Characterizing Unmanned Aerial Systems (UAS) networks and implications for sensor end-to-end applications

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Agenda

- Motivation
- Research Goal
- Methodology
- Testing
- Algorithm Advancement and Evaluation
- Future Research
- Conclusion
- Q & A

Motivation

- Modern warfare spans multiple domains
  - Land, Air, Sea, Space, and Cyberspace
- Systems and users must be able to communicate, coordinate, and execute across domains in a timely manner
  - Future systems will form a "sensing grid" to support kinetic and non-kinetic capabilities, ensuring accurate data from multiple domains to make decisions
  - Requires complex networking to efficiently transport data

This elaborate scenario can be decomposed into individual links

https://www.darpa.mil/attachments/STO-Mosaic-Distro-A.pdf

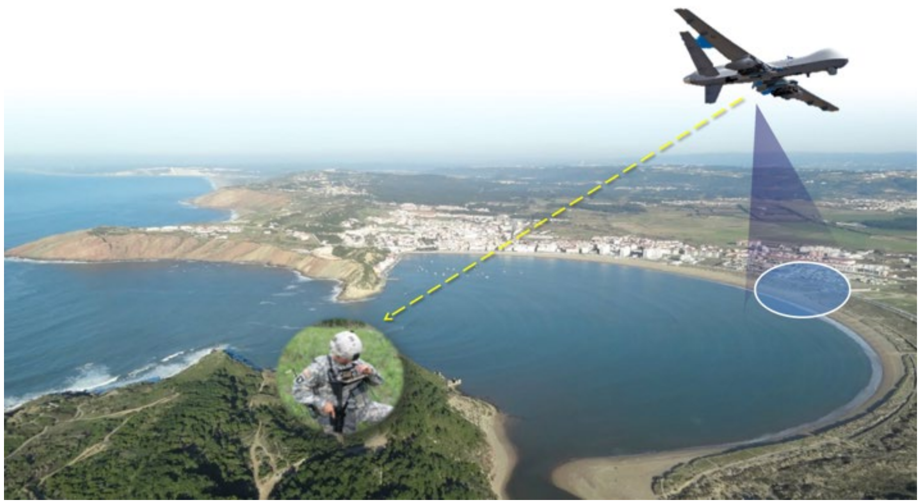
Motivation

- Truths of military systems:
  - More data to send than can fit in the network
  - Networking is taken for granted and expected to work all the time
  - Users push the system beyond design limits
- Our research focuses on advancing sensor end-to-end applications through system-level decisions based on network characterization
  - Focus on UAS sensing across multiple domains
  - Dynamic UAS environments add system complexity – further challenges arise when working with UAS, removing the human from the cockpit
  - Systems are often designed with significant network overprovisioning
    - Reduces risk but increases cost
    - Link is often not fully utilized. Can we design cheaper systems that still get the job done?

Is there a better way to utilize dynamic link capacity for end-to-end data transmission?

Research Goal

- Ensure high-quality and timely data to mission commander / consumers, given unreliable and dynamic networks
  - Design new data transmission algorithms
    - Validate with relevant UAS networking systems through real-world flight tests and relevant simulations
  - Understand how system-level decisions based on deep knowledge of UAS networks can lead to improvement in end-to-end applications
    - Take advantage of varying link performance to maximize efficiency
  - This research may be relevant to any characterized system



Methodology

Collect System Networking Data Through Flight Tests

- High Fidelity
- Latency
- Throughput
- Position and Orientation
- Signal-To-Noise Ratio (SNR)

Analyze, Characterize, and Emulate the Network Data

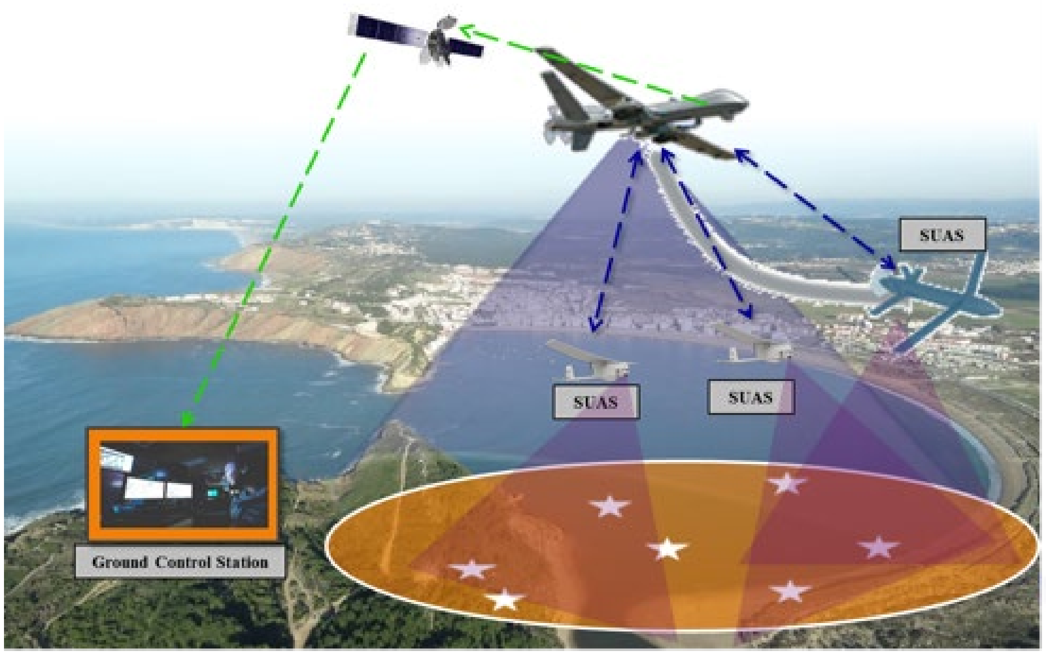
- Analyze and characterize network based on time, location, and orientation of the UAS
- Emulate in software

Test and Improve Sensor Data Transmission Algorithms

- Baseline existing algorithms
- Modify to utilize knowledge of network and relevant environment

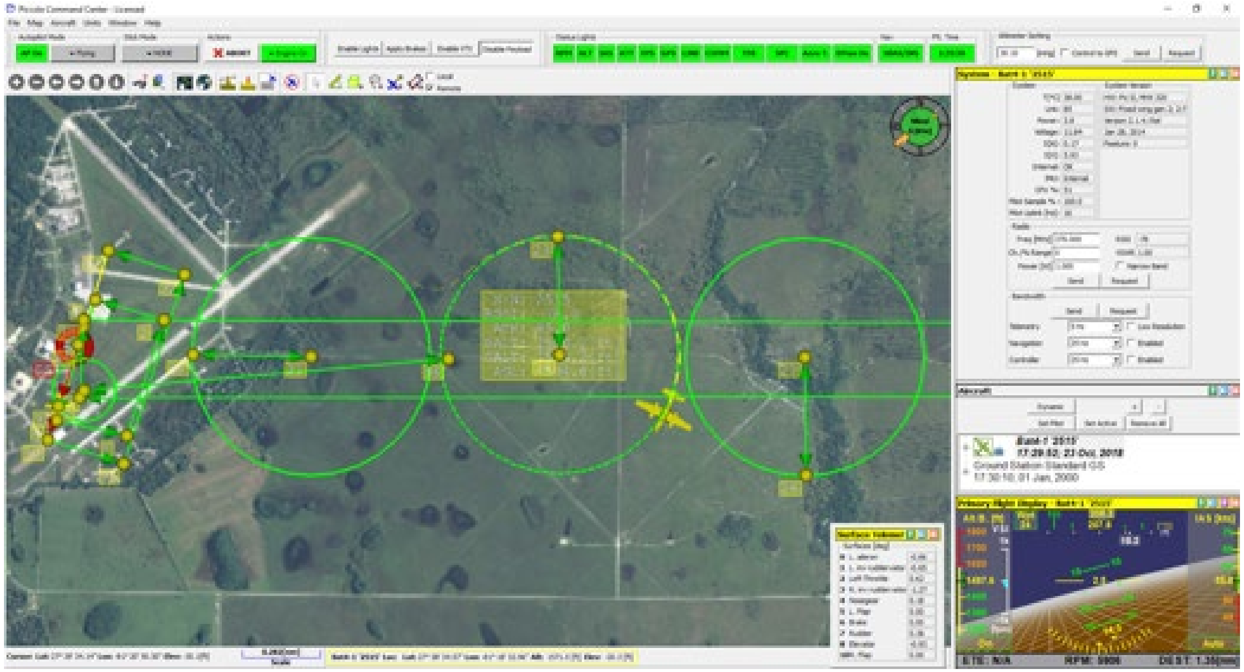
Research Roadmap

- Research methodology: crawl, walk, run approach
- 3-Phases, each increasing in complexity:
  - Phase 1: Single Platform / Single Sensor (Air-to-Ground)
  - Phase 2: Single Platform / Multi-Sensor (Air-to-Ground)
  - Phase 3: Multi-Platform / Multi-Sensor (Air, Ground, Space)



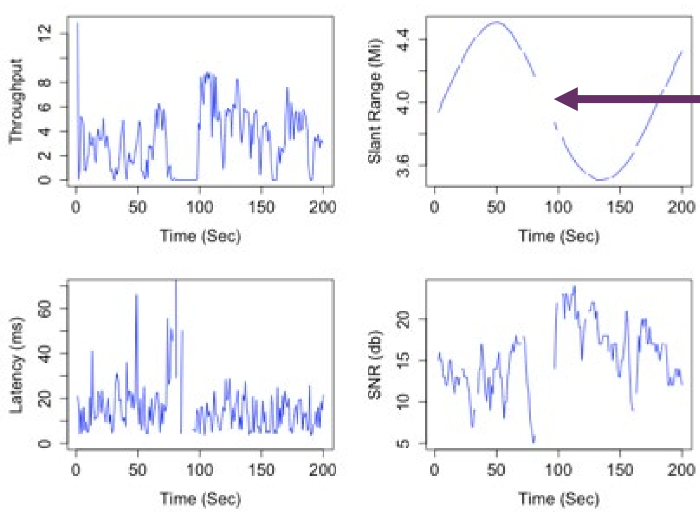
Flight-Test Execution

- Phase 1: Single Platform / Single Sensor (Air-to-Ground)
  - — We partnered with AFRL to flight test UAS networking using AFRL MANET radios
  - — Recorded network throughput, latency, and signal-to-noise (SNR) data
  - — Tested with omnidirectional and directional antennae types with different power levels and distances to record RF behavioral data under various settings

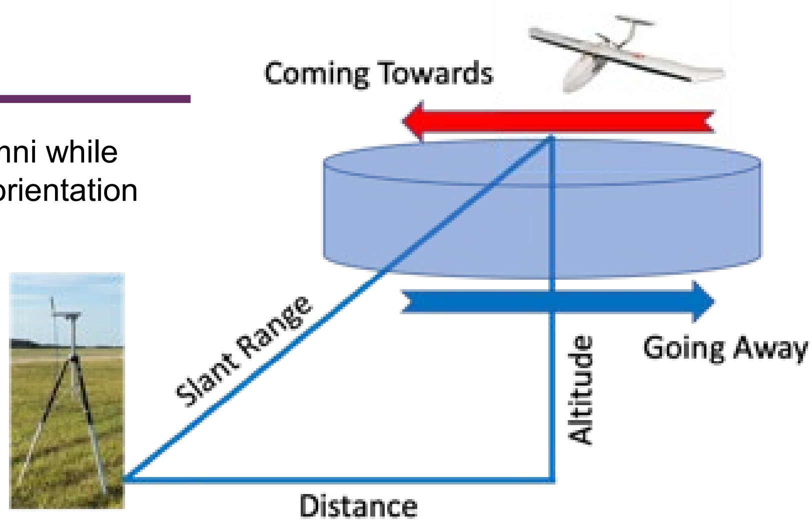


Modeling UAS Network Effects

- Phase 1: Single Platform / Single Sensor (Air-to-Ground)
  - Our algorithm design takes real-world effects in account
    - Flight path distance, plane orientation, antennae positioning, and noise
    - Characterize different UAS / network configurations and measure how the network performance changes with respect to time and distance
  - The dynamic nature of network performance requires our algorithm to be adaptive to fully take advantage of available network capacity



Dropout with Omni while coming toward orientation



Omni circle 3.5 – 4.5 miles from GCS

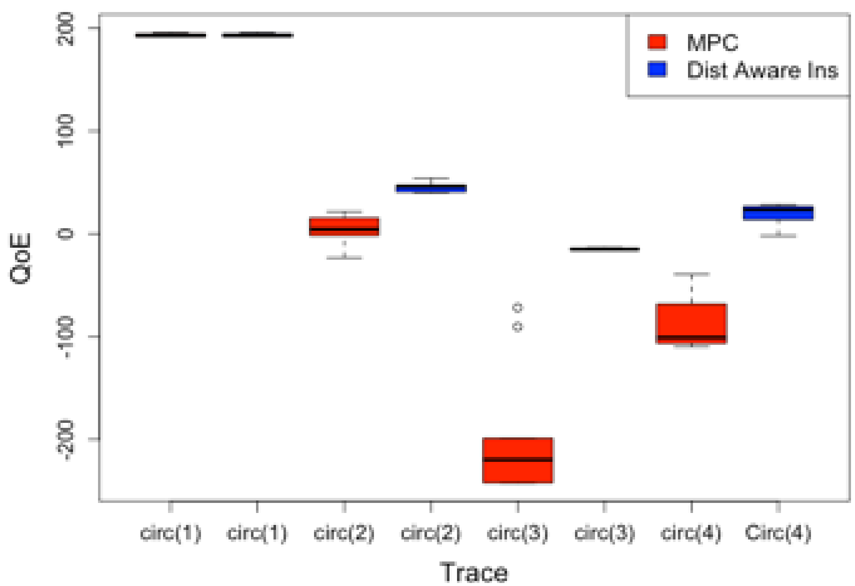
Algorithm Advancement

- Sensor Data Algorithm Improvement
  - Our method of theory-control algorithm improvement can extend to work with alternative sensors (we used video)
  - Rather than transmit video at a set bitrate, we used an Adaptive Bit Rate (ABR) algorithm
    - Allows for bitrate to dynamically and quickly change based on link quality and prediction
  - Based on mission requirements, we grade different qualities of sensor data
    - For example, we could transmit higher quality video with rebuffering and/or dropping frames or transmit lower quality video with less drops and a smoother experience
    - We refer to this grading as Quality of Experience (QoE). The mission commander makes this determination
    - We compare commercial state-of-the-art video streaming algorithm to an algorithm we develop, in which we utilize our UAS flight path and situational awareness

Evaluating Video Quality

- How effectively do we improve end-to-end sensor applications?
  - Using UAS characteristics improves the end-to-end experience
  - Our algorithm is robust to many different settings, showing end-to-end system improvement
  - Below shows the QoE for omnidirectional of circular flight patterns with the center of the circle distances 1-4 miles from the ground radio (higher QoE is better). MPC is current state-of-the-art and Dist Aware is our algorithm

QoE includes video quality, rebuffering, and the smoothness of the viewing experience.



Future Research

- Phase 1 demonstrated we can characterize the network performance of systems and use this information to improve end-to-end performance (Air-to-Ground)
  - We can go beyond the system threshold with our applications and utilize the dynamically changing network performance to improve our applications
  - We can vary the data sent based on sensors and mission priorities
- Phase 2: Single Platform / Multi-Sensor (Air-to-Ground)
  - Add multiple sensors, increasing the complexity of maximizing QoE
  - Sensors have different data, reliability, and timing requirements
- Phase 3: Multi-Platform / Multi-Sensor (Air, Ground, Space)
  - Use network science / graph theory to design complex systems and algorithms
  - Work with relevant partners, utilizing realistic simulators for testing

Conclusion

- The future of ISR will be a “sensing grid” of multi-domain systems
  - Systems made up of dynamic heterogenous links requiring new methods and algorithms to handle data more effectively
  - We developed a new control-theoretic algorithm for end-to-end sensor transmission, demonstrating networking improvement with UAS applications
    - Most challenging network trace scenario showed rebuffering ratio reduced from 23.97% to 8.16%, with a net QoE improvement from -198.84 to -14.72.
  - Given enough knowledge of the network, we can adapt our systems end-to-end applications and data transmission algorithms to optimize mission needs, based on dynamically changing networks

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