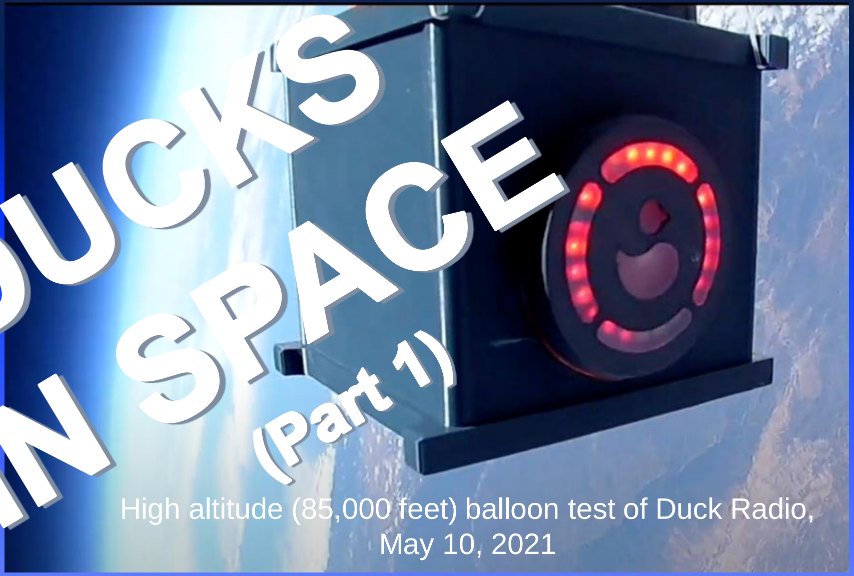
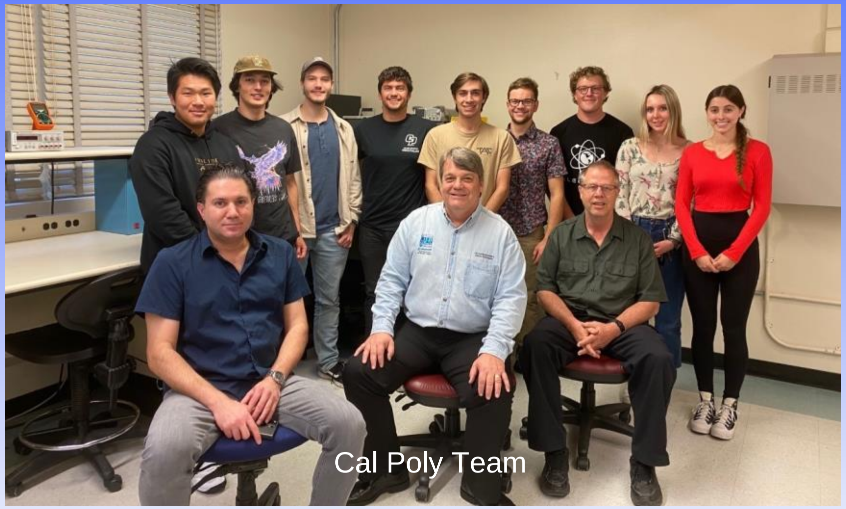
Ducks in Space:

Update on Improved Performance, Characterization and Path to Space for Project OWL's Duck Radios

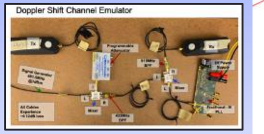
Rev: April 19th, 2023

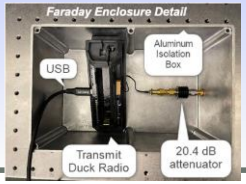


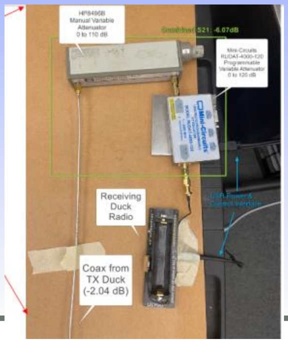
High altitude (85,000 feet) balloon test of Duck Radio, May 10, 2021

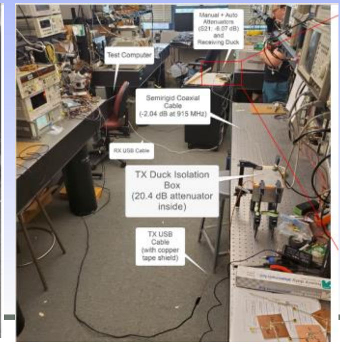


Lab Photos









OWL

CAL POLY
SAN LUIS OBISPO

Agenda

Part 1 – AERO (Wednesday)

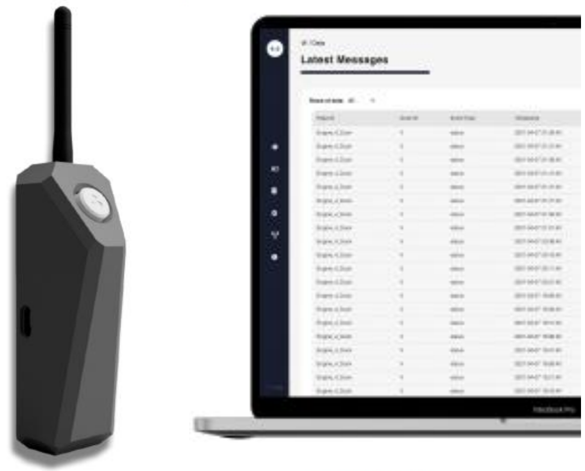
- **Background**
- **CONOPs**
- **Roadmap**

Part 2 – EE (Thursday)

- LEO Doppler Effects
- Alternate Frequency Bands
- CDP* Network Layer Research
- Contact Info

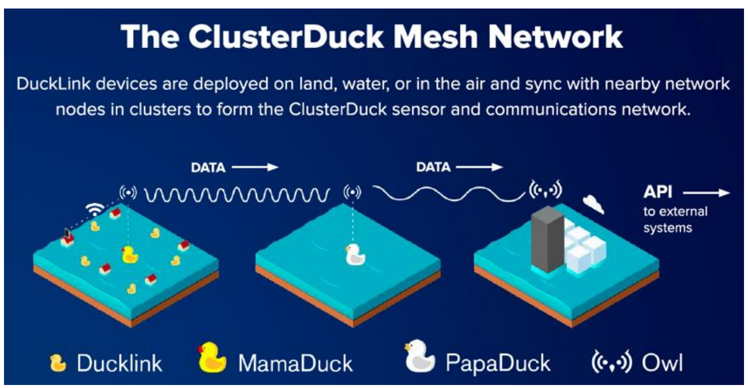
Project OWL Background

(•) OWL



Hardware
DuckLink Wireless Device

Software
OWL Data Management System (DMS)



- OWL provides **o**rganization, **w**hereabouts, and **l**ogistics through a simple communications and sensor network solution
- Mesh network protocol current using LoRa for PHYS layer
- Creates comm infrastructure where lacking or destroyed:
  - Remote locations (exploration) & war zones
  - Disaster (e.g., fire, blizzard, Post *Hurricane Maria* deployment Puerto Rico)
- LoRa based, open source "ClusterDuck Protocol"

www.clusterduckprotocol.org

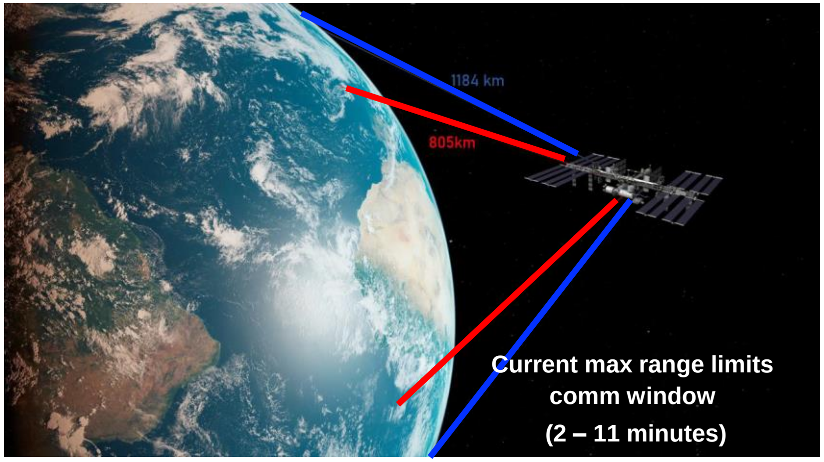
CAL POLY
SAN LUIS OBISPO

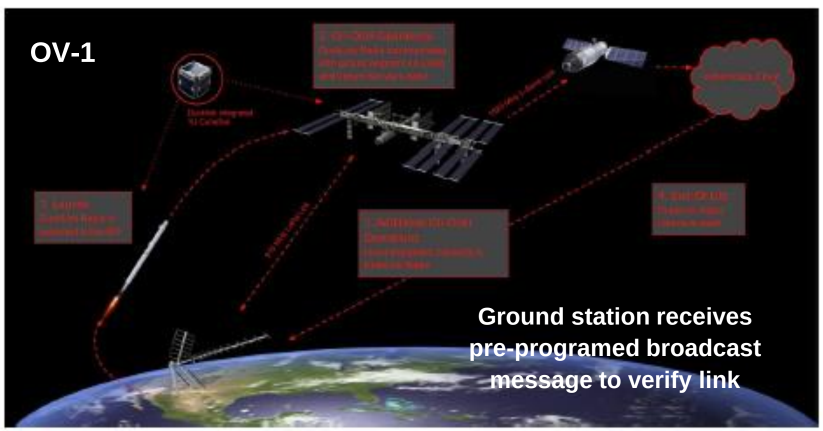
- Student & faculty support
  - AERO, CPE, EE, ME students
- Balloon launch resources
- Flight test / demonstrations
- Hardware and computing resources
- ***Lab characterization***
- ***Performance improvement***
- ***Path to space***

In 2021 Cal Poly Demonstrated 850 km range with reasonable BER at 2.4 kbps

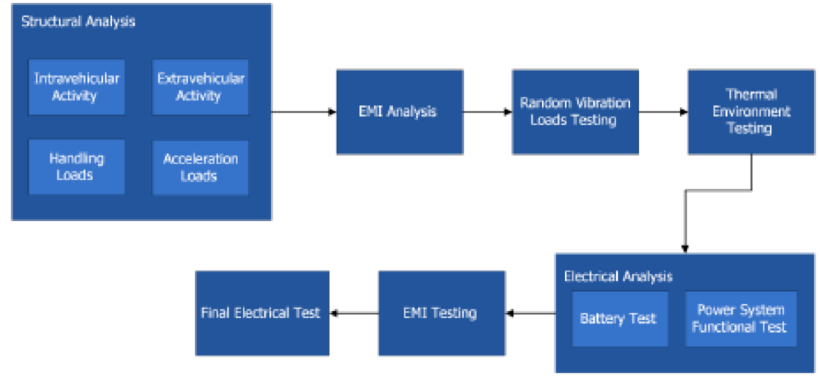
CONOPs & Space Test Plan

CONOPs

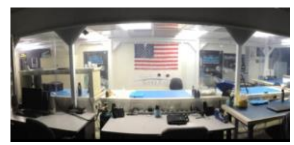




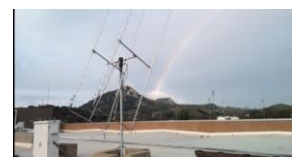
Test Plan & Facilities



Cal Poly Facilities



Cleanroom



Ground Stations

Airborne Test

Vibration Tables

TVAC Chambers

PolySat Team

Space-flight documentation developed
Cal Poly facilities & capabilities meet space test requirements

Project OWL-Cal Poly Roadmap

Developing & demonstrating a space capable product assures a robust platform for airborne and disadvantaged users

Key

✓ Complete
○ In work

Funding Sources

- Internal/ Private
- STTR I
- STTR II

Initial Capability & Updates → Space Feasibility → Improvements & Lab Tests → Productization & Pathfinder Demos

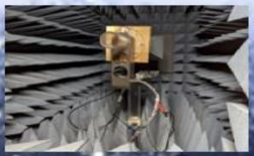
SpaceDuck One 2019

- ✓ Initial Electronics **(Foreign Chipset)**
- ✓ Initial High-Altitude Flight (Balloon)

SpaceDuck Two / Cal Poly Capstone 2020-2021

- ✓ Balloon Range Demo (Balloon) (>25 km)
- ✓ Improved Electronics **(Foreign Chipset)**

1st STTR 2022



- ✓ BER Test Environment (Lab)
- ✓ Space Range Demo (Lab) (850 km)

2nd STTR 2022-2023

- ○ Improved Firmware Demo (>25 km)
- ○ Improved Electronics **(Domestic Chipset)**
- ✓ Alt. Band Set-up for Improved Range (Lab)
- ✓ Improved Thru-put Firmware (>75%)
- ✓ Space Test Plan & CONOPs
- ✓ Static Doppler Simulation (Lab)

STTR II 2023-2024

- **Improved Electronics & Firmware Integrated Demo (Aircraft)**
- **Space Pathfinder Environment Test (Vibration, TVAC)**
- **Automated Electrical Test Environment**
- **Alt. Band for Improved Range Demonstration**
- **Dynamic Doppler Demonstration (Lab)**
- **Dynamic Doppler Simulation (Lab)**

Cal Poly Facilities

Airborne Test

Ground Stations

TVAC Test

Vibration Test

Cleanroom

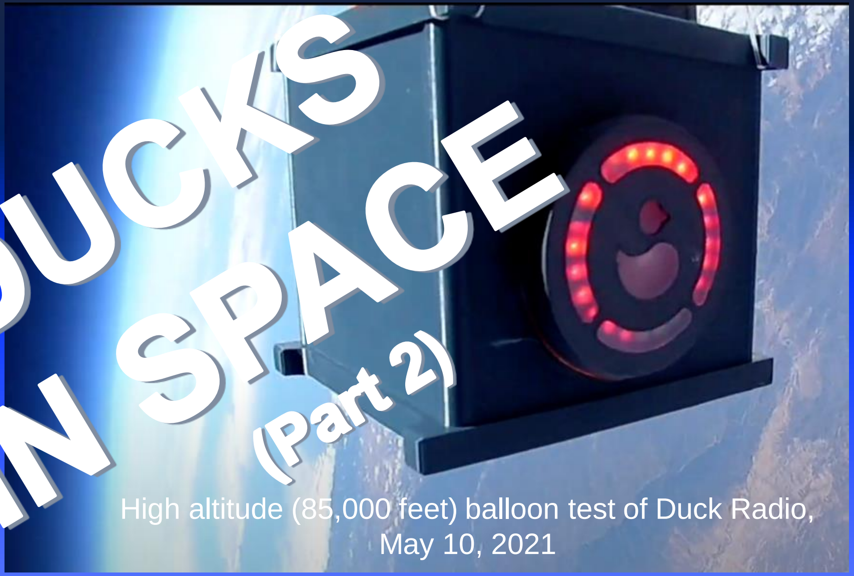
Questions

?

Ducks in Space:

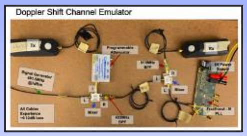
Update on Improved Performance, Characterization and Path to Space for Project OWL's Duck Radios

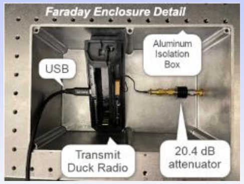
Rev: April 19th, 2023

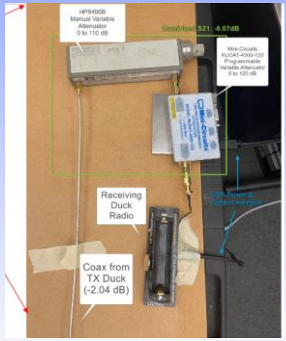


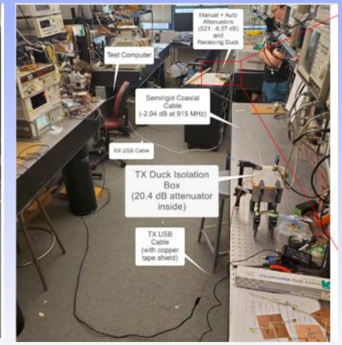
High altitude (85,000 feet) balloon test of Duck Radio, May 10, 2021

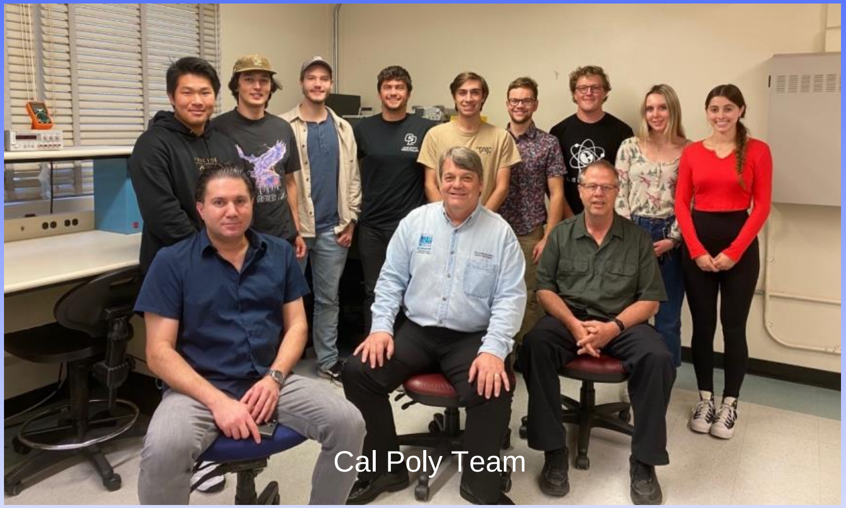
Lab Photos











Cal Poly Team

OWL

CAL POLY
SAN LUIS OBISPO

Agenda

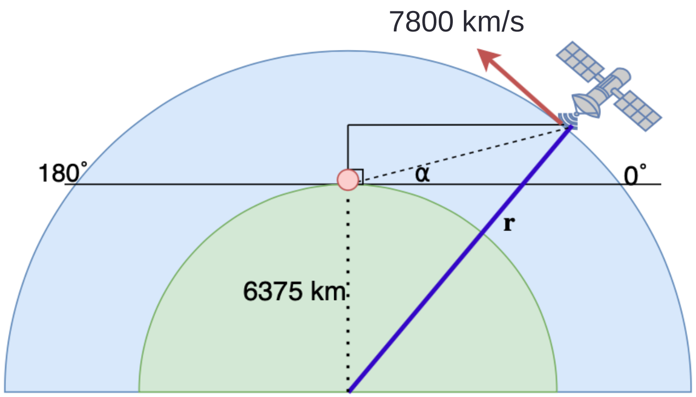
Part 1 – AERO (Wednesday)

- Background
- CONOPs
- Roadmap

Part 2 – EE (Thursday)

- **LEO Doppler Effects**
- **Alternate Frequency Bands**
- **CDP* Network Layer Research**
- **Contact Info**

LEO Doppler Effects

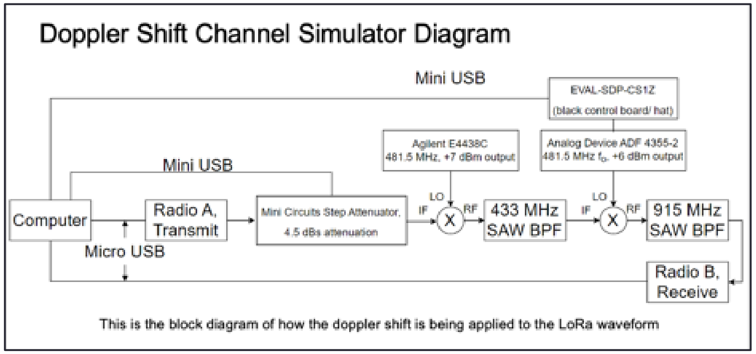


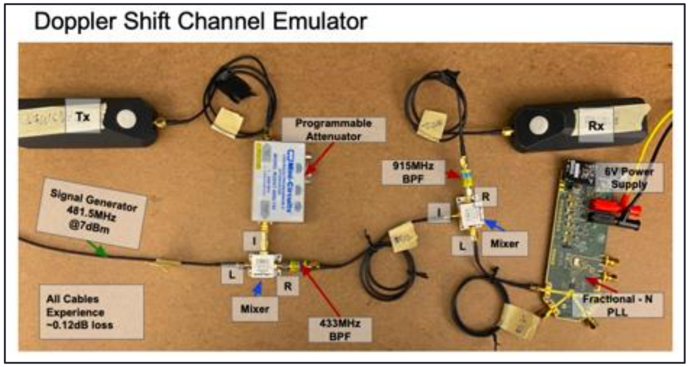
Relative motion of a LEOSAT to a ground station

Angle [˚]	Doppler Shift [kHz]
0	23.79
30	20.60
55	13.65
90	0.00

Doppler Shift at 7,800 km/s at 915 MHz, varying with angle of elevation

Test Set-up





Results & Next Steps

- ✓ Measured BER less than 7E-7 in the presence 23 kHz static doppler with high SNR
- ○ Measure performance over entire signal space of LoRa for static offsets at lower SNRs
- ○ Develop software that allows for dynamically control of the offset frequency

Reasonable BER performance demonstrated despite doppler shift (static), developing dynamic test environment

Alternate Frequency Bands

Goals

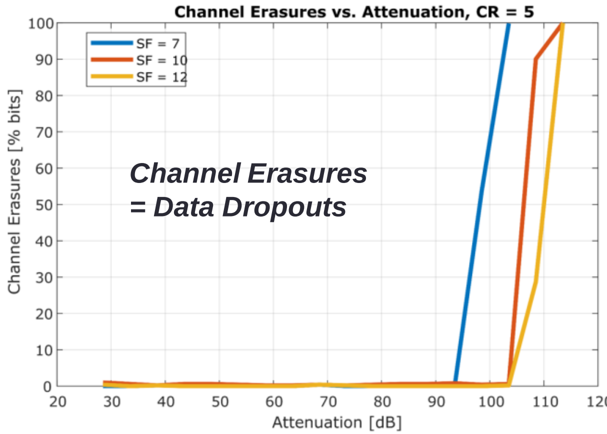
- Validate previous work by Nottberg, Gumus [1].
- Demonstrate a *robust* Duck Radio satellite-terrestrial link

Hypothesis

- Switch LoRa frequency to amateur band with higher authorized output powers to improve robustness/range

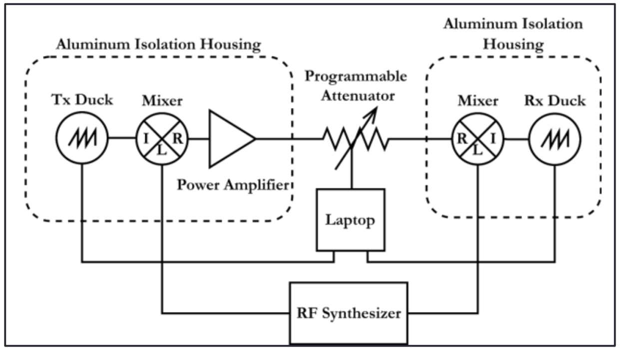
Frequency Band	Frequency (MHz)	Max Tx Power (dBm)	Range Factor 1X = 100%	Comment
ISM	915	30 (20 typ)*	1X	Current capability, experimental
33 cm	1270 - 1295	37	>3X	Possible alternative, computed
23 cm	2300 - 2310	40	>4X	Possible alternative, computed
13 cm	2390 - 2450	40	>4X	Possible alternative, computed

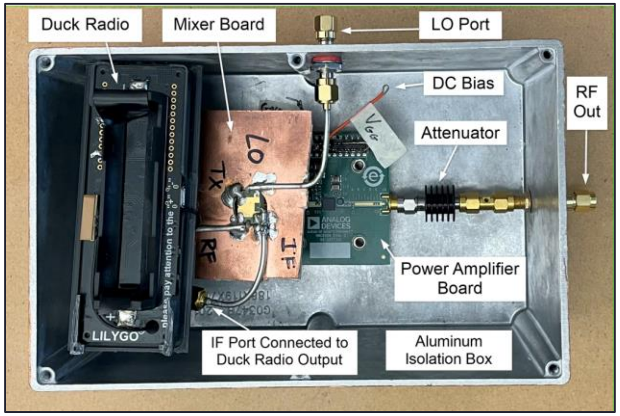
*14 dBm regulatory limit



As attenuation increases, the channel erasure rate increases

Test Setup





Transmitter module

Results & Next Steps

- ✓ Channel erasures accurately depict system reliability
- ✓ Improved Tx-Rx isolation
- ✓ Updated max power estimates
- ○ Perform amateur radio band data analysis, varying LoRa parameters
- ○ Verify estimates via performance tests

[1] K. Nottberg, O. Gumus, "Project OWL LoRa Device BER Estimation and Distance Test Report," 2021.

Implementing test environment to characterize performance in alternate bands

CDP Network Layer Research

Background

- OWL's Cluster Duck Protocol (CDP) mesh network allows users to transmit independently using a Pure ALOHA (p-ALOHA) methodology.
  - When a user has data to send, immediately send it
- This p-ALOHA method can result in interfering messages ("collisions"), reducing capacity and successful data throughput
- p-ALOHA significantly hinders network performance when there is high activity

Experiments to overcome p-ALOHA

- Implemented a lightweight Listen Before Talk (LBT) Backoff algorithm into network firmware
- This LBT is referred to as a Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) method
- Ran four 65-minute 19-node network tests:
  2 tests: p-ALOHA firmware network
  2 tests: CSMA/CA firmware network
- Measured successful data throughput for each test

Performance Metrics (65 minutes/test)

Received Packet Ratio:

- $$Received\ Packet\ Ratio = \frac{Total\ Packets\ Sent\ by\ DuckLinks}{Total\ Packets\ Received\ by\ PapaDuck}$$

ACK'ed Packet Ratio:

- $$ACK'ed\ Packet\ Ratio = \frac{Total\ Successful\ ACK\ Packets\ Received\ by\ DuckLinks}{Total\ Packets\ Sent\ By\ DuckLinks}$$

ACK'ed Data Ratio:

- $$ACK'ed\ Data\ Ratio = \frac{Total\ Number\ of\ Bytes\ Successfully\ ACKed\ (from\ ACK\ Packets)}{Total\ Bytes\ Sent\ by\ DuckLinks}$$

Successfully ACKed/Confirmed Data Throughput:

- $$ACK'ed\ Throughput = \frac{Total\ Number\ of\ Bits\ Successfully\ ACKed\ (from\ ACK\ Packets)}{Time\ of\ test\ in\ seconds\ (3900\ seconds)}$$

Summarized Test Results

Average of Results	Received Packet Ratio	ACKed Packet Ratio	ACKed Data Ratio	Successful / ACKed Data Throughput [bps]
Average non-CSMA MAC	0.55205	0.29877	0.25525	40.087
Average CSMA MAC	0.6459	0.4794	0.464	71.5265
Non-CSMA to CSMA Relative Improvement	1.170	1.605	1.818	1.784

>75% Improvement (1.784X) Demonstrated

Current Research Team Members

Faculty
- Steve Dunton (EE), Principal Investigator sdunton@calpoly.edu
- Dennis Derickson, Ph.D, P.E. (EE) dDericks@calpoly.edu
- Payam Nayeri, Ph.D (EE)

Graduate Student (EE)
- Firmware Lead and SME: Kevin Nottberg (EE)

Undergraduate Students (AERO)
- Lead: Abigail Outcalt
- Support: Cole Sterba

Undergraduate Students (EE)
- Doppler: John Gharib, Ariel Freiman
- Alternate Bands: Daniel Montgomery Lucas Lucia, Daniel Xu
- Support: Annabella Piercey

Sponsor
- Bryan Knouse, CEO, OWL Integration bryan@owlintegrations.com

Staff
- Contracts: Marianne Green
- Admin/Purchasing: Yvonne Lynch

Questions

?