UAS Air Traffic Management (UTM)

Assessing C2 Communications

Integrated Communications, Navigation, Surveillance (ICNS) Conference

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Assessing C2 Communications

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Introduction

Unmanned Aircraft Systems (UAS) Traffic Management (UTM) project works to develop tools and technologies essential for safely enabling civilian low-altitude UAS operations

- UTM develops comprehensive and validated airspace operations and integration requirements

Communications technologies to support UTM command and control (C2)

- Commercial networked cellular systems
- Industrial, scientific, and medical (ISM)
- Reliability, scalability, latency, integrity, cybersecurity, redundancy, etc.

Testing and Analysis of C2 Communications for UTM

- Development of a test platform for sensing and characterizing the airborne C2 communications environment
- Analysis of test results, simulation and modeling, and other analyses to understand potential performance of proposed C2 links and networks.

What is Unmanned Aircraft System Traffic Management (UTM)?

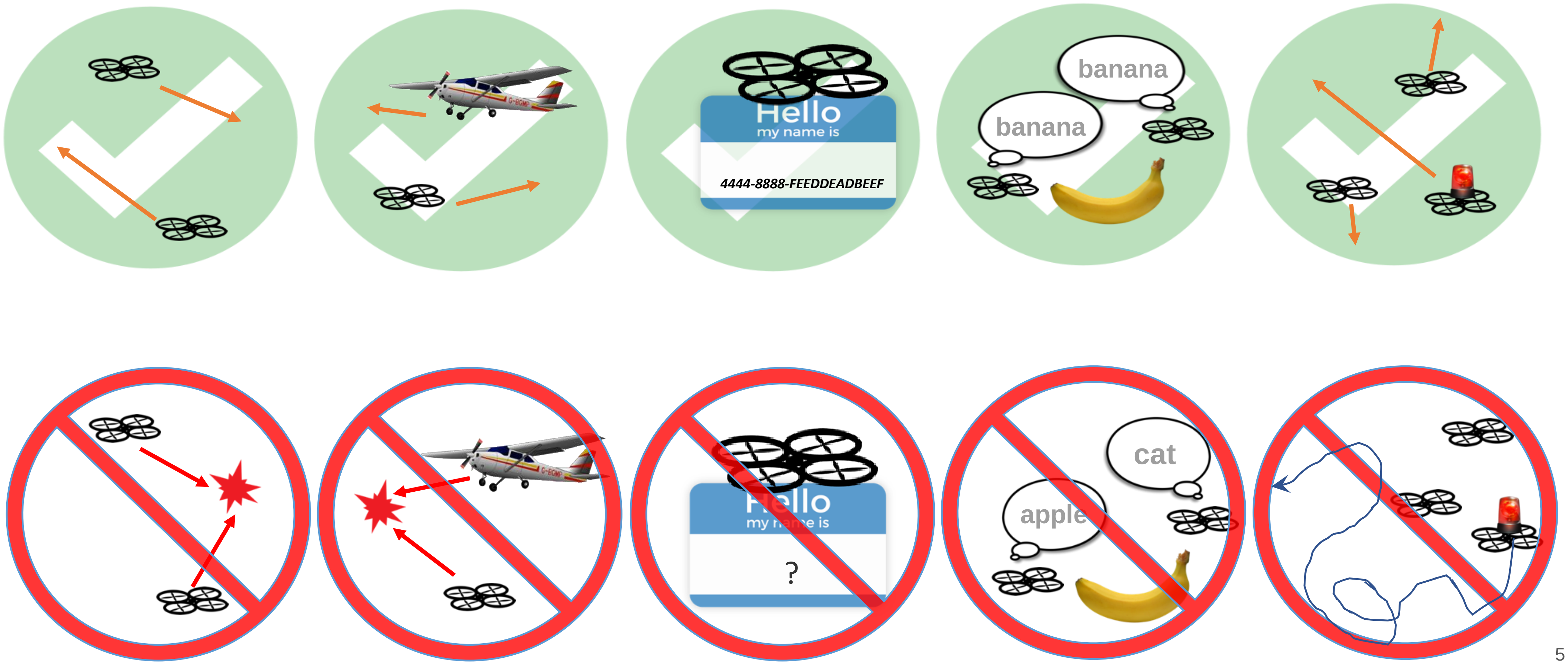
- **UTM is an "air traffic management" ecosystem for uncontrolled operations**
- UTM utilizes industry's ability to supply services under FAA's regulatory authority where these services do not exist
- UTM development will ultimately identify services, roles/responsibilities, information architecture, data exchange protocols, software functions, infrastructure, and performance requirements to enable the management of low-altitude uncontrolled UAS operations

UTM addresses critical gaps associated with lack of support for small UAS

UTM Project Overview

UTM Principles

(a.k.a. Things That UTM Will Help With…)



UTM Project Overview

Risk-based Conflict Mitigation Strategy

TCL1 (Remote)
- Visual Line of Sight
- Notice of Operation
- Position-Sharing (Optional)

TCL 2 (Rural)
- Beyond Visual Line of Sight
- Intent Sharing
- Strategic De-confliction
- Geographic Containment

TCL 3 (Suburban)
- Beyond Visual Line of Sight
- Intent Sharing
- Strategic De-confliction
- Geographic Containment
- Conflict Alert
- Detect and Avoid (DAA)

TCL 4 (Urban)
- Beyond Visual Line of Sight
- Intent Sharing
- Strategic De-confliction
- Geographic Containment
- Detect and Avoid (DAA)
- Vehicle-to-Vehicle (V2V)

TCL-3 Command and Control (C2)

TCL-3 CNS Testing

TCL-3 activities take place during Spring and Summer of 2018

TCL-3 activities focus on 4 areas: Communication, Navigation, and Surveillance; Sense and Avoid; Data and Information Exchange; and Concepts.

Three areas of testing under Communications, Navigation and Surveillance (CNS) cover the following:

- Test CNS1 – Maintaining control of the UA with a redundant C2 link - evaluate effectiveness of redundant C2 links in maintaining operational control of UA
- Test CNS2 - Remaining within Flight Geography using GNSS Navigation - to evaluate the impact of GNSS navigation error on UA's ability to stay within the flight geography
- Test CNS3 - RF Interference Baseline Monitoring - to characterize the RF environment UA operate in and evaluate its impact on UA's C2 link

TCL-3 Command and Control (C2)

Potential UTM C2 Communications

A number of candidate technologies are being tested for application to UTM C2 communications

Of particular interest are commercial cellular networks – LTE/4G, as well as the industrial, scientific and medical (ISM) bands

The RF channel sensing payload will examine the RF environment in the relevant LTE/4G and ISM bands

LTE Bands of Interest

Band	Base Station Transmit Bands	User Equipment Transmit Bands
700 MHz	717-768 MHz	699-716 MHz, 777-798 MHz
800 MHz	832-869 MHz	807-824 MHz
850 MHz	852-894 MHz	814-849 MHz
1700 MHz	N/A	1710-1780 MHz
1900 MHz	1930-1995 MHz	1850-1915 MHz
2100 MHz	2110-2170 MHz	1920-1980 MHz
2300 MHz	2350-2360 MHz	2305-2315 MHz
2500 MHz	2496-2690 MHz	2496-2690 MHz

ISM band of interest

5.725-5.875 GHz

TCL-3 Command and Control (C2)

C2 Issues Under Study

LTE/4G networks and hybrid systems

- Performance in the face of sudden high demand
- sUAS in flight will share the same LTE communications network
  - Capacity and service prioritization
- Quality of service, data integrity, latency, general system availability, coverage gaps, etc.
- Handoff performance
  - Between cell towers, between providers
  - Handoff performance between terrestrial and satellite communications systems in the case of hybrid terrestrial/satellite C2 systems
- Cybersecurity aspects

Testing, modeling and simulation, analysis to evaluate UTM C2 performance effectiveness

TCL-3 Command and Control (C2)

C2 Issues Under Study

LTE/4G, ISM

- Operations at altitude
  - Much longer radio line-of-sight compared to a user on the ground
  - Many more LTE/4G towers , many more ISM band transmitters will be visible
- Need to characterization the RF environment at altitude
- Need to measure link performance at altitude
- Correlate RF environment and link performance
- Model RF environment to support simulation and modeling

Need to perform independent RF link measurements to characterize the RF environment and link performance

Payload Design and Operations

RF Channel Sensing Payload

Understanding the RF environment and the potential performance of C2 links up to 400 ft AGL

Measure RF signals in the LTE/4G and ISM bands of interest for UTM C2

Use a software defined radio (SDR) design

- A-to-D conversion and post-processing delivers a frequency-domain spectrum analysis of a measured frequency band
- Later implementations will allow measurement of C2 link performance with various commercial providers or ISM band stations

Ettus^{TM} models E310/E312 have a larger Xilinx field programmable gate array (FPGA) allowing for more customized FPGA block processing.

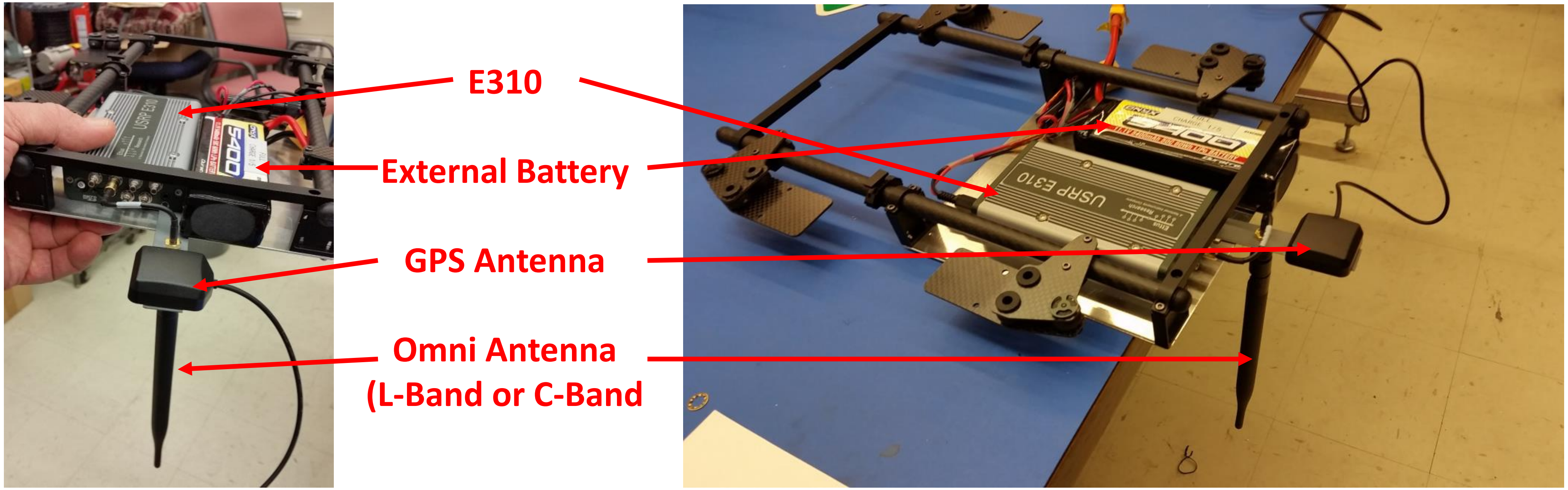
- The E312 includes an integrated battery, the E310 requires an external battery

RF Channel Sensing Payload

Ettus Models E310, E312

0-6 GHz receive band; A-to-D conversion and post-processing delivers a frequency-domain spectrum analysis of a measured frequency band

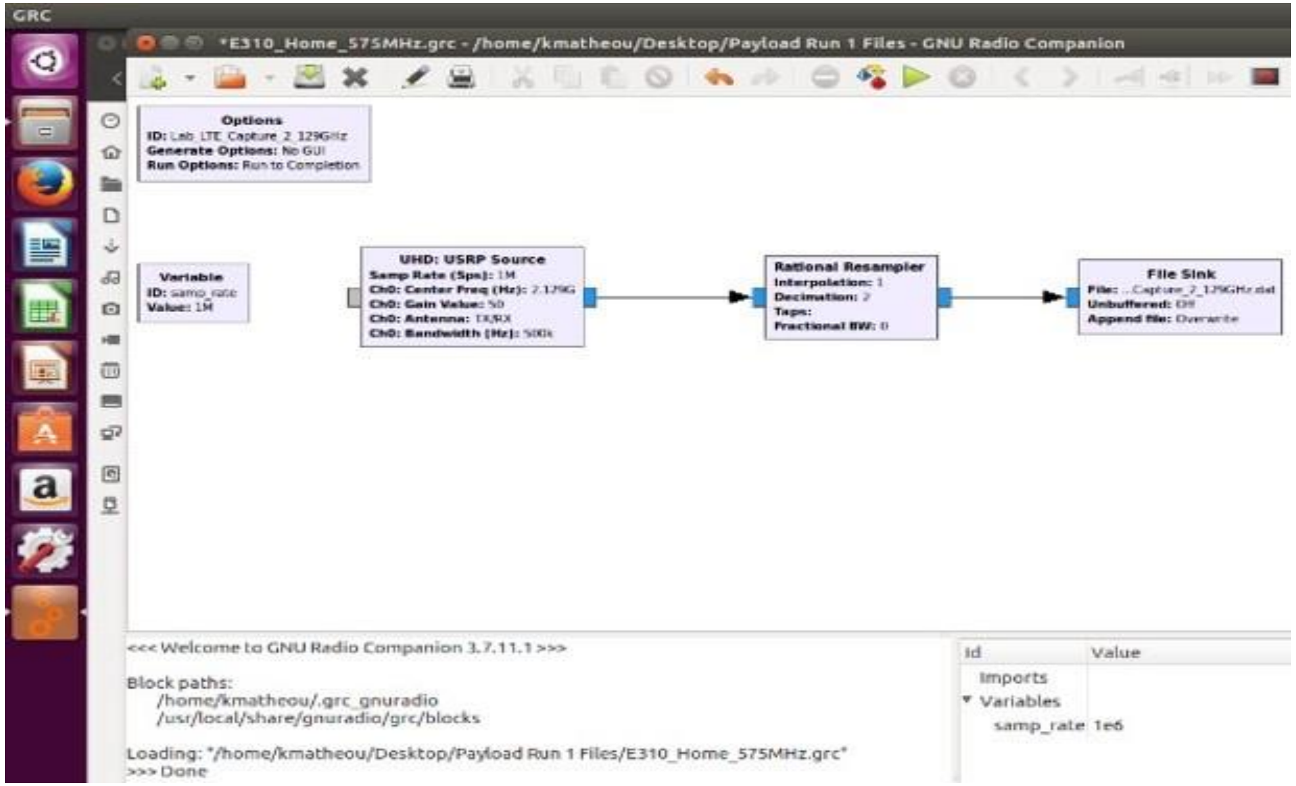
Payload mounts to the bottom of the DJI S1000 for the first set of flight tests



Payload Design

The current design using the GNU Radio Companion free software

- The GNU software uses function box type modules to create flow graphs
- From the flow graph, the GNU software creates python code, which is then transferred to the E310/312 via Ethernet communication



Payload Design and Operations

Payload Design

The current design has been programmed using the GNU Radio Companion shareware software

A-to-D complex samples are written to a micro SD card limit

- About 10-12 minutes of sampling can fit on the SD card
- This is similar to the length of flight time expected for each S1000 test flight

Sampling limitation

The sample rate writing to micro SD card limits measurement bandwidth to approximately 500 kHz complex bandwidth

- I and Q samples are 12-bit resolution from the ADC transferred to 16-bit when written to the hard drive

Future implementations, taking advantage of the E310/312 complex processing capability will add a DFT firmware based block to the FPGA image enabling larger bandwidths to be captured

Payload Operation

Preparation:

- Before the flight, the SDR is connected to a Linux laptop computer via an Ethernet cable. The Linux laptop will initiate the code to start running
- A two minute delay is initiated, allowing time to prepare for takeoff

Flight:

- Once the sUAS and payload are in the air, measurements will be made at several altitudes such as: 50 ft., 150 ft. and 400 ft AGL
  - Most LTE standalone towers range between 100-140 ft. AGL

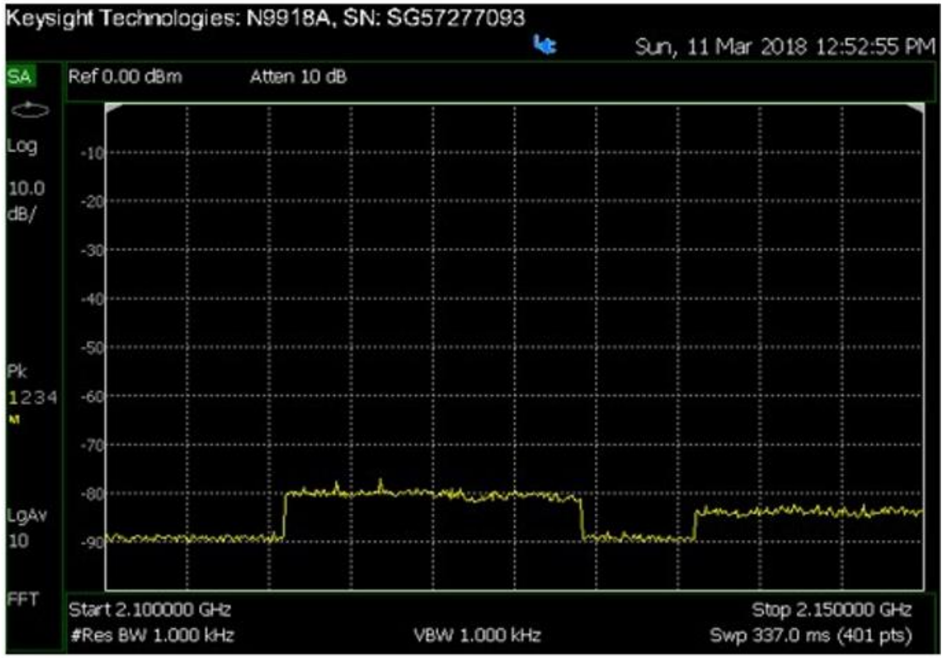
Post-flight:

- After 12 minutes of flight, the sUAS will land
- The sample data is recovered by ejecting the micro SD card
- Post-processing uses a Matlab code where the complex samples are read and spectrum plots produced

Payload Performance

Laboratory Testing

RF spectrum measurements have been captured in the laboratory at NASA Glenn to test the process of utilizing the SDR and capture free space spectrum data

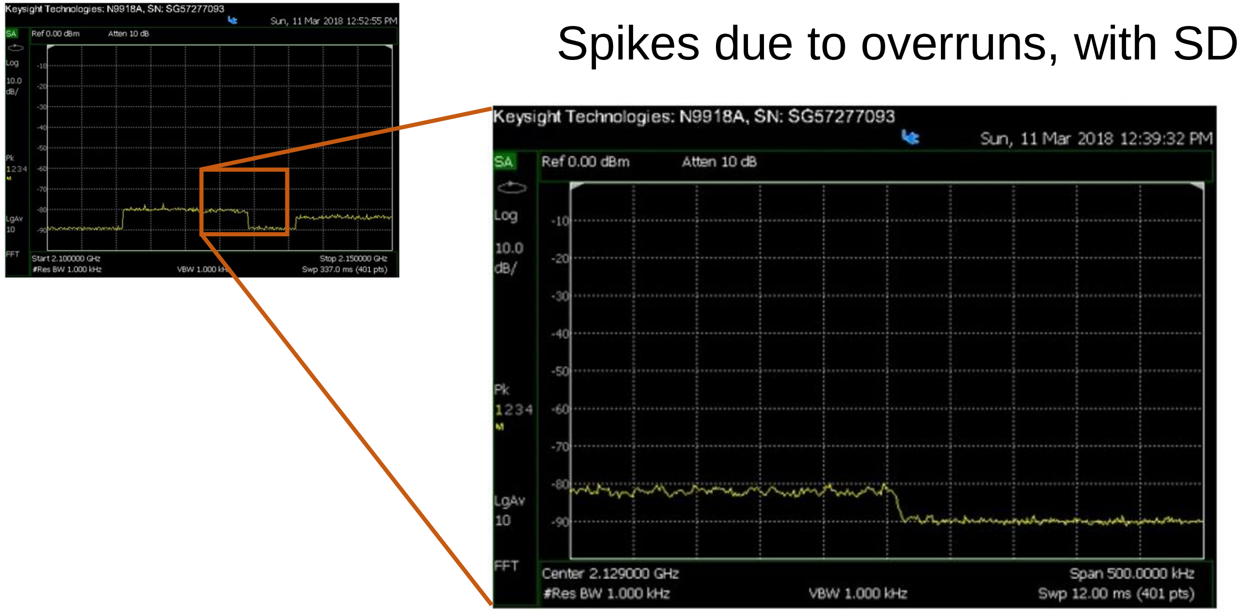


LTE/WiFi spectrum covering 2.1 GHz to 2.15 GHz recorded in the lab by a spectrum analyzer. The resolution BW is 1 kHz, and the overall BW is 50 MHz.

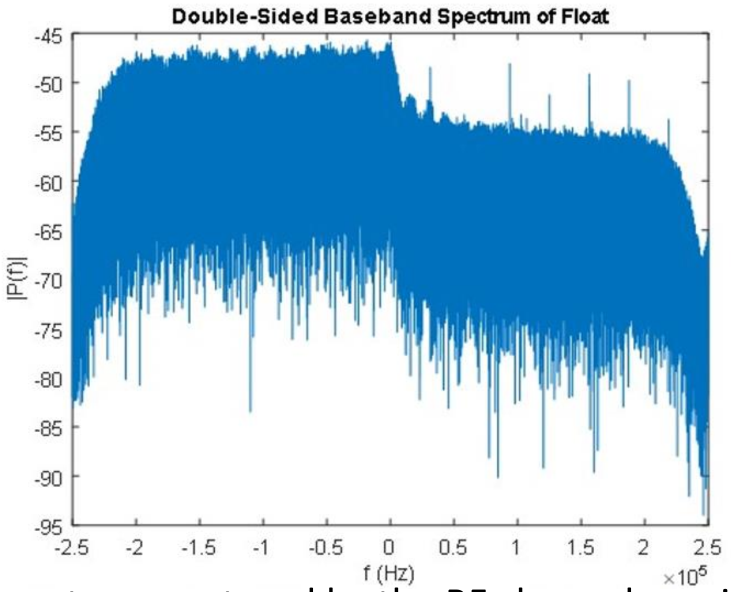
Payload Performance

Laboratory Testing

- Comparing the spectrum analyzer measurement with a spectrum plot produced by the RF channel sensing payload
  - Rolloff due to due to SDR downconverting and filtering
  - Spikes due to overruns, with SDR writing at its maximum sample rate



Zoom in on the spectrum analyzer plot to obtain a similar bandwidth (500 kHz)



The same spectrum captured by the RF channel sensing payload - measurement time 3 min, 7.2 million complex samples

Payload – sUAS Integration

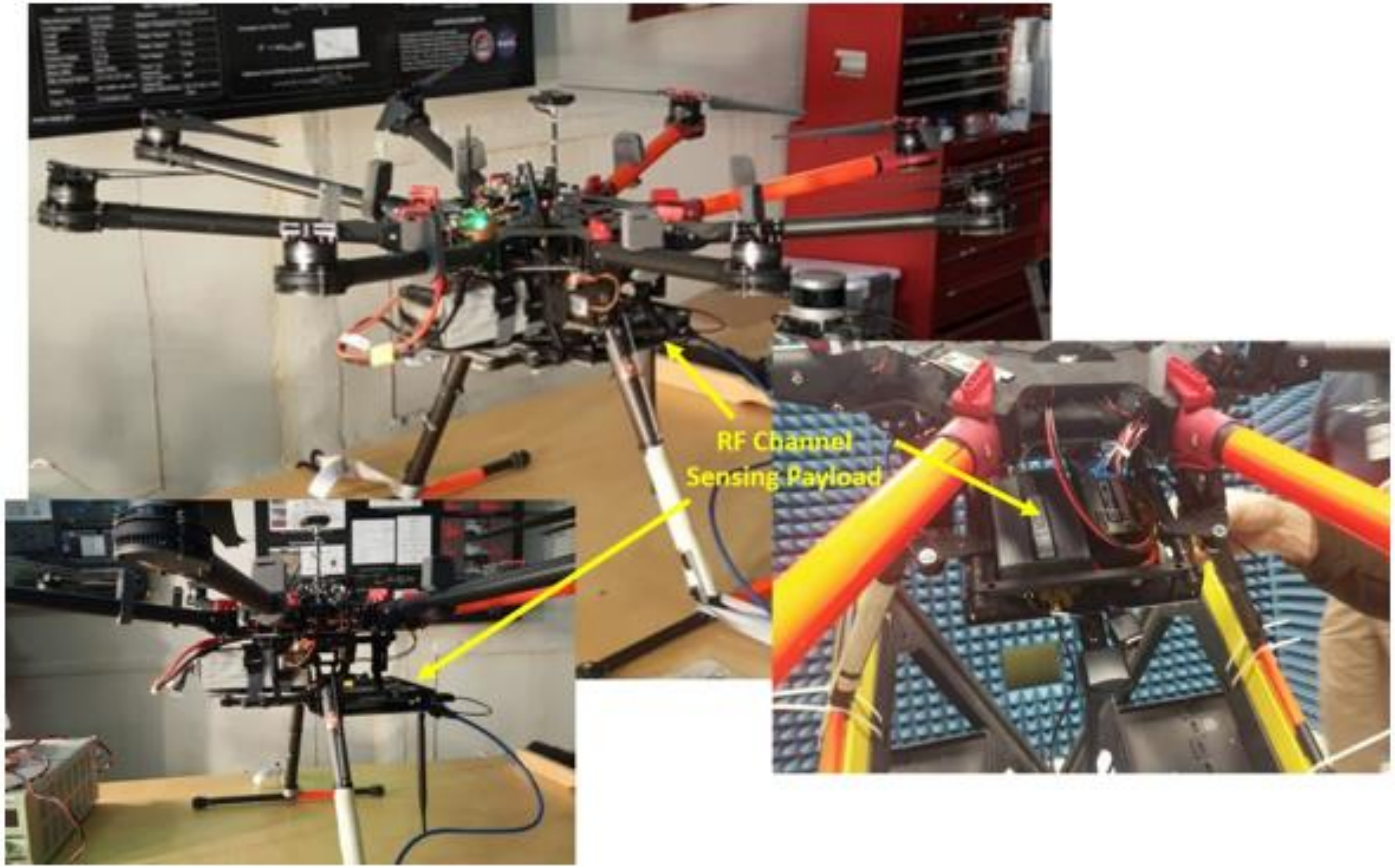
First flight tests – April 2018

The payload will be integrated with DJI model S1000, operated by NASA Ames Research Center for the first flight tests

- “Octocopter” with 8 4114 pro motors; 5 kg payload capability, 15 minutes flight time

Payload Design and Operations

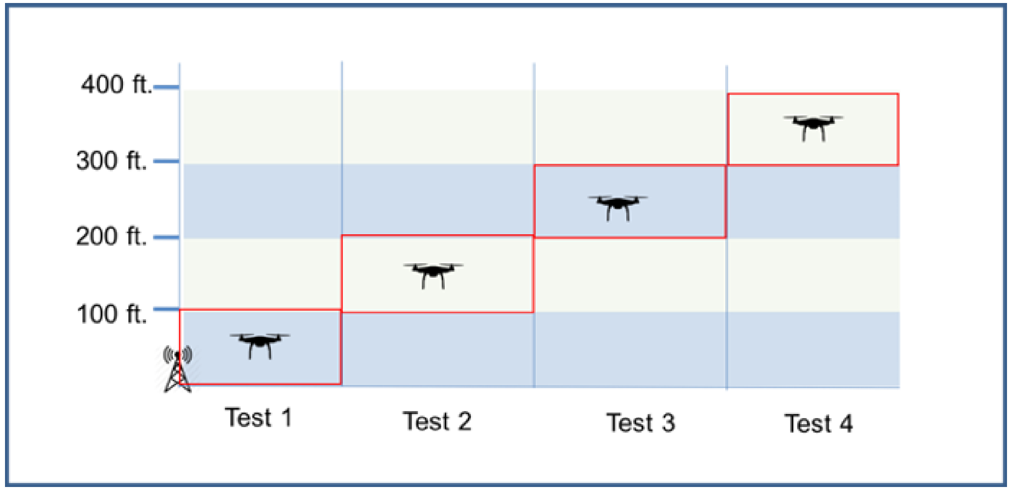
Payload – sUAS Integration



Flight Test

Initial flight testing will take place at NASA Ames Research Center/Moffett Field

- Evaluate three-dimensional spectrum coverage and signal strength provided by commercial wireless communications service providers in the vicinity of the test locations.
- A preliminary survey of the test area revealed the presence of AT&T, Verizon, Sprint and T-Mobile antenna systems located near testing locations.
- RF testing approach will consider samples at several altitudes between 0 and 400 ft. AGL utilizing an omnidirectional antenna



Flight Test Approach

Initial ground measurements

- Ground measurements of the RF environment will guide selection of the airborne frequencies of interest

Focus on LTE base station overhead transmissions

- Focus on LTE base station transmit bands, not on user equipment transmit bands
- Due to 500 kHz bandwidth limitation, look for main LTE channel where LTE overhead communication occurs

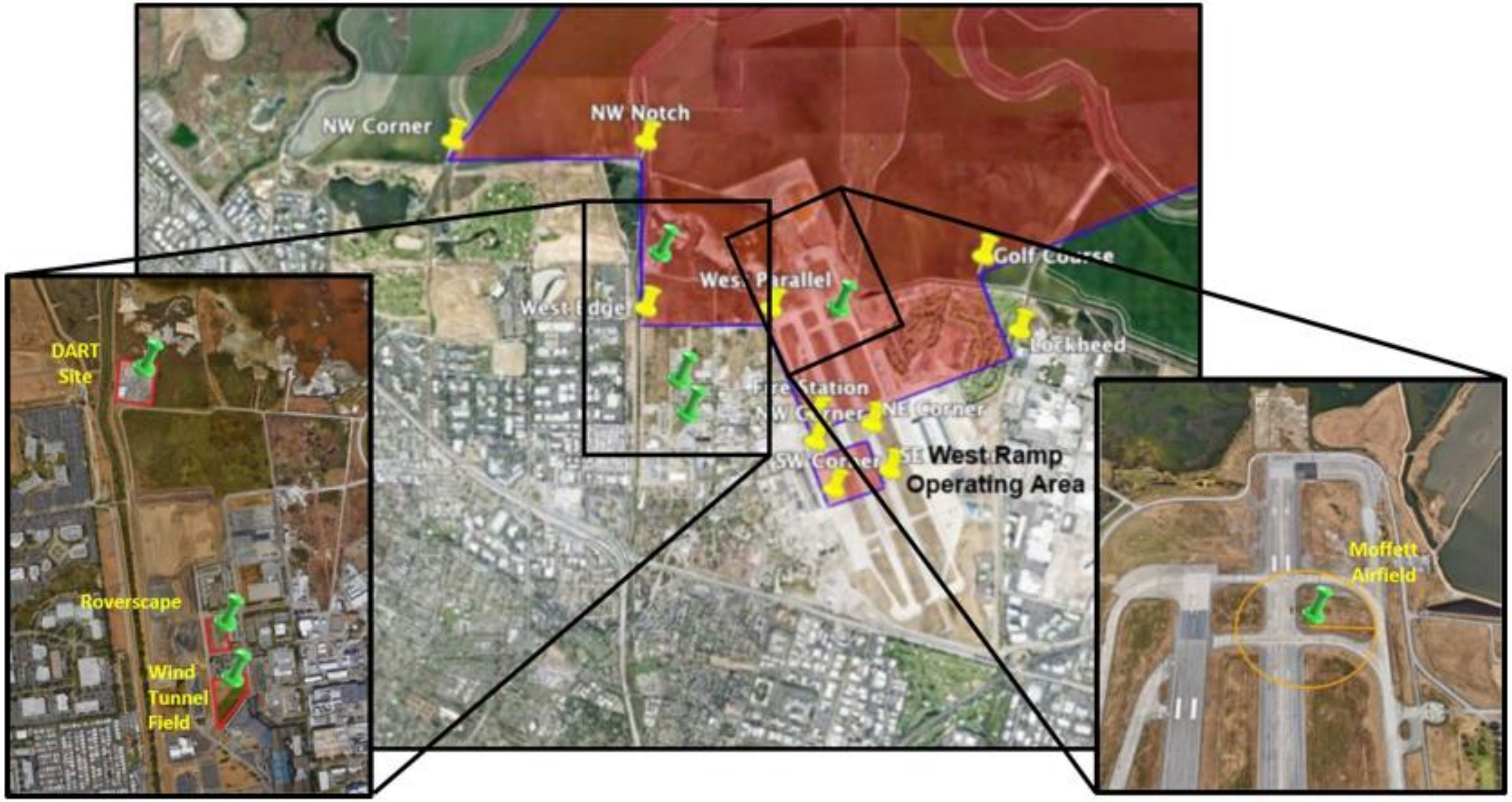
Measure altitude differences

- Capture enough spectrum data at 2 or 3 different altitudes at each service provider’s LTE frequency range
- Maximum altitude is 400 feet AGL

Flight Test

Possible flight test locations at NASA Ames

"DART" Site, Wind Tunnel Field, Roverscape, Moffett Airfield



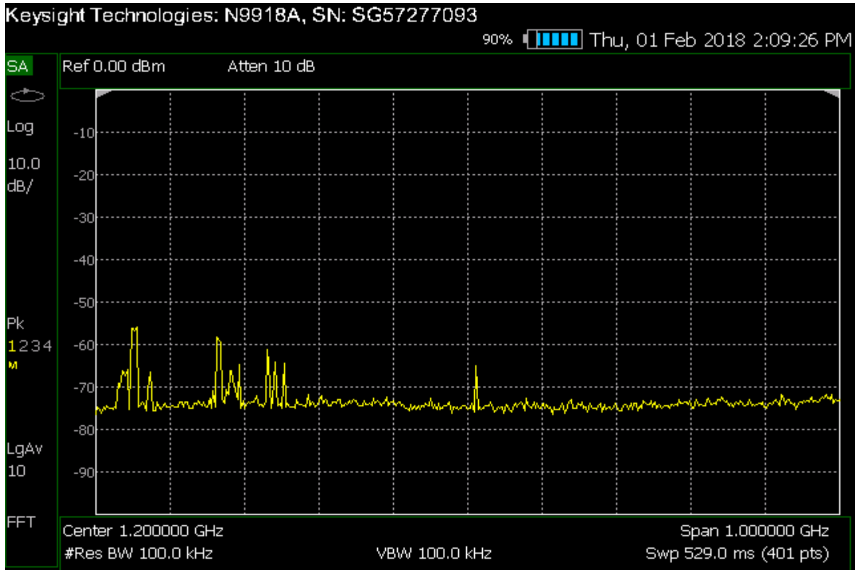
Flight Test

Flight Test Site Survey

Three possible flight test sites at NASA Ames Research Center/Moffett Field were surveyed during January 30-February 1 2018

- Moffett Airfield, the Wind Tunnel Field and the DART Site
- The site surveys considered physical suitability of the location for the RF channel sensing payload flight tests
- Surveys also included spectrum sensing surveys using a handheld spectrum analyzer to determine the presence of measurable signals

Signals in the 700-850 MHz LTE band are observed during the site survey at the DART Site



Summary

Summary

The NASA UTM Project aims to enable the safe and efficient integration of small UAS operations in large-scale at low altitudes

- Test and research activities are being conducted at six UAS test sites in the US

A key element under study is the performance of UTM C2 links

- Testing, modeling and simulation, and analysis of potential C2 performance

NASA Glenn has developed and will deploy an RF channel sensing payload

- The payload, based on SDR technology, will capture RF spectrum in several frequency bands of interest, in 500 kHz segments
- The payload fly on a DJI S1000, with first flight tests in April 2018
- Further development will increase the measurement bandwidth and add capabilities to analyze communications performance parameters, allowing C2 link performance to be correlated with the RF environment

Small UAS EMI Initial Assessment

Thank you!

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