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WEBINAR SERIES ON ADVANCED MOBILITY

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Technical Background and Research

- Ph.D. in Engineering and Applied Sciences, Yale University

Research Interests

- Exploration and innovations across the fields of wireless technology, cybersecurity, and computational science.

Wireless Interests

- Secure wireless communication for the critical infrastructure and nationwide unmanned aerial systems.
- Lead and focus wireless security research efforts for 5G and Beyond with national impact.

Acknowledgement

The presenter wishes to acknowledge the IEEE Vehicular Technology Society for their sponsorship of the Webinar Series on Advanced Air Mobility.

Secure 5G Network for a Nationwide Drone Corridor (Secure5GDrone)

- INL Lab Directed Research with North Carolina State University (NCSU)
- NCSU Professors:
  - ✓ Dr. Ismail Guvenc
  - ✓ Dr. Huaiyu Dai
  - ✓ Dr. Mihail Sichitiu



- NCSU Post Doc: Drs. Yavuz Yapici and Ender Ozturk

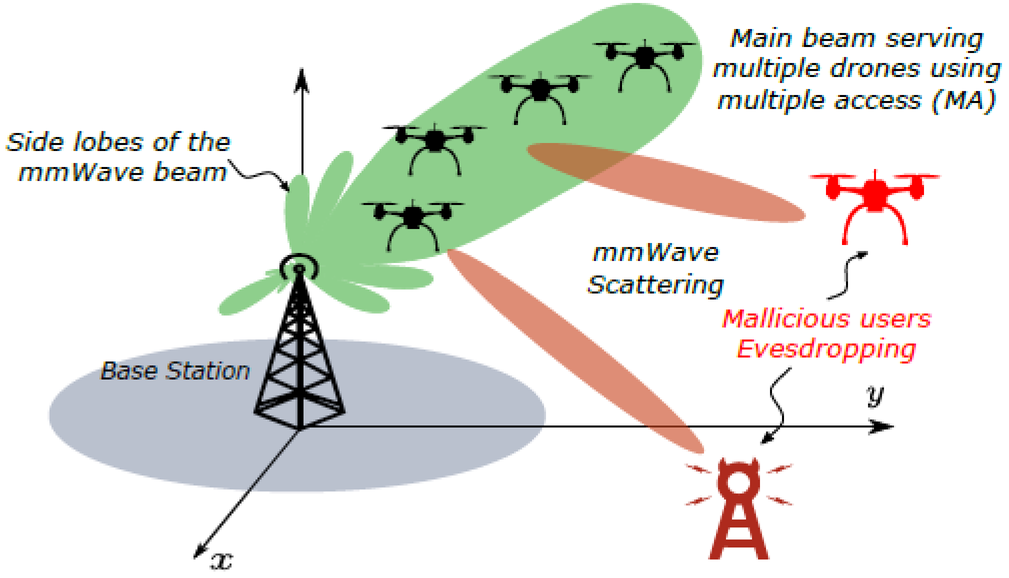

- NCSU Ph.D. Students:
  - ✓ Simran Singh
  - ✓ Ali Rahmati
  - ✓ Sung Joon Maeng
  - ✓ Md Moin Uddin Chowdhury




- Dr. Nadisanka Rupasinghe

Secure5GDrone Summary

- Validated use of an additional set of antennas for drone coverage versus currently optimized ground coverage
- RF coverage with frequency reuse and base station selection for the additional antenna set
- Coverage of a swarm of drones with uplink non-orthogonal multiple access (NOMA) and downlink rate-splitting multiple access (RSMA)
- Design of trajectories to maximize throughput and energy efficiency in the presence of interference
- Physical layer security with secrecy aware beamforming, precoding, transmission of artificial noise and fingerprint-based data authentication
- Security improvements utilizing protected zones



Secure mmWave cellular network for nationwide drone operation

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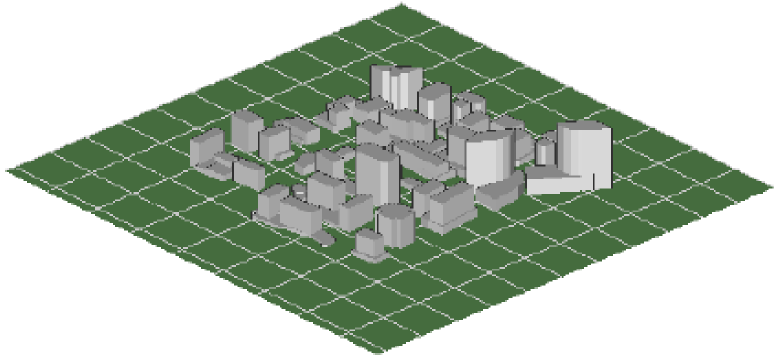
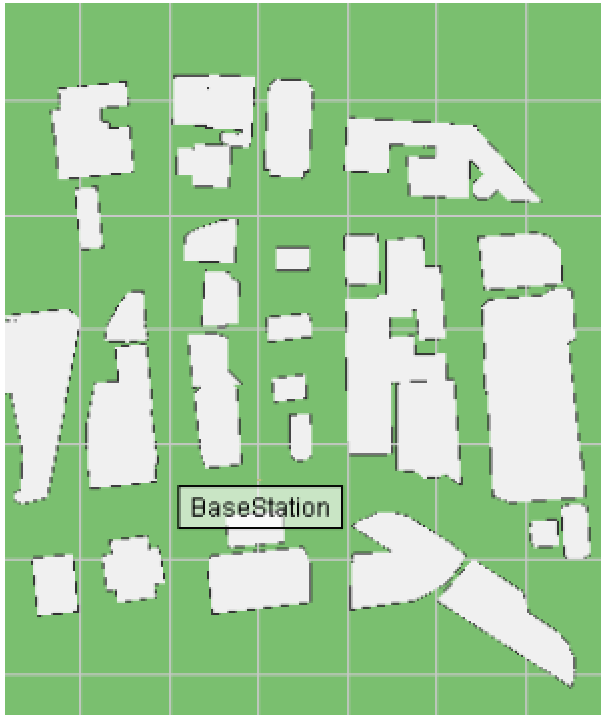
Secure 5G Network for a Nationwide Drone Corridor (Secure5GDrone)

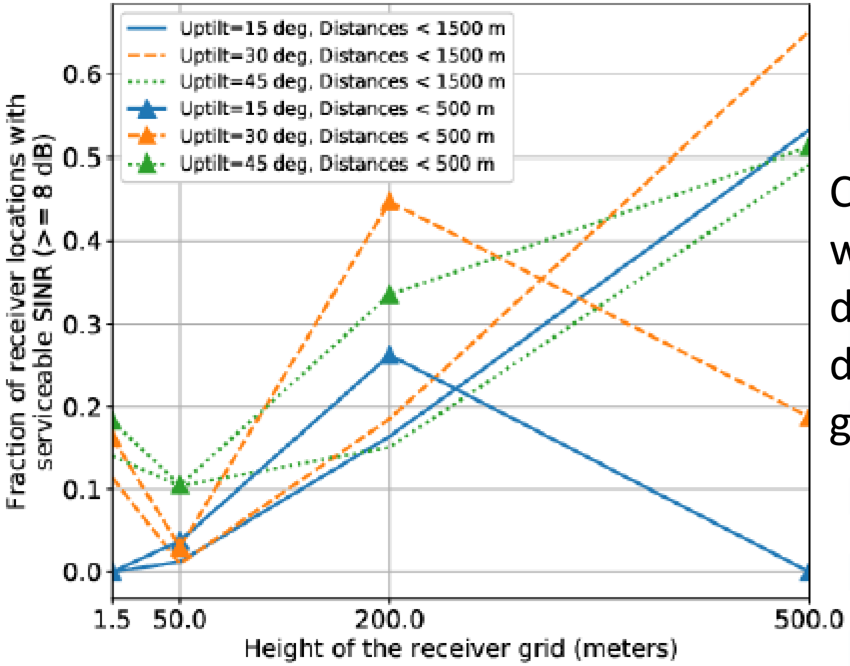
Capabilities	Secure5GDrone	Cellular LTE/4G Drone	Drone operated with Non-cellular RF e.g. Wi-Fi
Operation without line of sight to drone	X	X	
Provides reliable radio frequency coverage in the sky	X		
Joint design of drone corridor and cellular network	X		
Uses beam-based transmission for highest capacity	X		
Data Rate	Highest	At least 10 times lower	Variable
Latency	Lowest	At least 10 times higher	Variable
Utilizes multiple access technology for increased spectral efficiency	X		
Utilizes precoders to increase secrecy capacity	X		
Utilizes physical layer security	X		
Robust against interfering attacks	X		
Improved security in 5G	X		

RF Coverage with Frequency Reuse

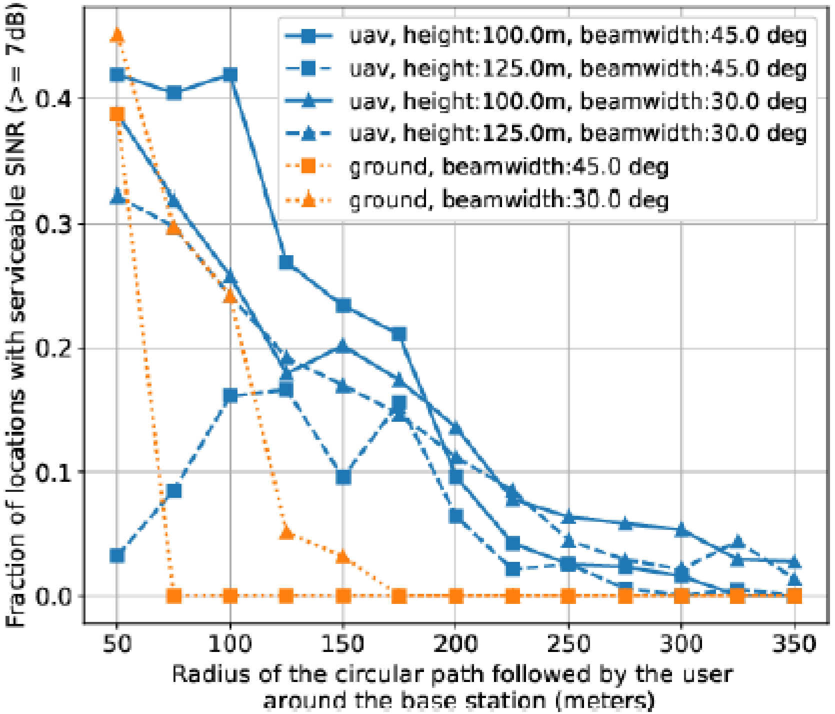




Outdoor environment used for ray tracing (based on Rosslyn, Virginia)

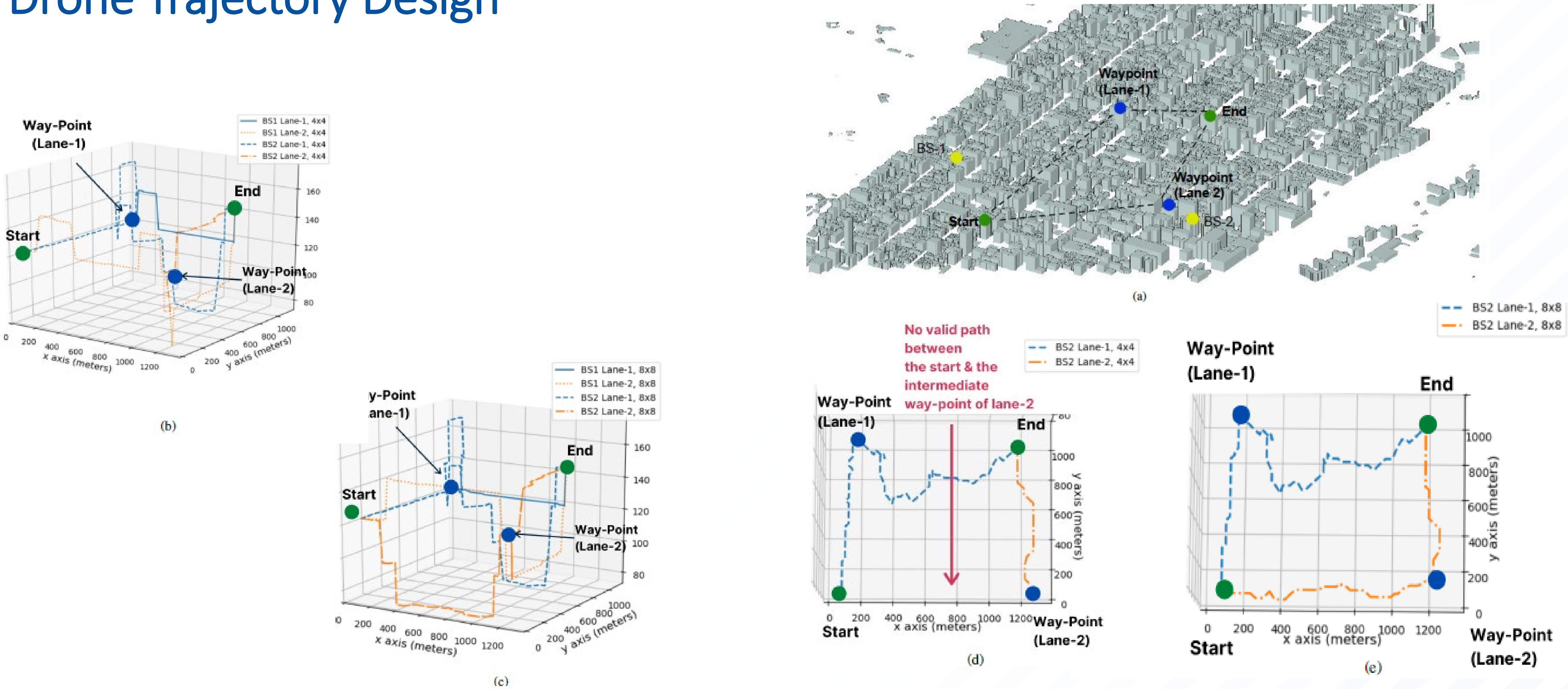


Coverage versus height with various uptilts for drone coverage with fixed downtilt of 10 degrees for ground coverage



Fraction of receiver locations that receive SINR > 7 dB at different distances from the base station

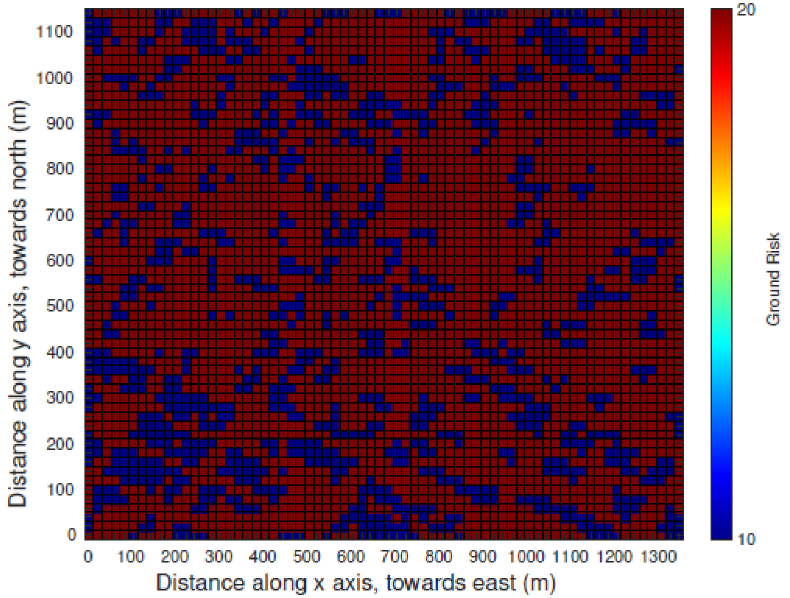
Drone Trajectory Design



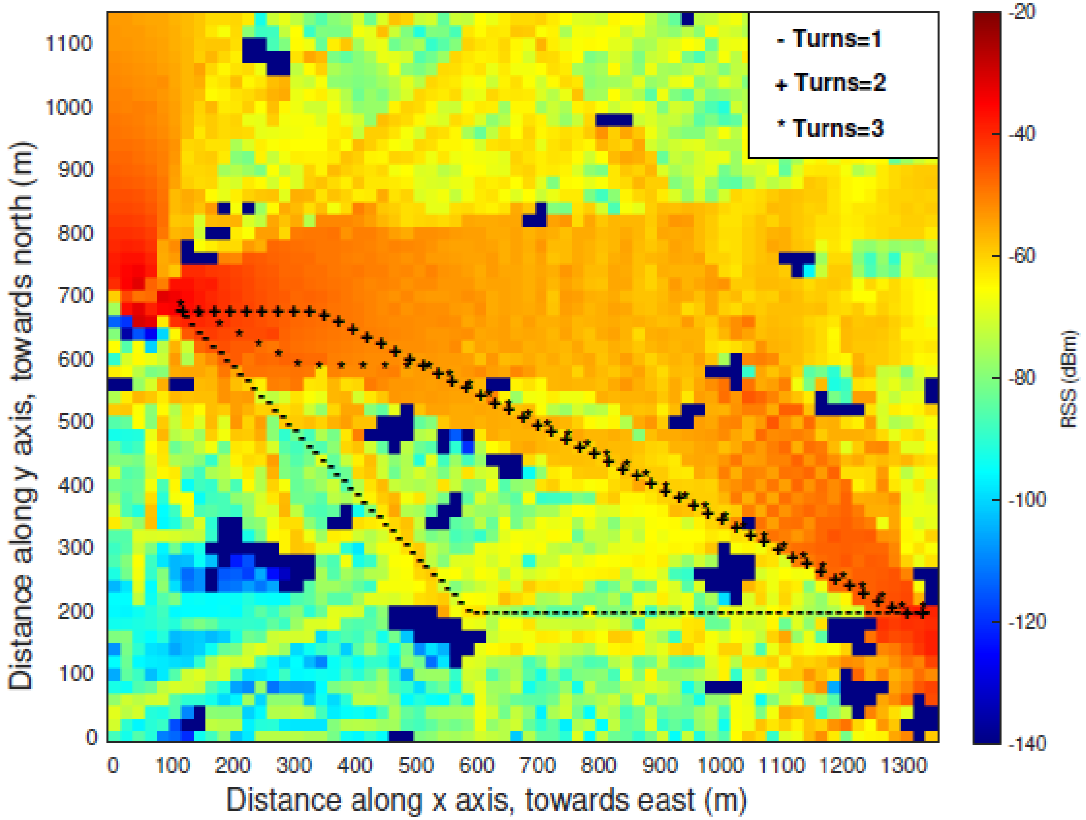
(a) Specifications of the drone corridor, in a region of East Manhattan. The corridor consists of two lanes, each with a start, an end, and an intermediate way-point; (b) 3D trajectories using 4x4 antenna array at the BS; (c) 3D trajectories using 8x8 antenna array at the BS. (d) Top view of trajectories with only BS-1 equipped with a 4x4 array. (e) Top view of trajectories with only BS-1 equipped with an 8x8 array.

Drone Trajectory Design for Pedestrian Safety

3D view of Manhattan environment model with two base stations

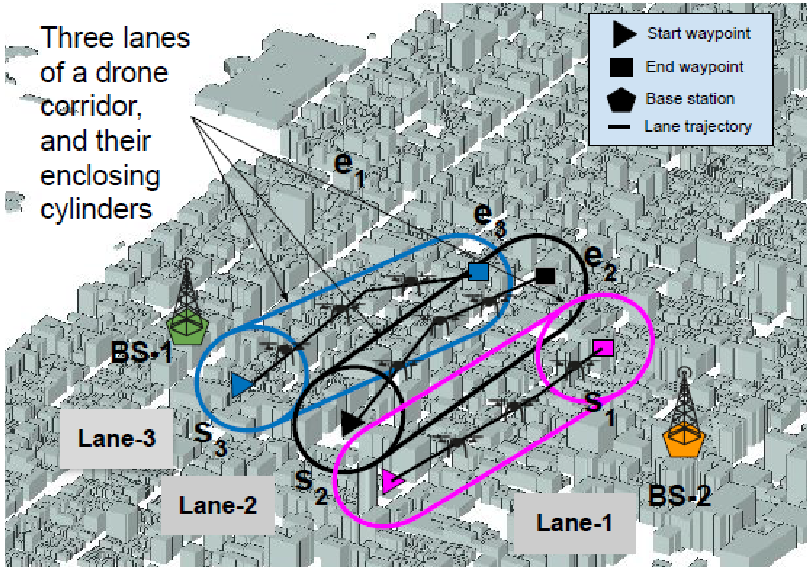


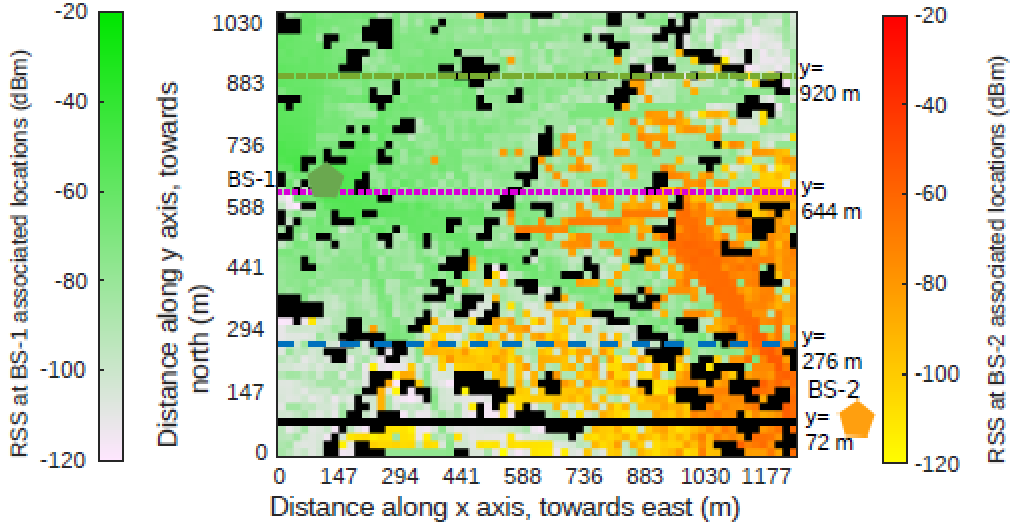
Ground Risk Map

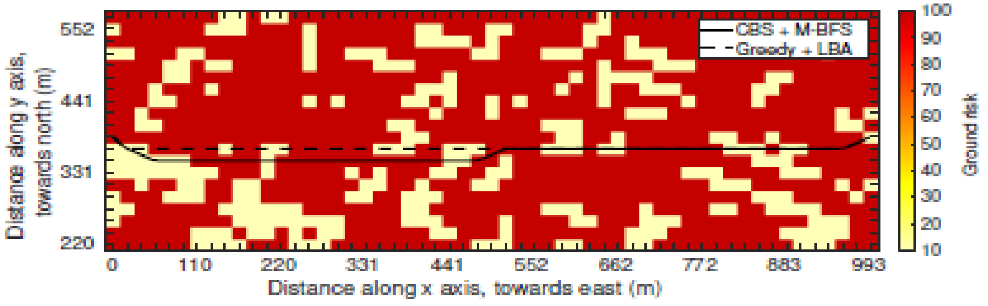


Drone trajectories

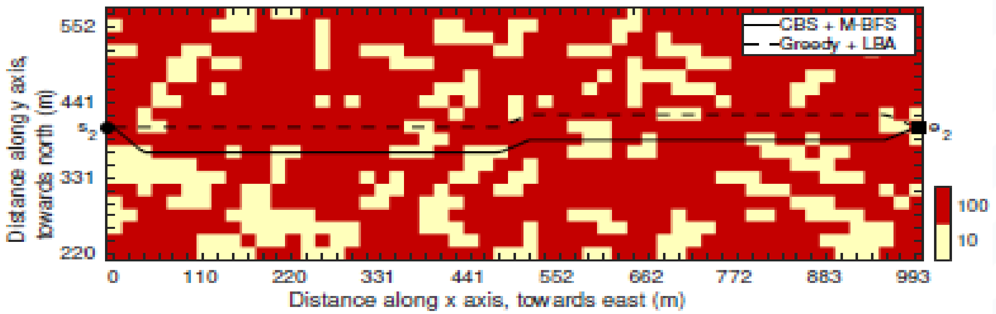
Drone Corridor Design to Minimize Ground Risk



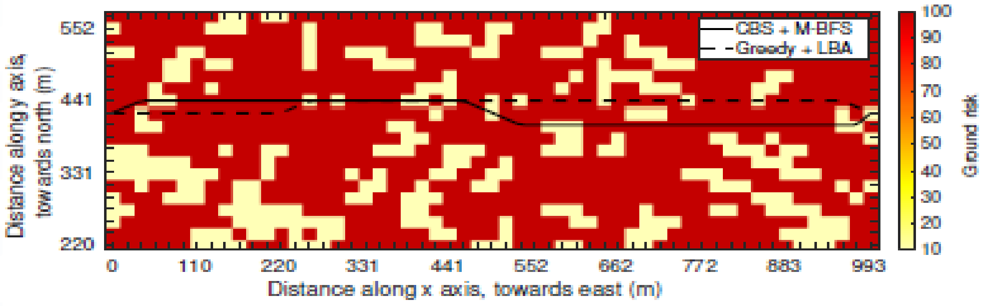




(a) Path of lane-1



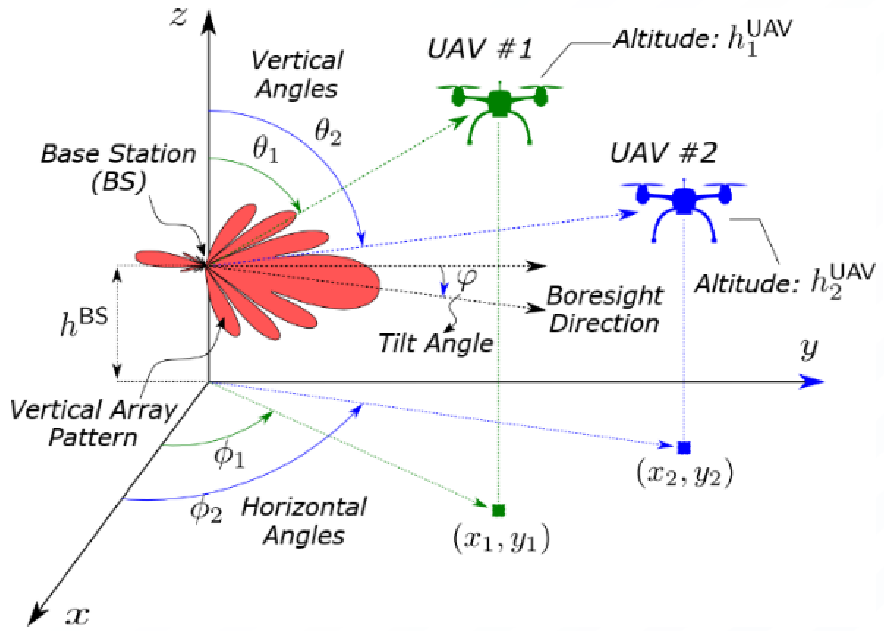
(b) Path of lane-2



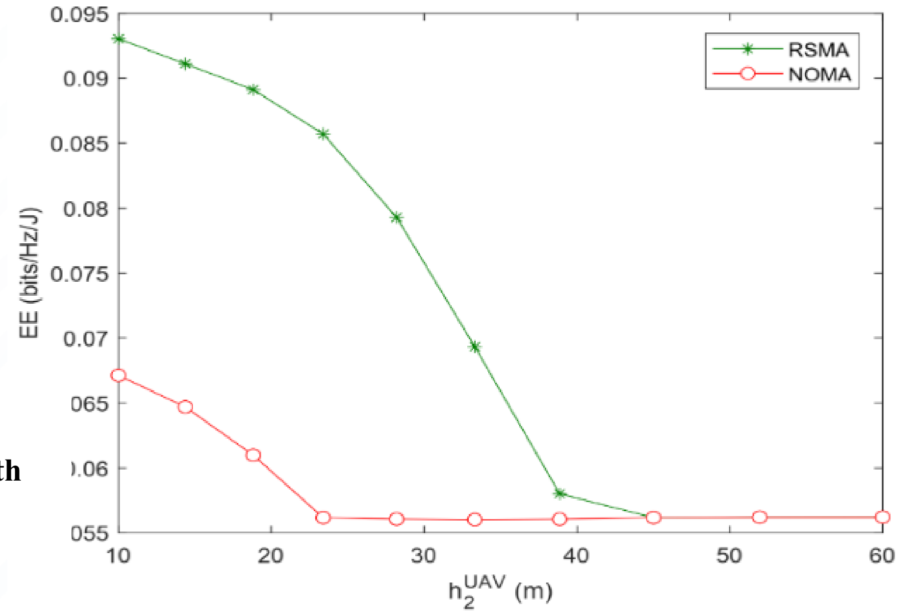
(c) Path of lane-3

Spectral Efficiency and Resiliency Improvements

- Use same radio resources for a swarm of drones with multiple access (MA) schemes
- Cellular links to a primary and a secondary drone in a swarm
- Repositioning of primary and secondary drones for optimal RF reception
- Use 5G device to device (D2D) aka Sidelink for Intra-swarm communication
- Compare Non-Orthogonal MA (NOMA) and Rate-Splitting MA (RSMA) for downlink transmission

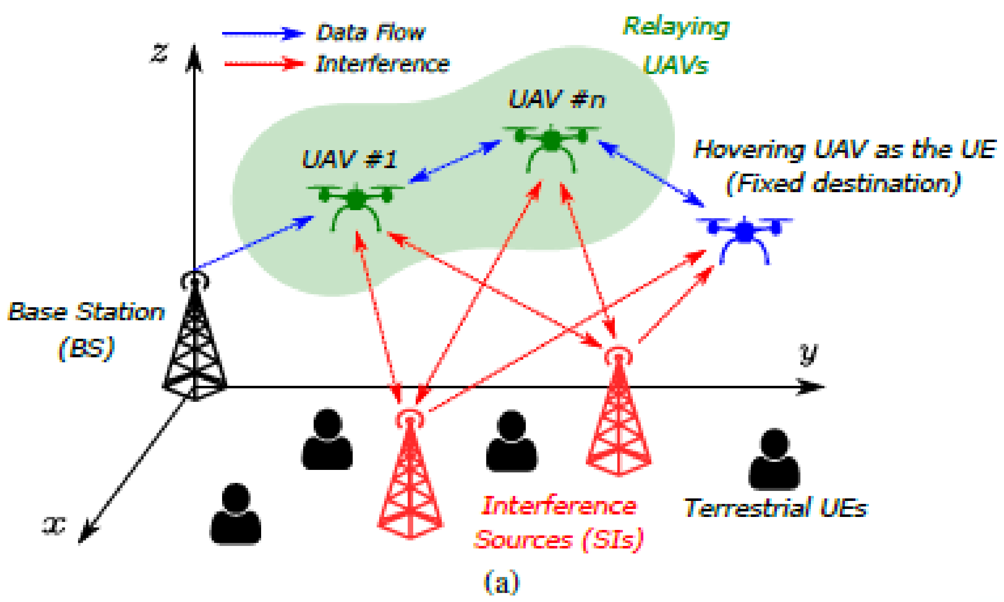


System model for mmWave serving multiple drones simultaneously with an 8-element antenna array

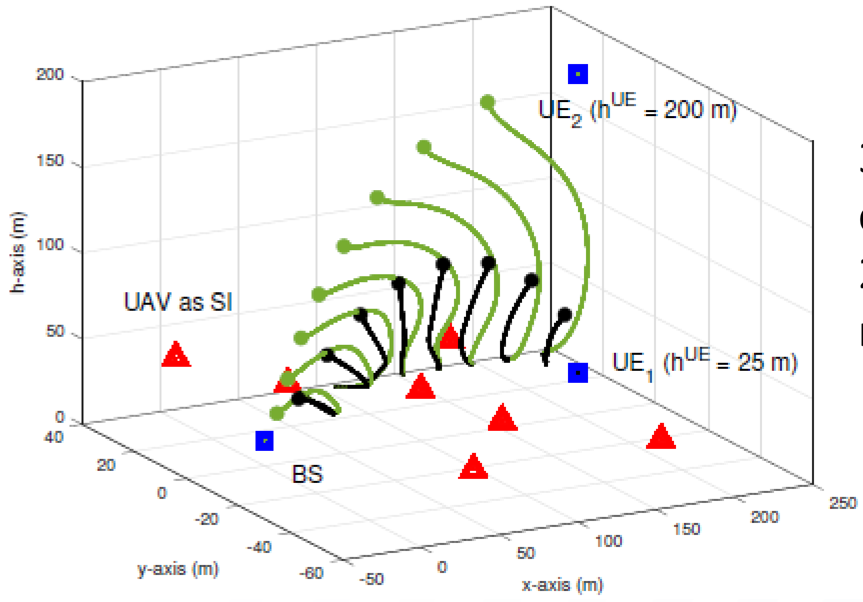


Sum energy efficiency versus the altitude of the 2nd UAV served with RSMA and NOMA.

Data Flow Optimization

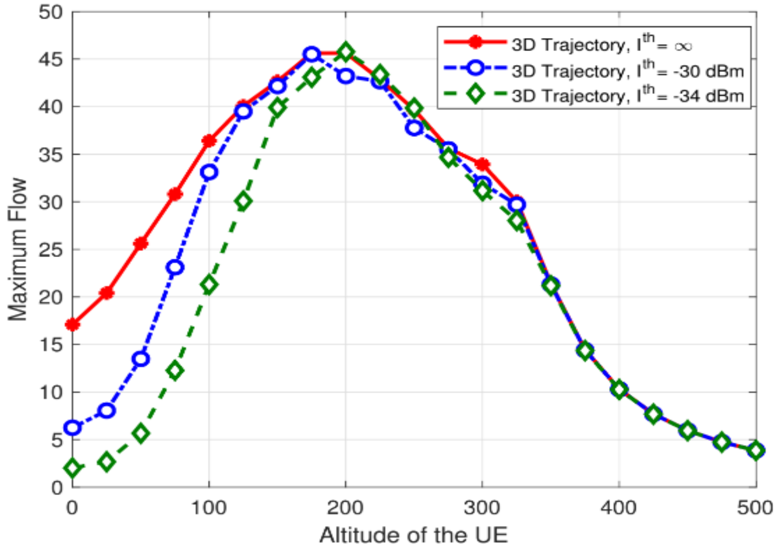


System model for data flow through a relay network in the presence of interference at fixed locations

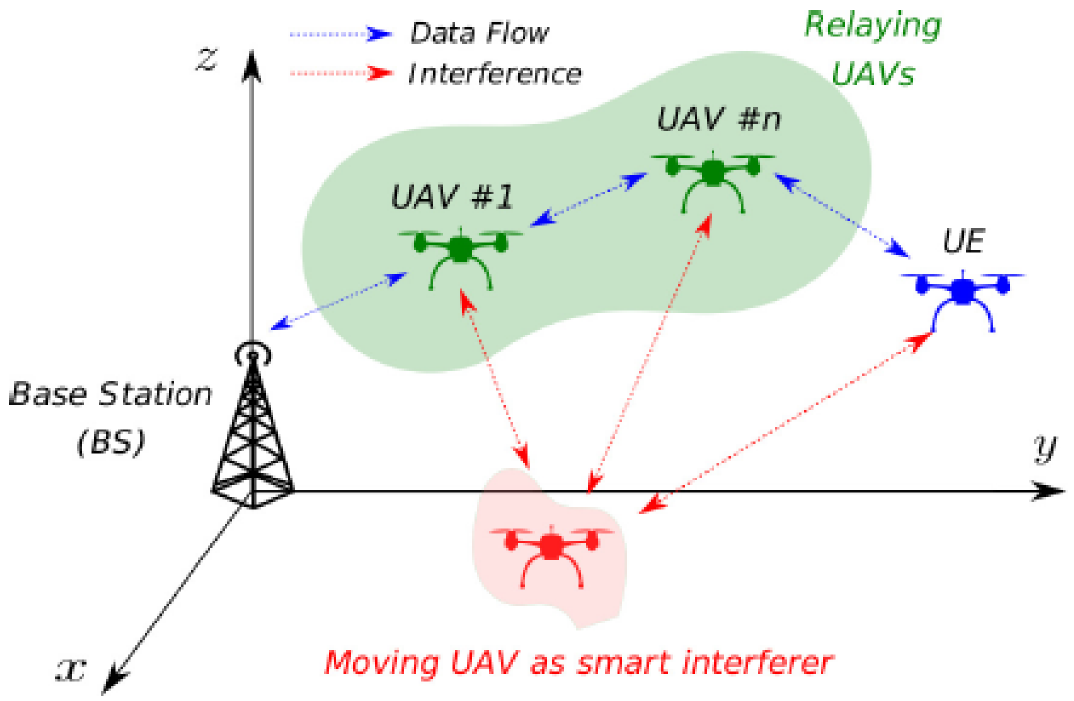


3D trajectories with destination UE height at 25 meter (black) and 200 meter (green)

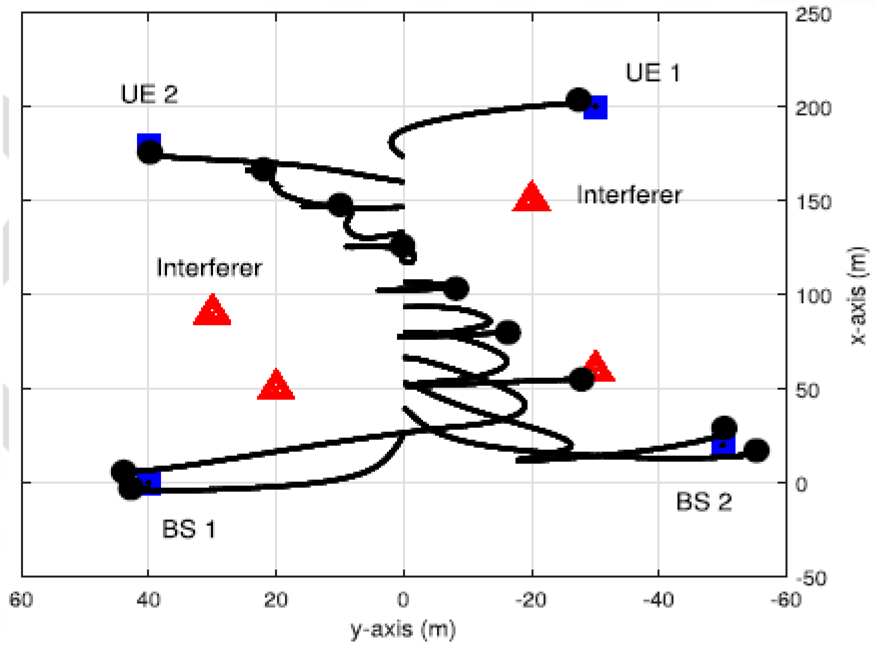
Maximum flow versus UE altitude for interference thresholds of -34 dBm, -30 dBm, and for no threshold



Drone Security in the presence of Smart Interference

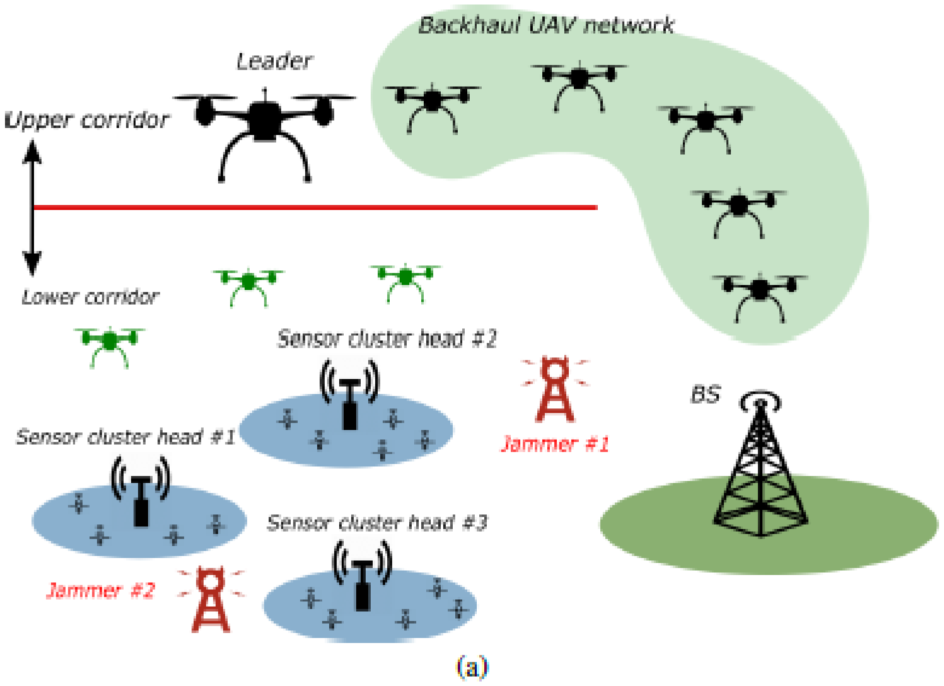


System model for the communications scenario with moving UAV as a smart interferer.

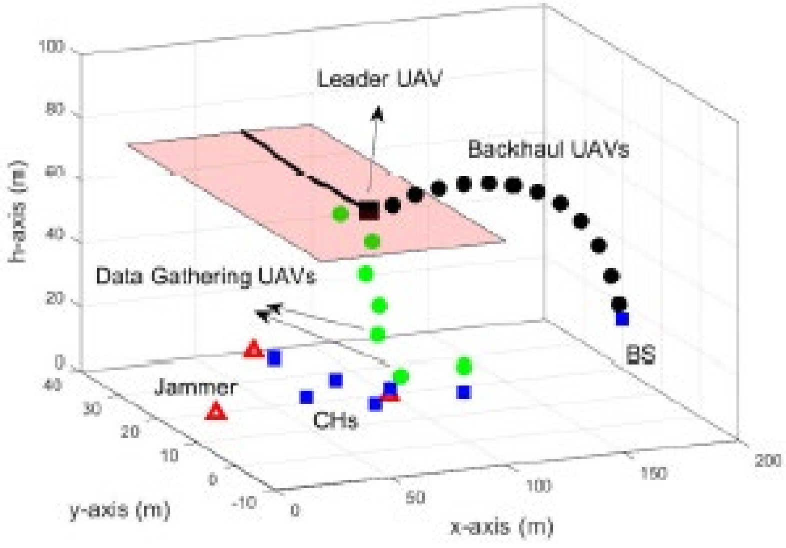


Top view trajectories of the UAVs.

Lifetime Maximization

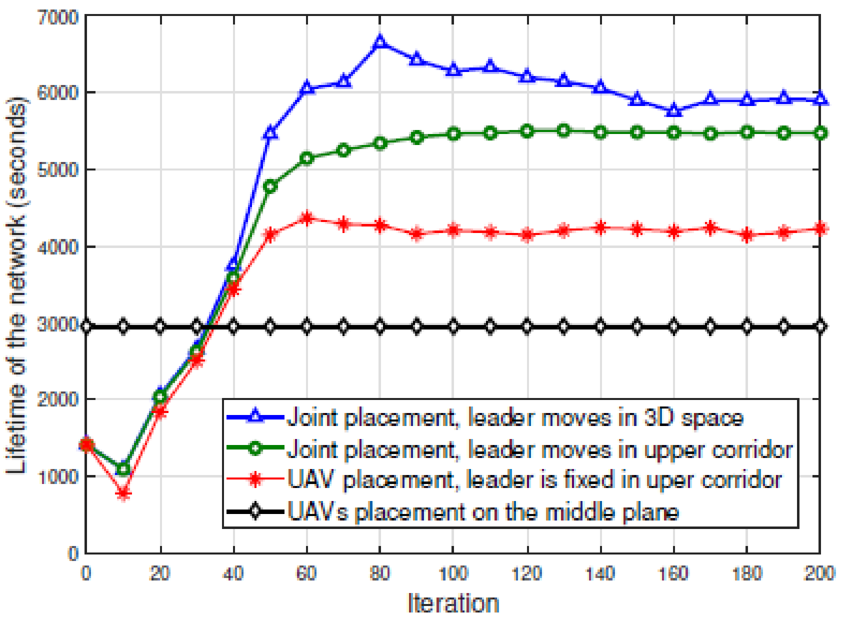


Network with sensor cluster heads and fixed interference

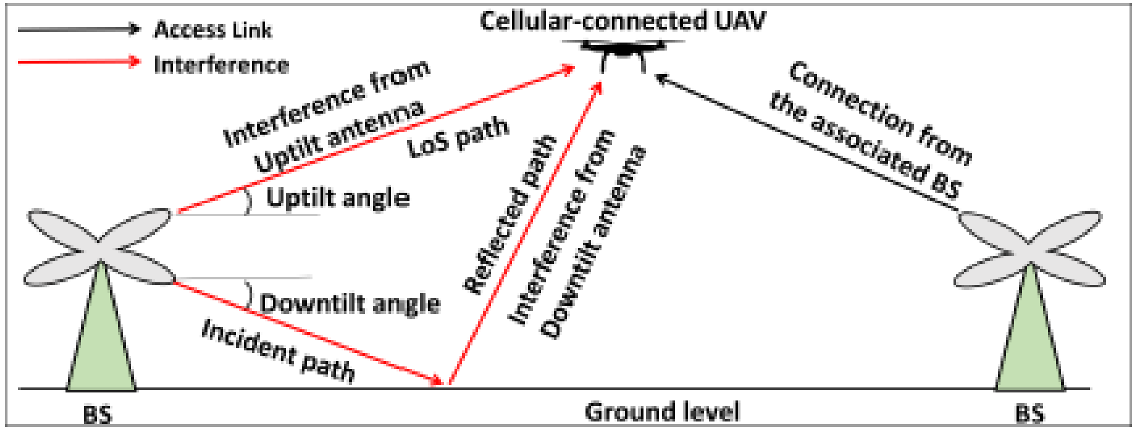


Trajectory of the leader in the presence of jammers.

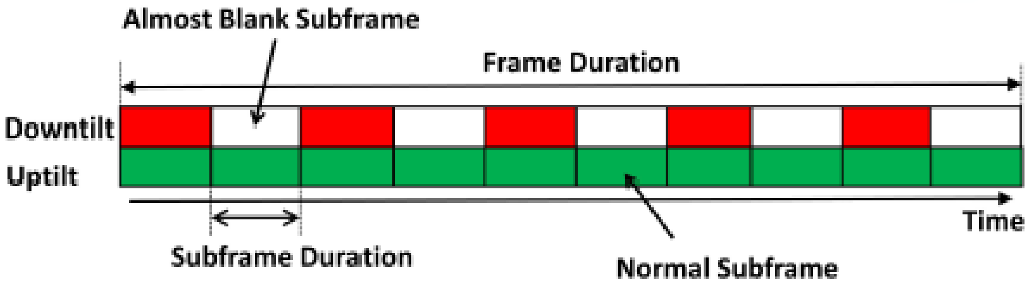
Optimized lifetime with various scenarios.



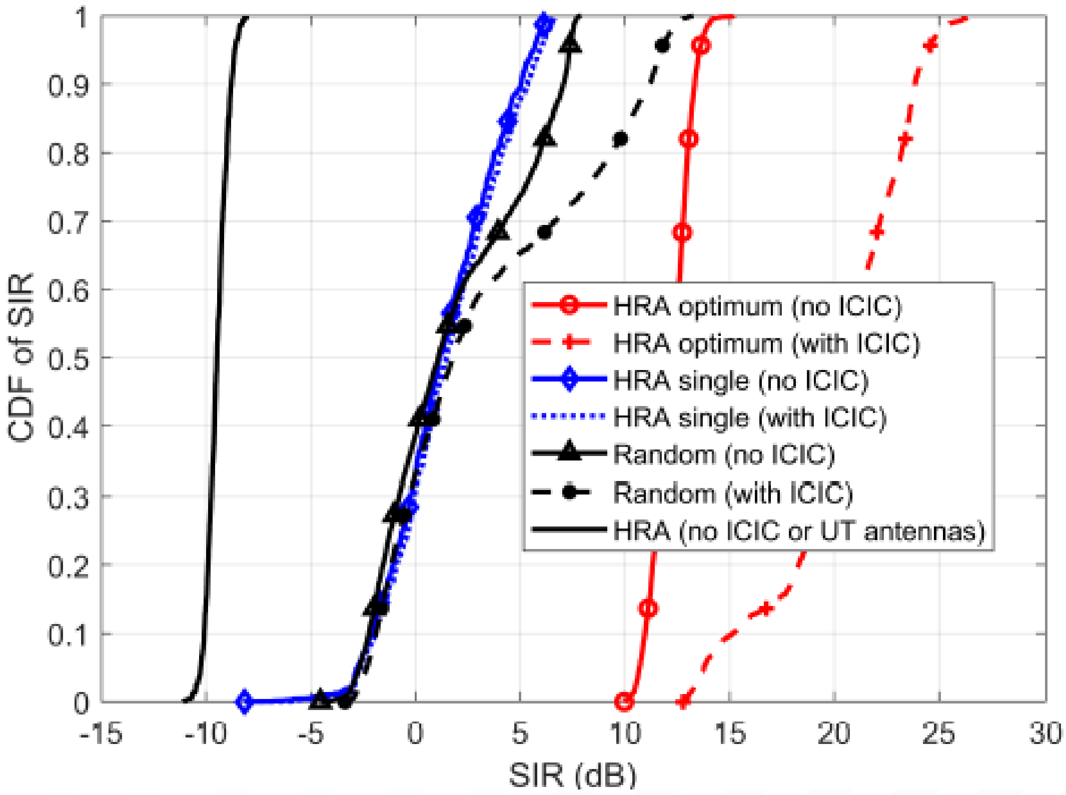
Cellular Drone Interference Management



Inter-cell interference at a cellular-connected UAV.

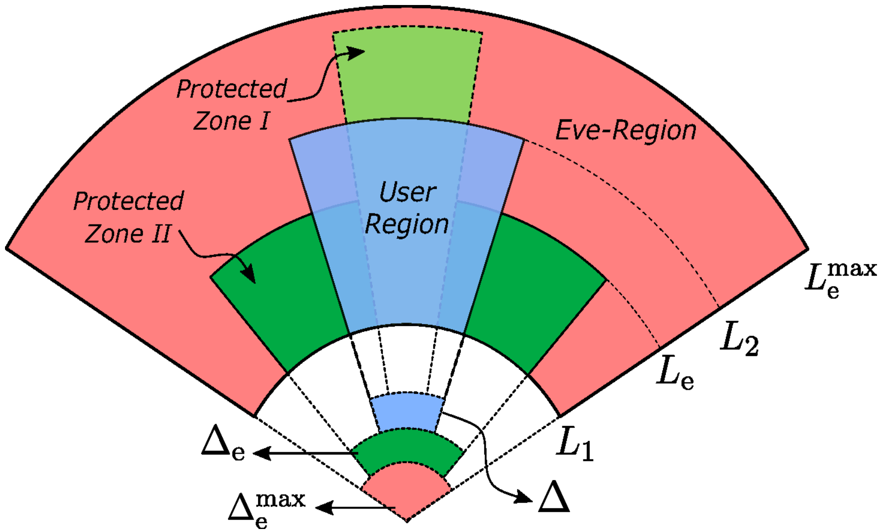


Basic principle of time-domain eICIC (enhanced inter cell interference co-ordination).

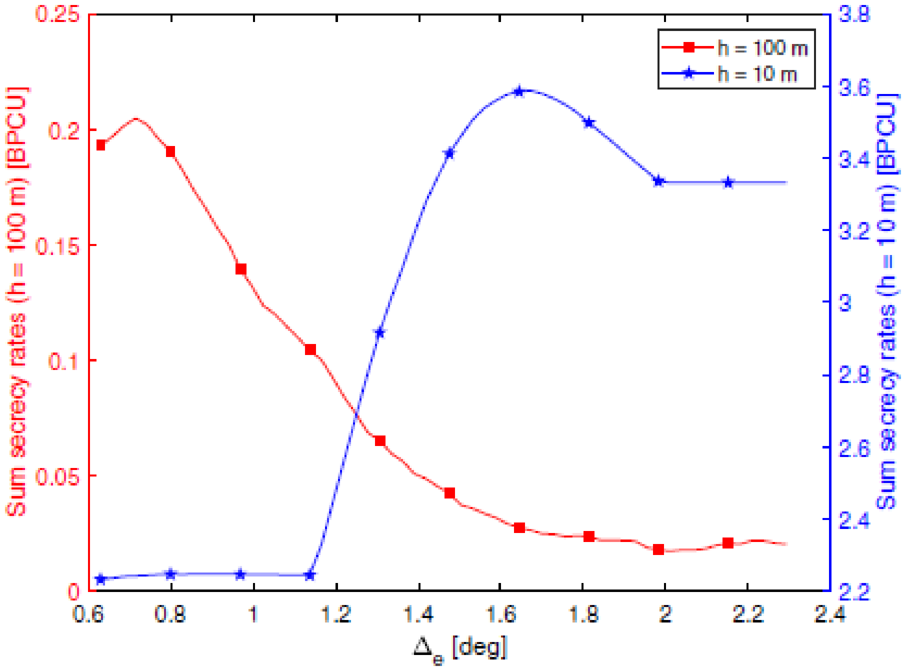


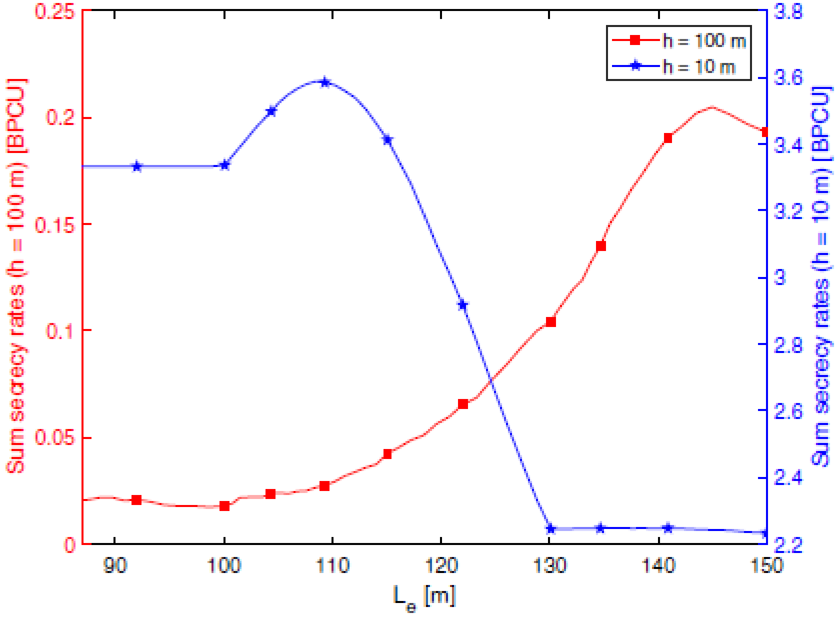
UAV signal-to-interference ratio (SIR) cumulative distribution functions for inter-site distance = 500 m and hUAV = 200 m.

Improving secrecy rate with protected zone



Placement of the user region and the surrounding protected zone alternatives





Sum secrecy rate along with varying angular width and distance of the protected zone at UAV altitudes of 10 and 100 meters

Secure5GDrone Publications

- 31 Conference and Journal papers and a Book chapter.
- Summary Papers:
  1. Advances in Secure 5G Network for a Nationwide Drone Corridor," IEEE Aerospace Conf., Mar 2022.
  2. Secure 5G Network for a Nationwide Drone Corridor," IEEE Aerospace Conf., Virtual, Mar 2021.
  3. Secure mmWave Cellular Network for Drone Communication," IEEE Vehicular Technol. Conf. (VTC), Sep 2019.
- Patent application: SYSTEMS, DEVICES, AND METHODS FOR MILLIMETER WAVE COMMUNICATION FOR UNMANNED AERIAL VEHICLES, Publication Number US 2021/0373552 A1, US application 17/309127, Filed 4/27/2021

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