Networking Research Challenges in Multi-UAV Systems

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Where Do We Come from?

Pertinent Research:

8 years of research on technology and deployment of *networks of multiple unmanned aerial vehicles (multi-UAV systems), in particular for emergency response operations*

Representative Projects and Objectives:

- *Collaborative Microdrones (cDrones)*
  - Flight formation and networked control
  - Cooperative aerial imaging to create overview pictures (mosaics) of disaster-affected areas
- *Self-organizing Intelligent Networks of UAVs (SINUS)*
  - Distributed coordination of UAV movements and task execution
  - Reliable aerial networking for robust multimedia streaming

Portfolio in Aerial Robotics

Research Topics:

- Autonomous navigation and coordination
- Mission and path planning
- Image processing
- Wireless (multimedia) comm.
- Human-UAV interaction

Application Areas:

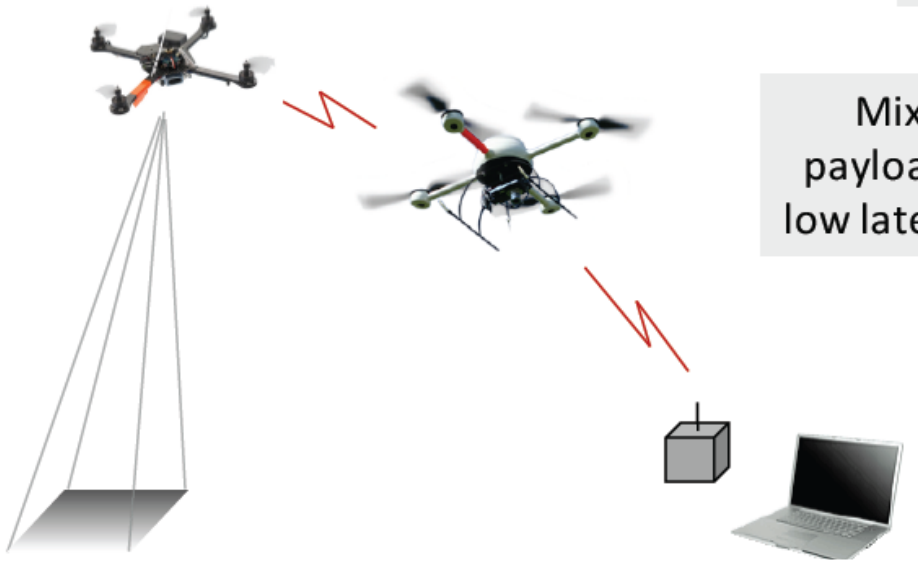
- Search and rescue
- Aerial surveillance
- Precision agriculture
- Delivery of goods

Findings w.r.t. Networking and Communication (I)

1. Communication requirements are manifold

COMM. REQUIREMENTS / TRAFFIC TYPES

Scenario:

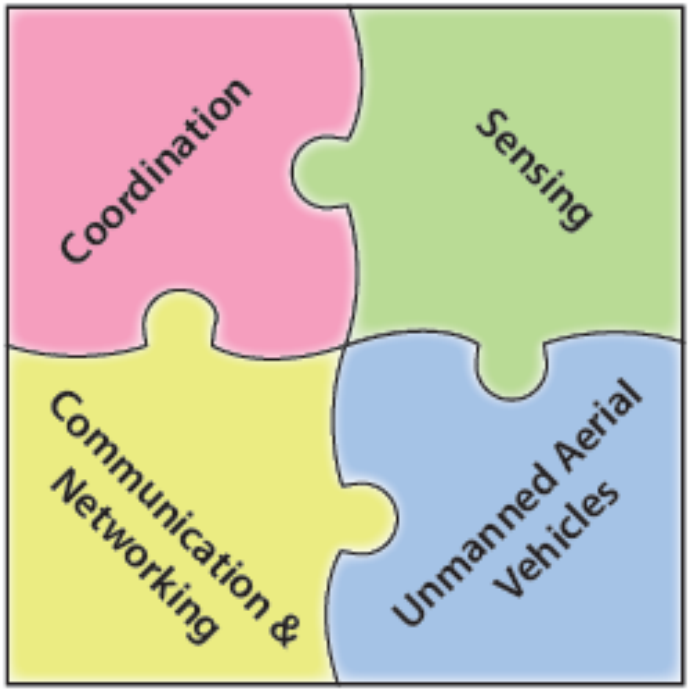


Traffic Type	Requirements
UAV control	Low latency & high reliability
Vision-based navigation	High data rate & low latency
Multimedia applications	High data rate & QoS support

Findings w.r.t. Networking and Communication (II)

1. Communication requirements are manifold
2. **Communication network of a multi-UAV system and their other components are highly interdependent**

Interdependence of (Multi-)UAV Components

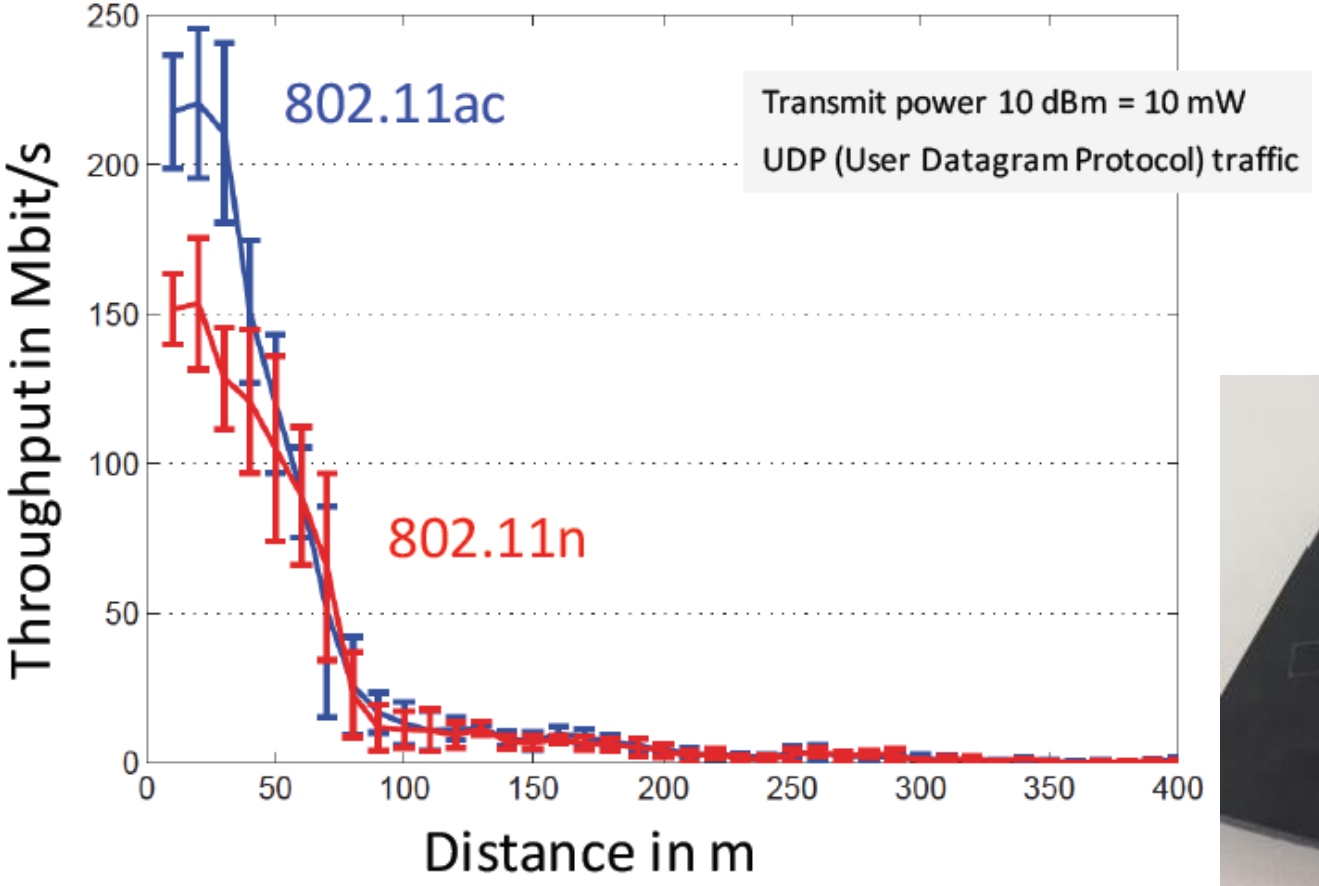


Findings w.r.t. Networking and Communication (III)

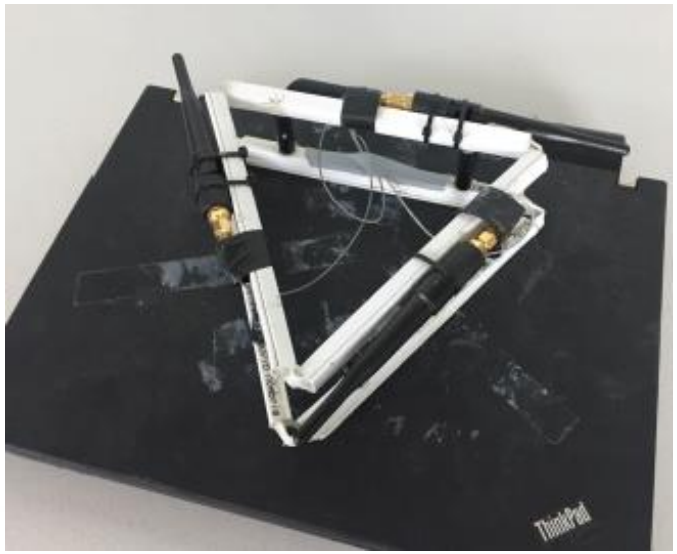
1. Communication requirements are manifold
2. Communication networks of a multi-UAV system and their other components are highly interdependent
3. **Off-the-shelf IEEE 802.11 WLAN is not well suited for 3D communication and agile network nodes (UAVs)**

SAMPLE THROUGHPUT PERFORM. RESULT

IEEE 802.11n and 11ac over outdoor drone-to-ground link



Special antenna setup



Findings w.r.t. Networking and Communication (IV)

1. Communication requirements are manifold
2. Communication networks of a multi-UAV system and their other components are highly interdependent
3. Off-the-shelf IEEE 802.11 WLAN is not well suited for 3D communication and agile network nodes (UAVs)
4. **Cooperative relaying or/and specific protocols are needed to support the multi-UAV mission**

Wireless Multi-Hop Communications

- UAVs may serve as **relays** for traffic from other UAVs
- UAVs may form a **mesh** network using IEEE 802.11s
- UAVs may exploit **cooperative diversity** to make links more robust
- Large drone network may use **ad-hoc routing** protocols
- Large drone network may use concepts from **delay-tolerant networking** for certain applications

Different approaches for each traffic type possible

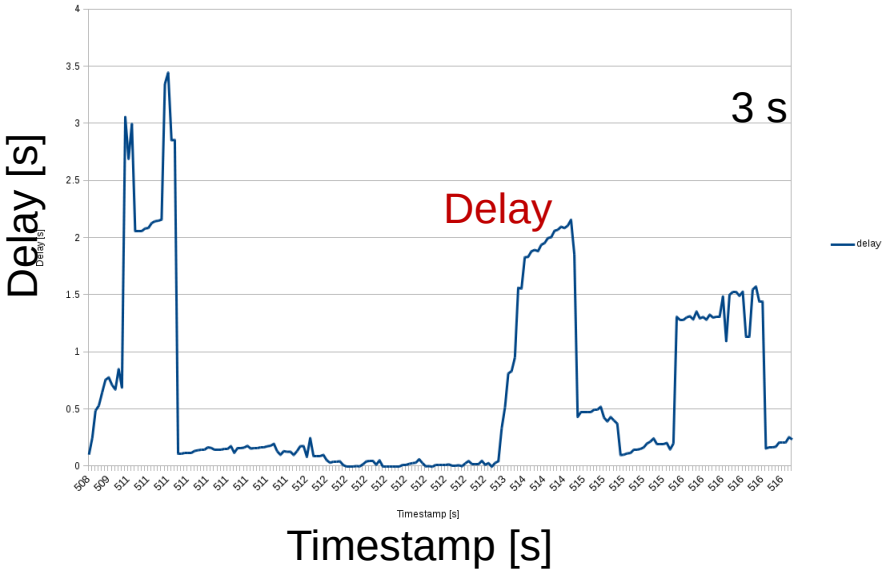
Findings w.r.t. Networking and Communication (V)

1. Communication requirements are manifold
2. Communication networks of a multi-UAV system and their other components are highly interdependent
3. Off-the-shelf IEEE 802.11 WLAN is not well suited for 3D communication and agile network nodes (UAVs)
4. Cooperative relaying or/and specific protocols are needed to support the multi-UAV mission
5. **Adaptation of payload data (e.g., pictures) in terms of quality/data rate, to network conditions at hand, helps**

EXPERIMENT: ADAPTIVE VIDEO STREAMING

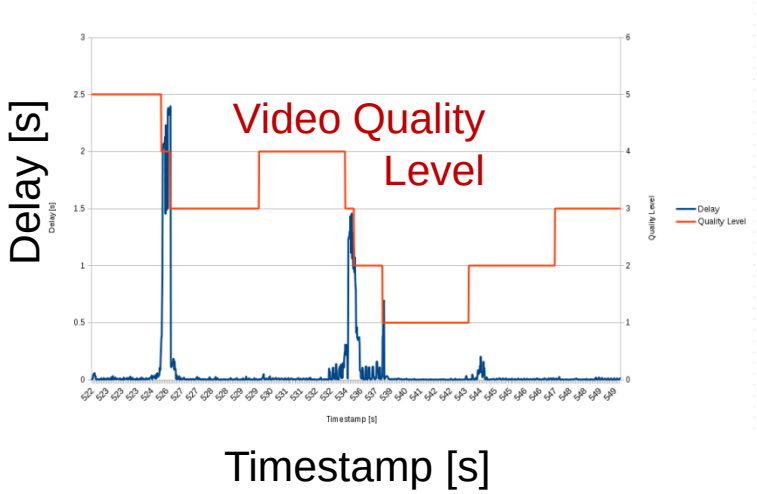
Video packets‘ queueing delays and video quality …

… *without* video adaptation



… *with* video adaptation

(Current heuristic:
- Downgrade if delay > 0.3 s
- Upgrade if delay < 0.1 s for 250 p.)



Where to Go from Here?

Research Objective:

To make multi-UAV systems fully autonomous

Doctoral Programme:

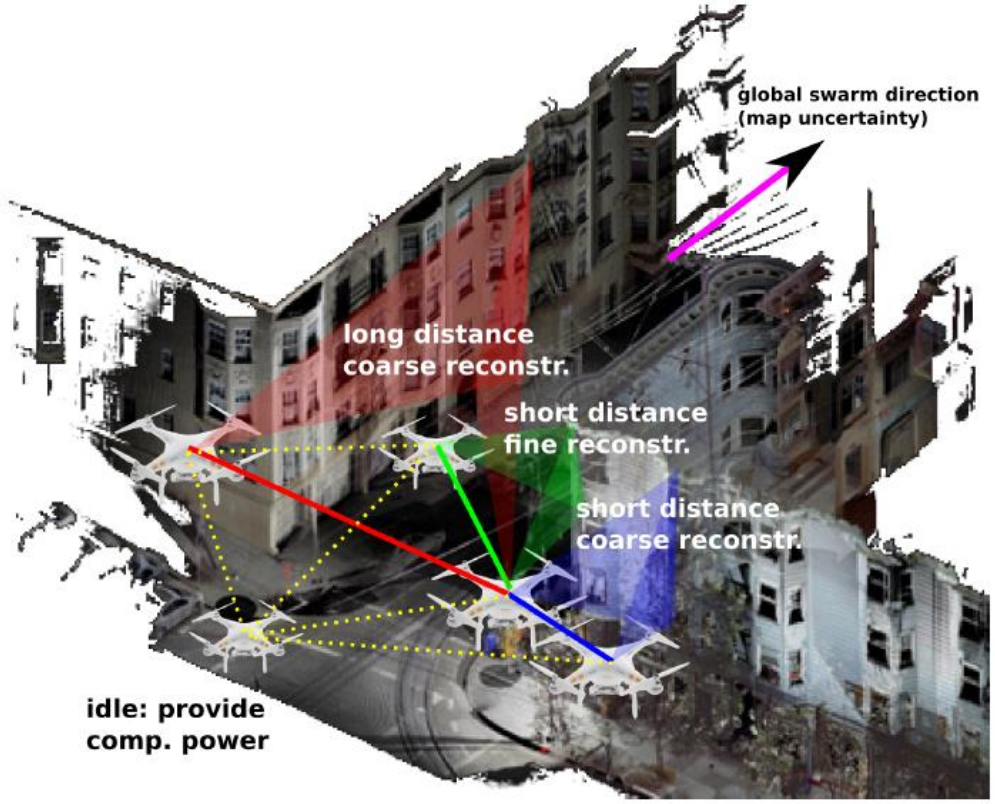
- *Networked Autonomous Aerial Vehicles (NAV)*
- Faculty: Bettstetter, Hellwagner, Rinner, Weiss
- Funding: ~0.5 M€ granted by AAU, 3 years

Networking Research Challenges …

… partially addressed

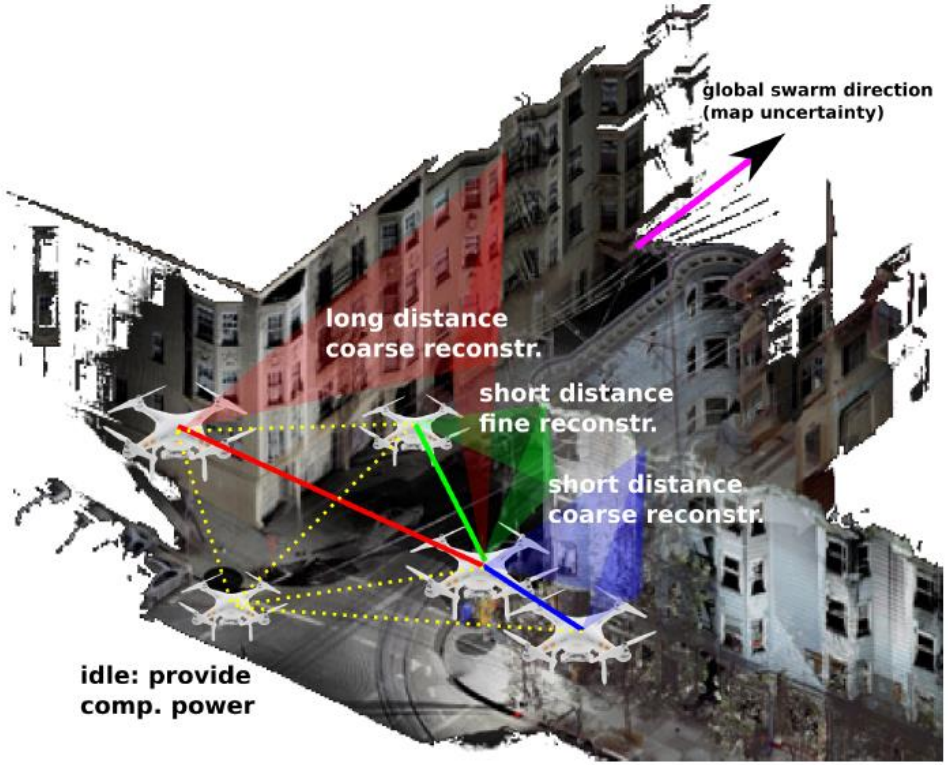
Networking Research Challenges

1. **Autonomous, collaborative 3D environment reconstruction and navigation of the UAVs will have to be supported**



Networking Research Challenges

1. Autonomous, collaborative 3D environment reconstruction and navigation of the UAVs will have to be supported
2. **Fine-granular temporal synchronization between aerial vehicles will have to be established**
3. **Ad-hoc multipoint-to-multipoint communi-cation and coordination will be needed**



Networking Research Challenges

1. Autonomous, collaborative 3D environment reconstruction and navigation of the UAVs will have to be supported
2. Fine-granular temporal synchronization between aerial vehicles will have to be established
3. Ad-hoc multipoint-to-multipoint communication and coordination will be needed
4. **Security and safety of an autonomous multi-UAV system will become of utmost importance**
5. **Availability of dedicated spectrum for mission-critical UAV networks will have to be discussed**

WHY TNC‘17?

Challenging networking research topics

Multi-UAV systems increasingly used for **creative businesses,** e.g.:

- Picture and movie productions
- **Arts performances, e.g., *AE Linz*, “Drone 100” (Intel)**
- Entertainment, e.g., Arrowonics

*What if **creative persons and artists** could easily interact with a massive UAV swarm, e.g., **by gestures?***

→ **New types of aerial shows, fireworks, entertainment**

→ **New networking research challenges**

SELECTED PUBLICATIONS

T. Andre, K.A. Hummel, A.P. Schoellig, E. Yanmaz, M. Asadpour, C. Bettstetter, P. Grippa, H. Hellwagner, S. Sand, S. Zhang. “Application-Driven Design of Aerial Communication Networks”. *IEEE Communications Magazine,* May 2014.

S. Hayat, E. Yanmaz, C. Bettstetter. “Experimental Analysis of Multipoint-to-Point UAV Communications with IEEE 802.11n and 802.11ac”. *Proc. 26th IEEE Int’l. Symp. on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Hong Kong, 2015.

S. Hayat, E. Yanmaz, R. Muzaffar. “Survey on Unmanned Aerial Vehicle Networks for Civil Applications: A Communications Viewpoint”. *IEEE Comm. Surveys & Tutorials*, 2016.

S. Kacianka, H. Hellwagner. “Adaptive Video Streaming for UAV Networks”. *Proc. 7th ACM Int‘l. Workshop on Mobile Video (MoVid)*, Portland, OR, USA, 2015.

E. Yanmaz, R. Kuschnig, C. Bettstetter. “Achieving Air-Ground Communications in 802.11 Networks with Three-Dimensional Aerial Mobility”. *Proc. 32nd IEEE Int’l. Conf. on Computer Communications (INFOCOM)*, Turin, Italy, 2013.

E. Yanmaz, S. Hayat, J. Scherer, C. Bettstetter. “Experimental Performance Analysis of Two-Hop Aerial 802.11 Networks”. *Proc. IEEE Wireless Communications and Networking Conf. (WCNC),* Istanbul, Turkey, 2014.

E. Yanmaz, S. Yahyanejad, B. Rinner, H. Hellwagner, C. Bettstetter. “Drone Networks: Communications, Coordination, and Sensing”. *Ad Hoc Networks* (invited for submission).

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