to OpSat-X. This operation found US troops severely undermanned in the middle of the densely populated Somali capital city of Mogadishu. Their urban surrounding implied restricted long-range vision and limited situational awareness, particularly as it applied to the whereabouts of multiple bands of armed mobs roaming the streets. Moreover, the skies above the city were not safe for available airborne assets, so they could not gain situational awareness sufficient for a safe egress using their normal means.

They will:

1. Use an internet based PDA such as one showed below to log in to satellite to obtain an image of the city

Figure 3. A typical internet capable cell phone.

2. A simple screen will ask for login information to authenticate the user, then ask for the MGRS coordinates of the target to be imaged.
3. Once the troops enter in the coordinates, the contact will be sent via web to the ground station server.
4. The ground station server will calculate which satellite in the OpSat constellation will be able to provide an image fastest to the user.
5. The ground station will send commands via Geosynchronous Satellite to OpSat-X the satellite that is scheduled to fly over the area in next 10 minutes.
6. Since this is a high priority request, OpSat-X will transmit down to ground a delayed message to any other task it had scheduled to do at that time providing an explanation a higher priority task had been requested. It will then accept this task, propagate its orbit and calculate the time at which the image will be available. It will then tell the user image will be taken in 10 minutes.
7. OpSat-X will have slewing solar arrays and a low gain transmit and receive antenna so there will be no impact to power collection and communication link during any phase of this exercise.
8. Since OpSat-X is a Synthetic Aperture Radar, there is no impact to imagery due to weather or nightfall.
9. Opsat-X will slew rapidly and accurately to the target
10. OpSat-X will take the image and clip out the area as specified by MGRS. This will reduce the image size by 98%.
11. Opsat-X will then convert the image to an National Imagery Transformation Format using JPEG 2000 compression scheme to further reduce data size by 1400% and have image in a user specified format.

12. At this time the image is roughly 0.14% of it's original size and is transmitted in seconds from OpSat-X through a geosynchronous communications satellite to ground station server.
13. The ground station server sends an email at specified time to the user with the photograph.
14. The user determines the safest route away from the armed mobs back to the main base.

This scenario successfully uses all the lessons learned from the Tacsat-2 military exercises listed below:

- Reduce time between data request and data receipt by
    1. Enabling a constant contact with satellite via a GEO satellite
    2. Using sensors that can be used in night and in cloudy weather
    3. Providing user a time when data will be available
    4. Minimizing number of components such as servers or personnel between user and satellite that can breakdown
    5. Maximizing ground footprint of system by
        i. Using a high altitude satellite
        ii. Using a constellation of Low Earth Orbit satellites
        iii. Using sensors with wide field of view (if using a low earth orbit satellite)
        iv. Using a fast attitude control system for sensors with narrow field of view
    6. Minimizing data transfer by:
        i. Allowing user to download partial not complete data
        ii. Using compression algorithms such as jpeg to reduce data transferred
- Simplify Satellite operations by:
    1. Allowing attitude independent operation by
        i. Using sun tracking solar arrays
        ii. Using omni directional antennas or slewing high gain antennas
    2. Using dedicated ground stations
    3. Allowing precise geolocation of sensor data
    4. Allowing access via world wide web with
        i. Non technical commanding terminology
        ii. Minimized number of steps for commanding
        iii. A common time format such as GMT along with a converter displayed on web page
        iv. MGRS coordinates
        v. Data product associated with user/time
        vi. A priority scheme to facilitate multiple users

5. Conclusion

TacSat 2 successfully proved all parts of the concept of a close support vehicle. It allowed the end user to task the vehicle, it collected data, and it downloaded data in a format understandable by the end user. It also provided the community with valuable insights in how to optimize a close space support vehicle.

6. References

1. U.S. Department of Defense (September 3, 2003). "Joint Tactics, Techniques, and Procedures for Close Air Support (CAS)"