ADAPTIVE DRONE FLIGHT USING REAL-TIME 5G RF DATA

PROJECT BACKGROUND & OBJECTIVES

Drones show promise as wireless service devices but often face signal loss at higher altitudes due to down-tilted cell sites and ground-focused signal mapping [1].

To address this, we aim to design an adaptive flight planning algorithm for reliable 5G connectivity in 3D airspace, supporting future aerial network services.

Fig. 1. Aurelia X4 Drone used for test flights.

In this project, we...

- Analyze radio frequency (RF) key performance indicators (KPIs) and signal patterns.
- Develop a path-planning cost function.
- Test and refine the algorithm via simulation and real-world flights.

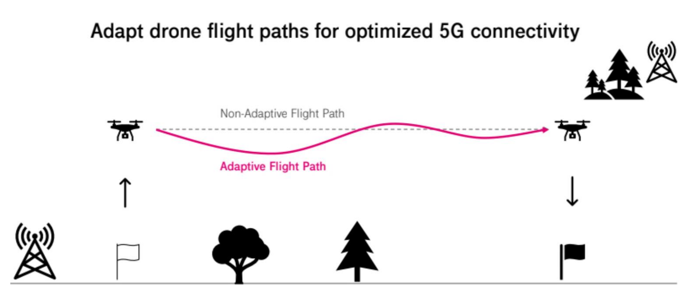

Fig. 2. Diagram of potential adaptive flight path.

FLIGHT DATA COLLECTION

Three flight strategies were used for RF data analysis:

1. **Baseline** – Straight flight path from A to B (non-adaptive) (Fig 3).
2. **Zigzag** – Adaptive path to observe RF variability (Fig 4).
3. **Grid** – Dense area coverage for simulation data (Fig 5).

Fig. 3.

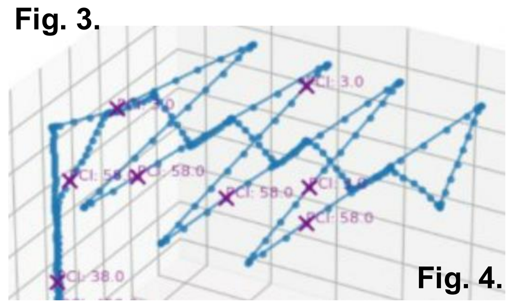

Fig. 4.

Flights were conducted at **Sixty Acres Park** (Redmond, WA) using an Aurelia X4 drone with a 5G smartphone onboard as user equipment (UE).

Altitudes ranged from **100-400 ft**, and logs were processed via Accuver **XCAL/XCAP**.

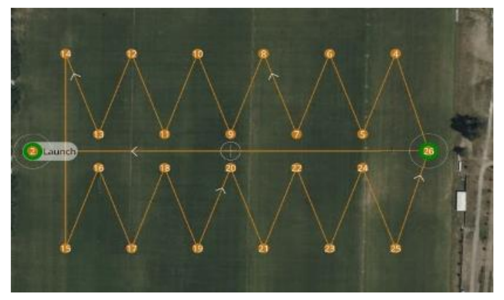

Fig. 5. Grid Flight Path

ADAPTIVE FLIGHT ALGORITHM

A **Graph-Based Model** was used to develop the adaptive flight algorithm, with simulation data.

Each node corresponds to a 3D point in space storing the following data:

- Latitude, Longitude, Altitude
- RSRP values for top 4 PCIs (PCI_1 to PCI_4)

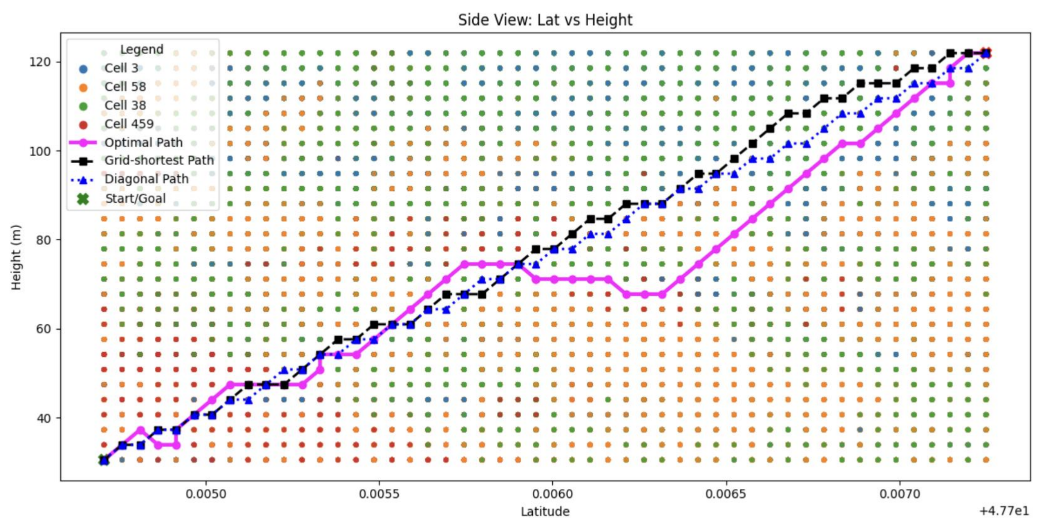

Fig. 6. 3D Graph-Based-Model

RF KPI ANALYSIS

With the goal of maintaining high RSRP and reducing throughput drops, we analyzed key causes of connectivity loss along the flight path.

Points of interest

- **PCI changes**: Switches between cell towers
- **Throughput drops**: Sudden decline in data rate
- **Handoff zones**: Areas where tower switching occurs

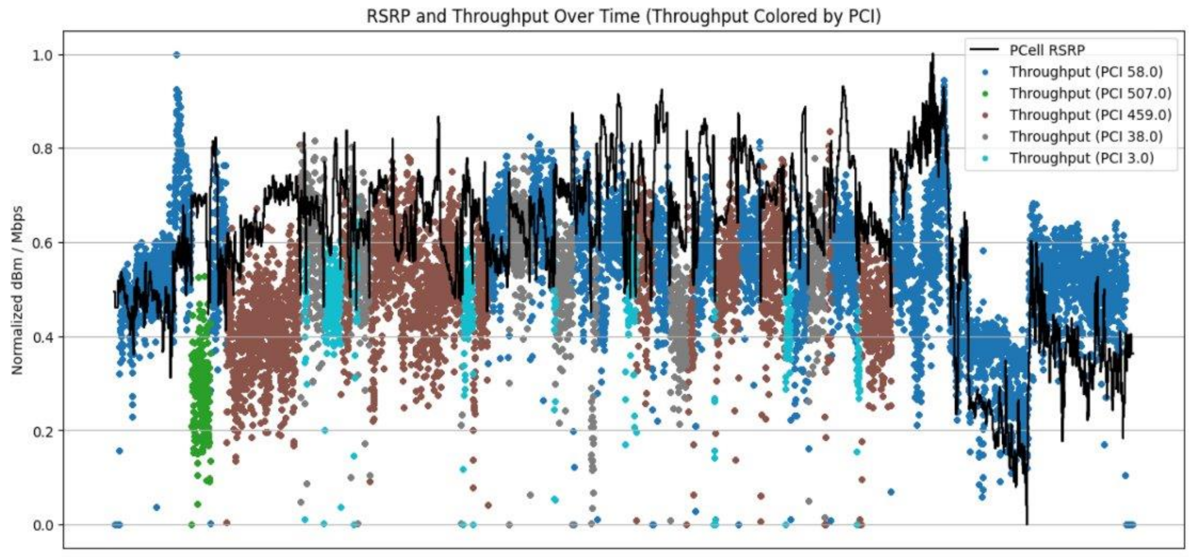

Fig. 7. RSRP and Throughput over Time for Real-World Grid Flight

Key Insights

- Throughput drops often align with PCI changes, signaling handovers
- RSRP declines before handovers occur

PCI Instability and Handoff Zones from Simulation

- Penalized nondominant PCI zones due to unstable coverage and handoff risk.

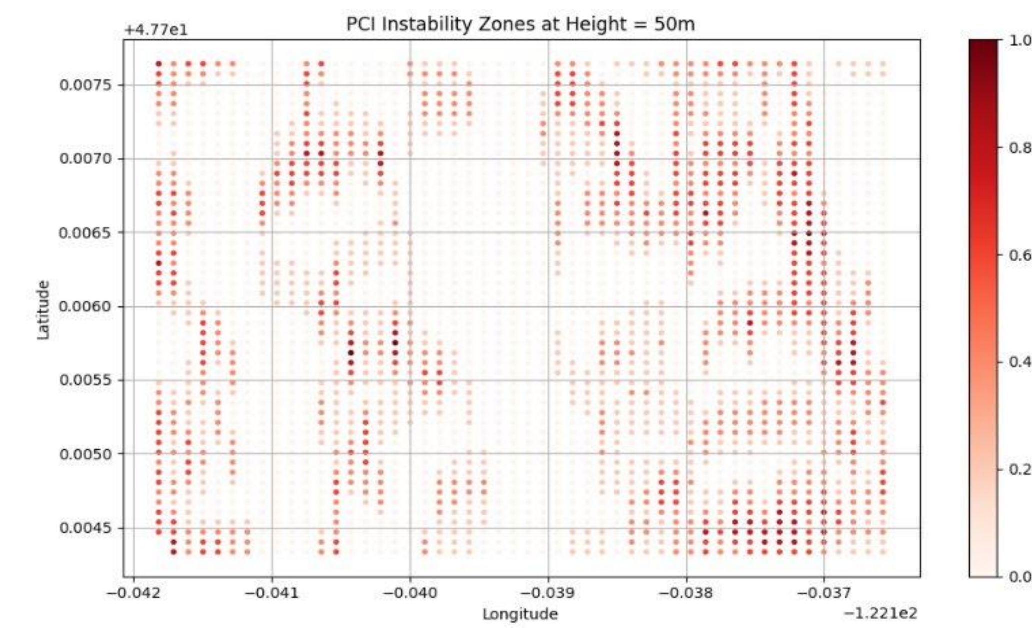

Fig. 8. PCI Instability zones at 50m at Sixty Acres Park

Cost Function Applied to the Model

$$\text{Cost}(i,j) = w_d \times \underbrace{\frac{d_{ij}}{d_{max}}}_{\text{Euclidean Distance}} + w_r \times \underbrace{\frac{R_{max} - R_j}{R_{max} - R_{min}}}_{\text{RSRP Penalty}} + \underbrace{w_h \times H(i,j)}_{\text{Handover Penalty}}$$

Fig. 9. Cost Function Weights: $w_{d(Distance\ weight)} = 0.5, w_{r(RSRP\ weight)} = 0.2, w_{h(Handover\ weight)} = 1$

REAL-WORLD TESTING OF PATH ALGORITHM

Flights	RSRP (dBm)	RSRP (mW)	SINR (dB)	Throughput (Mbps)	Pathloss (dB)
400ft Baseline	+6.77%	+278.4%	+68.7%	+190%	+18.63%
300ft Baseline	+1.19%	+24.36%	+13.4%	+3.68%	-1.4%
200ft Baseline	-1.02%	-15.52%	-17.29%	-12.82%	-3.5%
100ft Baseline	+1.42%	+40.96%	-19.10%	-11.15%	+1.3%

Fig. 10 Comparison of KPIs: Adaptive Flight vs. Baseline Flight

Our algorithm is best suited for higher altitudes to maximize RF connectivity.

RAYTRACING SIMULATION

Simulation is critical for testing and refining cost functions, enabling safe, low-cost optimization before real flights. Its value depends on how closely it mirrors real-world flight data, verified through comparison.

NVIDIA Omniverse

Used Aerial Omniverse Digital Twin to simulate drone flights over UW campus. While promising, it was designed for ground-based models and required heavy GPU resources, leading us to pursue alternative solutions.

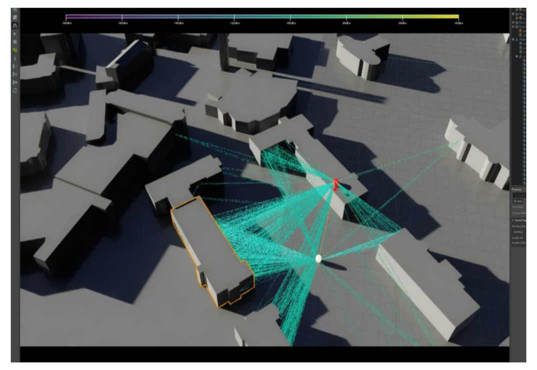

Fig. 11. UW Quad multipath propagation modeled through NVIDIA Omniverse.

MATLAB

Used MATLAB Antenna Toolbox with ray-tracing for accurate RF modeling of a Sixty Acres site. Integrated OpenStreetMap buildings, USGA terrain, and T-Mobile antenna specs.

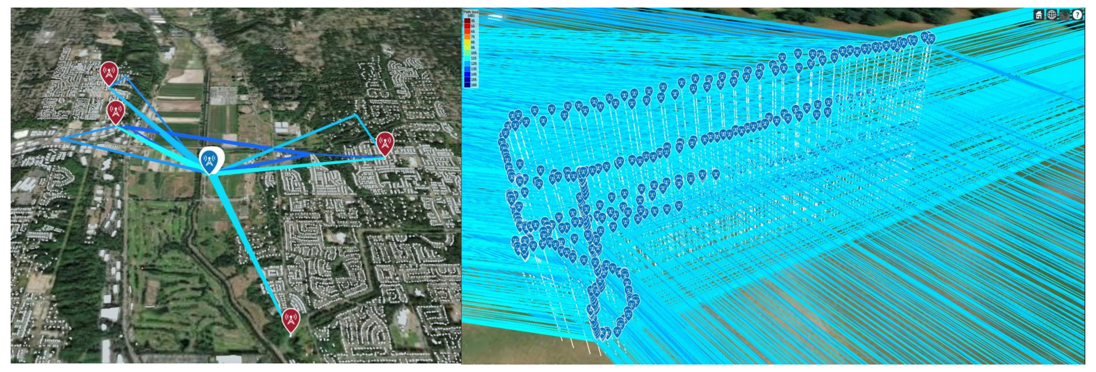

Fig. 12. Sixty Acres Park Site with Antenna and UAV Receiver Rays

We modeled signal fading from shadowing, Rayleigh Effects, and terrain properties - resulting in simulation data closely matching real-world behavior (see Fig. X)

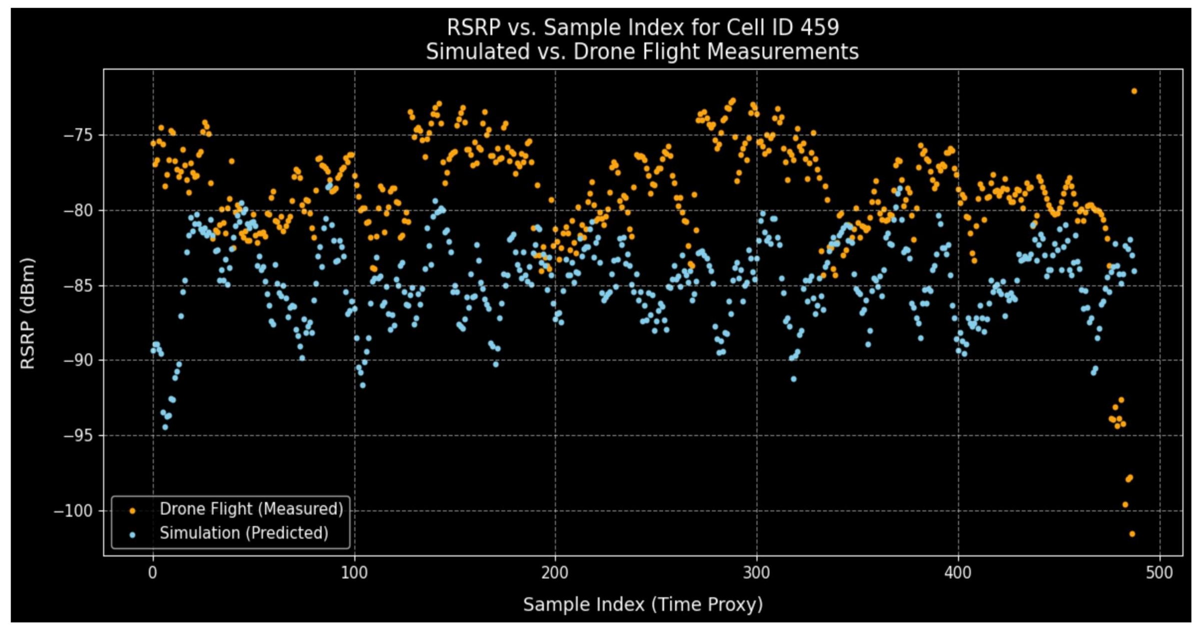

Fig. 13. RSRP Comparison: Simulation VS Real Flight

Gridded box simulations revealed spatial RSRP dynamics critical for adaptive flight planning, highlighting:

- **RSRP Fading**
- **Dominant PCI**
- **Handoff Zones**
- **Band Variations**

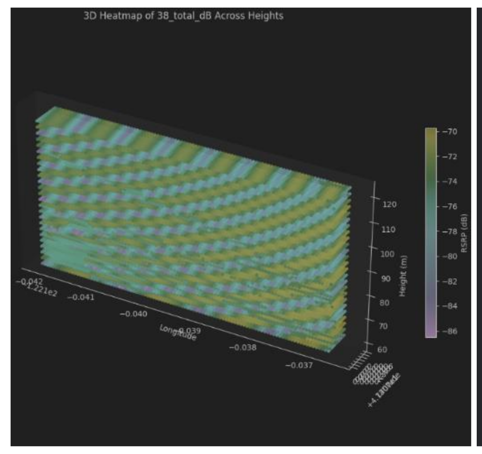

Fig. 14. RSRP Fading

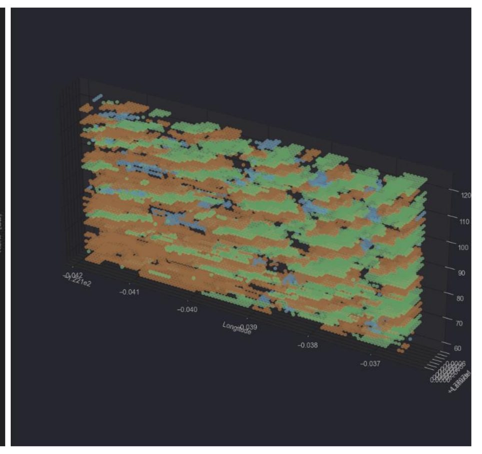

Fig. 15. Dominant PCI and Handoff Zones

FUTURE WORK

- Expand compatible KPIs in simulation and cost function (e.g. throughput, SINR, pathloss)
- Improve simulation accuracy with detailed antenna patterns and locations
- Implement Q-learning (reinforcement learning) to reduce reliance on simulation
- Design on-board implementation integrated with drone controls

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