DACA
Test Experiment Report

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Contents

1 Executive Summary

On July 2, 2013, the Oceus Networks-Space Data team successfully completed a test demonstrating the transmission of a 4G Long Term Evolution (LTE) signal from high-altitude in support of the Federal Communications Commission (FCC) Deployable Aerial Communications Architecture (DACA) proceeding. The test, performed in Colorado, used a 4G LTE base station placed aboard a high altitude balloon-borne platform. Oceus Networks and Space Data partnered on this initial test and demonstration at the suggestion of staff from the FCC's Public Safety and Homeland Security Bureau.

As identified in the FCC's 2012 notice of inquiry on DACA[1], despite the many efforts that have been undertaken to improve post-disaster communications problems exposed by events such as 9/11 and Hurricane Katrina, there remains "a gap during the first 72 hours after a catastrophic event when communications may be disrupted or completely disabled due to damaged facilities, widespread power outages, and lack of access by restoration crews into the affected area."[2] The DACA NOI acknowledges that the use of technologies by US armed forces "could potentially fill this gap for civilian communications" thus serving to "further strengthen and enhance the security and reliability of the nation's communications infrastructure."[3] Both Oceus Networks and Space Data Corporation have extensive experience developing solutions to meet demanding operations for military tactical communications.

This first use of a 4G LTE cell aboard a high altitude balloon platform stems directly from the both the military tactical use of Oceus Networks-supplied LTE base stations and the years of effective use of Space Data's balloon technologies to extend the range of military tactical communications. In combining these technologies into a common capability, the testing served to demonstrate how such a solution could support aims stated by the FCC in it DACA NOI.

The experiment evaluated four test cases:

- Initiate signal transmission from ground
- Determine whether ground based user devices could communicate with DACA
- Assess performance of platform as it rose into the stratosphere (70,000 ft)
- Explore potential interference issues with non-synchronized terrestrial networks

During the test, the ground team took the DACA balloon platform in a controlled ascent to 70,000 feet. The ground team contacted the 4G LTE payload and initiated signal transmission. Devices on the ground were able to successfully receive transmission. During the flight and as confirmed by data collected from the DACA platform after the balloon was recovered, the DACA platform was affected by the atmospherics at high-altitude. The rapid temperature changes affected the 4G LTE payload during certain periods of the testing.

Key findings from this initial test are summarized below:

1. Long range or "boomer cell" operation with LTE is possible provided the "extended range" parameter is implemented and set within the eNodeB. Stations both at the center and edge of cell were able to receive the signal.
2. All equipment flown during DACA operation must be hardened to withstand the harsh environment of high altitude operation. Hardening should include, but might not be limited to, frequency reference oscillators, GPS and timing reference equipment, and heat generating components (like power amplifiers).

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[1] Utilizing Rapidly Deployable Aerial Communications Architecture in Response to an Emergency, PS Docket No. 11-15, Public Notice (rel. May 24, 2012) ("DACA NOI").
[2] Id at para 2.
[3] Id

3. Some level of interference between non-synchronized systems was detected. Further test data would be required to exactly quantify.

The experiment was successful in demonstrating that a DACA LTE platform could provide communications to first responders on the ground. These successful initial tests in Colorado have provided important groundwork for future proof-of-concept and early operational use of these capabilities to support first responders and potentially the general populace in the critical first 72 hour period following a disaster. The FCC should further study the feasibility of certain DACA configurations with special focus on how it could give FirstNet the flexibility to use this delivery platform within its overall architecture if FirstNet deemed it appropriate.

2 Background and Introduction

Oceus Networks and Space Data Corporation (DACA Test Partners) teamed to participate in an experiment to evaluate the effectiveness of a high-altitude Deployable Aerial Communications Architecture (DACA) platform to support emergency communications both in disaster recovery and capacity enhancement scenarios in support of the FCC's 2012 DACA NOI[4] Combining Space Data's expertise in system design, payload integration, and flight operations with high-altitude balloons, and Oceus Networks' military-grade deployable LTE solution, *Xiphos*, the team developed a DACA platform that housed a portable 4G LTE cellular basestation (Xiphos LTE Payload) onto a high-altitude balloon platform (SkySite®). This report describes the test goals, the plan, hardware used, test performance, and results.

This initial experiment assessed the ability of a LTE signal transmitted from high-altitude to effectively communicate with traditional off-the-shelf LTE Public Safety User Equipment (UE) operating on the ground. A deployable 4G LTE transmitter was integrated onto a high-altitude airborne balloon platform and transmitted a signal to equipment on the ground. Measuring how well the communication link performs under these conditions informs how this platform or similar platforms could provide broadband coverage to first responders on the ground during a disaster event. Tests conducted did not assess other necessary components of a DACA solution to provide seamless public safety communications operations. Future testing would be required to assess how a DACA solution could provide handoff capability, DACA/terrestrial interference quantification, system capacity and other needed requirements.

The DACA Test Partners conducted its initial experiment on July 2, 2013. The test was conducted in coordination with the National Telecommunications and Information Administration (NTIA), National Institute of Standards and Technology (NIST), and the Public Safety Communications Research (PSCR) program near government facilities in Boulder, Colorado.

The SkySite/Xiphos LTE platform rose in a controlled ascent to 70,000 feet. DACA Test Partners and government observers took measurements during the ascent and at the platform's peak height. The ground team initiated signal transmission to determine whether a UE device could receive the signal. At full height, the ground team observed that a 4G LTE UE could receive the signal over a 100 km (62 mi) radius. The team used UE devices provided by Motorola Solutions including data modems (model VML 700) and smartphones (model LEX 700). These devices communicated with the mobile airborne LTE network node. The ground team used data collected from these devices to characterize the performance of a high altitude 4G LTE Public Safety system.

Spectrum: The DACA Test Partners designed its solutions to operate on frequencies that FirstNet is licensed to use to deliver public safety broadband communications. The First Responder Network Authority (FirstNet), with support from the FCC and NTIA, provided Oceus Networks and Space Data the temporary authorization to use the public safety broadband spectrum in the 700 MHz band (3GPP LTE Band Profile 14). By using the same frequencies that will be utilized in the forthcoming nationwide public safety broadband network, the test

[4] Id.

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demonstrated to FirstNet, states, and local public safety communities one use case for a deployable solution within the overall public safety communications architecture.[5]

3 Testing Overview

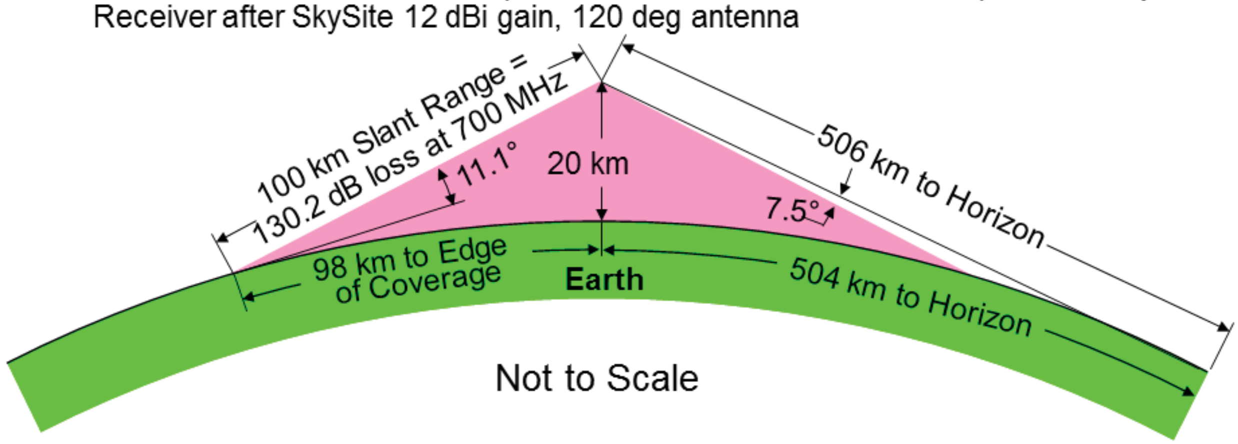
3.1 Purpose

The test was designed to assess the performance and communications range of a LTE signal transmitted from high-altitude (between 65,000 feet and 75,000 feet) with LTE User Equipment (UE) operating on the ground.

3.2 High Level Use Case

The geometry of the DACA demo is roughly shown below:

- Coverage Circle size limited by timing and link budget
  - Link budget compensated by UE ERP and gain of antenna, LNA, at SkySite
  - Protocol timing (max timing advance for LTE = 0.67 us or 100 km round trip)
- At 20 km altitude (65,617 ft) and max. slant range to user of 100 km
  - Delta from nearest to farthest user = 100 - 20 = 80 km
  - Free space path loss is –130.2 dB at 700 MHz
  - Min. user elevation angle is 11.1° equivalent to being 0.2 miles. from a 200-foot tower
- Motorola LEX 700 handset output is 23 dBm results in -95.3 dBm power at SkySite Receiver after SkySite 12 dBi gain, 120 deg antenna



Representative DACA high altitude-based test geometry characteristics

Testing Assumption: If the LTE DACA platform is transmitting at 20 W with a 12 dBi antenna, the expected signal strength on the ground at the coverage edge should be roughly -75 dBm (ignoring any losses other than free space losses). The signal at the DACA receiver was expected to be about -95 dBm.

[5] Deployable solutions could be housed on a multitude of platforms including vehicle, ship, manned aircraft, or trailer.

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3.3 Summary of Test Cases Considered

In order to fully understand the potential of DACA, several test scenarios were considered. Not all test cases were executed during the July 2013 test. Future tests may be conducted to allow a phased approach to be completed as time, resources, and finances are available. A summary of the potential test scenarios from simplest to most difficult are listed below.

Note: This test series evaluates three methods to mitigate interference between a DACA LTE system and a terrestrial LTE systems: (A) interference noise temperature approach with both networks operating co-channel but at different signal strength levels at the User Equipment, (B) splitting the 10 x 10 MHz Public Safety Broadband channel into two smaller channels during various phases of a disaster recovery, and (C) the two networks cooperating through backhaul links to coordinate resource block sharing.

1. **Test the DACA network alone**. While operating in an isolated area, an area without fixed infrastructure operating (i.e FirstNet's 700 MHz network), turn on the DACA LTE transmitters, establish connectivity between User Equipment (UE) and DACA, drive UE to Loss of Signal to determine edge of coverage. This test will both prove the link budget, as well as verify that "Extended Range" timing of LTE is properly functioning.

2. **Test with DACA and PSCR both operating.** The first step in this test case is to characterize the performance of an existing terrestrial network without the DACA system operating. For this test we propose using the PSCR test bed located in Boulder, Colorado. Connect a UE to the terrestrial system and characterize performance over a pre-defined drive route within the coverage area. It is best if the drive route includes both strong signal and cell edge coverage. The second step is to enable the transmitter on the DACA system and repeat the drive route. This tests baseline interference without any coordination between networks.

3. **Test interoperation of DACA and PSCR.** Provision the UE for both the DACA and the PSCR terrestrial networks. With UE connected to the PSCR eNodeB, turn off the PSCR eNodeB transmitter, turn on the DACA transmitter and measure the time required for UE to connect to the DACA eNodeB. This requires provisioning of UE on both networks.

4. **Test various bandwidth combinations.** Repeat test 3 above with the UE provisioned on both networks with various combinations of DACA/PSCR bandwidths in both non-co-channel mode: 5 MHz/5 MHz as well as overlap modes such as 5 MHz (DACA) / 10 MHz (PSCR), 10 MHz (DACA) / 5 MHz (PSCR). This requires changing the configuration of the PSCR network several times. During the initial phases of a disaster that has completely disabled the terrestrial LTE network, the DACA network could be allocated the full 10 x 10 MHz channel, then as the terrestrial network gets partially restored the spectrum could be split so that the terrestrial and the DACA networks each get an independent 5 x 5 MHz channel, once the terrestrial network is fully restored the entire 10 x 10 MHz channel can be allocated back to terrestrial-only operation.

5. **Test roaming.** Establish a network management link between the DACA Core in the sky and the PSCR Core on the ground. In the non-overlap configuration of 10 MHz / 10 MHz test hand off from PSCR to DACA and DACA to PSCR. This involves downlink from DACA, establishing roaming between the two cores, UE provisioned to roam both networks. Another possibility is to control the DACA eNodeB directly from the PSCR core via an unlicensed (4.9 or 5.8 GHz) point-to-point backhaul link.

6. **Test roaming in various bandwidth configurations.** Repeat test 5 progressing from 10 MHz DACA / PSCR Off initially to 5 MHz DACA / 5 MHz PSCR to DACA Off / 10 MHz PSCR. This simulates a complete outage of the terrestrial network with DACA using all available spectrum then slowly bringing up terrestrial network and providing more spectrum to PSCR and less to DACA as terrestrial networks are recovered. Depending on the interference observed in test 4, various overlapping channel configurations can be tested as well. This involves same effort as test 5 plus multiple reconfigurations of both networks.

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7. **<u>Test Fully Coordinated Operation.</u>** With network management link between two cores, dynamically allocate Resource Blocks between the two networks to evaluate the two networks operating in an overlapped 10 MHz / 10 MHz configuration with capacity dynamically allocated between the networks as needed.

All the above tests can be done in light load and maximum load scenarios. Light load is just two UE communicating with each other through the network(s). Maximum load is when enough UEs are part of the test to fully utilize the capacity available on both networks. Obviously the maximum load scenarios are more difficult to implement as they involve many more participants and more UE.

While it is desirable to execute all test cases listed above, and useful knowledge will be obtained from each test case, the limited time and funds available will likely dictate a reduced set of tests be executed.

4 Test Plan - Initial Phase

4.1 Demonstration Purpose

The purpose of this initial demonstration was to assess the performance of the LTE link from the Deployable Aerial Communications Architecture (DACA) SkySite platform to LTE Public Safety User Equipment (UE). The link quality and strength were assessed by Oceus Networks Test Equipment.

Follow-on tests outside the scope of this initial demonstration will assess additional factors such as handoff capability, DACA/Terrestrial interference quantification and capacity.

4.2 Scope

This test report covers three test scenarios executed in the first phase.

1. Phase 1 – Test 1: Initial configuration, assembly and basic functionality tests in lab.

   This testing was performed in the Oceus Networks R&D Labs located in Plano, TX to verify the initial configuration of the DACA payload, proper assembly of all components, and basic functionality. Additional tests were performed to verify:

   - High Altitude Qualification
   - GPS timing reference
   - Extended Range functionality
   - Out of Band emissions to adjacent narrowband operations.

   Note: These tests were not identified in the original test plan outline defined in Section 3.3.

2. Phase 1 – Test 2: Terrestrial range/interference testing near Phoenix, AZ.

   a) Independent DACA system test to determine coverage limit

   Note: These tests were not identified in the original test plan outline defined in Section 3.3.

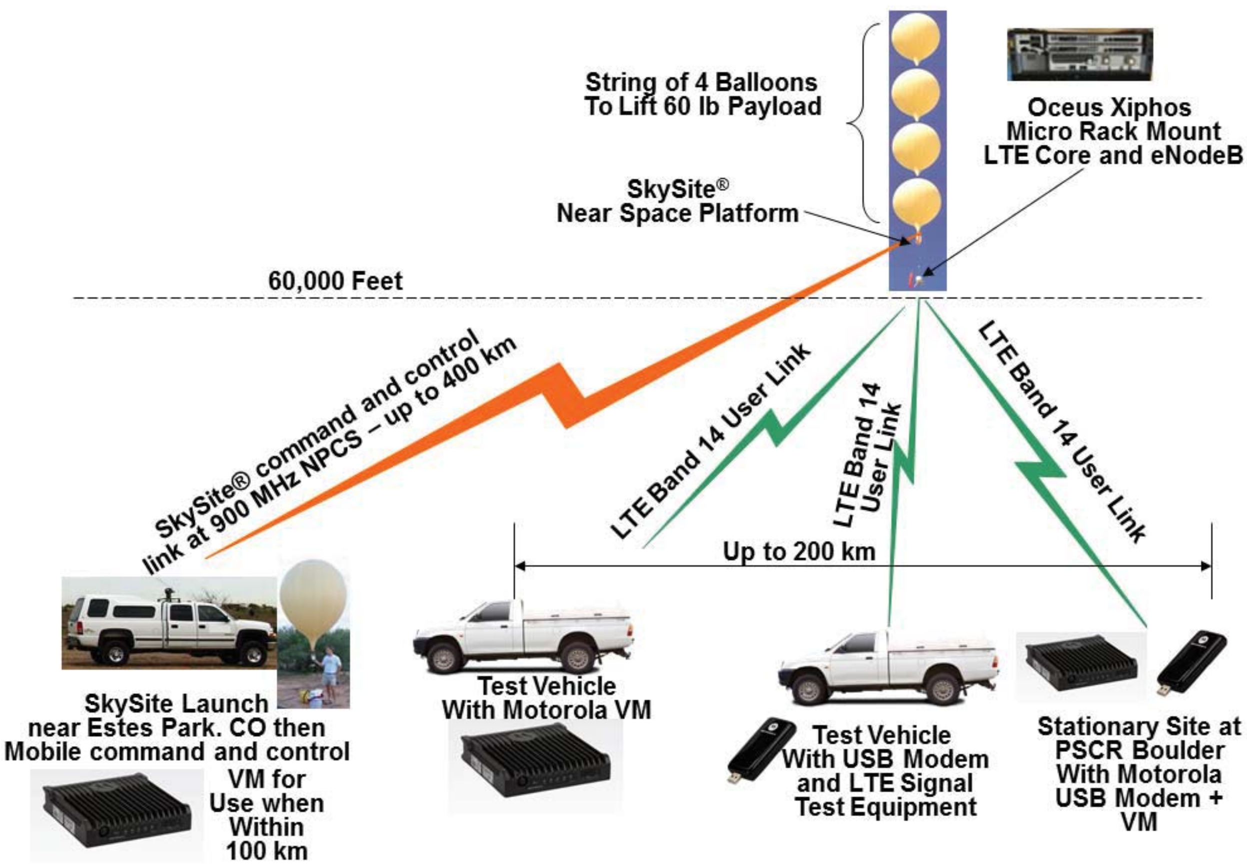
3. Phase 1 - Test 3: Airborne range and interference testing near Boulder, CO.

    a) Independent DACA system test to determine coverage limit

    b) DACA system test w/ PSCR operating to determine interference effect

    Note: These tests are identified in the original test plan outline defined in Section 3.3 as Test Case 1 and Test Case 2.

4.3 Demonstration Description



Demonstration Architecture

4.4 Flight Description

The experiment consisted of one SkySite® flight in Colorado near the PSCR terrestrial network in Boulder, Colorado. The goal of the flight was to measure user link performance, not to demonstrate a final operational DACA system. As the current generation of LTE equipment utilized is fairly heavy, the payload exceeded the 12 pound weight limit required for the flexible operations allowed by Federal Aviation Regulation (FAR) 101.1. The worldwide ecosystem of LTE infrastructure manufacturers is pursuing programs that are reducing the Size, Weight and Power (SWAP) of LTE equipment. Thus, it is projected that by the time the Federal Communications Commission (FCC) would adopt service rules for DACA systems, LTE equipment will be available that allows operation under FAR 101.1 requirements. However, configurations developed for this initial flight testing could support near-term use of heavier hardware for real-world requirements pending the development of lighter-weight solutions. Due to the platform's initial weight, extensive coordination was conducted with appropriate Federal Aviation Administration (FAA) authorities leading up to and during actual flight testing, thereby establishing a process that would support operational use of a heavier configuration if required more near-term.

The test flight was planned to last approximately 4 hours, or until the desired data was collected. The flight altitude was adjusted based on the winds at float, but was expected to be in the range of 60,000 to 70,000 feet. SkySite altitude and position were recorded approximately every 4 seconds for use in later link budget analysis.

The planned flight profile was as follows:

The launch crew arrives at the predetermined launch site at 6 AM. The balloon configuration is filled (40 minutes) while the SkySite® Platform and the Oceus LTE Core are checked out. The demonstration coordinator approves the launch at 6:30AM and the SkySite® rises at approximately 1,000 feet per minute to an altitude of at least 65,000 feet where it automatically levels off and hovers. The vehicles with LTE UE either drive in a radial pattern away from the SkySite® or simply wait in one location as the SkySite® moves. When the SkySite® leaves the area or the RF test truck(s) are done recording, the SkySite® will be handed over to the recovery team to release from the balloons when appropriate. The recovery team will command the SkySite LTE System to release from the SkySite Platform and descend on a parachute for recovery. The LTE payload is tracked to the ground along with this SkySite Platform. Once recovered both payloads can be refurbished and returned for future flight testing. Oceus will supply data such as time stamped signal strength data, receiver sensitivities, and drive truck environment/location data while Space Data provides data such as time stamped SkySite® location data, transmit power, and antenna pattern information. This data will be jointly combined for link budget analysis. A common data format, such as Microsoft Excel, will be used for the data exchange. The data will be compared and reconciled after each flight.

4.5 Demonstration Location

DACA Testing Partners selected the demonstration launch site to be just east of Greeley, CO. The selection of launch site was based upon weather forecast information and local winds at the time of launch. This launch location facilitated the DACA payload to fly-over Boulder, Colorado where PSCR has three terrestrial sites, allowing for interaction between the DACA LTE network and the PSCR terrestrial LTE network.

As the Oceus Networks Xiphos system utilizes an Evolved Packet Core (EPC) onboard the SkySite balloon, there was no need for a ground station with backhaul for the experiment. Command and control of the SkySite was performed using narrowband 900 MHz NPCS spectrum for which Space Data is licensed nationwide. This link has a range of up to 300 miles (radius). Command and control of the Xiphos payload was supported over this link as well via an ASCII serial link.

4.6 LTE Modulation Modes

The Xiphos system is capable of transmitting at 20 W at the following modulation types:
QPSK, 16 QAM and 64 QAM. The demonstration flight utilized both of these modulation modes.

The initial flight tested the Xiphos at a 20 W output mode. While the Xiphos is capable of transmitting up to 60 watts, the extra power draw and heat created by operations in this mode will likely prevent operation in this mode unless it is for short periods of time.

The Xiphos system is also capable of transmitting in both 5 MHz and 10 MHz channel bandwidths. Due to resource constraints this demonstration was done at 10 MHz channel bandwidth only.

4.7 Spectrum

The LTE links were in 3GPP Band 14: the Xiphos transmitted at 758-768 MHz and the UE transmitted at 788-798 MHz. Use of this spectrum was authorized via Special Temporary Authority (STA) that was coordinated by the FCC Public Safety and Homeland Security Bureau, with the NTIA, PSCR and FirstNet.

The command and control of the SkySite was over Space Data's licensed 900 MHz NPCS spectrum on a 12.5 kHz channel pair (12.5 kHz at 940 MHz and 12.5 kHz at 901 MHz). This link has a range of up to 300 miles as long as it is not blocked by terrain. Space Data's chase vehicles with tracking yagi antennas provided control of the payload altitude as well as pass low data rate ASCII commands to the Xiphos system.

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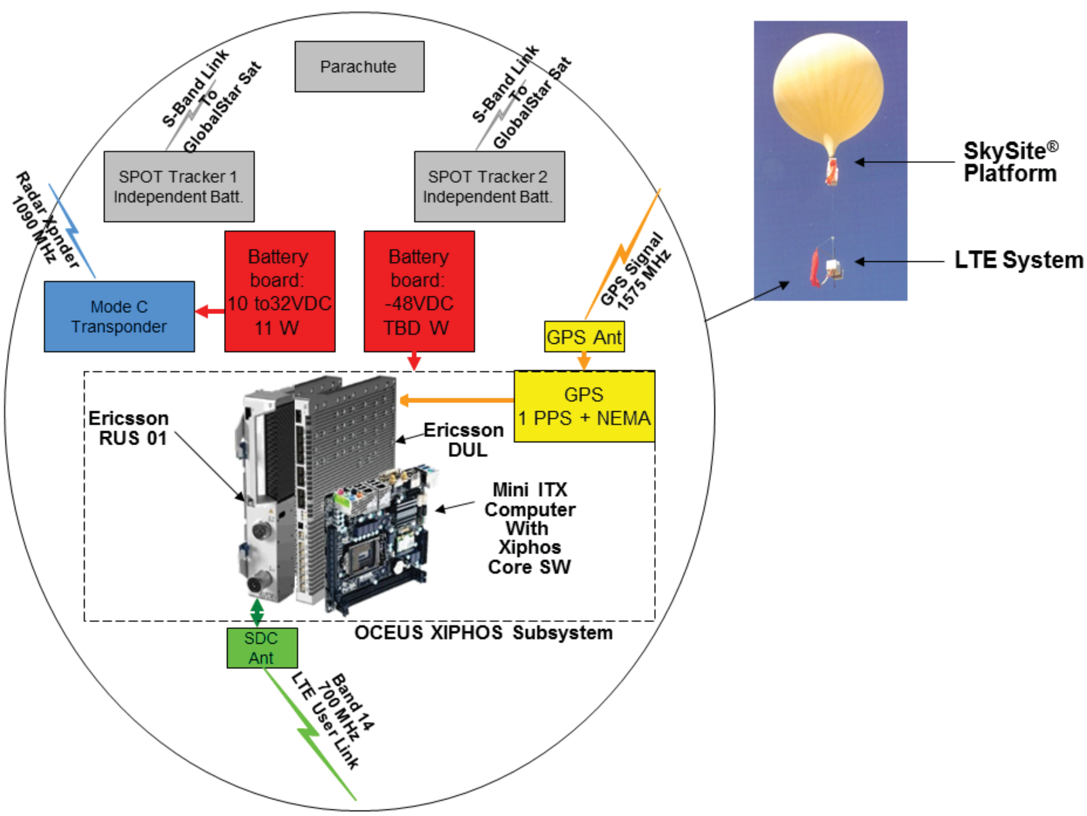
5 Hardware Components: The SkySite Xiphos payload

5.1 SkySite Description

The flight hardware consisted of two separate payloads, the SkySite® Platform and the Xiphos LTE Payload. The SkySite® Platform contained all the mechanical, electronic, and software systems necessary to provide a stable, controlled, high altitude platform and flight for any electronics payload. The Xiphos LTE Payload held the Xiphos software on a Mini ITX computing platform, GPS, Ericsson Digital Unit for LTE (DUL), Ericsson Radio Unit (RUS 01), batteries, and antenna needed to perform the functions of an LTE eNodeB and MSC. In addition, the Xiphos LTE payload contained a parachute and an integrated tracker for recovery. The SkySite® platform, which was attached directly below the balloon, towed the Xiphos LTE Payload up to near space altitudes. For the purposes of the demonstration, only the Xiphos LTE Payload is discussed in detail as the SkySite® Platform has been in service for over 20,000 flights to date. As this balloon flight had more than 12 pounds of payload weight, in addition to the standard SkySite electronics, the SkySite carried a Mode C transponder and a radar reflector to be compliant with FAR 101 Subpart D: Unmanned Free Balloons.



Block diagram of the SkySite-Xiphos DACA Payload

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5.2 Environment

Thermal regulation of the Xiphos LTE payload was accomplished using a passive thermal radiation system similar to that used in the current Space Data payloads. Due to the reduced air density at the float altitudes, cooling via convection and conduction were only minimally effective. Because of this, cooling of the RUS, DUL and Computing System could be achieved by thermal transfer to a radiative cooling plate or forced air cooling. The temperature range for the Xiphos system is 0 to 50 C and the RUS internal circuitry turns off the PA if temperature range is 2 C outside of this range.

The Xiphos temperature was accessed during the flight through the Xiphos system management software. It was expected at the reduced RF loading on this flight that heat dissipation requirements would be about 70% less than the RBS 6000 system was designed for in a terrestrial environment at 50 °C ambient temp. Also, any air cooling at flight altitudes will be with air at 10% of sea level density but at -40 °C temperature.

The reduced air pressure was not expected to affect any of the electronics present in the Xiphos LTE Payload other than the reduction in cooling mentioned above. The flight hardware was altitude chamber tested to confirm this.

5.3 Power Supply

The equipment was powered directly from lithium batteries. As lithium batteries have a flat discharge curve a battery pack design was chosen that kept the maximum and minimum voltage over the discharge curve of the pack within the operational range of the equipment voltage requirements as well as providing ample inrush current to start up the equipment.

5.3.1 Power Requirements

The standard Ericsson RBS 6000 Element Modules operate on -48 VDC nominal. As specified by Ericsson, the actual voltage range allowed is -40.0 to – 57.6 V DC for operation. The non-destructive voltage range is 0 to -60.0 V DC. The inrush current could be as high as 47 Amps for <10 ms. The average power draw of the RUS and DUL is 167 W at 15% RF loading. The computing system is expected to draw 200 W average for a total average draw of 367 W. Thus, the average current draw will be 7.6 A.

5.3.2 Battery Pack Design

Two different battery packs were used to power the DACA payload: a -48VDC supply for the Xiphos equipment and a 14.4 VDC supply for the computing system. The -48VDC supply was configured by connecting 3 large, 16 cell packs in parallel. Each pack of 16 cells used SAFT 26SXC with an output voltage of 3V each for a connected output voltage of 48 VDC. 3 of these packs were required to meet equipment surge current requirements and overall test flight Ah capacity. A 14.4 VDC battery pack supply was constructed using SAFT LSH batteries with an output voltage of 3.6 V each. 4 packs of 4 cells each were connected in parallel to handle the surge current requirements and overall test flight Ah capacity.

5.3.3 Remote Shutdown

A payload generated remote shutdown command is not necessary as the Xiphos System will cease transmitting with a command through the Xiphos system management software and the PA automatically shuts off at 52 C to prevent damage from overheating. Thus the Xiphos LTE Payload will be powered up from launch to altitude which will be about a one hour ascent.

5.4 RF Backhaul

As the Xiphos LTE Payload has all components of Mobile Switching Center (MSC) implemented onboard in software running on the computing system there is no need for a broadband backhaul link. On future flights if the desire is to integrate the DACA LTE system with terrestrial MSCs then this may be a requirement. Eliminating this requirement greatly simplifies the test as a ground station location with low latency, low jitter backhaul to a remote MSC is not required. Command and control of the SkySite and the Xiphos LTE Payload will be via a low speed (<10 kbps) long range (300 mile) link in the 900 MHz NPCS band.

5.4.1 Backhaul Antenna Pointing/Despin

As there is no broadband backhaul required, the need to despin and point a broadband backhaul antenna is eliminated for this demonstration. The 900 MHz command and control link uses an omni-directional antenna.

5.5 Xiphos LTE Payload

5.5.1 Description

Xiphos LTE Payload is derived from the Oceus Xiphos 4G LTE System that has been developed as a compact, modular LTE network designed for rapidly deployable applications for military and federal users. As the Xiphos LTE Payload is more weight constrained and has lower shock and vibration requirements that the Xiphos Small Rack 1 RU system, some components have the Xiphos system have been eliminated or weight reduced. The Xiphos LTE Payload used for these demonstrations consists of the following Oceus components; the Digital Unit for LTE (DUL), the Radio Unit (RUS), the Global Positioning System receiver (GPS), and the Evolved Packet Core (EPC) computing platform.
To save weight the standard Xiphos rack, patch panels, and power supply will not be flown. Space Data designed and built a custom, lightweight structure to house, power and cool the Xiphos components.

5.5.2 Digital Unit for LTE (DUL)

The digital control components used in this experiment is the Digital Unit LTE (DUL) design by Ericsson for the main terrestrial LTE carrier market worldwide. Thus it has not been optimized for high altitude deployable applications.

The demonstration will not exercise all the functionality of the DUL. The Ericsson DUL is capable of supporting up to three-sectors with two transmit chains per sector. The DACA experiment is for a single sector with a single transmitter chain and two diversity receiver chains. It is expected that the power draw in the experimental DACA configuration will be approx. 60W.

5.5.3 Radio Unit (RUS)

The radio frequency components used in this experiment is the software defined Radio Unit LTE (RUS) design by Ericsson. This component, as also is the case for the Ericsson DUL, is designed for the main terrestrial LTE carrier market worldwide. It also has not been optimized for high altitude deployable applications.

The demonstration will not exercise all the functionality of the RUS. The Ericsson RUS is capable of supporting a single sector with one transmit chain and two receiver chains. The DACA experiment will utilize is for a single sector with a single transmitter chain and two diversity receiver chains.

This demonstration will use the RUS 01 for LTE at Band 14. It was Type Approved by the FCC under Type ID: on TA8AKRC11895-1 on 21 October 2011. While capable of operating at up to 60W the demonstration will be run at 20 W in order to reduce the power and heat dissipation requirements. The demonstration is single transmit x diversity receiver configuration. It is expected that the power draw will be approximately 107W not the 400W the RUS can draw at full power. This should reduce the heat dissipation from the 310 W design specifications for terrestrial networks to 87W for this DACA demonstration.

5.5.4 Computing System

The standard Xiphos Deployable LTE system utilizes a rack mounted server as the computing system for the Core Network. Due to SWAP constraints for this DACA LTE demonstration, Oceus is porting their EPC core to a Mini ITX form factor computer with a solid state hard drive. It is currently projected that the computing system will draw 200W on average.

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5.5.5 GPS Receiver

The standard Ericsson GPS Receiver will be provides a 1 Pulse per Second (PPS) and NEMA 0183 information via serial port to the DUL. This provides the timing reference used by the Xiphos system to stabilize frequencies. FCC Type Approval testing showed the RUS had at most 8 Hz of frequency error across the range of operational supply voltages and temperatures, which is much better than the +/- 50 Hz required.

Space Data flew the standard Ericsson GPS receiver to altitude on a separate integration flight and determined it was incapable of operating above 60,000 feet. GPS receivers for export are required to lock out the navigation solution if 1) greater than 60,000 feet above sea level AND 2) moving at greater than Mach 1. As the DACA demonstration balloon will be well below Mach 1 speeds this should not present a problem. However, in the 1990s there was debate if this export requirement should be 1 OR 2 versus the 1 AND 2 requirement ultimately adopted. At the time several GPS manufacturers decided to be conservative and code their firmware to the more restrictive 1 AND 2 requirement as they never foresaw any market for GPS receivers traveling above 60,000 feet. This artifact of the past continues to exist in various manufacturers of GPS receivers.

Since a precision timing reference is required for LTE operation, there were a few possible options.

1) Obtain a substitute GPS receiver. Space Data has several GPS receivers that put out 1 PPS and NEMA 0183 serial data that have been tested thousands of times above 60,000 feet.
2) Operate the system using a NTP server and Stratum reference. This solution would require additional hardware be added to an already overweight payload.
3) Operate the system in “Holdover Mode.” This is a mode where operation can continue in the absence of GPS timing information for up to 24 hours while maintaining full LTE performance.

For time, size and weight factors, it was decided to operate our initial experiments using holdover.

5.5.6 User Link Antenna

Space Data delivered the custom antenna for the Xiphos LTE Payload. This moderate gain, omni antenna is similar to other antennas Space Data has flown in the 800 MHz and 900 MHz bands. If more gain is required to provide reliable links the antenna can be fit with a flat back reflector to provide a single 120 degree sector, which would increase the gain approx. 4.5 db. As vendors reduce the SWAP of LTE equipment in the next couple years it is likely possible to develop a 3 sectored version of a DACA LTE SkySite that will provide a full 360 degrees of coverage. For the demonstration, none of the SkySite based antennas will be steered. For future experiments, if additional link margin is required, or a reduced coverage pattern or area is necessary, a directional antenna could be utilized. In that case the directional antenna will be de-spun and pointed at a constant angle relative to magnetic north.

The figure below shows the antenna design and the predicted antenna pattern in the uplink and downlink bands.

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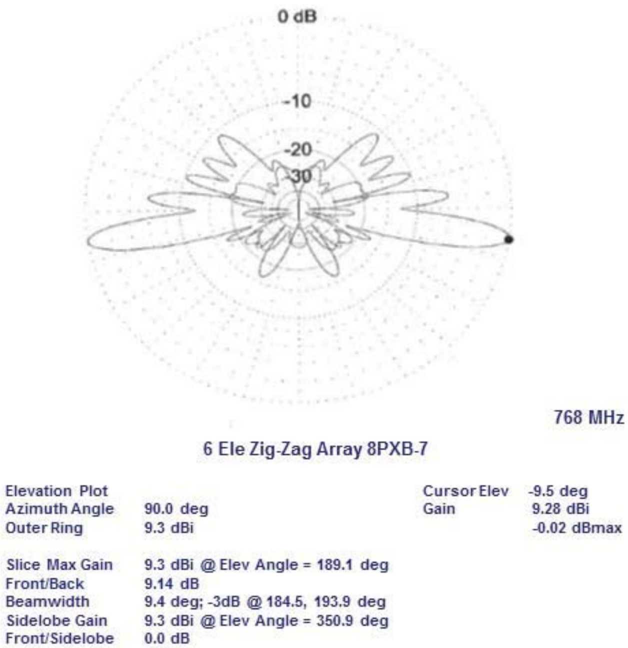
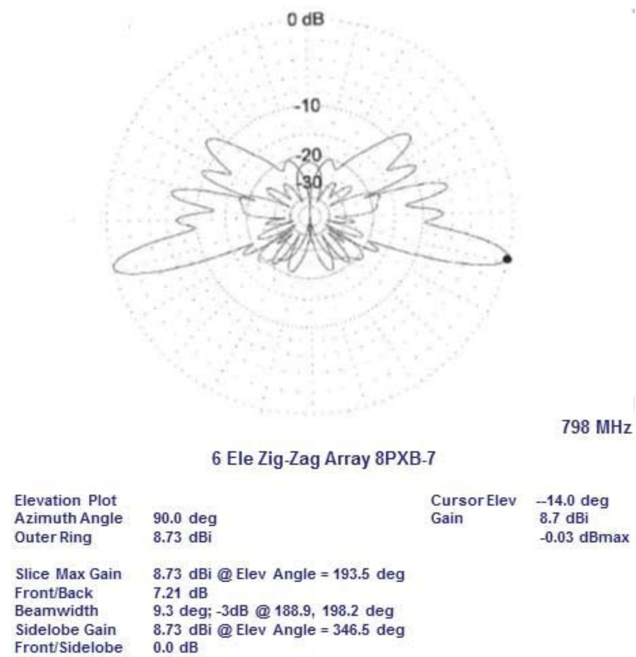


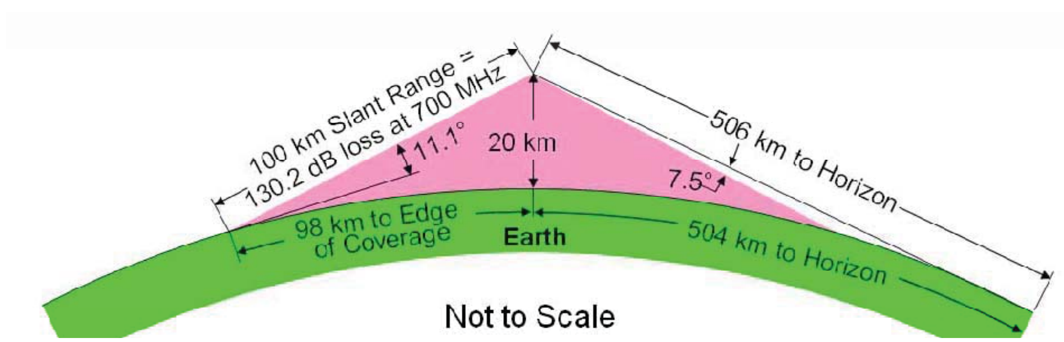
Downlink Antenna pattern



Uplink Antenna pattern

5.5.7 Time Offset

For the experiment, no timing offset will be used to adjust for the SkySite altitude. This means that the most distant user may be up to 100 km (62 miles) line of sight from the SkySite before running into the LTE standard limit for maximum link length. For a float altitude of 65,000 feet, this geometry is shown in the figure.



Test geometry with zero time offset as limited by 100 km max link range

5.5.8 Delay Link Budget

The delay link budget is not required for this demonstration as the Evolved Core is being flown on the SkySite and thus there is no backhaul delay between the RUS and the Core. The round trip delay for the link is approximately 0.7 ms versus the much longer 240 ms delay for geostationary satellites that would be an alternative to DACA.

5.6 Integrated Tracker

A tracking device will be integrated into the Xiphos LTE Payload to assist in the recovery after each flight. As described earlier, the SkySite Platform remains at altitude while the Xiphos LTE Payload parachutes to the ground. Upon landing, the integrated tracker transmits its GPS coordinates to the SkySite Platform for relay to the Ground Station. The recovery crew uses this location to recover the payload. As a back up the Xiphos LTE Payload will be equipped with two SPOT trackers that provide GPS location once back on the ground via the GlobalStar satellite network.

6 Ground Station

6.1 Description

The ground infrastructure included the equipment, manpower, and logistics of the launch and recovery systems, the ground station, backhaul between the ground station and the host, and the host system.

6.2 SkySite Control System

Space Data was responsible for the entire electronic and RF systems necessary for the SkySite Platform command and control. The SkySite Platform can be controlled either from Space Data's Network Operations Center (NOC) in Chandler, Arizona or directly from a remote or mobile Ground Station.

7 RF Test Vehicles

7.1 Vehicles

Oceus Networks provided the LTE test equipment, crews and vehicles necessary for the in-field signal measurements during the demonstration. Data from the drive test truck software will be shared and combined with SkySite position data supplied by Space Data.

7.2 User Devices / Equipment (UE)

Motorola Solutions USB modems (model UL 1000) and Vehicle Modems (model VML 700) were used to establish data session through the DACA LTE SkySite to measure uplink and downlink throughput as well as other parameters.

In addition, two Motorola Solution LEX700 handheld smartphones were added at the last minute to the test plan. Due to the lack of smartphone applications, only UE attach information and signal-bar information was recorded.

7.3 Test Equipment

Traditional test tools, such as an LTE mobile diagnostic monitor software with an associated device, were not available for the UE devices obtained from Motorola Solutions. Instead traditional IP packet diagnostic programs were utilized to characterize the performance of the LTE DACA system. These programs included iPerf and jPerf, NetPerSec, and generic ping and FTP programs. In addition the RF signal strength was recorded from the Motorola Solution devices using their associated user displays.

8 Test Execution: Launch & Recovery

8.1 Launch

The launch procedure and configuration were developed by Space Data over a period of several weeks, coordinating closely with FAA personnel in Arizona, New Mexico (Albuquerque Center) and Colorado (Denver Center). Flying a 50-pound payload—the LTE base station—requires a number of special mechanical and safety considerations not required for Space Data's typical 6-12 pound configurations that are compliant with limitations described in FAR 101. Flight safety is paramount so several added measures were taken including use of a standard aircraft transponder, carrying a radar reflector, and providing regular position and altitude reports to appropriate FAA contacts throughout the flight, particularly when the balloon-borne DACA platform is climbing or descending through altitudes below 50,000 feet. Final FAA clearance to launch was also obtained.

The launch process was honed through a series of pre-tests leading up to the 2 July event in Colorado. The development and test flights led to a stable multi-balloon configuration whereby two of the four latex balloons could be vented to level off the payload at an appropriate altitude above 60,000 feet and otherwise maneuver the platform during flight; the standard Space Data SkySite platforms attached to the two lowest balloons in the vertical string also contained a ballast system to support ascent from a level float.

The balloons were filled and raised one at a time, with a specially designed tether interconnecting the full string of four balloons. Once the fourth balloon (that is, the bottom balloon) was aloft, the LTE payload was attached below the lower SkySite, and gently raised of the ground using a pulley system. After the entire payload configuration, including antennas and the radar reflector, were off the ground, the pulley tether was released for a controlled lift-off east of Greeley, Colorado. Immediate confirmation of FAA tracking via the integrated transponder was obtained as the entire balloon-payload configuration began its nominal 1,000-foot-per-minute climb to a maximum altitude of 75,000 feet.

Four-balloon flight configuration

Payload configuration close-up

8.2 Recovery

Recovery was accomplished in the South Park region of Colorado, approximately 65 miles southwest of Denver. The SkySite flight control system provided platform position updates to the ground every four seconds throughout the flight. Space Data's proprietary Predictor software supported flight planning based on National Weather Service upper air wind data and provided up-to-the-minute prediction of the landing zone of the payload configuration once it descends on its parachute. The launch site near Greeley and the recovery site near Garo, Colorado, were selected based on the best suited altitude and winds, and the minimum required time aloft to effectively support the described sub-tests. The South Park area west of Colorado Springs provides a recovery zone with minimal challenges compared to the surrounding Rocky Mountain terrain.

This successful recovery demonstrated the control Space Data's balloon flight systems provide after some 15 years of development, testing, and operational evaluation of the mechanical systems and software. Not only does such a controlled recovery mechanism help ensure the safe return of a valuable payload but, more importantly, it provides the necessary safety measures that help prevent landing the large payload configuration in heavily populated areas or other locations where people or property may be threatened.

Remote but reachable recovery site

9 Test Results

9.1 Test Result: Phase 1 - Test 1

9.1.1 Description

This testing was performed in the Oceus Networks R&D Labs located in Plano, TX to verify the Initial configuration of the DACA payload, proper assembly of all components, and basic functionality. Additional tests performed to verify:

- High Altitude Qualification
- GPS timing reference
- Extended Range functionality
- Out of Band emissions to adjacent narrowband operations.

9.1.2 Results

The Xiphos payload used in the experiment was placed in an environmental chamber capable of simulating the temperature and air density found at altitudes up to 55,000 feet above the Earth's surface. The Xiphos was placed into operation and critical measures of performance were observed while the environmental chamber was cycled from sea level to 55,000 feet and back.

The temperature values of the LTE components (Digital Unit, Radio Unit and GPS Receiver) were observed for overheating. During the test cycle, all components remained within the specified temperature tolerance ranges. The test confirmed we did not require an additional or modified cooling system on the payload.

The system throughput was also observed and maintained a constant value during the test. No additional work was deemed required.

The GPS receiver was known to have issues maintaining lock at altitudes above 15,000 feet. Later research indicated that this is very common for commercial GPS receivers. Since the DACA test flights were limited in number, as well as being limited to durations less than 4 hours, we determined that all flights would utilize "holdover mode." In Holdover Mode, the Ericsson Digital Unit is able to provide an adequate timing reference to allow LTE operation for a period up to 24 hours. An initial GPS sync in order to "train" the on-board oscillator is required. All test flights will include this 24 hour training period immediately prior to flight.

Utilizing a Radio Frequency Channel Emulator, we were able to simulate the long distance paths (up to 100 kilometers) which would be typical of DACA to ground communications. Lab tests did establish that UE connection and data transfer are possible when the Extended Range / Extended preamble function was enabled.

Testing in the PSCR Boulder labs was also executed to assure that DACA test operation would not impact operational public safety narrowband communications. Several narrowband systems are known to be operating in the adjacent 700 MHz frequency block allocation in both Arizona and Colorado. The standardized tests executed in the PSCR lab showed there was sufficient attenuation of adjacent channel energy and no interference risk to public safety was observed.

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9.2 Test Result: Phase 1 - Test 2

9.2.1 Description

A terrestrial-based test was executed to verify Extended Range and the RF Link Budget. This test was executed in Arizona where Space Data has its headquarters, selecting widely separated high-elevation points to establish near-calculated protocol range limits (approximately 100 Km UE to base station) can be achieved prior to flight.

For this test the Xiphos payload was temporarily installed in a Space Data vehicle with on-board power inverter and azimuth-elevation controllable antenna mount. Rather than the omnidirectional vertical antennas proposed for the DACA test flight, two directional yagi antennas were utilized. The coax feedline length was adjusted to compensate for the slightly higher gain of the yagi antennas versus the omnidirectional vertical antennas. The goal was to match the Effective Radiated Power of the DACA system to within 1dB. All tests were conducted using a “SIMO” 1 Transmit @ 20 watts / 2 receive LTE, Band 14, 10 x 10 MHz FDD configuration.

A second Space Data vehicle was equipped with a Motorola VML700 vehicular modem. On this vehicle a mix of yagi and vertical antennas were utilized. Then yagi antennas would be used for the initial test due to their higher gain. After the RF link was established and characterized, the lower gain mobile omnidirectional whips would be utilized.

The locations selected were

- High View Point (34.43136° N, 111.3371° W)
- Four Peaks (33.6840° N, 111.3253° W)

These two locations were selected since they provided a line-of-sight path over an 80 kilometer distance with comparatively low terrain between the selected high-elevation sites.

9.2.2 Results

The first test established a link between UE and Xiphos with a data throughput of approximately 20Mbps. The antennas on the Xiphos were two yagi antennas (one TX/RX, and a second for RX diversity). The mobile station configuration was a single yagi and a single 5/8 wavelength omnidirectional vertical whip antenna.

A second test replaced the mobile station antenna with two 5/8 wavelength omnidirectional antennas. The result was approximately 18 Mbps data throughput.

Summary: Through this testing, determination was made that we have adequate signal link budget to proceed to high altitude DACA testing using traditional vehicular omnidirectional whip antennas. If necessary, we can switch to directional yagi antennas if we are unable to establish a link with the DACA payload during our flight tests.

9.3 Result : Phase 1 - Test 3

9.3.1 Description

This test was our initial flight of the Oceus Networks Xiphos payload aboard Space Data SkySite high altitude platform. Testing was performed near Boulder, CO. Our goal was to learn more about the feasibility of DACA through the following test cases.

- Independent DACA system test to determine coverage limit and characterize RF Link Budget.
- DACA system test w/ PSCR operating to determine interference effect.

Based upon forecasted winds, we selected a launch site approximately 25 miles northeast of Greeley, CO. The SkySite balloon track would initially ascend to the target altitude of 65,000 feet by traveling south from the launch site, transition to a westward track when positioned at 65,000 – 75,000 feet, and then resume a southward track during descent. Recovery would be in central Park County, CO.

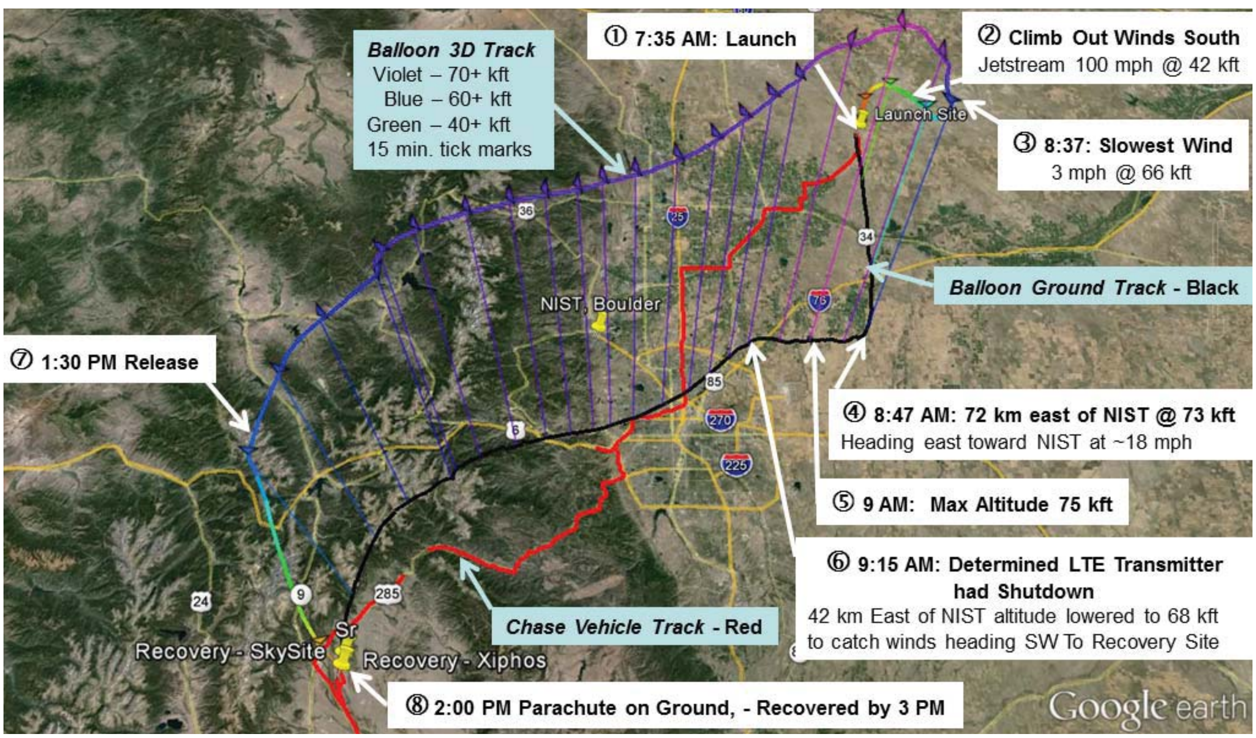
Our goal was that the projected balloon trajectory would allow us to collect data during several sub-phases of this test case:

1) Test 3.1: UE Connection status and data throughput while ascending.

2) Test 3.2: UE Connection status and data throughput while operating East of Boulder, CO outside the coverage area of the PSCR ground based test bed.

3) Test 3.3: UE Connection status and data throughput while operating over Boulder, CO with the PSCR ground based test bed active.

4) Test 3.4: UE Connection status and data throughput while descending into Park County.



Sequential synopsis of SkySite Xiphos platform flight from launch to recovery

9.3.2 Results

9.3.2.1 DACA Launch

Launch of the DACA payload was achieved at approximately 07:36am MDT.

9.3.2.2 Sub-test 3.1

Communication between the ground test units was immediately established and recorded. Reliable communication was observed during ascent of the SkySite and Xiphos from northeast of Greeley. The first connection and bandwidth report was observed at 7:36am MDT. Reliable communication continued through approximately 8:15am MDT.

9.3.2.3 Sub-test 3.2

During the ascent portion of the flight, several bandwidth tests were performed using the DACA payload and associated ground station. These were recorded between 7:36am and 8:15 am MDT. Results are shown below in the detailed test data table.

9.3.2.4 Sub-test 3.3

At approximately 08:15am MDT, the DACA payload had ascended to a sufficient altitude to provide coverage to a ground test station operating within the Boulder PSCR test bed. Communication between this test station and the PSCR system was established and data throughput was observed. Note: The system identifiers for the two systems were intentionally different, making this PSCR test vehicle a jammer with respect to the DACA system. Vice versa, the DACA transmitter was considered a jammer to the PSCR test vehicle attempting communication with the PSCR test bed.

For a short period of time, it was observed that communication between the DACA Xiphos payload and the DACA ground based test station was not possible. This was first observed at approximately 08:23am MDT. At this time operation between the PSCR test vehicle and the PSCR test bed system had commenced. It is suspected that the PSCR test vehicle had significant signal level into the DACA system to cause sufficient interference to the DACA uplink.

PSCR reported seeing a noted signal from DACA at the edge of their coverage area. From this position within the PSCR coverage area, operation is possible but at noted reduced data rates. This operation was at the “cell edge” for the PSCR system. The level of signal observed from DACA (as observed by the PSCR test vehicle) would have been sufficient to prevent access to PSCR.

Before the flight, engineers from SpaceData, Oceus Networks and PSCR met to discuss possible interference cases. With all system operating without backhaul synchronization, some levels of interference are expected at cell edge. Our goal was to capture and quantify the amount of interference. Small degradations in system performance within an existing system might be justified when creating disaster restoral coverage for other large un-served areas. Unfortunately there was not sufficient data collected (due to a system failure outlined below) regarding this test case and further research is suggested.

9.3.2.5 Unscheduled Test Case

As the SkySite was ascending through approximately 50,000 feet, a sudden temperature drop was observed using the on-board measurement and logging system. This sudden temperature change caused the reference oscillator to drift outside of the 3GPP LTE reference frequency limits required, causing automated safeguards inside the Ericsson Digital Unit (DUL) to engage. Since the reference oscillator was off-frequency, possibly causing interference to systems operating in the adjacent channel, the transmitter was automatically shutdown. This occurred at approximately 9:05am MDT. With the transmitter shutdown, no further data on Band 14 LTE was collected.

9.3.2.6 Sub-test 3.4

No data was collected during this sub-test phase due to the transmitter shutdown condition.

9.3.3 Detailed test data

Time	Observation	State	RSSI	RSRP	RSRQ	Current	Average	Max	Lat	Long	Additional Info
MST			dB	dB	dB	Mbps	Mbps	Mbps			
7:36am	Launch	attached							40.643787 N	104.338104 W	
7:36am	Initial readings	attached	-71	-90	-8		7.5	10.1	40.643787 N	104.338104 W	test run from launch during initial climb.
8:02am	Fixed test	attached	-89	-119	-9	6.4	6.4	10.6	40.643787 N	104.338104 W	test run from launch during initial climb.
8:11am	Mobile test	attached	-82	-101	-2		5.9	10	40.643787 N	104.338104 W	Moving at launch site
8:15am	Mobile test	attached	-76	-101	-8		5.8	9.8	40.537743 N	104.393727 W	near CR71, 25 miles due north of DACA. DACA was at 48K feet, estimated 47 miles to Boulder.
8:23am	Mobile test	attached	-96	-118	-8	0	0	0	40.488480 N	104.473457 W	Registered. No data transfer.
8:27am	Mobile test	attached	-85	-104	-2	0	0	0	40.478220 N	104.543106 W	Registered. No data transfer.
8:27am	Mobile test	trying to attach				0	0	0	40.428238 N	104.564690 W	NOT ATTACHED. No data transfer.
8:33am	re-registration	trying to attach									
8:38am	position report	trying to attach									payload was at 65K feet, 43 miles from Boulder
8:43am	position report	trying to attach									payload 32 mi S/SE of Greeley. NE of DIA. 40 mi due east of Boulder. Heading W at 30 mph
8:46am	mobile test	trying to attach									Oceus1 vehicle at Wireless Advanced Comm in Evans, CO
8:53am	position report										Payload at 74K' 38mi E Boulder.
8:53am	mobile test	trying to attach	-91	-117	-9						Gilcrest HWY85. Note: started suspecting accuracy of VML reporting of signal.
9:03am	mobile test	trying to attach									Millers Farmers Market
9:05am	position report	trying to attach									74K', 34 miles E of Boulder

9.4 Conclusions

Conclusions from the DACA trial are as follows.

1. Long range or "boomer cell" operation with LTE is possible provided the "extended range" parameter is implemented and set within the eNodeB. Provided that antennas with sufficient gain are utilized, antennas with sufficient gain to overcome the free space loss of a 100 kilometer path, reasonable data rates can be observed using traditional user equipment. Our initial experiment was successful with stations both at the center and edge of cell.

2. All equipment flown during DACA operation must be hardened to withstand the harsh environment of high altitude operation. Hardening should include, but might not be limited to, frequency reference oscillators, GPS and timing reference equipment, and heat generating components (like power amplifiers).

3. Test data collected by PSCR staff in Boulder, Colorado indicate detection of the DACA payload when positioned near the edge of their PSCR test bed coverage area. Their measurements, taken from the very edge of their test bed, indicated a dominate signal from DACA. This level of signal would be sufficient to prohibit communication with PSCR. As the PSCR test vehicle moved back into the primary coverage area of the test bed system, hence increasing the signal level from the PSCR test bed, communication with the test bed system became possible. Some level of interference between non-synchronized systems was expected, and further test data would be required to exactly quantify.

Items which remain unanswered after our initial test include:

4. Interference between the ground based PSCR and high altitude DACA test bed remains unanswered due to the early shutdown of the DACA payload. Further experiments in an unsynchronized mode would be required to determine the exact level of inter-system interference, and to determine if this level of interference is acceptable.

5. Establishment of a IP backhaul connection between DACA and PSCR would allow experiments in a synchronized mode to be conducted. In this configuration we could determine if there is a reduction of interference by utilizing the handover techniques (over the S1 interface) and interference resolution algorithms (ICIC) defined within the LTE standard.

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9.5 Recommendations

Currently DACA operation is not authorized under FCC rules. Further study is recommended to determine the feasibility of DACA configurations. This could include experiments conducted utilizing high altitude balloons, medium altitude aircraft or UAV platforms, or low altitude tethered balloons. An appropriate delivery mechanism could be utilized specific to the equipment and the experiment. The cost of implementing additional DACA experiments is not trivial, but would be considered if there is sufficient interest from government regulators.

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