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Optimised Deployment of Wi-Fi HaLow FANETs for Terrain-Constrained Search and Rescue

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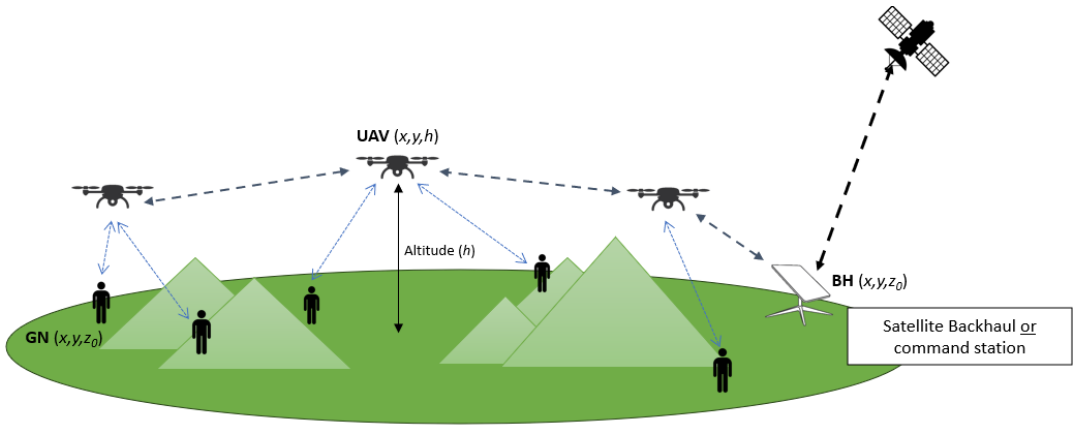
Background

- Over 2000 missing person SAR operations occur every year
- Terrain is complex and responders are spread out
- Communication methods have low uptime and bandwidth
- SES Australia is currently looking for more efficient communication methods

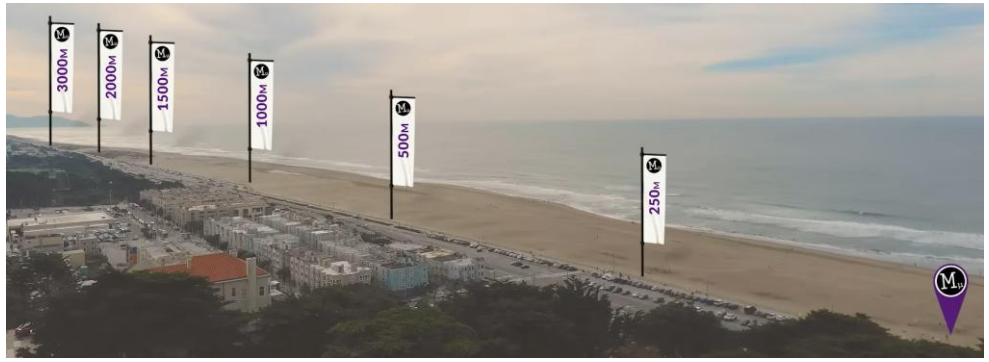
SAR = Search and Resuce

Wi-Fi HaLow FANETs as a solution

- UAVs relay data back to a backhaul
- Multi-hop mesh over terrain
- Placement using optimisation algorithm

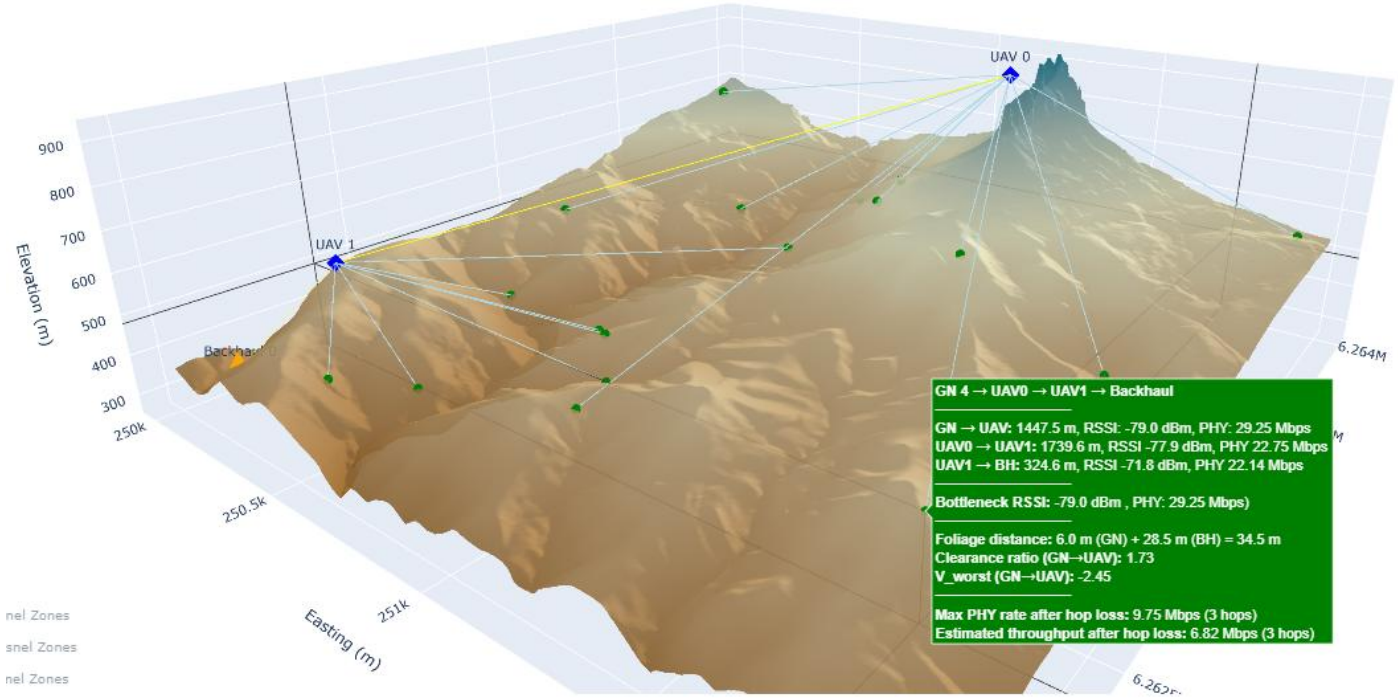


- Wi-Fi HaLow at sub-1 GHz
- Long range, low power, high penetration.
- Uses Wi-Fi IEEE standard.
- Supports meshing



Algorithm Methodology

- Multi-objective optimisation
- Uses NSGA-II genetics algorithm
- Solves for coverage and throughput
- Link model:
  - LoS, Fresnel, foliage, diffraction
  - RSSI → MCS → throughput
  - Multi-hop bottleneck throughput



NSGA = Non-dominated Sorting Genetic Algorithm II
LoS = Line of Sight
MCS = Modulation Coding Scheme

RSSI = Received Signal Strength Indicator

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Verification of HaLow

- Three (3) test campaigns:
    1. Longreef >3km G2G tests.
    2. G2A interference testing.
    3. Centennial Park G2G and G2A comparison.

- Used to tune the signal and throughput models.







G2G = Ground to Ground
G2A = Ground to Air

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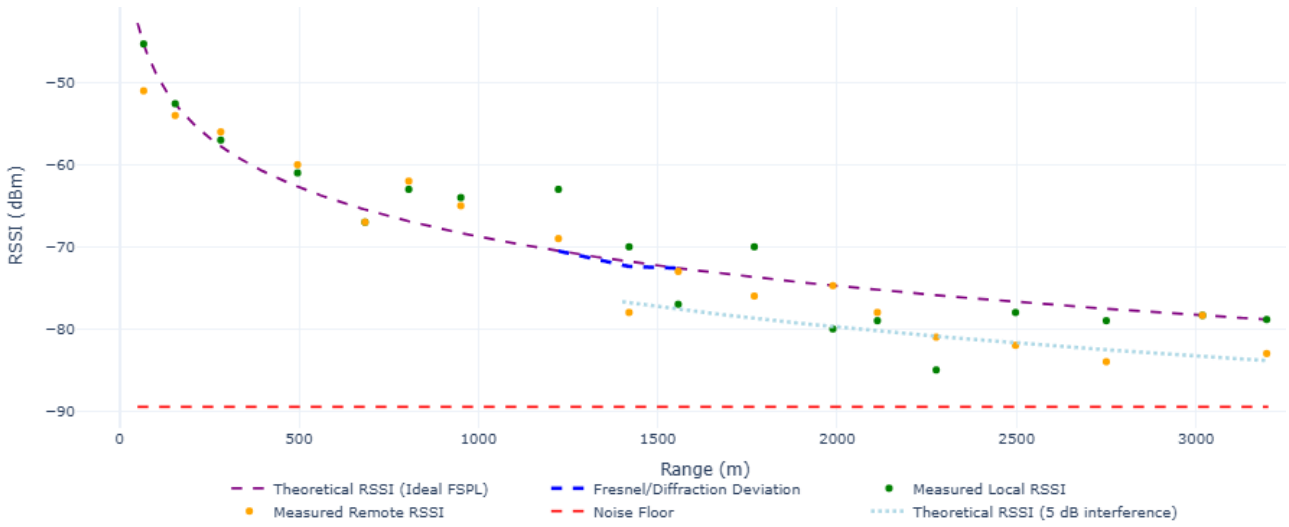
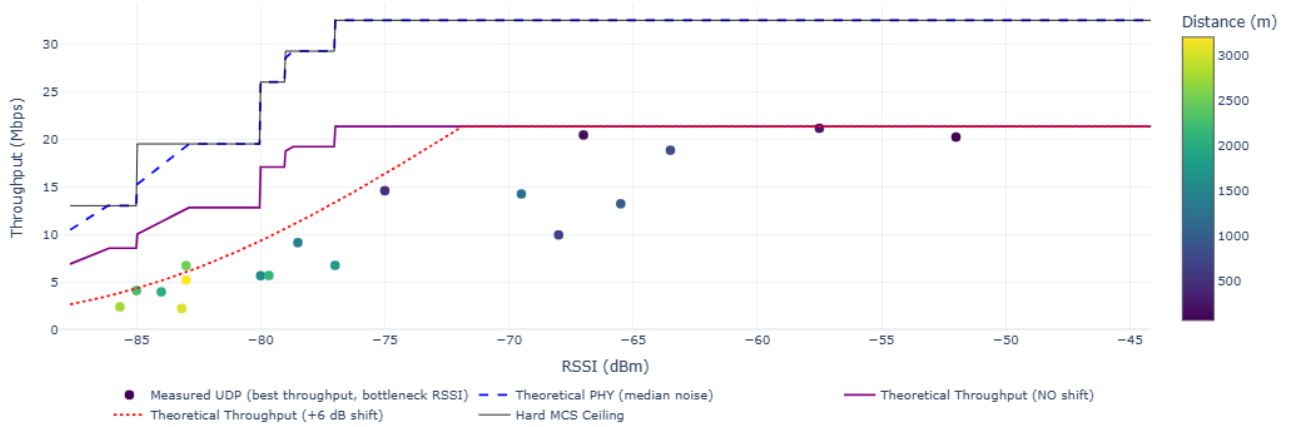
HaLow Results : G2G





Signal VS Range

- RSSI vs Range follows FSPL.
- 5dB environmental interference at range >1.4km

Signal VS Throughput

- RSSI vs Range follows Shannon's Capacity.
- 6dB SNR shift observed.

RSSI = Received Signal Strength Indicator
FSPL = Free Space Path Loss
SNR = Signal to Noise Ratio

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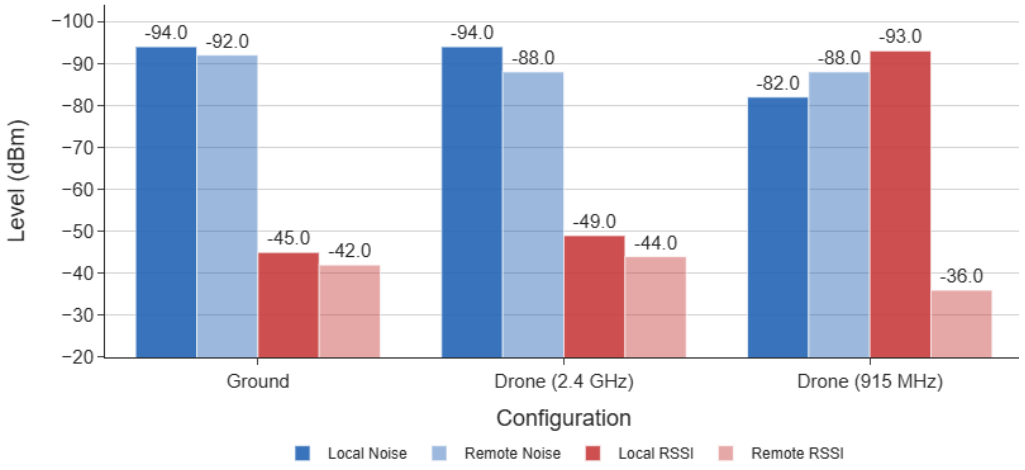
HaLow Results : Impact of Airframe and Avionics

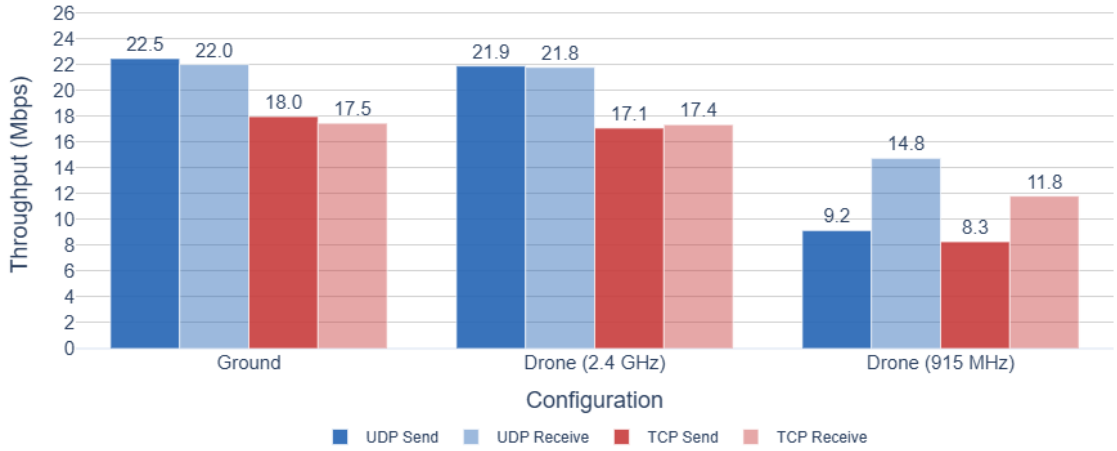
RSSI and Noise

- 915Mhz telemetry link causes notable interference
- Airframe cause a ~4dB noise increase



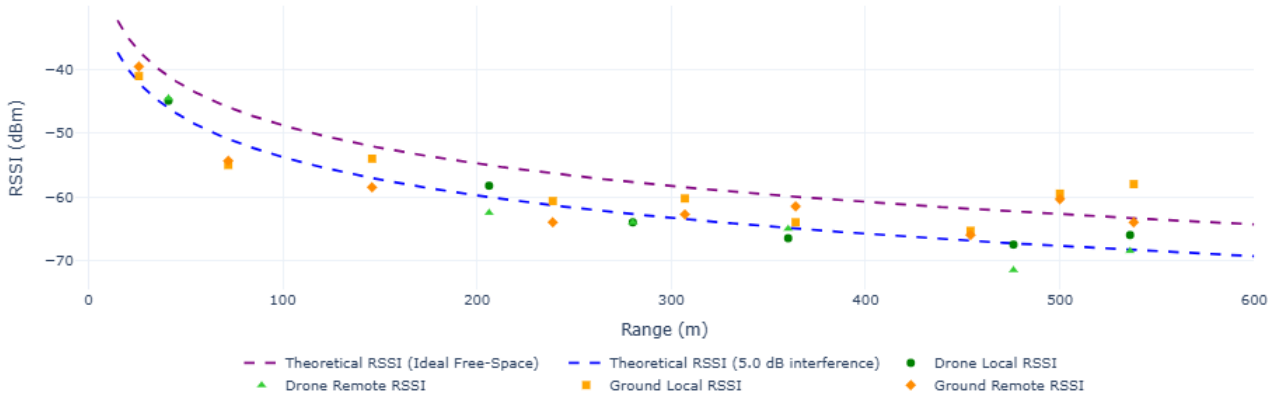
Throughput

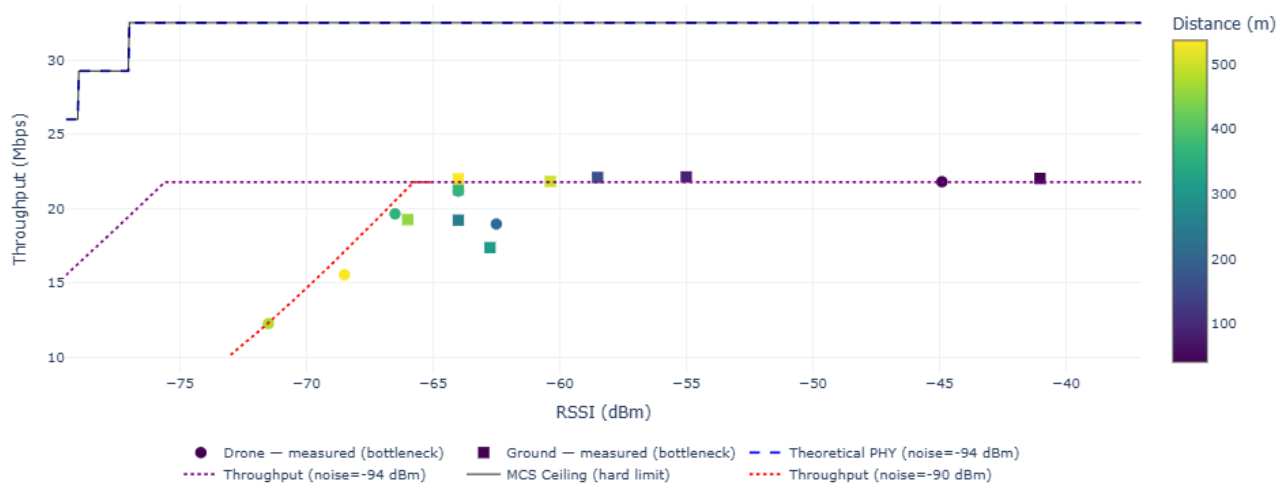
- Little difference due to airframe alone.
- 915Mhz telemetry link causes drastic throughput loss.



RSSI = Received Signal Strength Indicator
Noise = Background interference. Lowest level of signal that can be detected

HaLow Results: G2G vs G2A





Signal VS Range

- RSSI vs Range follows FSPL.
- 5dB environmental interference for both G2G & G2A.

Signal VS Throughput

- RSSI vs Throughput follows Shannon's Capacity.
- Same 6dB SNR shift observed.
- Higher Noise observed at drone

RSSI = Received Signal Strength Indicator
FSPL = Free Space Path Loss
SNR = Signal to Noise Ratio

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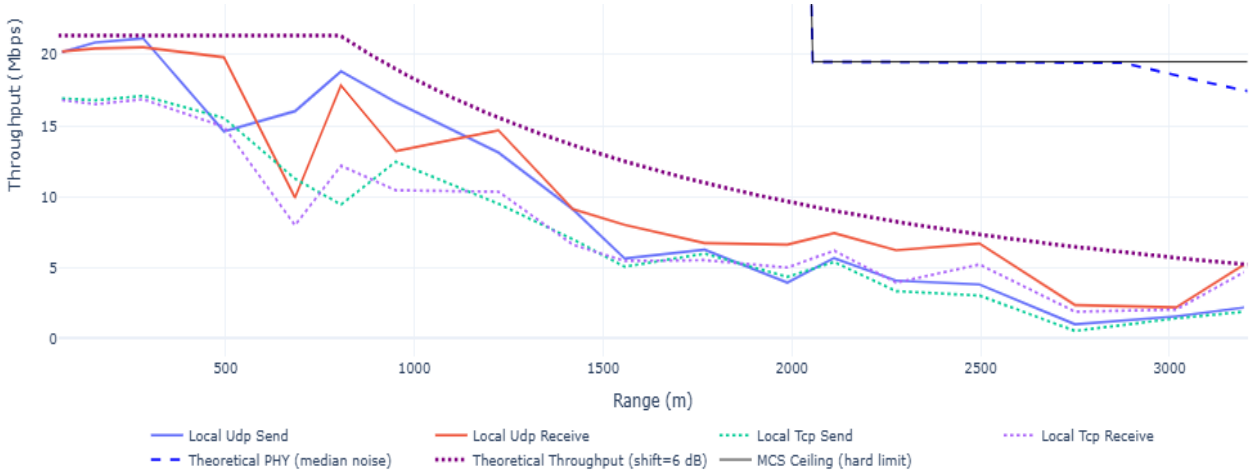
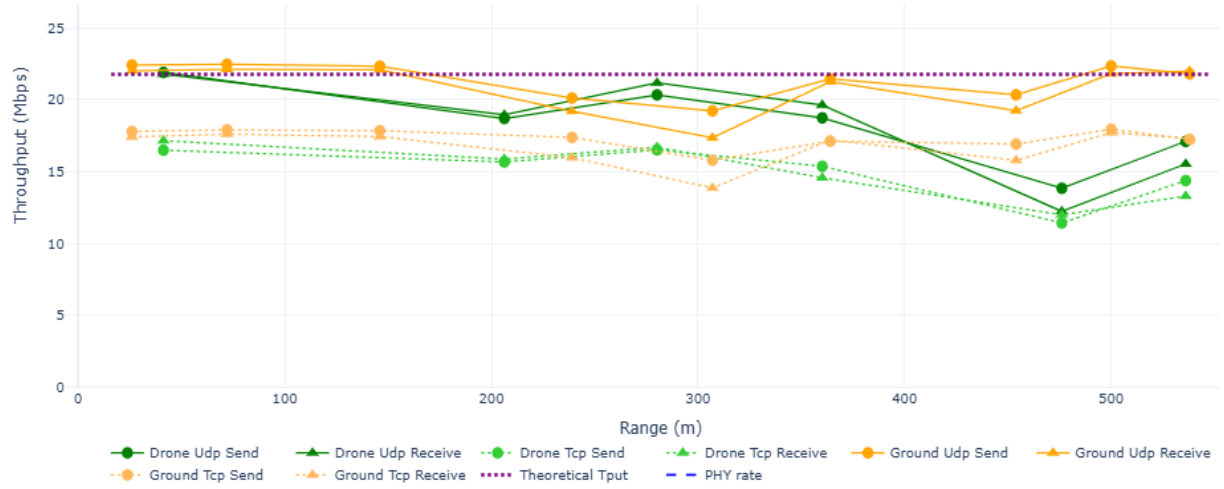
HaLow Results: Throughput vs Range





G2G

- G2G test align with theoretical model.
- Can be used for UAV placement.
- Multi-Mbps to several km (G2G)

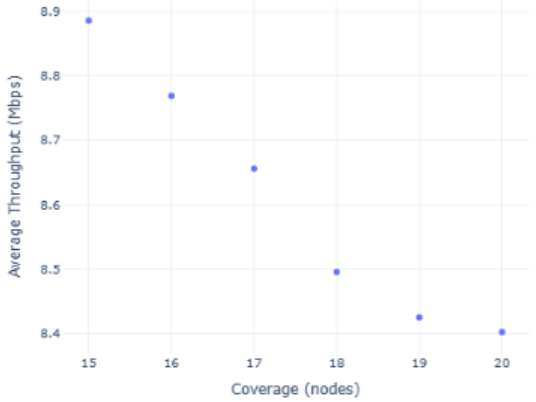
G2G and G2A Comparison

- Similar G2G and G2A throughput.
- Evidence of earlier MCS divergence for UAV.

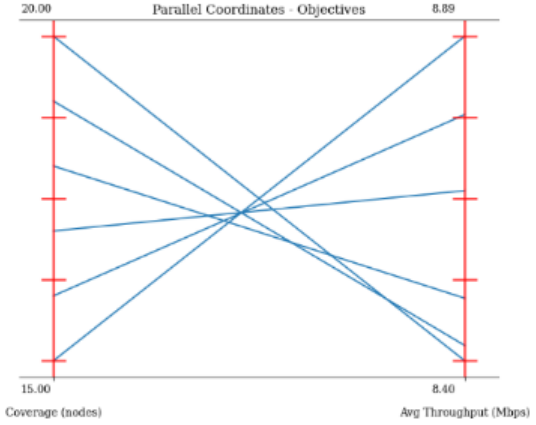
Verification of Algorithm

3 UAVs

- Clean Pareto front.
- Clear objective trade off.
- Sufficient number of UAVs



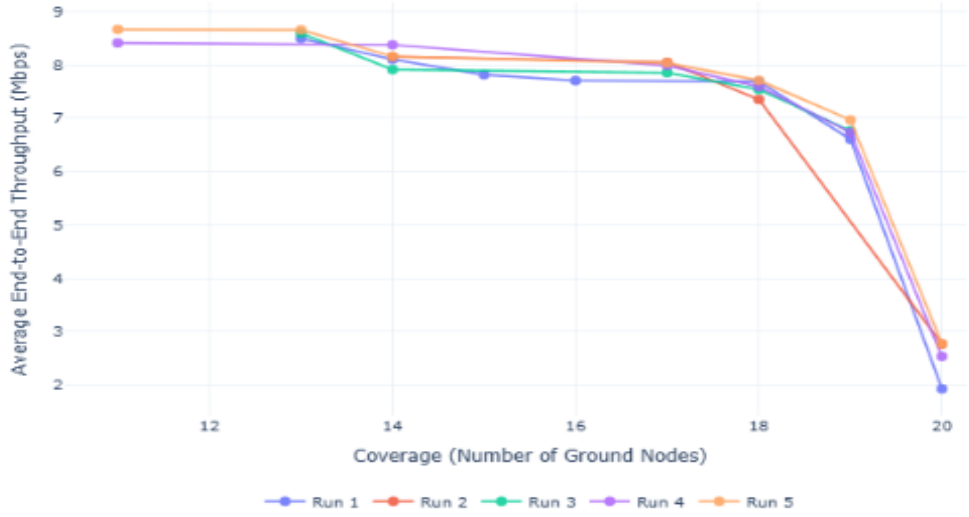
(a) Pareto front: coverage vs throughput.



(b) Parallel-coordinates view of the same non-dominated set.

2 UAVs (multiple runs)

- Consistent across runs.
- No enough UAVs for max coverage.



Pareto Front = The set of non-dominated solutions in which no single solution is better than all others across all objectives

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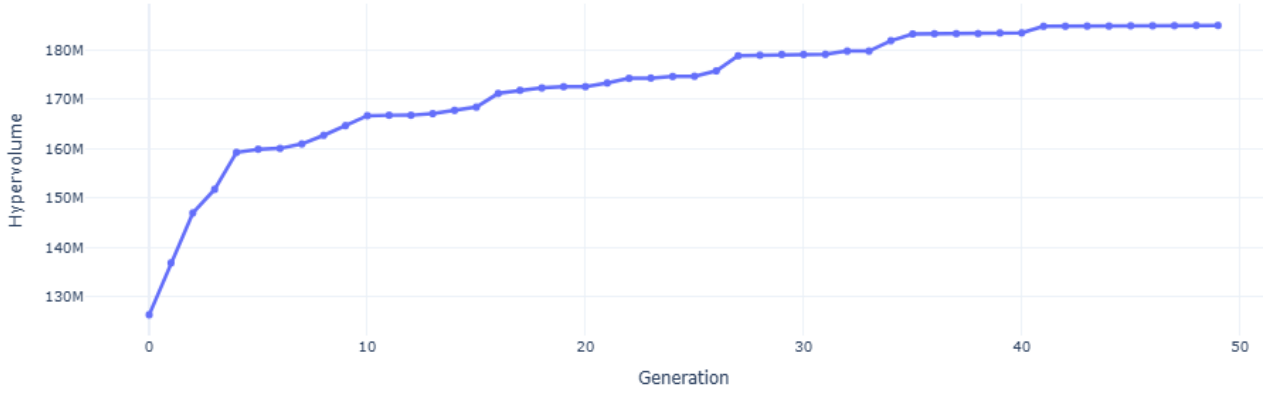
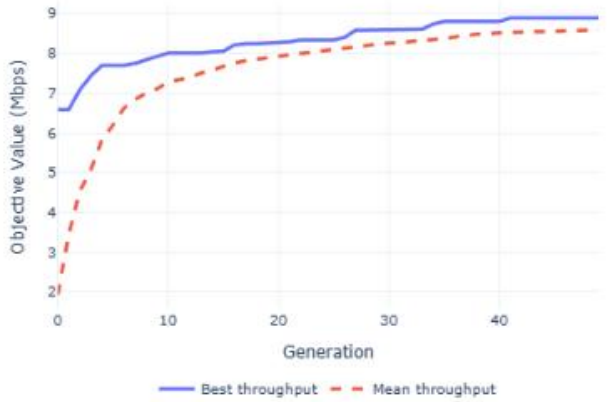
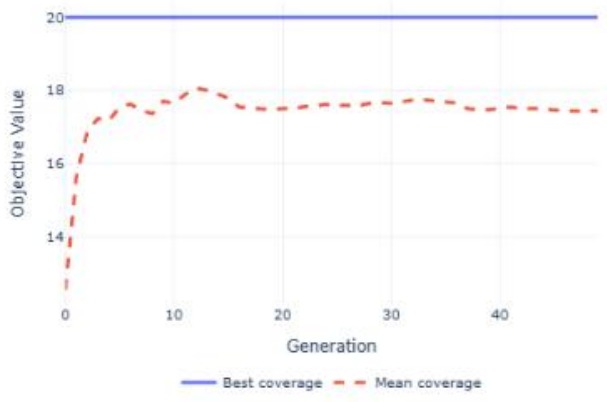
Verification of Algorithm

- Fast solution convergence.
- Coverage refined first.
- Small throughput optimisation made over time.
- Jumps in hypervolume show:
  - New LoS conditions
  - MCS index changes
  - Backhaul path changes





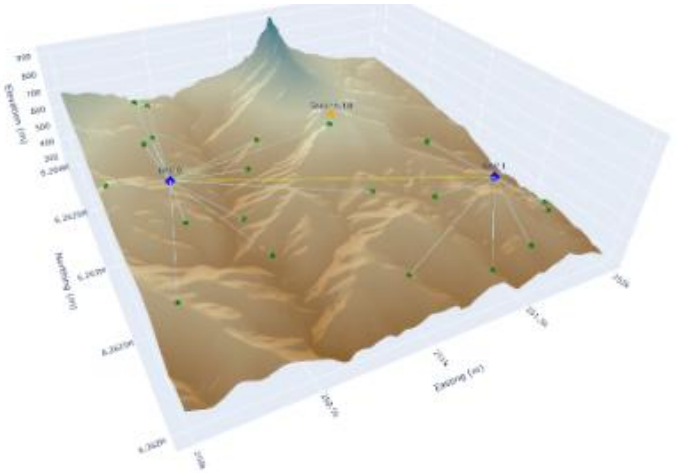
(a) Throughput objective convergence.



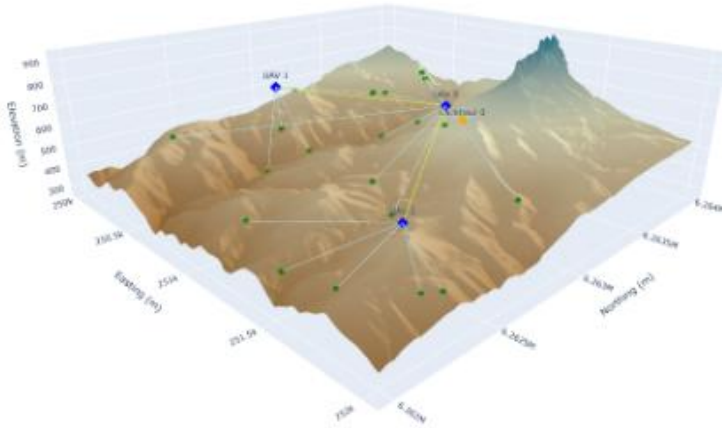
(b) Coverage objective convergence.

Hypervolume = A metric that measures the total volume of objective space dominated by the current Pareto front.

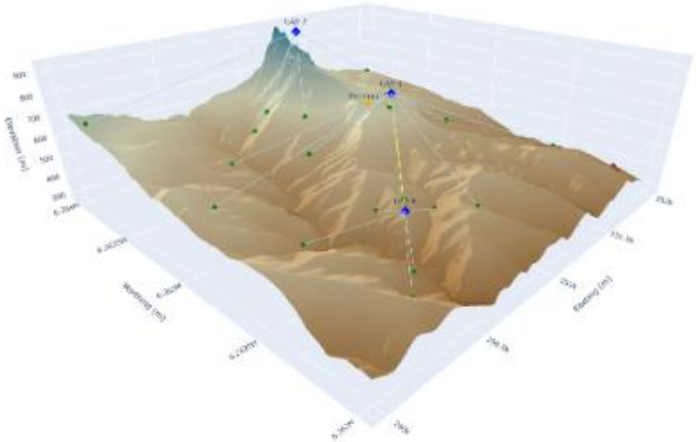
Representative Deployments



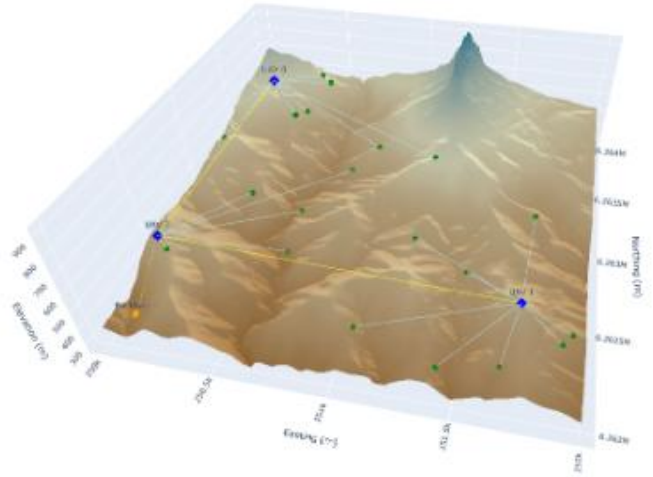
(b) Two-UAV configuration.



(a) Baseline three-UAV deployment.



(c) Three-UAV using a different GN seed.



(d) Challenging backhaul location.

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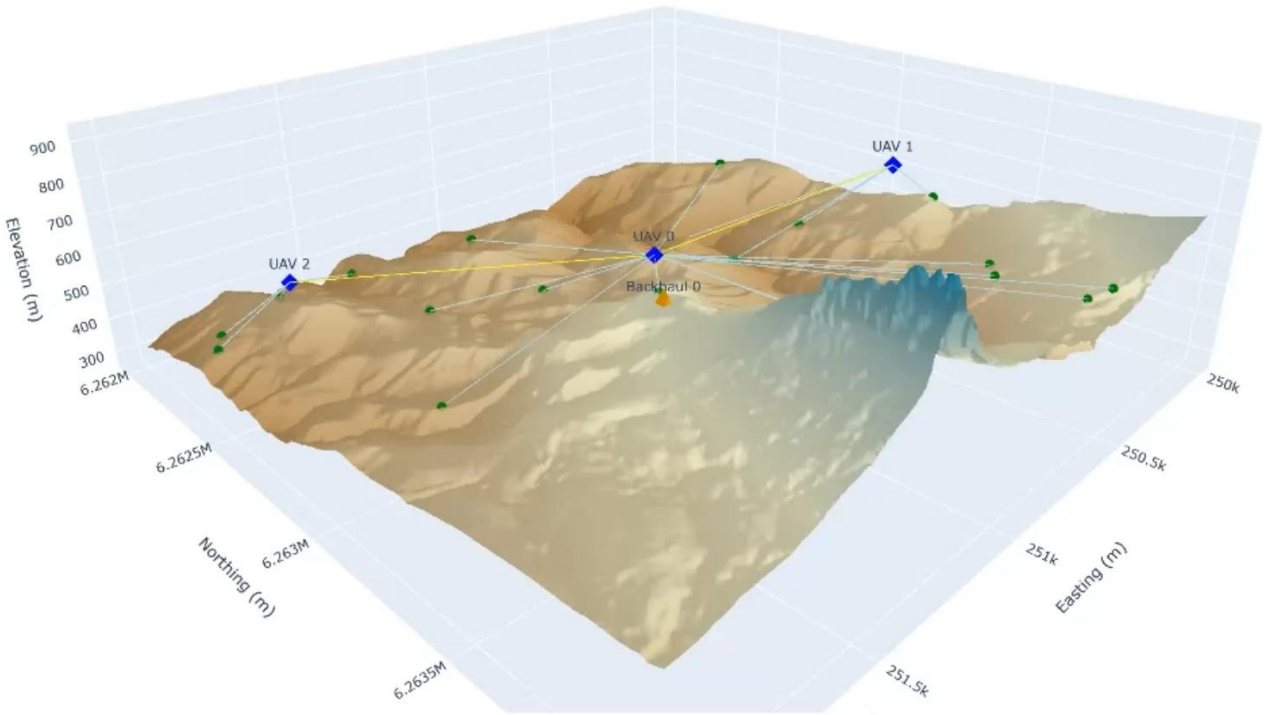
Conclusion



- HaLow can deliver multi-Mbps links at SAR scales
- Terrain-aware placement is essential
- Small UAV fleets can cover many responders
- Future work:
  - Automated deployment
  - Long range G2A tests
  - Foliage loss measurements
  - End to end field testing

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