Unmanned Aerial Systems (UAS) Sensor Data Networking

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Agenda

- Background and motivation
- Research goals and process
- Research progress and future work
- Conclusion
- Q & A
Background and motivation
• Unmanned Aerial Systems (UAS) continue to grow at rapid rates both within the DoD and commercially.
  — UAS are often equipped with sensors (e.g., video, radar, LiDAR), providing excellent vantage points for surveillance and oversight.
    o Can push into hostile territory without risking the pilot’s life.
    o Small UAS (SUAS) can often be operated by an individual, providing efficient aerial oversight in a variety of mission scenarios.
  — UAS are often more economical to build and operate than their manned counterparts, since they don’t need to account for the pilot.
• UAS sensor data needs to be disseminated.
  — Send to a human or connected system for decision-making.
  — Requires complex communication networking to reliably transport data.

• DoD has very capable and well-connected systems.

• But... There are also truths of military systems that present research opportunities (these parallel the commercial world).
  — Networking is taken for granted and expected to work all the time.
    o Systems are often ‘over-provisioned’ to meet requirements, increasing cost.
  — Data requirements increase over time.
    o There is typically more data than can fit in the network.
    o If the data fits, we create better sensors and the network is congested again.
  — Users often push the system beyond design limits.
  — Examples on the next slide.
• Examples:
  — The left figure shows an example network trace of a period of throughput with an over-provisioned network.
  
  o The system requires 5 Mbps (dotted line), but there is quite a bit of remaining throughput available (this is wasted if it is not used).
  
  — The right figure shows a system struggling to keep up with requirements. This could be from the user pushing beyond the design limits (e.g., the mission extends to a further distance than the system was designed for).

Throughput falls below threshold
Research goals and process
• Ensure high-quality and timely UAS sensor data to mission commander / consumers, given unreliable / dynamic networks.
  — Optimize data sent to take advantage of excess throughput, but carefully scale back when throughput is limited.
    o Most current systems are not dynamic and don’t do this automatically.

• Collect flight data + characterize the communication network.
  — Understand and validate relevant networking systems through real-world flight tests, synthetic trace generation, and relevant simulations.
  — Understand how system-level decisions based on deep knowledge of UAS networks can lead to improvement in end-to-end systems.

• Focus on the end-to-end system.
  — For improved user experience.
Network process / 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
- Develop models to create relevant synthetic traces
- Emulate in hardware and software

Test and Improve Sensor Data Transmission Algorithms
- Baseline existing algorithms
- Utilize different sensor data requirements and mission scenarios
- Modify to utilize knowledge of network and relevant environment
Research progress and future work
✓ Completed:

✓ Phase 1: Collected and characterized real-world UAS flight network communication data.
  ✓ Captured + analyzed high-fidelity flight network communication data.
  ✓ Used Tactical Radios, providing long-range connectivity without pre-existing infrastructure.
  ✓ Built emulation test bed to mimic real-world flight communications.

✓ Phase 2: Optimized end-to-end mission effectiveness with single platform / sensor in dynamic flight environment.
  ✓ Dynamically predicted and adapted sensor data transmission based on UAS flight path, communication network model, and mission parameters.
  ✓ Expanded mission to the edge of network connectivity (out of spec).
  ✓ Optimized user experience beyond state-of-the-art commercial adaptive sensor data algorithms.
Phase 1: Collected and characterized UAS flight network communication data.

- We partnered with AFRL to flight test UAS networking using relevant Tactical 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.
• Understand real-world effects on network communication metrics.
  — 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.

Dropout with Omni while coming toward orientation at about 4 miles slant range.

Omni circle 3.5 – 4.5 miles from GCS

For more data, please see our publication: “Measuring Fixed Wing UAS Networks at Long Range.”
• Characterize and understand throughput variations with regards to different bins of ground distance and UAS orientation.

- Understand dropouts and periods of uncertainty (especially at the network edge).

For more data, please see our publication: “Measuring Fixed Wing UAS Networks at Long Range.”

Phase 2: Optimized end-to-end mission effectiveness with single platform / sensor in dynamic flight environment.

- How?
  - Adaptive Bitrate (ABR) video streaming algorithms.
    - Used commercially (Netflix, Google, Facebook, etc).
    - Take best-of-breed from commercial Internet and adapt to UAS.

- Why?
  - UAS network communication throughput is dynamic and varies even more than traditional Internet.
  - Send more data when throughput is good (use the extra throughput capacity and don’t let it go to waste).
  - Reduce sending when throughput is poor (otherwise we end up with a congested, and stuck, network).

Publication is pending review.
We designed Proteus, a new ABR video streaming algorithm optimized for UAS flight network communication.

- Based on a control-theoretic ABR approach (can extend to other sensor types, but we choose video for our purposes, since it is widely used).
- Integrates knowledge of the UAS flight path into its design, carefully choosing algorithm parameters as a function of both distance and UAS orientation.
- Optimizes decision of what to send (e.g., quality, size, etc) based on the end user (e.g., mission commander) preferences.
Proteus performs better than a widely used state-of-the-art algorithm (MPC).

- Eliminates rebuffering video events.
- Quantifying results with a standard user Quality-of-Experience (QoE).

Proteus has higher QoE than the state-of-the-art and widely used commercial algorithm (MPC).
• Current: Optimize end-to-end mission effectiveness for single platform / multi sensor scenarios.
  
  — Focus on long-term flight planning for sensor communication optimization.
  
  — Increase distance and flight pattern integration options.
  
  — Heterogenous sensor integration with mission optimization based on flexible QoE metrics that expand beyond video to meet different scenarios (e.g., SAR + Video, but expandable to others).
  
  — Develop online learning techniques tailored to UAS flight sets, to enable optimization in previously uncharted and dynamic environments.
• Future Work:

— Add next-gen network protocol (QUIC) to testbed for further system testing and improvement.
  
o QUIC is being developed by large commercial tech companies (e.g., Google, Facebook, and more) and combines best of TCP and UDP into a new network transport protocol.

— Create and develop synthetic network throughput trace generation tool to enable emulation of any flight paths, with different noise and dynamic UAS flight settings.
  
o High-fidelity (e.g., seconds) to allow for use in emulating and designing new algorithms for demanding sensor environments.

— Generalize measurements to new data sets / radios.
  
o Our current data was conducted with multiple flight tests but the same widely used radios.
  
o It would be beneficial to add an additional set of data with additional radios.
Conclusion
• UAS usage is rapidly expanding and will continue to grow.

• UAS systems often provide aerial surveillance with sensing capabilities coupled with network communication.
  — The UAS flight path and growing amount of data creates challenges.
    o The network is often over-provisioned, resulting in wasted throughput capacity.
    o On the other hand, users often go beyond mission limits (or system specs), resulting in an intolerable experience, if not properly planned for.

• Our research implementation improves UAS sensor data end-to-end communication.
  — We tested with video sensing but have a flexible approach that can be adapted to different users, mission scenarios, UAS types, and sensors.

• Our process is to collect and characterize data, build new and robust algorithms to optimize based on our new data and commercial state-of-the-art, and expand use-cases.
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Questions?