



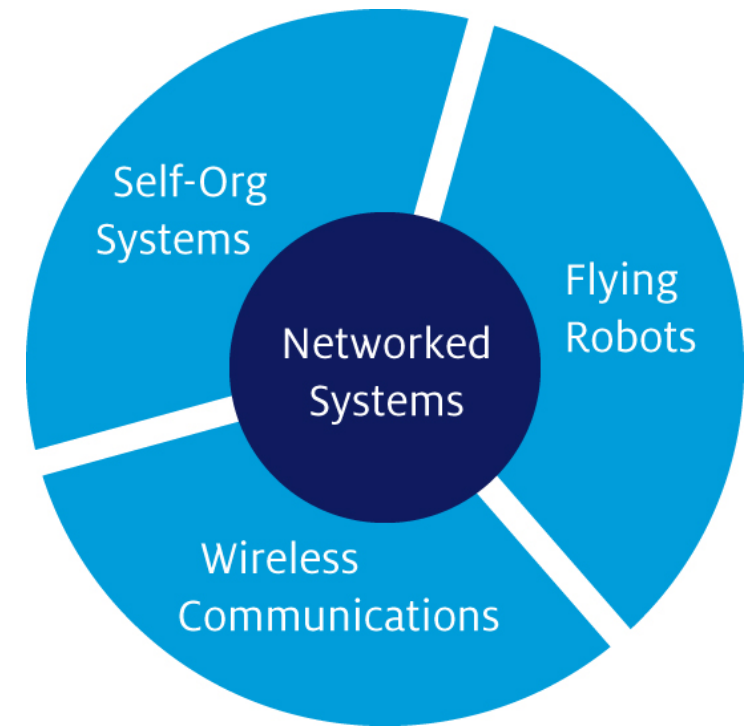
Aerial Imaging and Wireless Communications with Multiple Autonomous UAVs

Univ.-Prof. Christian Bettstetter and Dr. Evsen Yanmaz
Lakeside Research Days, 9 July 2013

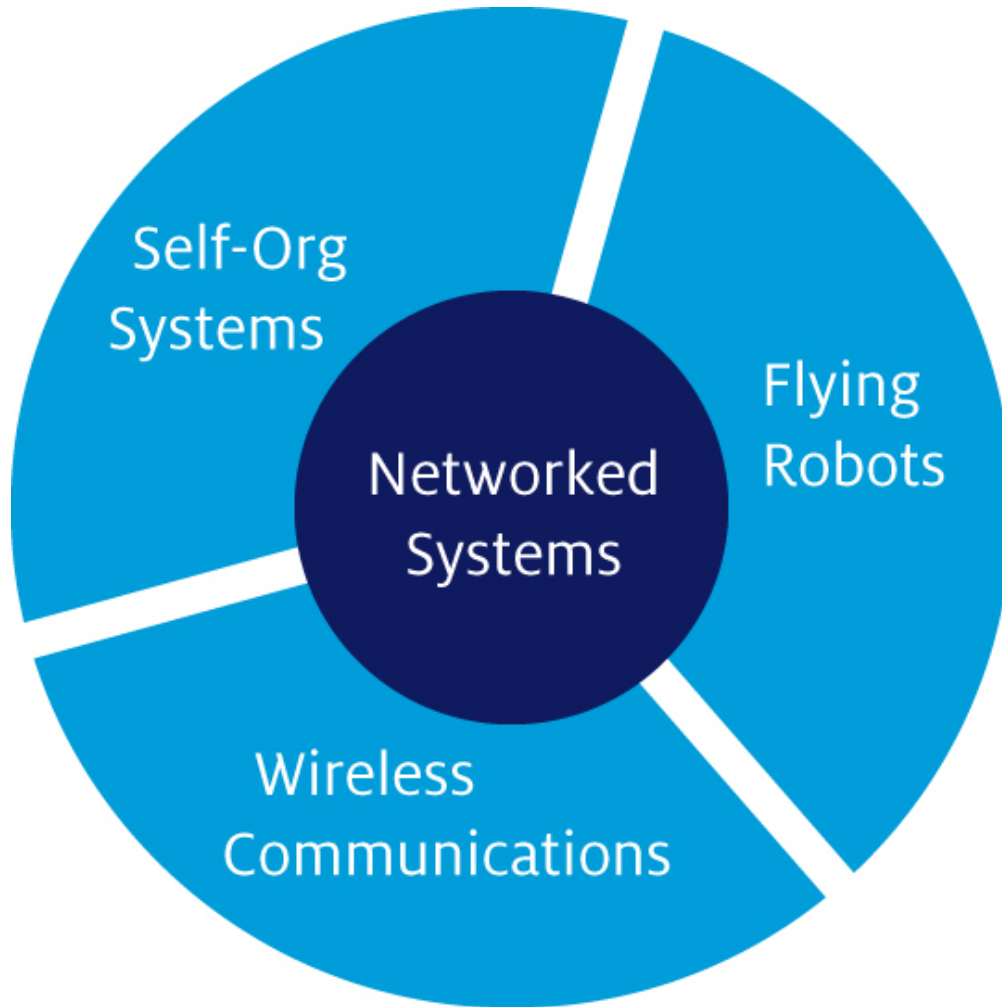
Lakeside Labs

Bettstetter Group

- 1 full professor, 1 secretary, 4 senior researchers, 10 PhD students
- Multidisciplinary and international
- Over 700 T€ **third-party funding** / year
- **Collaborations** with Orange, DOCOMO, Max Planck Society, U Porto, Athens UEB, TU Munich, and others
- Methods from **maths** (stochastics, graph theory) over **simulation** and **protocol engineering** to **prototyping** on hardware
- Striving for a good mix of **fundamental** and **applied** research, more and more also **interdisciplinary** research



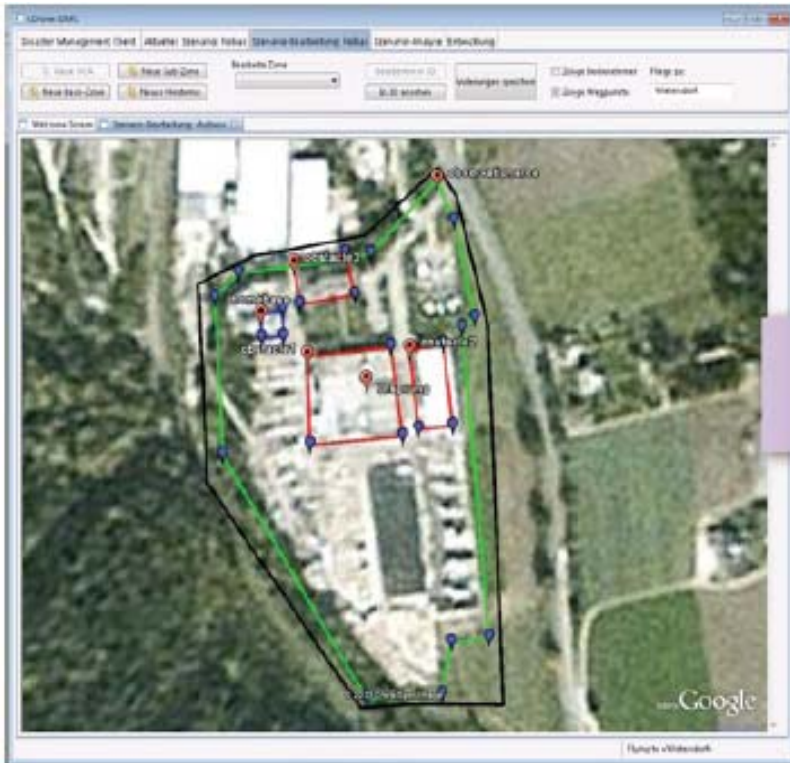
Research Portfolio



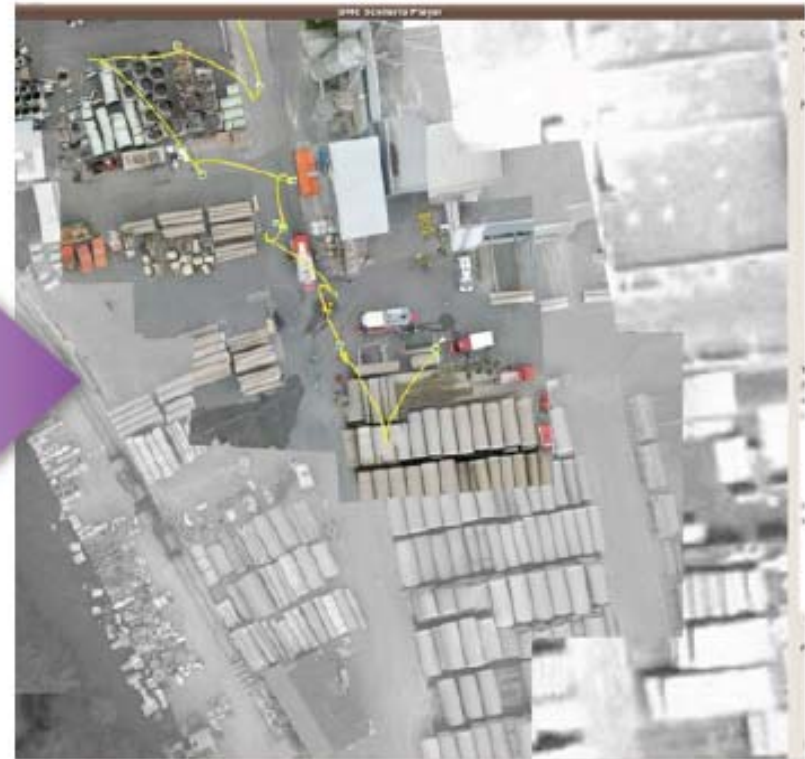
Current Projects

- Cooperative relaying in wireless networks
- Interference dynamics in wireless networks
- Self-organizing synchronization
- Communications and coordination of flying robots

Starting Point: Disaster Management

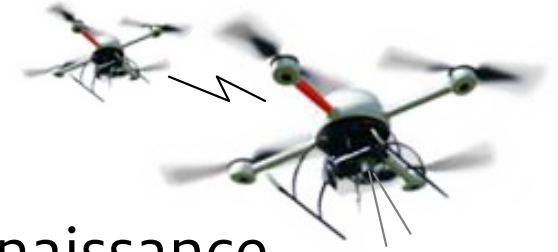


User defines high-level tasks
(e.g. observation area)



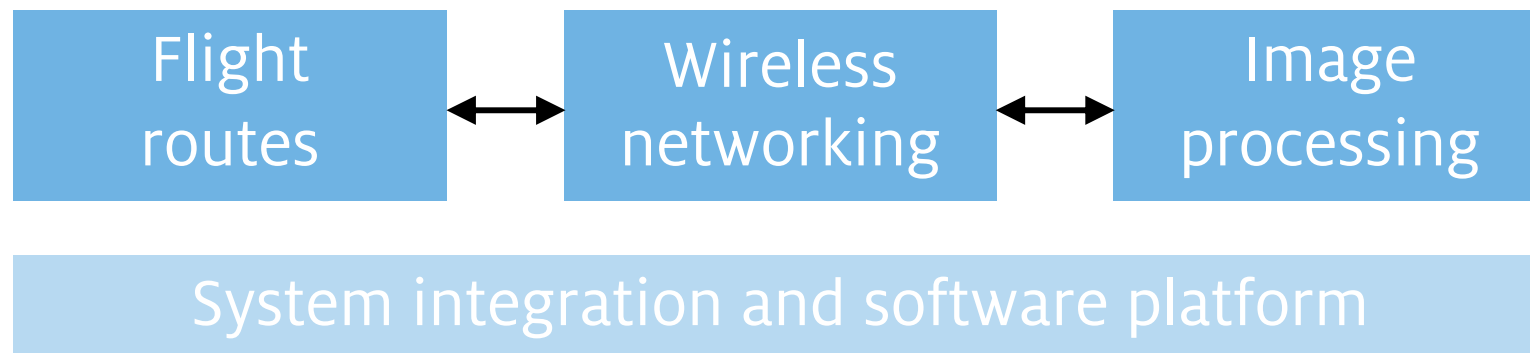
User obtains **real-time**
high-quality overview image

Goals and Research Issues



- Develop **autonomous** system for aerial reconnaissance
- Support first responders in **disaster management**
- Use **off-the-shelf**, small-scale, low-altitude multicopters equipped with high-quality cameras and GPS
- Deploy **multiple** drones to achieve fast area coverage

Research Issues



Flying High: Multi-UAV Aerial Imaging



Challenges

- Strong **resource** limitations:
Flight time, payload, computation
- Coordination of **multiple** drones:
Centralized vs. distributed approach
- Multimedia network with **dynamic, three-dimensional** mobility
- Non-trivial **user** interface with prompt response
- Aspects of **experimental** research:
Safety, legal issues
- Application **partners**, project **funding**



Image Processing: Stitching



Using position data
(GPS)



Using position
and orientation
(GPS and IMU)



Exploiting feature
detection
(Image data)

Apparatus and method for generating an overview image of a plurality of images using an accuracy information. European patent pending, EP2423871 (A1), 2012



3D Landscape Models in Disaster Areas



- Covering 45 km² in Haiti in six days
- System that local people can use
- E.g.: Understand flow of water



Switzerland

Applications Beyond Disaster Response



3D mapping



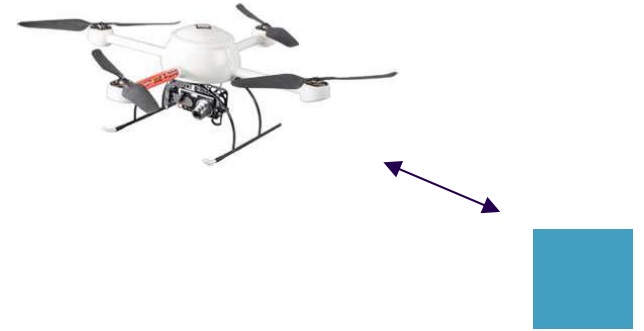
Person and object tracking

Industrial site monitoring, police support, accident documentation, and many others

Wireless Communications

Issues to consider

- Which technology? Which antennas?
- Which UAV?
 - 3D motion, tilting
 - Hardware **limitations** (payload, placement)



Basic question

- How **far** can we deliver data at which **data rate**?

Experiments Conducted

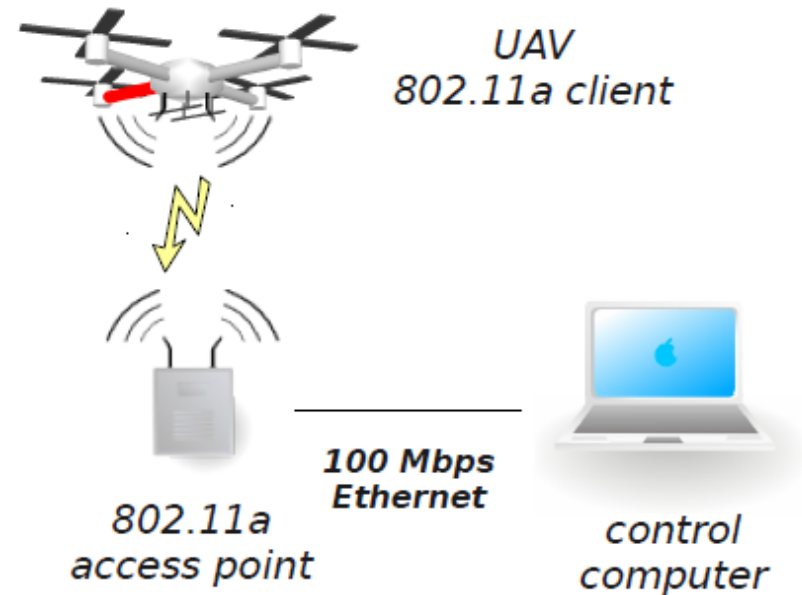
- Flew quadrotor with waypoint navigation
- Generated UDP traffic (uplink and downlink) over WLAN

Performance metrics

- Received signal strength (RSS)
- Throughput and delay
- Packet loss

Test influence of

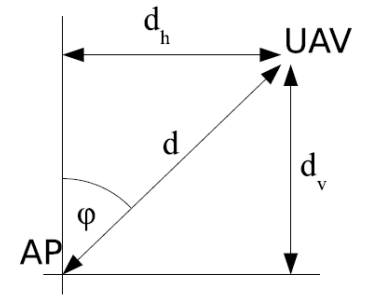
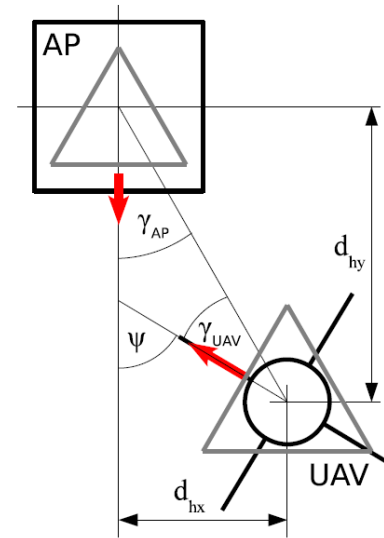
- Height and distance
- Orientation UAV-base station
- Antenna setup



A Simple Extension to IEEE 802.11a

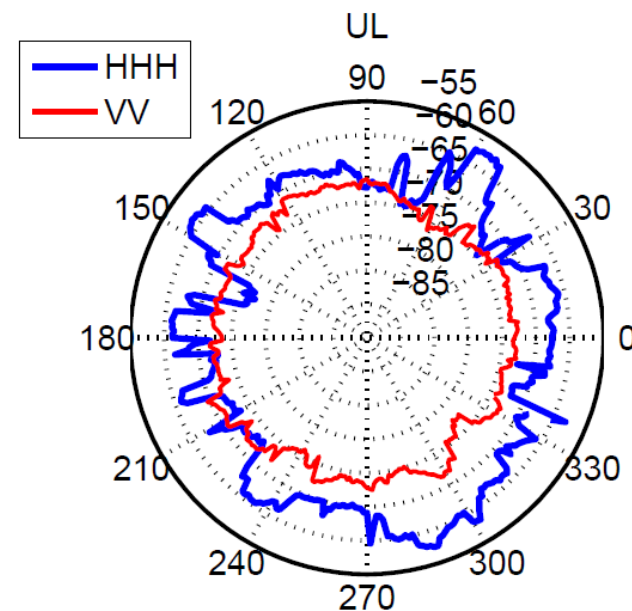
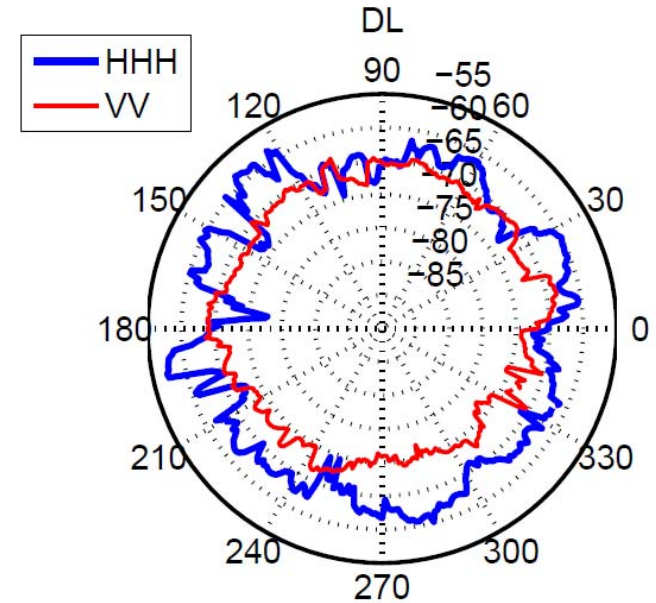
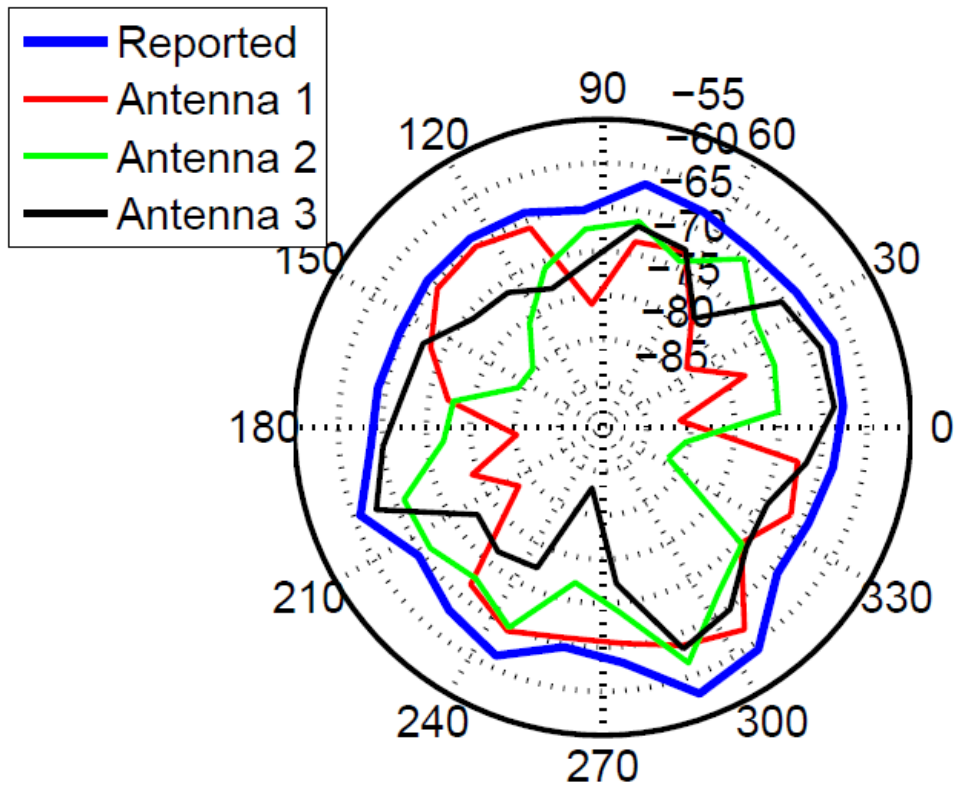


HHH



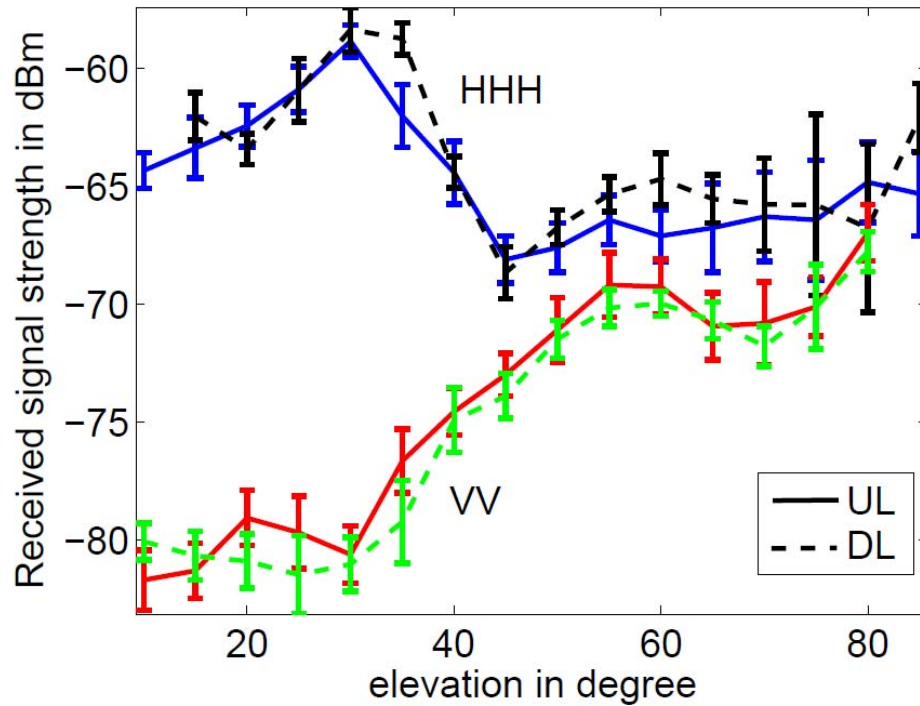
Radiation Pattern (HHH setup)

UAV rotating around its z-axis at 100 m distance from the AP

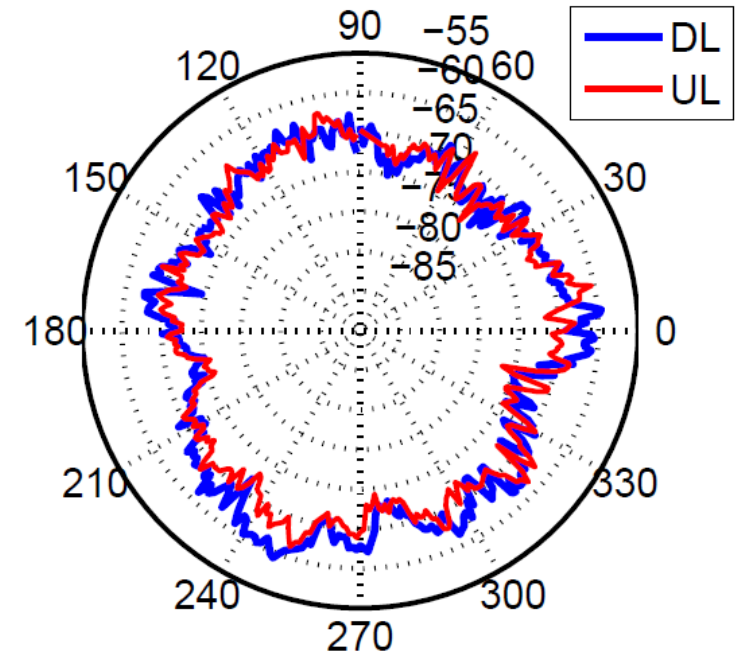


Radiation Pattern (HHH setup)

UAV ascending on the surface of a sphere



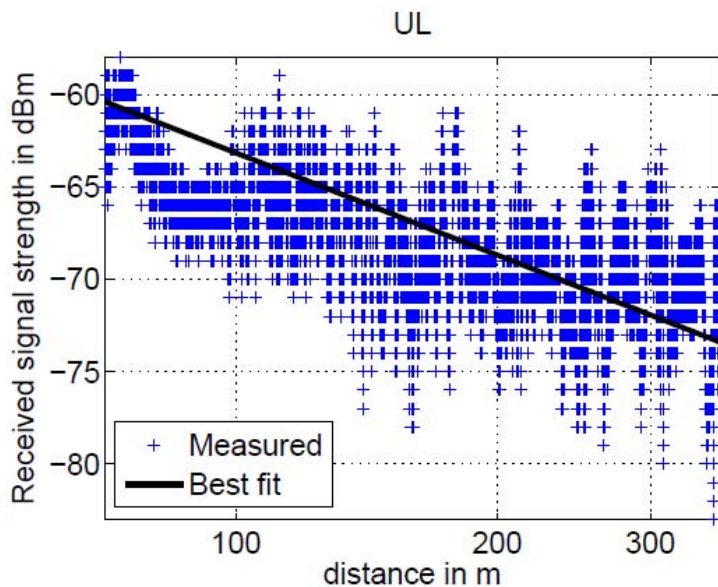
UAV flying around the access point at fixed altitude



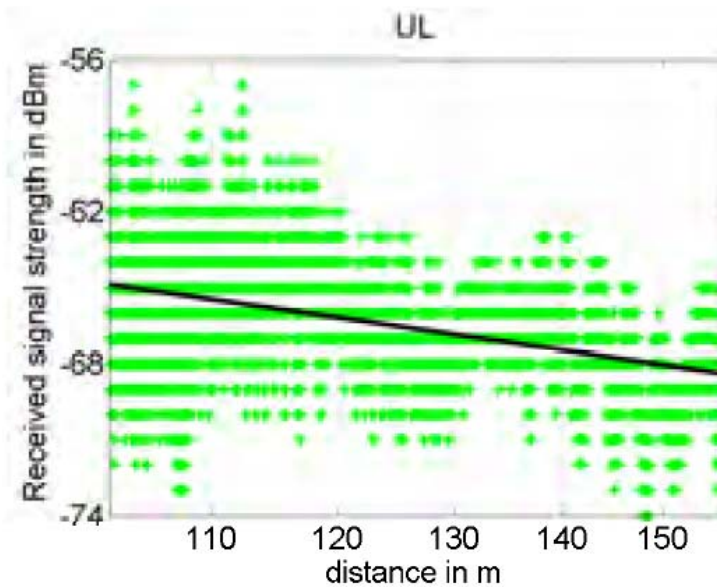
Path Loss Between UAV and Access Point

Path loss coefficient is ~ 2 ; consistent with free-space path loss

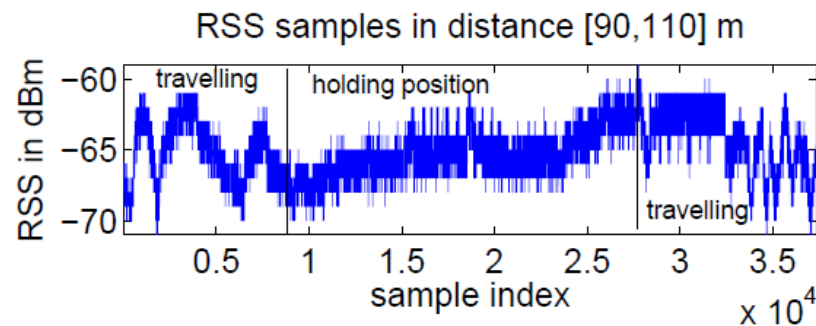
$$PL(d) = PL(d_0) + 10\alpha \log_{10} \left(\frac{d}{d_0} \right)$$



(a) Horizontal: moving away

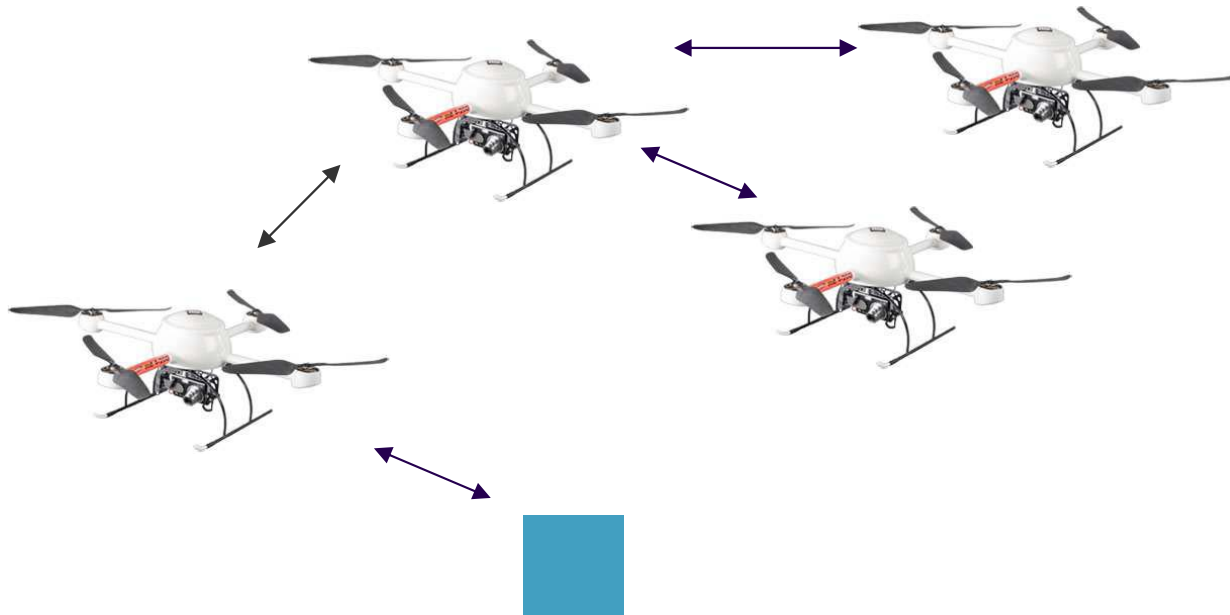


(b) Vertical: ascending



From Communications to Networking

- Wireless UAV **mesh network** based on WLAN 802.11s
- Use of **cooperative relaying**
- Interaction between UAV **coordination and networking**



Concluding Remarks

- Work on **routing**, **image stitching**, and **wireless communications**
- Challenges due to **multidisciplinary** and **experimental** character
- Various **applications**, several **startup** companies
- Various **legal** and **privacy** issues
- Attractive for **students** and **PhD researchers**



Selected Publications

- E. Yanmaz, R. Kuschnig, C. Bettstetter: Channel measurements over 802.11a-based UAV-to-ground links. In *Proc. IEEE GLOBECOM-WiUAV Workshop*, 2011.
- V. Mersheeva, G. Friedrich: Routing for continuous monitoring by multiple micro UAVs in disaster scenarios. In *Proc. Europ. Conf. Artificial Intellig.*, 2012.
- E. Yanmaz: Connectivity versus Area Coverage in Unmanned Aerial Vehicle Networks. In *Proc. IEEE Intern. Conf. Communications (ICC)*, 2012.
- E. Yanmaz, R. Kuschnig, C. Bettstetter: Achieving air-ground communications in 802.11 networks with three-dimensional aerial mobility. In *Proc. IEEE INFOCOM*, 2013.
- T. Andre, C. Bettstetter: Assessing the value of coordination in mobile robot exploration using a discrete-time Markov process. Accepted for *IEEE/RSJ Intern. Conf. on Intelligent Robots and Systems (IROS)*, 2013.

Acknowledgements

