Measuring Fixed Wing UAS Networks at Long Range

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Unmanned Aerial Systems (UAS) Today

- Rapid growth.
  - FAA predicts low, base, and high forecast of 17%, 25%, and 36%, respectively, for professional-grade UAS through 2023 [FAA Aerospace Forecast 2019-2039].

- UAS are often used for sensor data collection.
  - Collect and send to ground (e.g. Video, SAR, LiDAR).

	Total non-Model Fleet (no. of '000 units)		
year	Low	Base	High
2018	277	277	277
2019	369	400	426
2020	460	545	638
2021	552	711	932
2022	588	789	1,112
2023	603	835	1,290

FAA growth predictions

SAR Image

Video

Motivation:

- Limited understanding of UAS networking at long distances.
  - UAS networking studies have been executed at short distances.
  - Limited work in extensive distances (e.g. exceeding miles). Mostly only theory.
  - Current FAA regulations typically limit UAS flights to visual line of sight and altitude of 400 feet, however, there is much interest in going to larger distances and regulations are beginning to support this worldwide.

- We seek to understand how UAS networking performs at the edge of connectivity?
  - How does networking performance vary with the dynamic nature of flight?
  - How does the orientation or flight path of the UAS affect performance?

Contributions:

- Conduct a long range measurement study from a fixed wing UAS over a 2-day period at distances exceeding traditional civilian regulations.

- Distinguishing aspects:
  - Long range distances (compared to work within visual line of sight).
  - Fixed wing UAS (compared to multirotor).
  - Tactical Radios (compared to LTE / WiFi).

- Findings:
  - Throughput and periods of dropout varies with flight path.
  - Orientation of the plane relative to the ground node also significantly impacts the network performance.
    - More relevant to fixed wing UAS.

Background: UAS fixed wing vs. multirotor.

- Differences.
  - Fixed wing are similar to traditional aircraft (central body and two wings).
  - Multirotor are similar to a helicopter, with four (quad) or more rotors.
  - We focus on fixed wing systems, since UAS surveillance applications benefit from the longer endurance fixed wing UAS.

Fixed wing

Multirotor

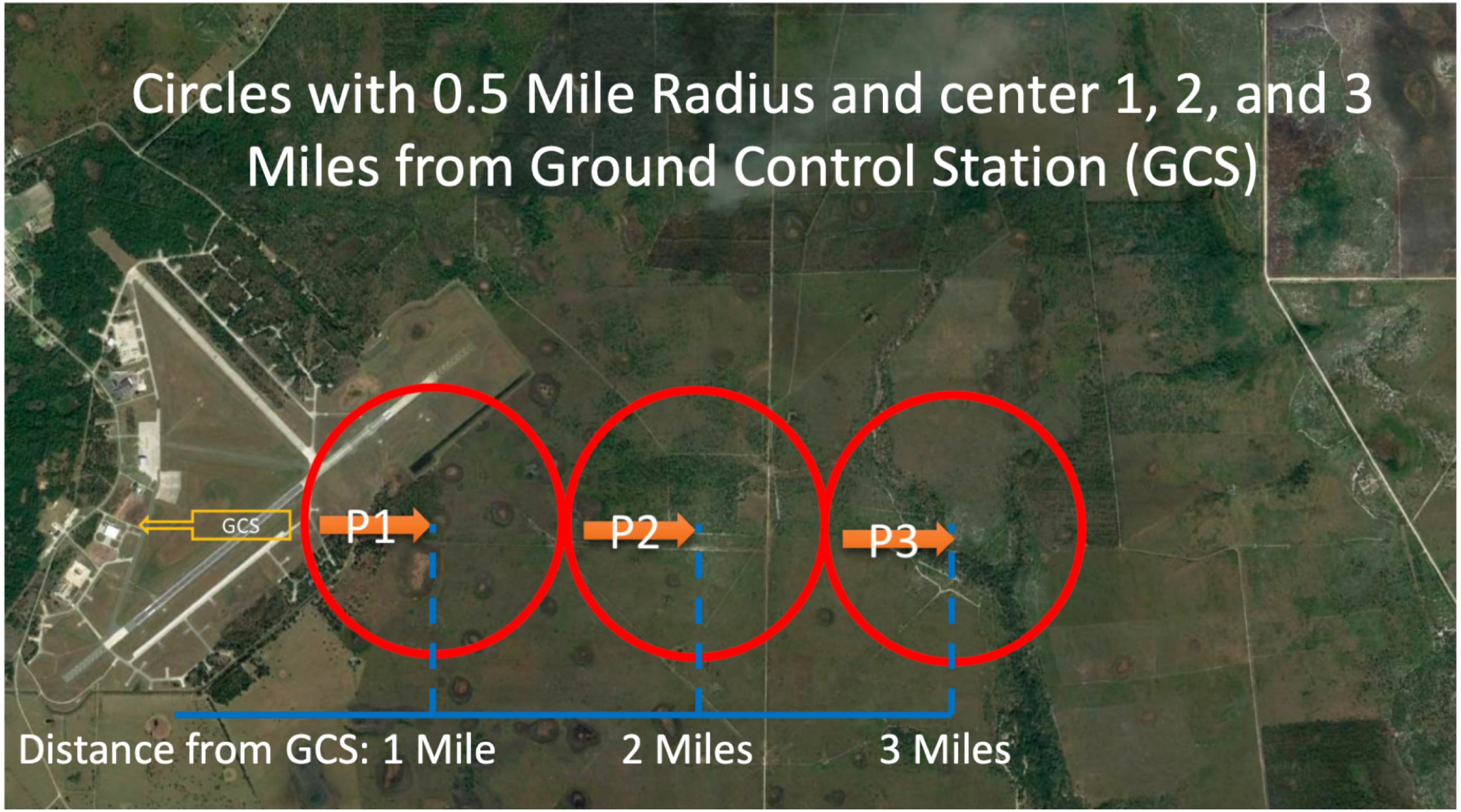
Radios communication

- Tactical radios.
  - Used in military for years, but since adopted by Government and commercial entities.
  - Commonly used to achieve goals in disaster relief, fighting wildfires, law enforcement, and crowd management and surveillance.
  - Full infrastructure in each radio (no pre-existing infrastructure required).

- Antenna Types.
  - Both omnidirectional (omni) and directional are relevant for ground.
  - Omni on UAS with dynamic flight.

Flight plan

- Worked with Air Force Research Laboratory (AFRL) for approval to fly beyond FAA limits.
  - Flew Bat-4 (made by Martin UAV) at 1500 ft altitude (AGL) and 50-60 kts airspeed.



Flight Plan

Data analysis on config / distance:

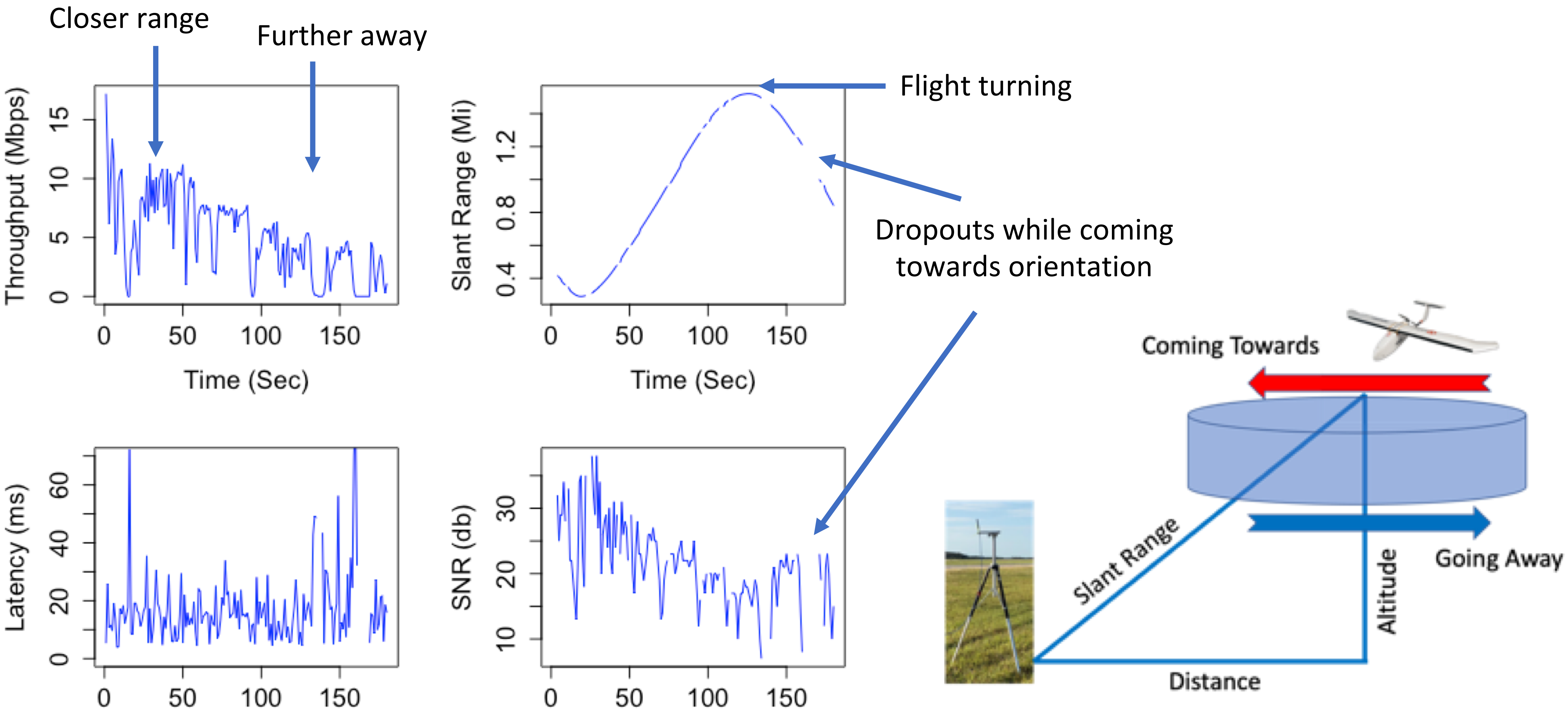
- Network testing.
  - Used iPerf to push data through the network and record throughput.
  - Recorded throughput, latency, Signal-to-Noise Ratio (SNR), and location data.
- We focus on the long distance test cases (especially with the omni antenna on the ground).
  - Provides interesting results at the edge of connectivity.
  - Varied power to emulate different types of directional antenna gain – refer to low power 63mW as “directional” (equivalent to 12 dBi gain directional antenna).
  - Paper provides more details on directional results.

Config:	1 Mile	2 Miles	3 Miles	4 Miles
Omni 2W	5.03	2.31	0.97	1.32
Dir 2W	15.40	13.20	12.00	10.80
Dir 63mW	10.80	6.90	4.92	3.26

Circle Orbit Average Throughput

Data analysis: 1 mile omni orbit

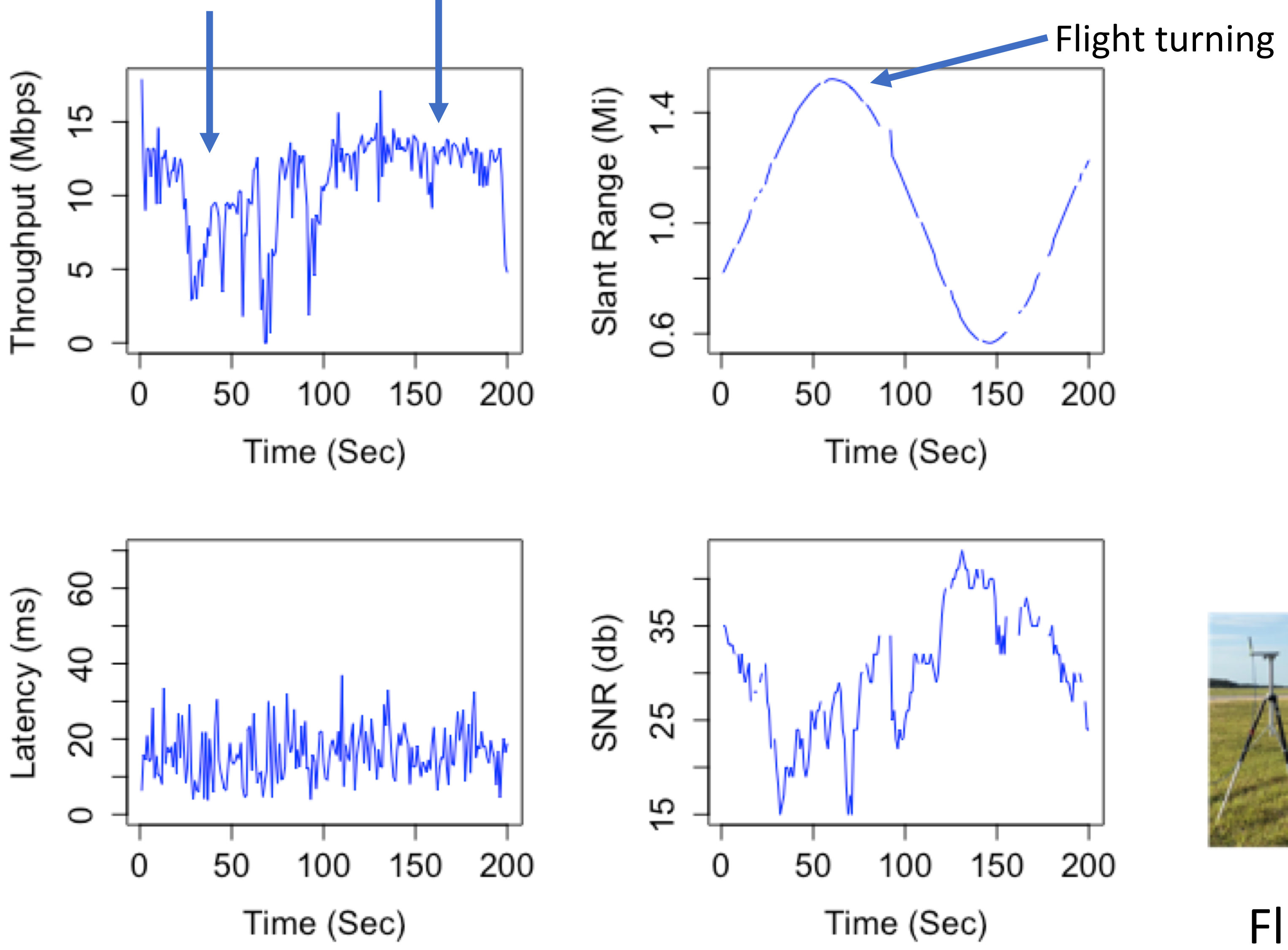
- 5.03 Mbps Average Throughput.

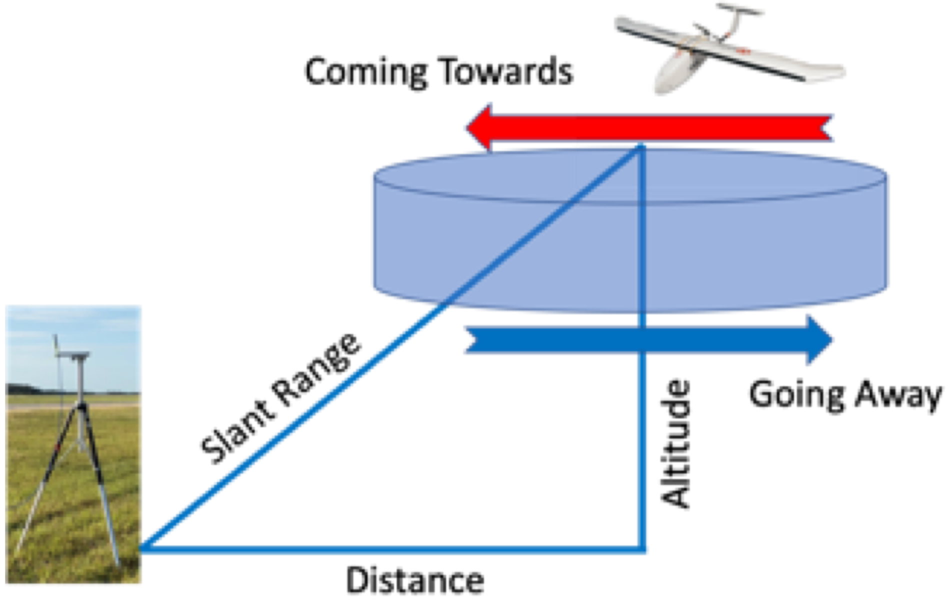


Flight Orientation Terminology

Data analysis: 1 mile directional orbit

- 10.80 Mbps Average Throughput.

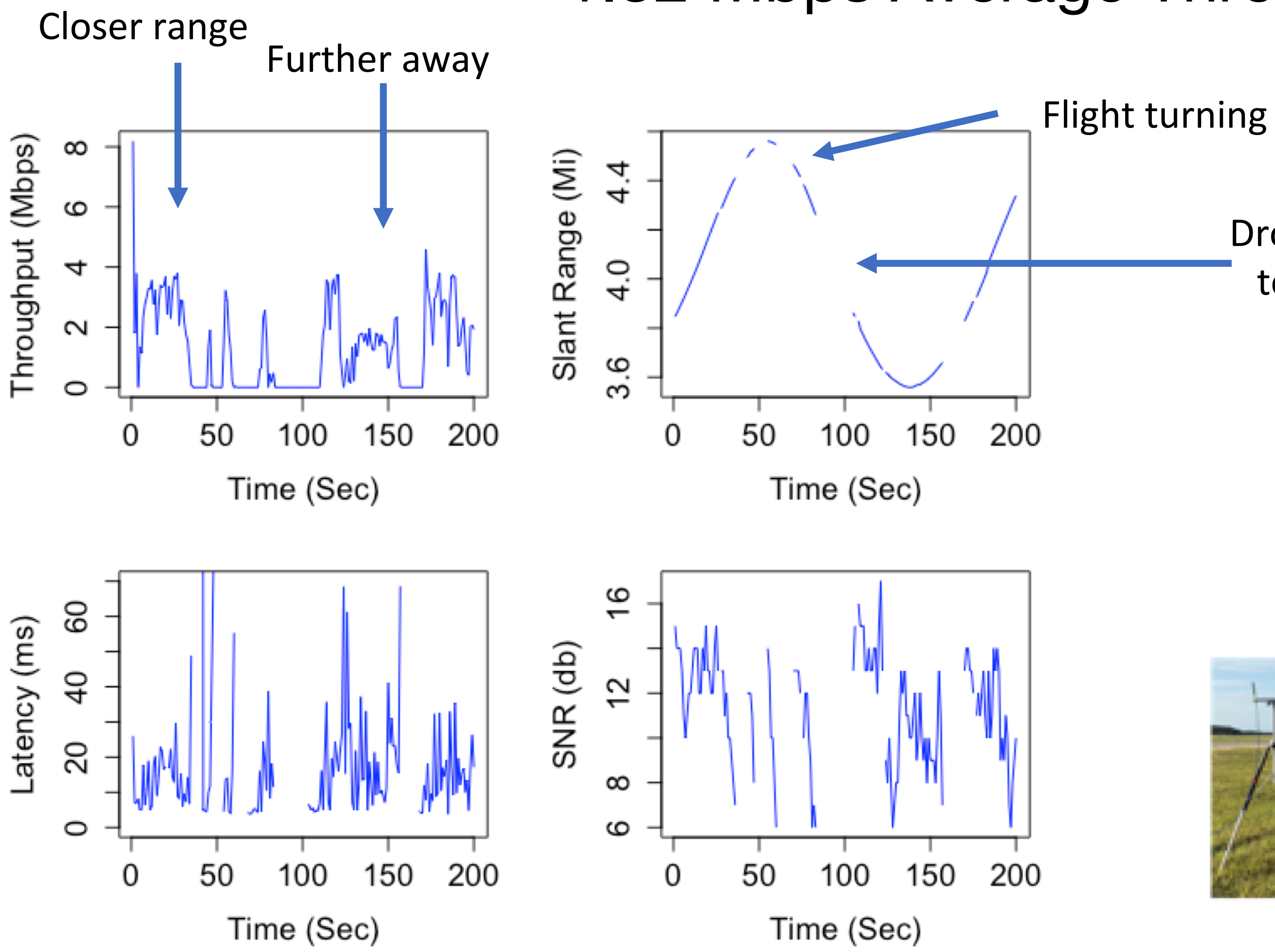


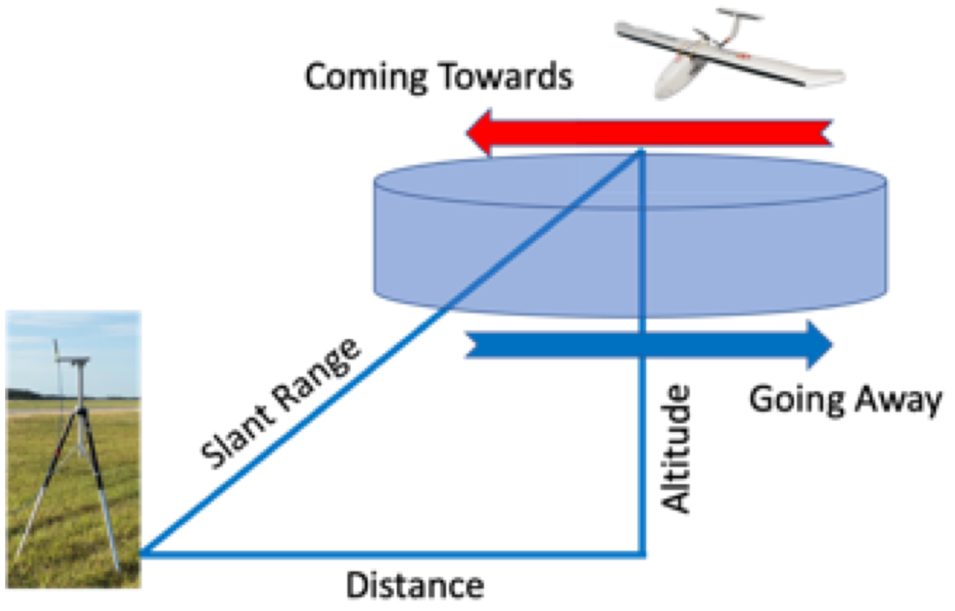


Flight Orientation Terminology

Data analysis: 4 mile omni orbit

- 1.32 Mbps Average Throughput.

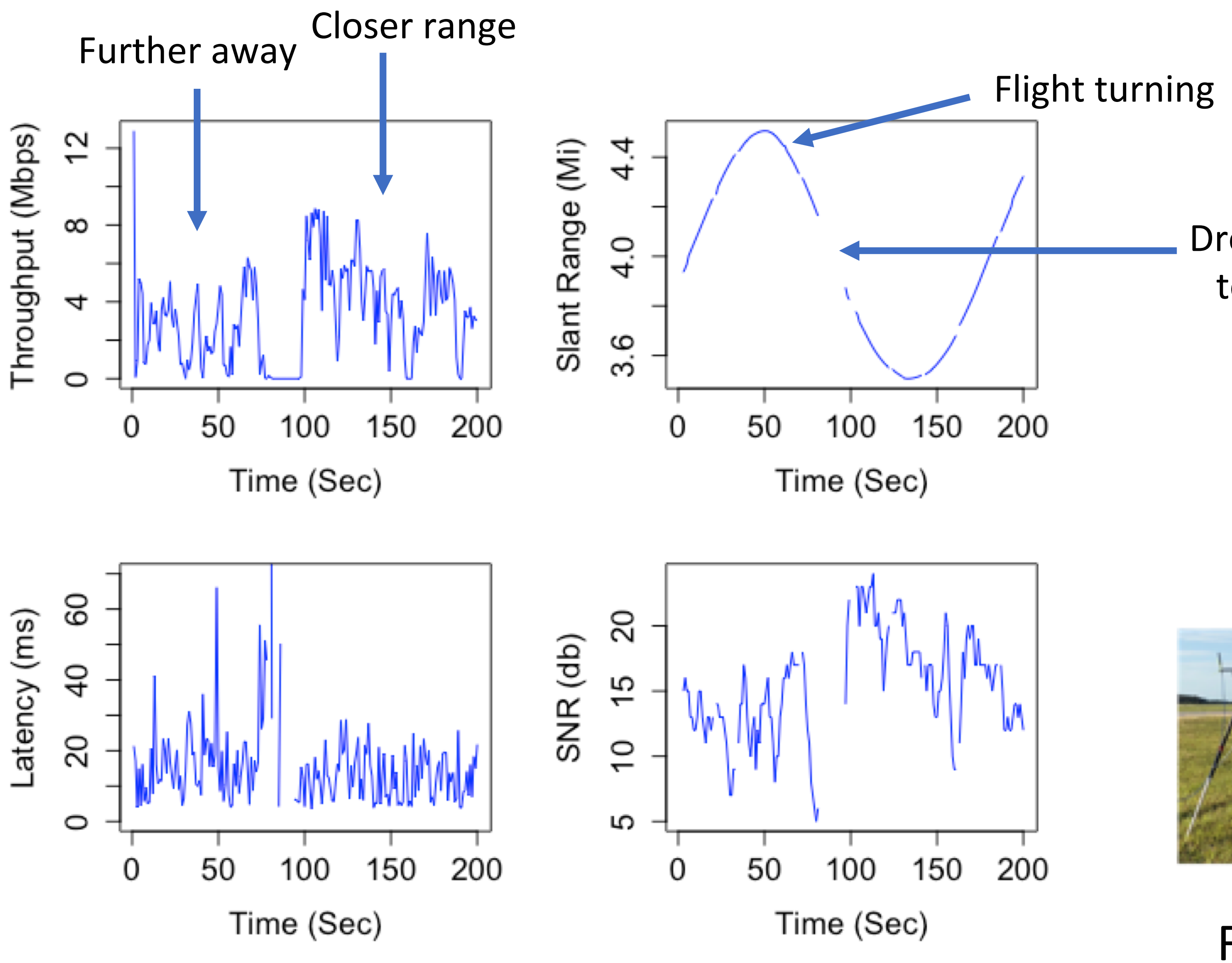


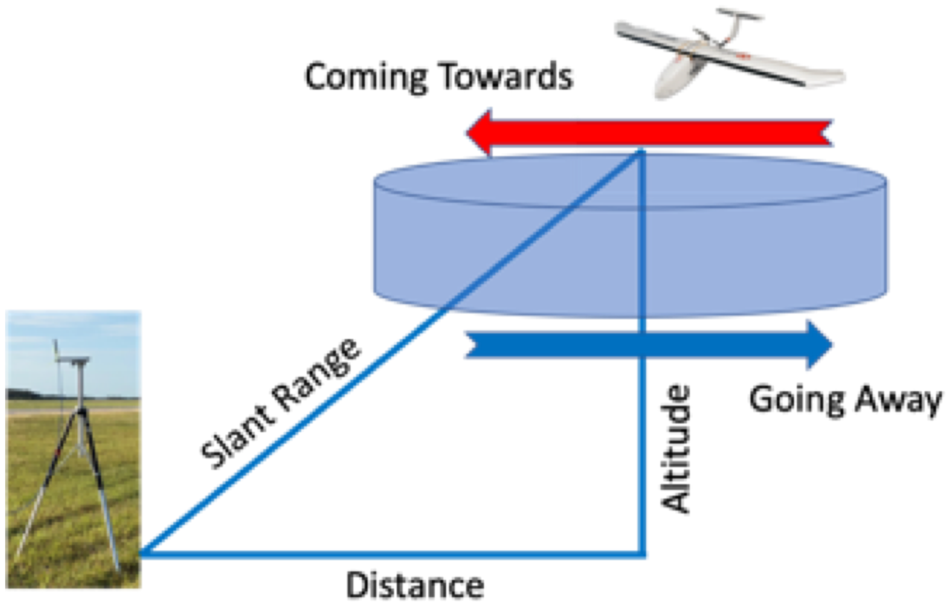


Flight Orientation Terminology

Data analysis: 4 mile directional orbit

- 3.26 Mbps Average Throughput.

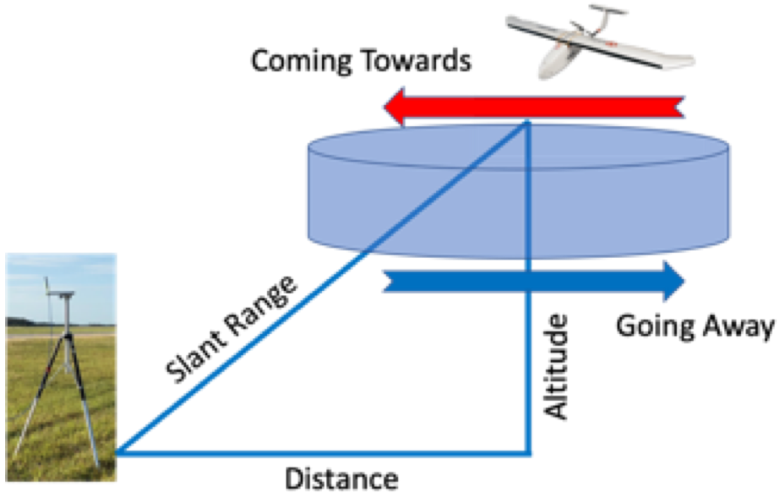


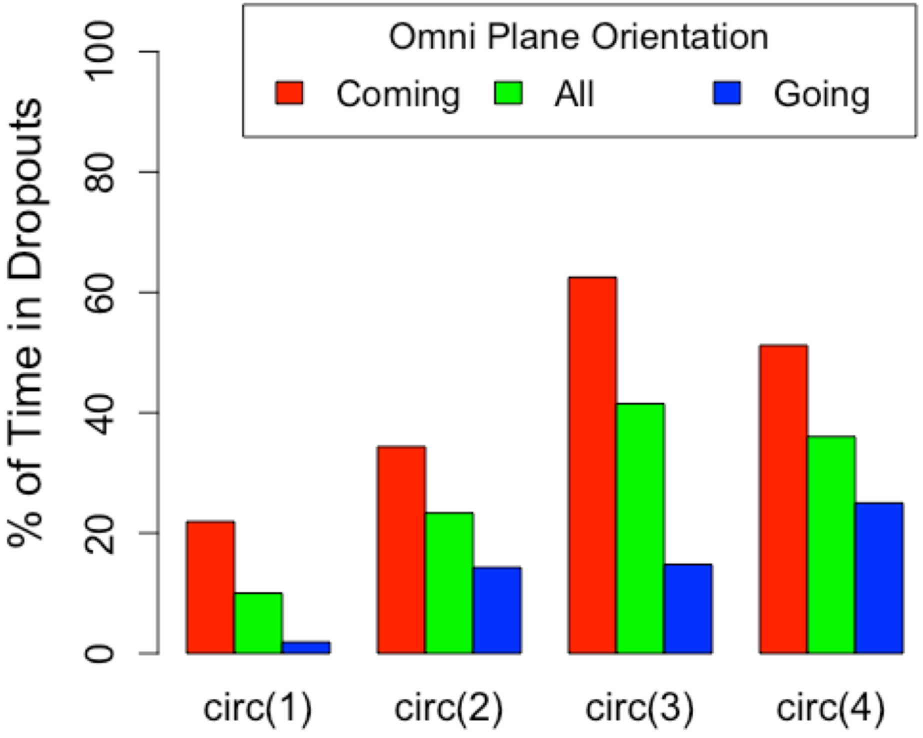


Flight Orientation Terminology

Dropout analysis

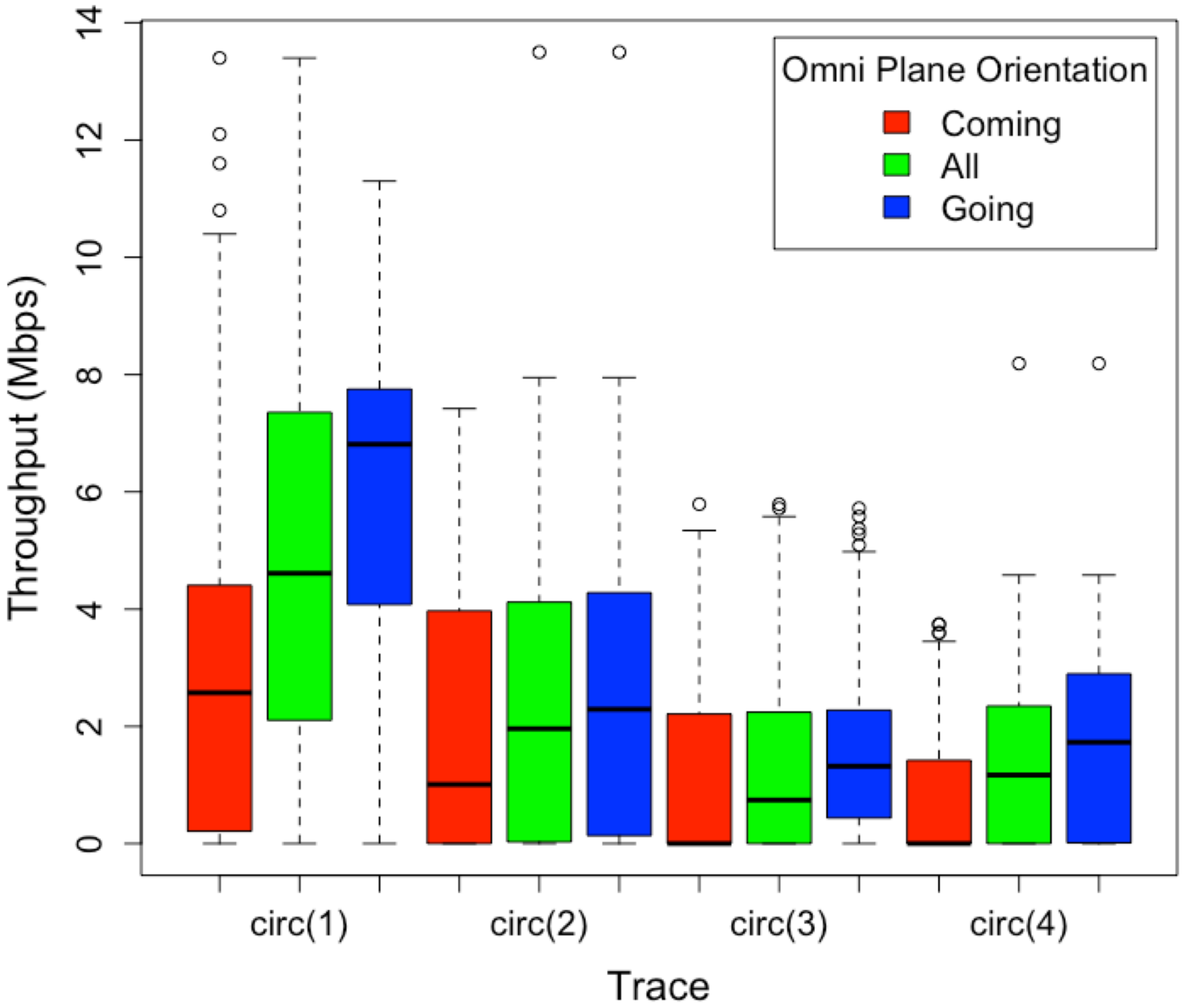
- Observations:
  - Higher dropout when coming towards orientation than going away.
  - Performance decreases as distance increases.
  - A decrease in dropout from circ(3) to circ(4).
    - This is due to the UAS having more time in the going away orientation during circ(4), compared to circ(3).





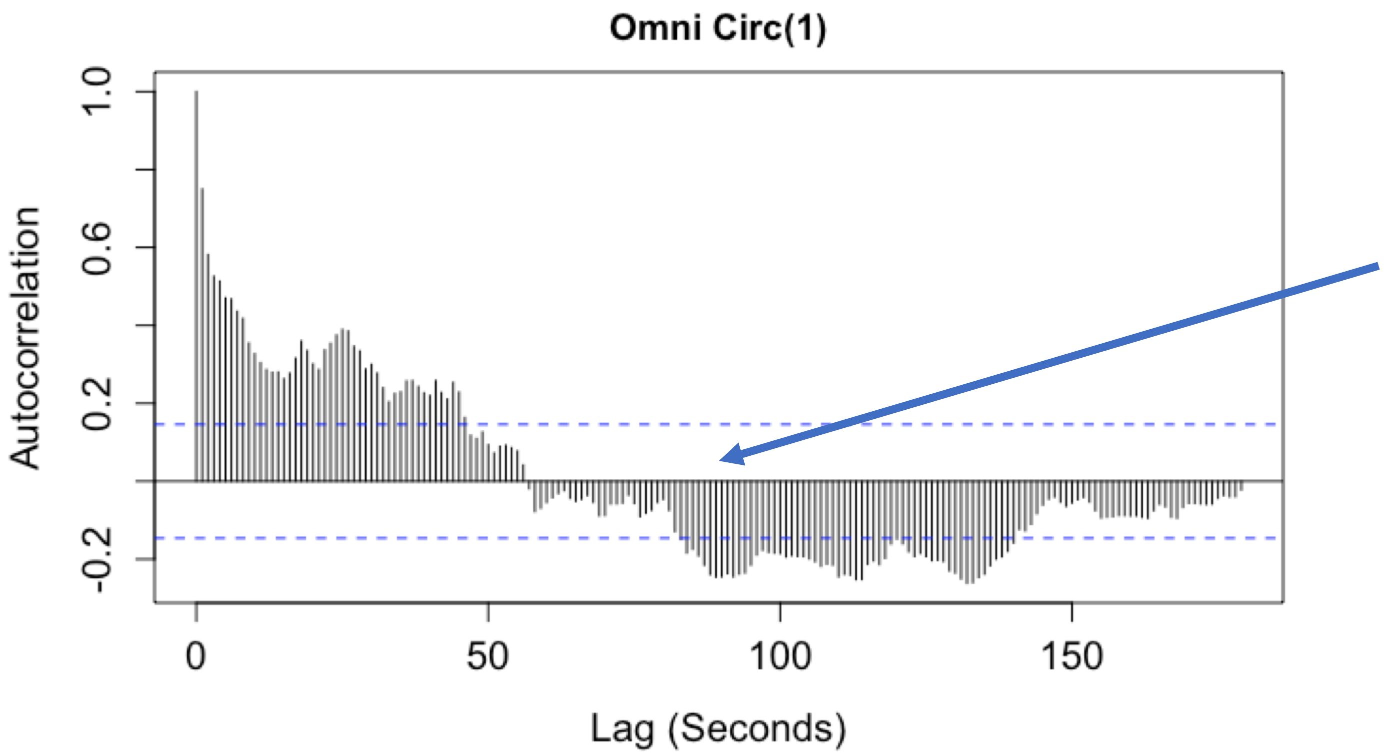
Throughput analysis (boxplot)

- Observations.
  - Throughput decreases as distance increases.
  - Performance better when in going away orientation.



Throughput time series analysis

- Autocorrelation: how much correlation of previous throughput over time.
  - Dashed lines indicate a 95% confidence interval for an uncorrelated process.
    - In other words, if the samples were uncorrelated over time, we would expect the sample autocorrelation at each lag to be inside the indicated bands with 95% confidence.
  - Implications for predictability of throughput based on delay (lag) of correlation of data.
    - Below 0 indicates negative correlation (above is positive correlation).



Correlation when close together.
Anti correlation further away
(switch of plane orientation)

Conclusions and implications

- Measured network performance across flight tests over a 2-day period at distances exceeding civilian regulations.

- The uniqueness of our measurements is in:
  - Fixed wing UAS, long range distances, and tactical radios.
- Large impact of orientation, with expected variance based on distance.
  - Quantified performance for future system design.

- Our results show promise for creating UAS networking applications at long distances with tactical radios.
  - Even in the worst case at the edge of connectivity some sensor applications could be utilized, but dropouts must be considered.

Thank you!

Questions? Please email..

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