Networked Drones

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University of Klagenfurt and Lakeside Labs

European Wireless, Dresden, May 18, 2017

Photo: ffly/Fotolia


… to healing machines.

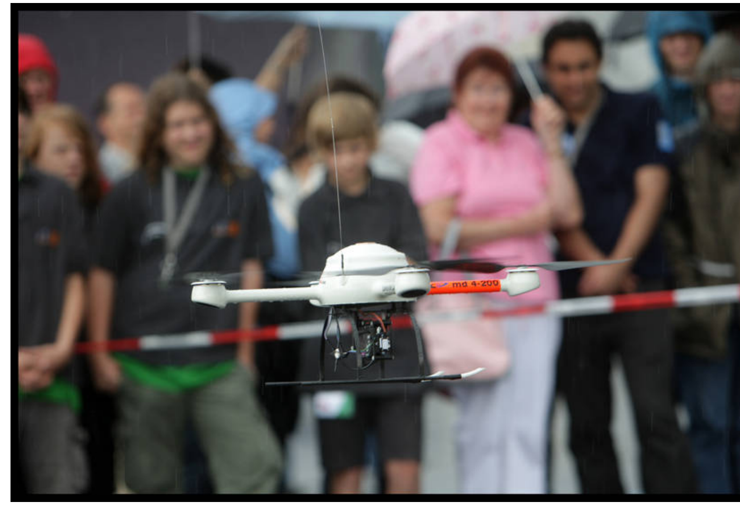
Research on Networked Drones in Klagenfurt

Topics

- Autonomous navigation
- Coordination
- Human-drone interaction
- Image processing
- Mission and path planning
- Wireless communications

Applications

- Aerial surveillance
- Delivery
- Digital farming
- Search and rescue



Key facts

Started 2008

8 Profs, 15 PhDs, Postdocs

9 funded projects

~ 60 publications

Lakeside Labs

Wireless Communications for Multicopters

- What are the requirements?
- Are standard antennas suited?
- How to model the radio link?
- How does IEEE 802.11 work?
- What throughput is achieved?
- What are common research issues of control, vision, and networking?

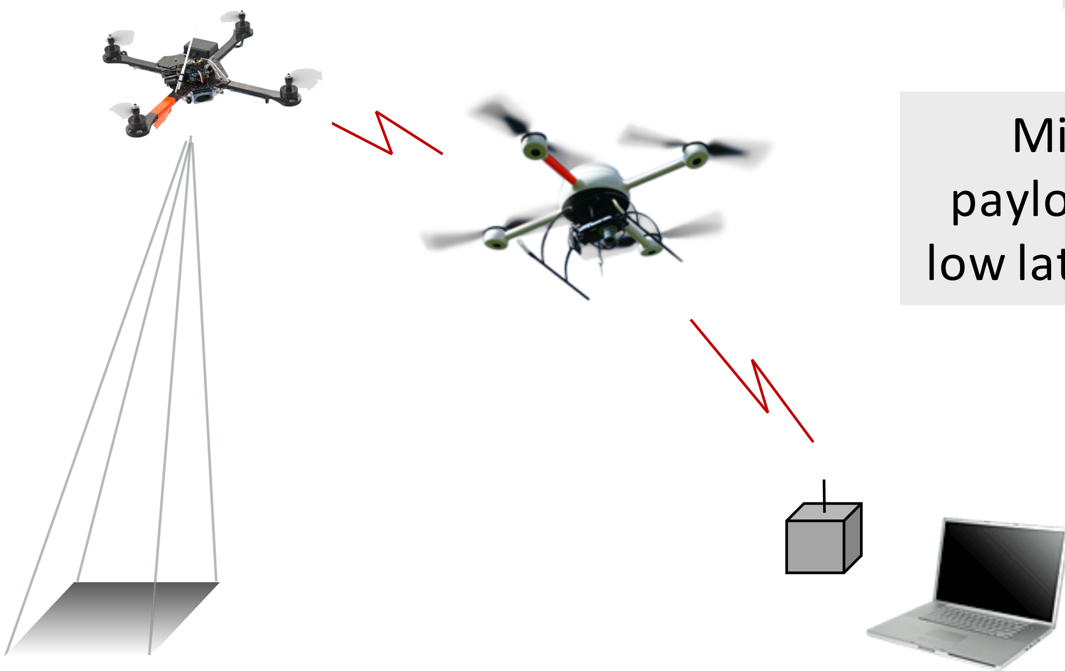
Wireless Communications for Small Drones

Scenario and requirements

3D mobility

Infrastructure and mesh networking

Reliability and robustness against interference

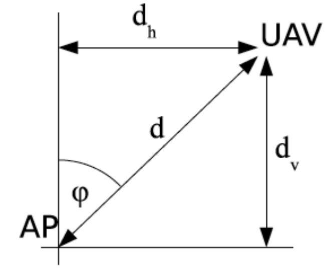


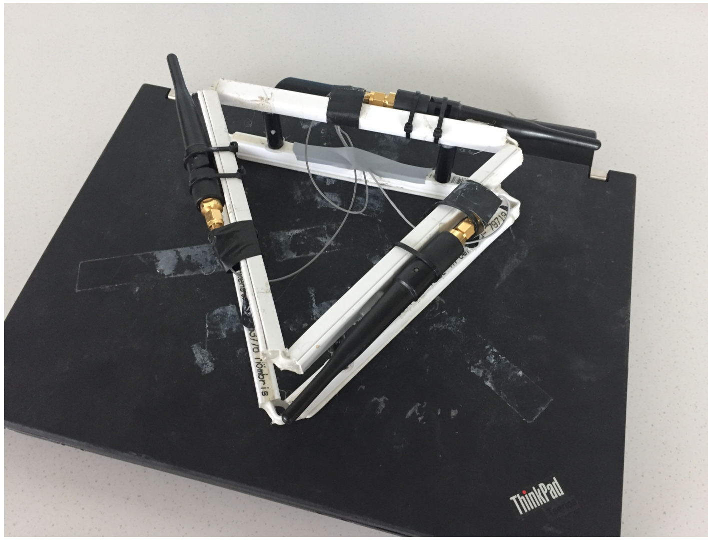
Mix of traffic types, payload and control, incl. low latency, high data rates

Precise time sync and localization

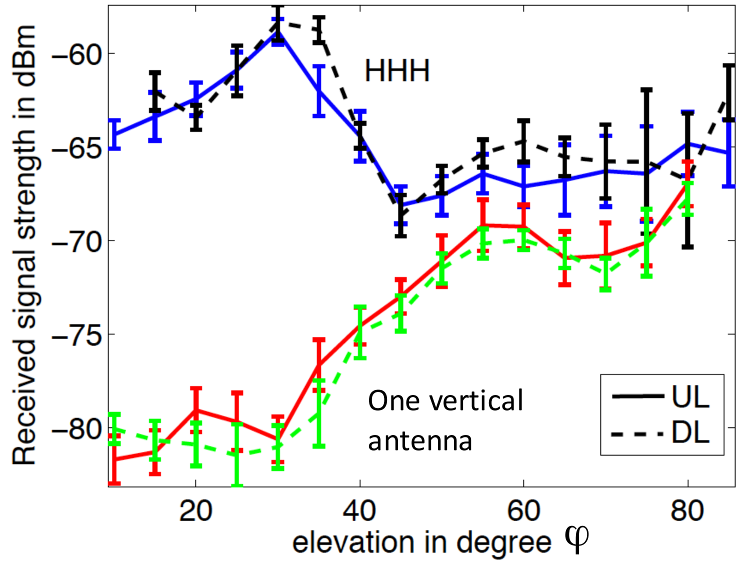
Antennas

A simple proposal to improve range





Three horizontal antennas (HHH)



Uplink
Downlink

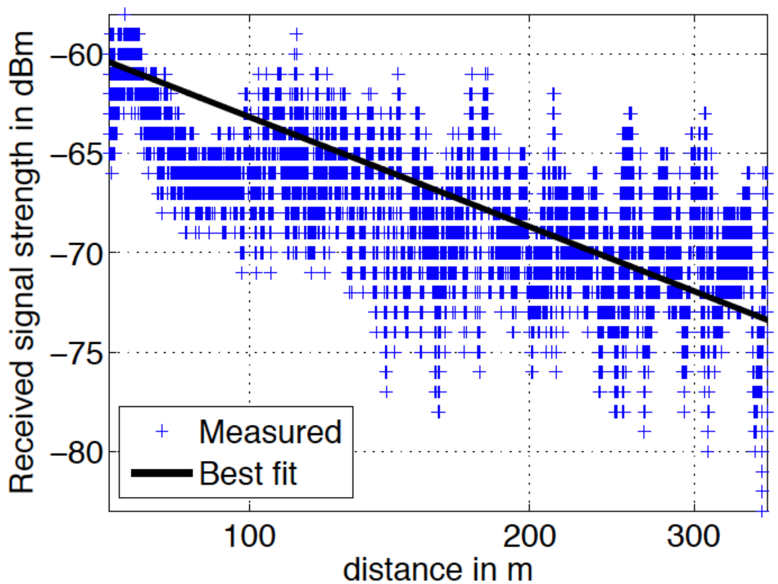
Measurements with IEEE 802.11a

at distance of 100 m

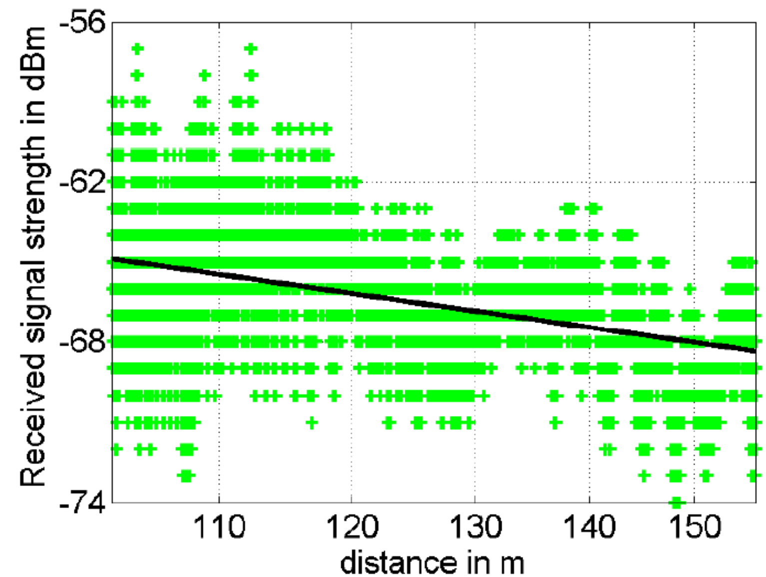
E. Yanmaz, R. Kuschnig, C. Bettstetter. Achieving air-ground communications in 802.11 networks with three-dimensional aerial mobility. In *Proc. IEEE Intern. Conf. on Computer Commun. (INFOCOM)*, Turin, Italy, 2013.

Radio Propagation Environment

Path loss exponent for outdoor *ground-to-drone* link



(a) Horizontal: moving away



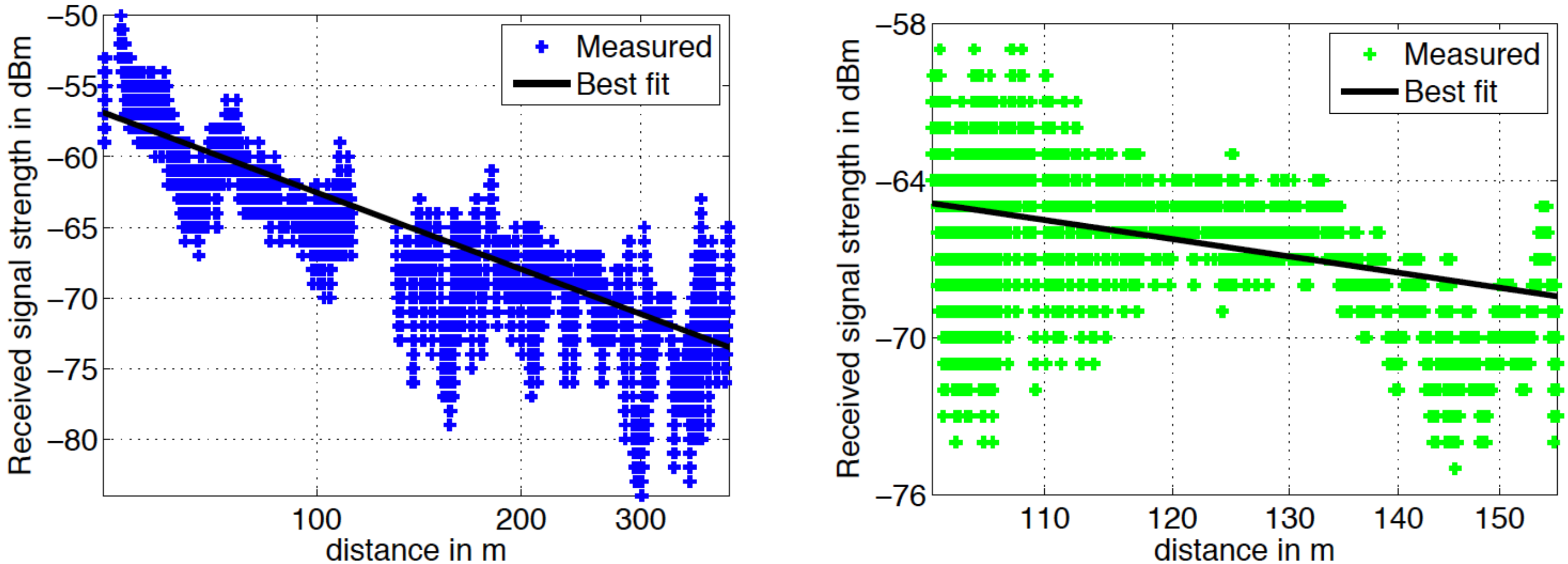
(b) Vertical: ascending

Experiments yield α = 2.01 independent of mobility type.

E. Yanmaz, R. Kuschnig, C. Bettstetter. Achieving air-ground communications in 802.11 networks with three-dimensional aerial mobility. In *Proc. IEEE Intern. Conf. on Computer Commun. (INFOCOM)*, Turin, Italy, 2013.

Radio Propagation Environment

Path loss exponent for outdoor *drone-to-ground* link



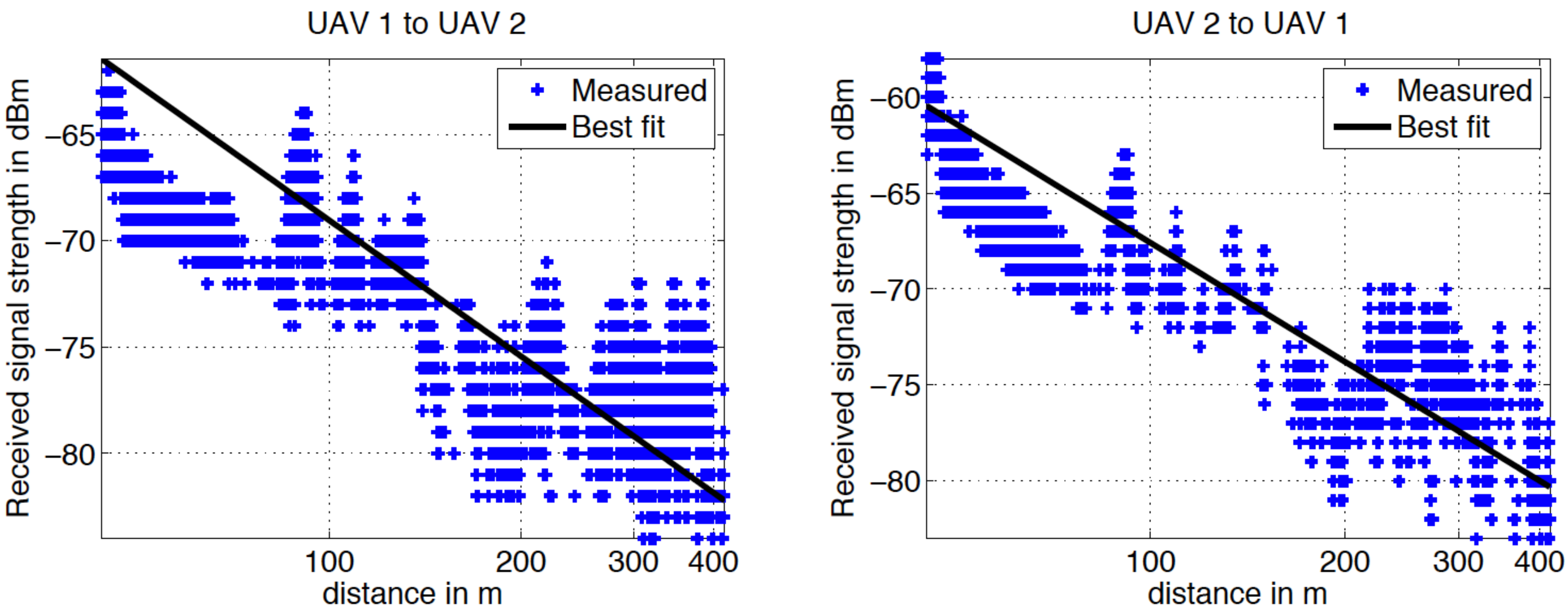
(a) Horizontal: moving away (b) Vertical: ascending

Experiments also yield α = 2.01 independent of mobility type.

E. Yanmaz, R. Kuschnig, C. Bettstetter. Achieving air-ground communications in 802.11 networks with three-dimensional aerial mobility. In *Proc. IEEE Intern. Conf. on Computer Commun. (INFOCOM)*, Turin, Italy, 2013.

Radio Propagation Environment

Path loss exponent for outdoor *drone-to-drone* links



(a) (b)

Experiments yield $\alpha = 2.03$.

E. Yanmaz, R. Kuschnig, C. Bettstetter. Achieving air-ground communications in 802.11 networks with three-dimensional aerial mobility. In *Proc. IEEE Intern. Conf. on Computer Commun. (INFOCOM)*, Turin, Italy, 2013.

Radio Propagation Environment

Nakagami model for small-scale fading

- The received power is gamma distributed with shape parameter *m* and scale parameter μ/*m*.
- The probability that the received power is larger than a certain threshold Θ is:

$$\mathrm{P}\left[p_{\mathrm{r}} > \Theta\right] = \frac{\Gamma\left(m, m\frac{\Theta}{\overline{p}_{\mathrm{r}}}\right)}{\Gamma(m)}$$

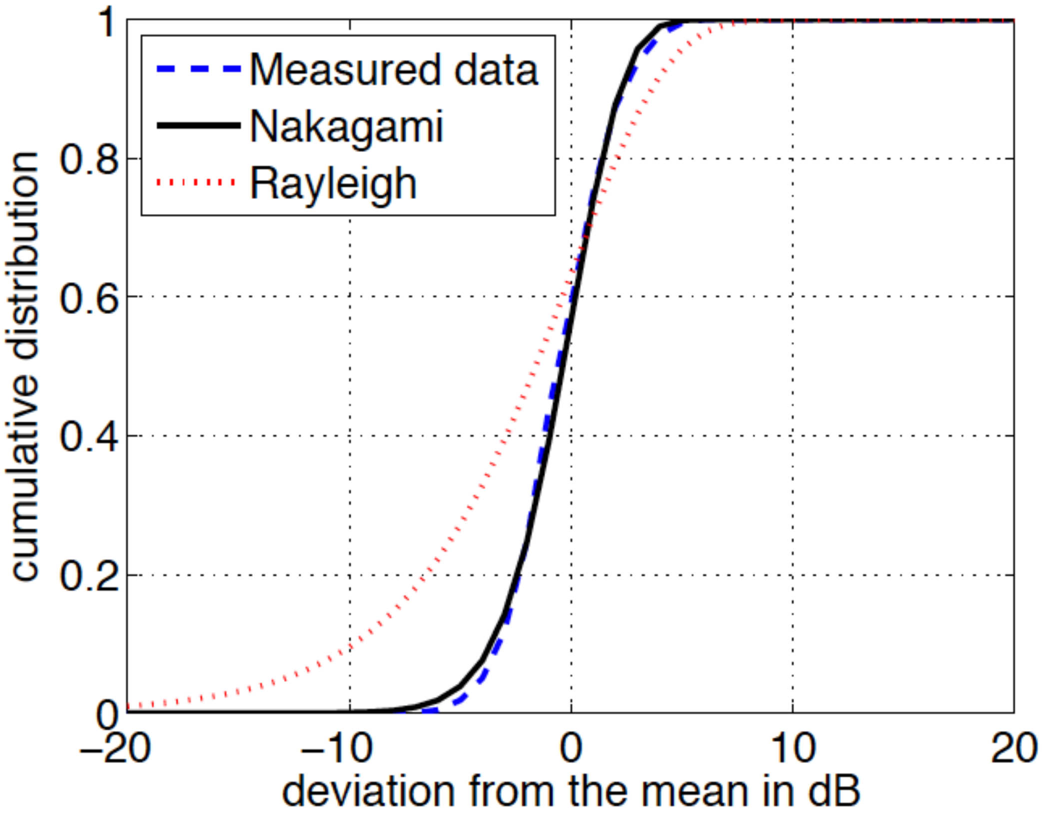
Gamma function $\Gamma(\,.\,)$

Incomplete Gamma function $\Gamma(\,.\,,\,.\,)$

- The severeness of fading can be tuned by $m \in [0.5,\infty)$. Nakagami fading with $m = 1$ is Rayleigh fading.

Radio Propagation Environment

Small-scale fading in outdoor drone-to-ground link



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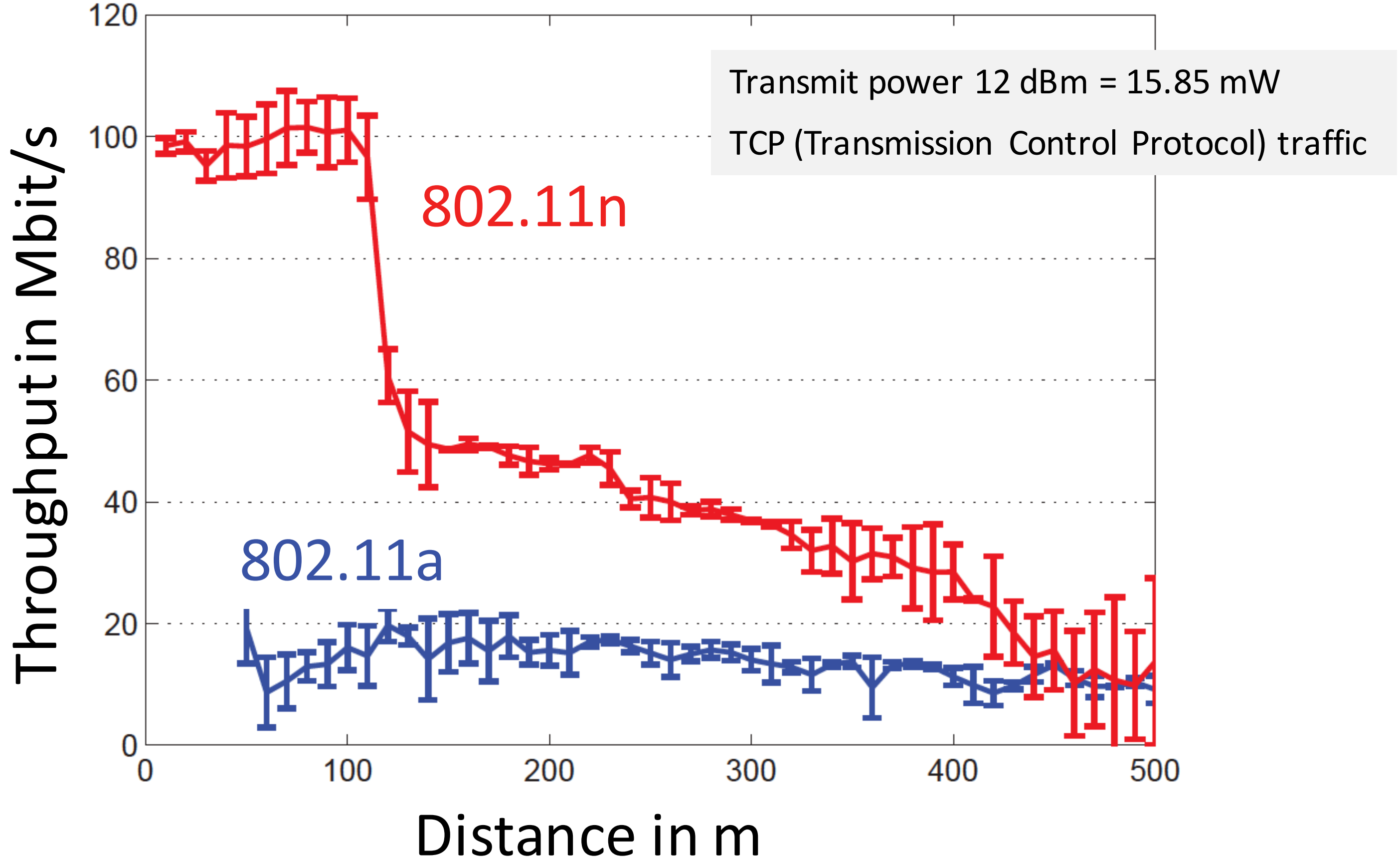
Throughput Performance

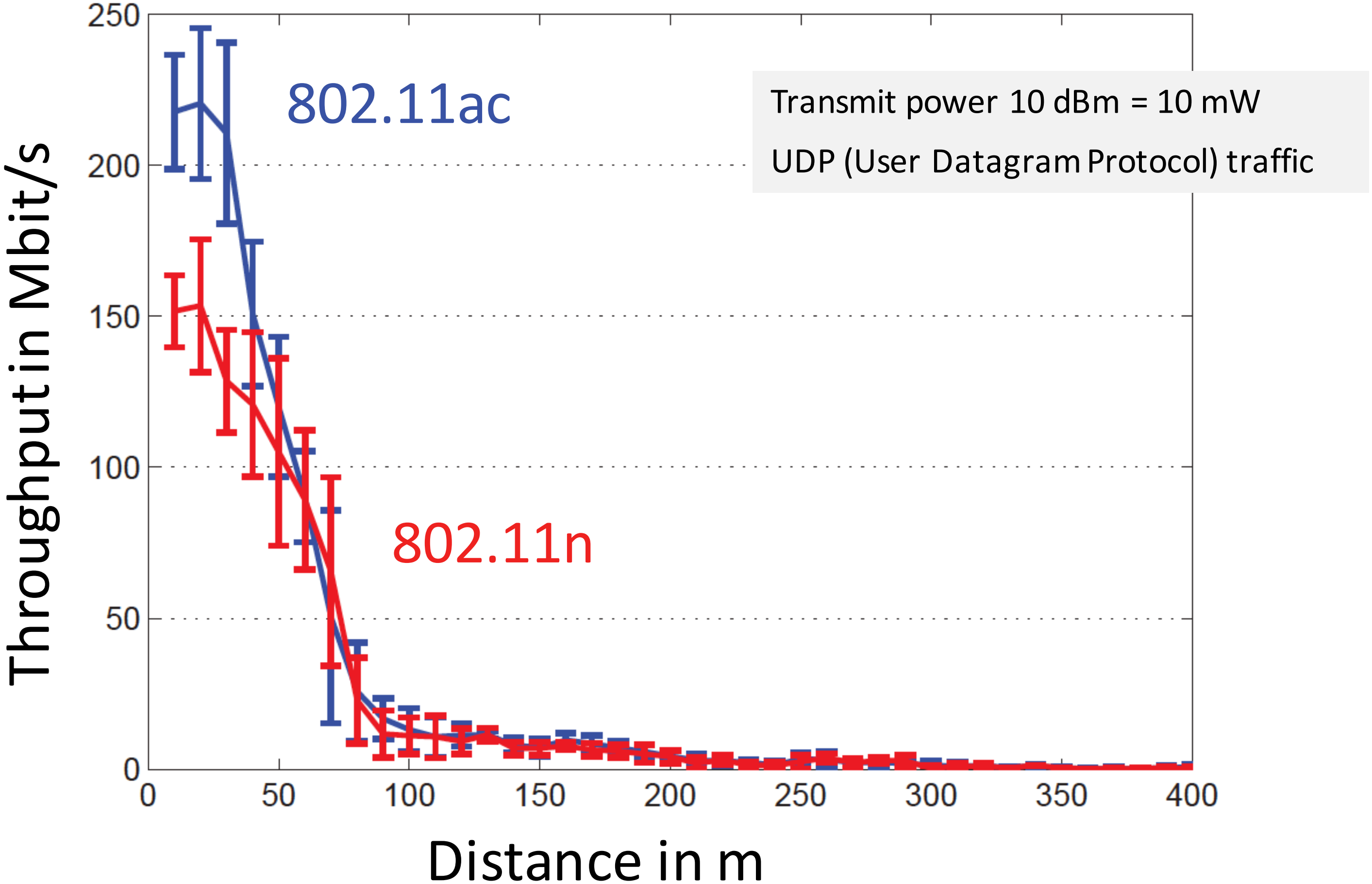
802.11a and 11n over outdoor drone-to-ground link



S. Hayat, E. Yanmaz, C. Bettstetter. Experimental analysis of multipoint-to-point UAV communications with IEEE 802.11n and 802.11ac. In *Proc. IEEE Intern. Symp. on Personal, Indoor, and Mobile Radio Commun. (PIMRC)*, Hong Kong, 2015.

Throughput Performance

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



S. Hayat, E. Yanmaz, C. Bettstetter. Experimental analysis of multipoint-to-point UAV communications with IEEE 802.11n and 802.11ac. In *Proc. IEEE Intern. Symp. on Personal, Indoor, and Mobile Radio Commun. (PIMRC)*, Hong Kong, 2015.

Wireless Multihop Communications

- Relaying
- Cooperative relaying
- Mesh (IEEE 802.11s)
- Ad hoc routing
- Delay-tolerant networking

Dependency and interaction with flight path planning

E. Yanmaz, S. Hayat, J. Scherer, C. Bettstetter. Experimental performance analysis of two-hop aerial 802.11 networks. In *Proc. IEEE Wireless Communications and Networking Conf. (WCNC)*, Istanbul, Turkey, 2014.

S. Hayat, E. Yanmaz, T. X Brown, C. Bettstetter. Multi-objective UAV path planning for search and rescue. In *Proc. IEEE Intern. Conf. on Robotics and Automation (ICRA)*, Marina Bay, Singapore, 2017.

Wireless Communications for Drones

Take home messages

- Tune antenna configuration to improve radio range if needed
- Model channel by standard path loss and Nakagami fading
- Use latest IEEE 802.11 technologies with certain limitations
- Aim for joint optimization of networking, path planning, and sensing in certain applications

Wireless Communications for Drones
Outlook

- Test prototypes of new wireless technologies (5G) for low-latency, high-throughput, real-time aerial applications
- Lobby for spectrum allocation for drone communications
- Develop complete protocol stack for drone networks, including security/safety, time synchronization, and localization
- Develop special antennas for small drones
- Develop networking solutions for large drone swarms

Job Selection for Drone-Based Delivery Services

2

- Is aerial delivery interesting?
- How to model such a transport system?
- How to dimension it?
- How to coordinate drones to satisfy customer demands?

Drone-Based Delivery Services
Urgent goods

Drone-Based Delivery Services

Last mile problem in rural areas

Zipline raises $25 million to deliver medical supplies by drone

Posted Nov 9, 2016 by Lora Kolodny (@lorakolodny)

Zipline International Inc. has raised $25 million in a Series B funding round to expand its humanitarian delivery drone business in Rwanda, the U.S. and beyond.

The startup builds drones and runs delivery services, dropping crucial medical supplies to clinics or hospitals in areas that aren't accessible by land.

Recently, TechCrunch visited Zipline's headquarters in Half Moon Bay, California for a behind the scenes look at the company's fixed-wing drones, launchers and unique landing rigs.

Crunchbase

Zipline

FOUNDED
2011

OVERVIEW
Zipline builds products that improve access to healthcare and saves lives. Zipline created Zip, a small robot airplane designed for a high level of safety, using many of the same approaches as commercial airliners. It can carry vaccines, medicine, or blood.

LOCATION
San Francisco, CA

CATEGORIES
Drones, Robotics, Logistics

Screenshot: TechCrunch

Drone-Based Delivery Services

Last mile problem in crowded cities

Photo: Fotolia (Melpomene)

Mercedes-Benz and Matternet unveil vans that launch delivery drones

Posted Sep 7, 2016 by Lora Kolodny (@lorakolodny)

Mercedes-Benz Vans and drone tech startup Matternet have created a concept car, or as they're calling it a Vision Van, that could change the way small packages are delivered across short distances.

The Vision Van's rooftop serves as a launch and landing pad for Matternet's new, Matternet M2 drones.

The Matternet M2 drones, which are autonomous, can pick up and carry a package of 4.4 pounds across 12 miles of sky on a single battery charge in real world conditions.

They are designed to reload their payload and swap out batteries without human intervention. They work in conjunction with Mercedes-Benz Vans' on-board and cloud-based systems so that items within a van are loaded up into the drone, automatically, at the cue of software and with the help of robotic shelving systems within the van.

Crunchbase

Matternet –

FOUNDED
2011

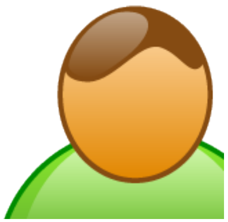
OVERVIEW
Matternet build world-class flying vehicles and intelligent control software, integrated into a complete solution for automated aerial logistics. They are passionate about achieving the highest quality in their products and operations, and partner with the world's most innovative technology and logistics companies and most impactful non-governmental organizations. They build world-class flying ...

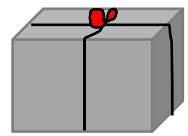
LOCATION
Menlo Park, CA

Screenshot: TechCrunch

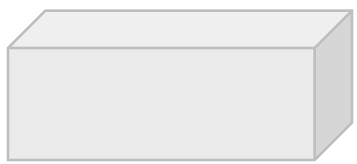
Drone-Based Delivery Services

Modeling the system





Customers request Goods that are

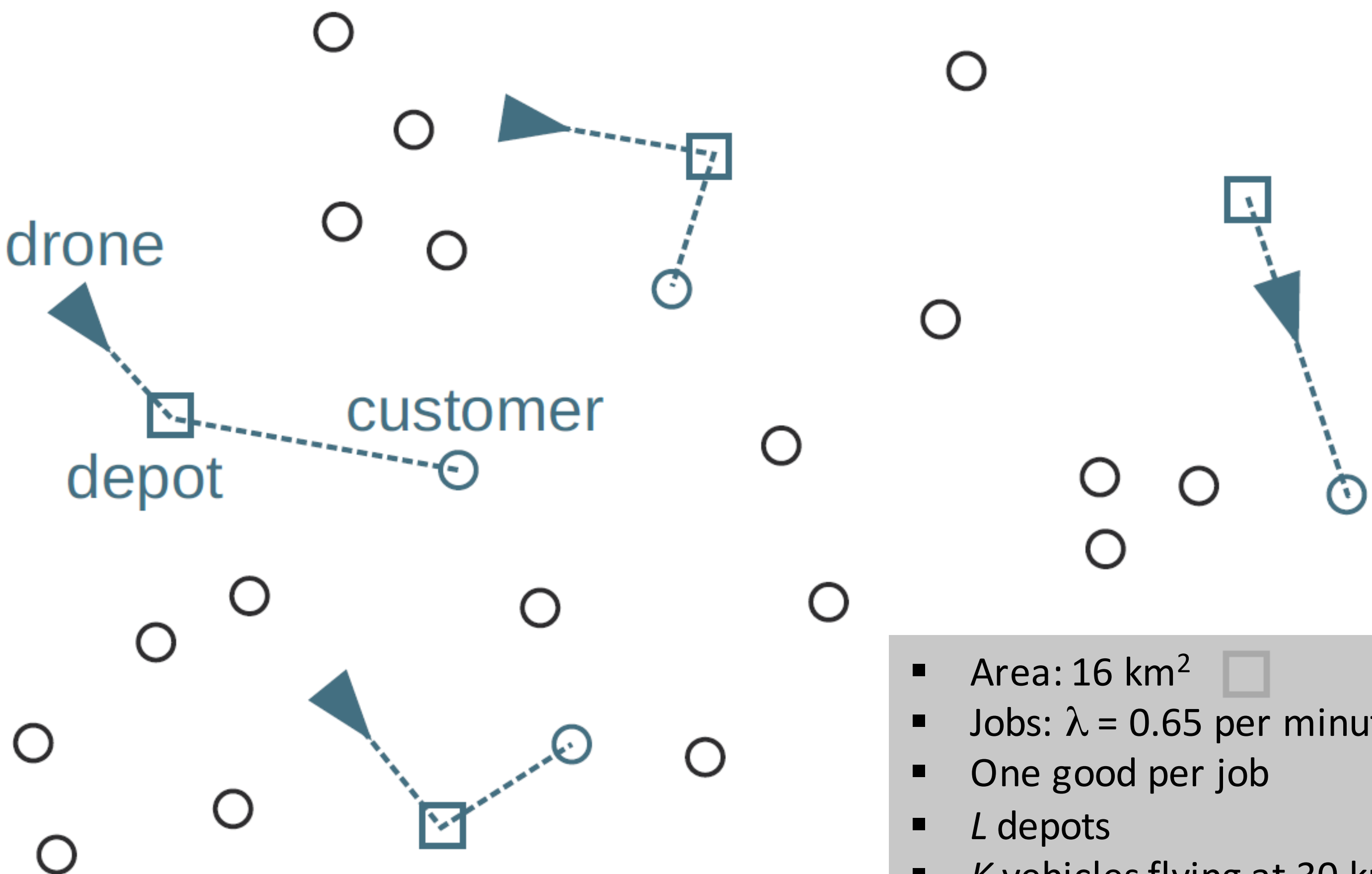


stored in Depots (L) and delivered by Vehicles (K) .

Customer demands (jobs) arrive over time on certain locations according to a space-time stochastic process.

Drone-Based Delivery Services

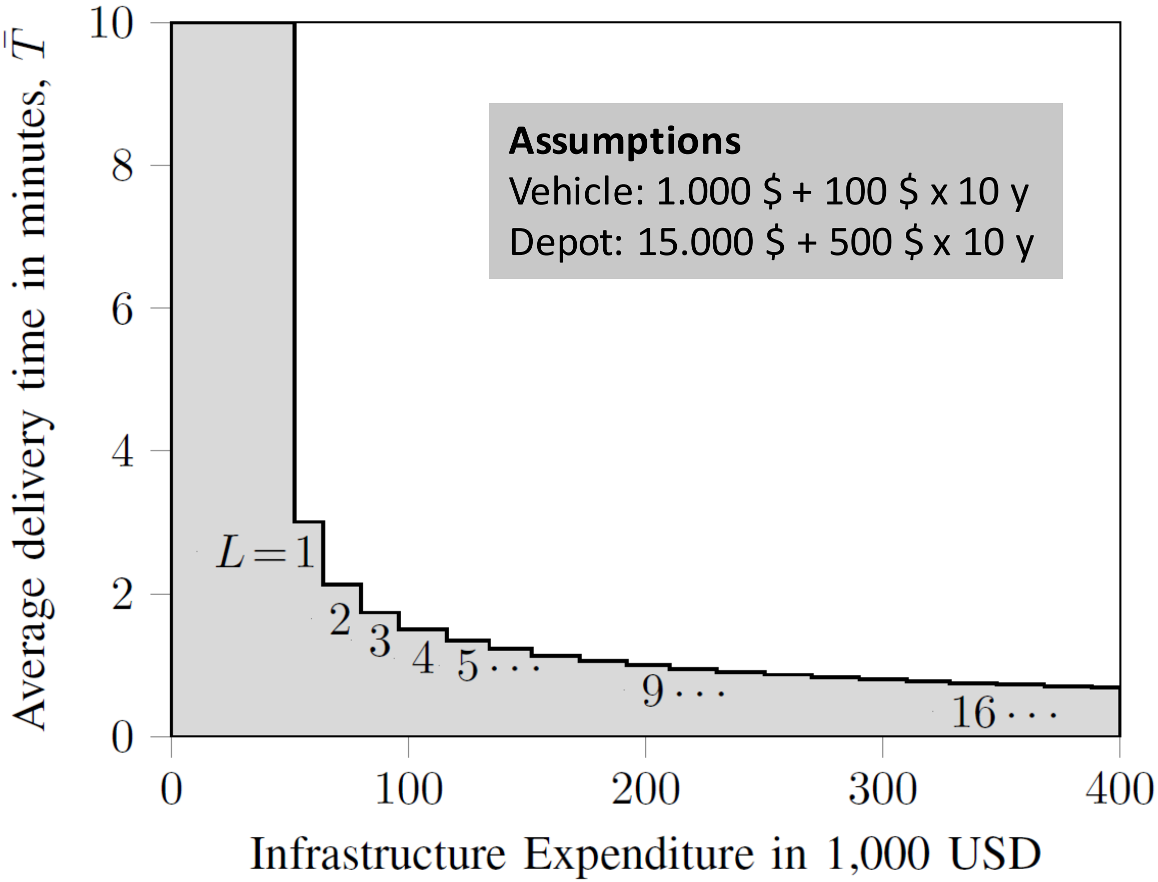
Modeling the system



- Area: 16 km^2
- Jobs: λ = 0.65 per minute (Poisson)
- One good per job
- *L* depots
- *K* vehicles flying at 30 km/h
- Air-to-charging time ratio: 1/3

Drone-Based Delivery Services

Network planning: How much to invest?



P. Grippa, D. A. Behrens, C. Bettstetter, F. Wall. Job selection in a network of autonomous UAVs for delivery of goods. Accepted for *Robotics: Science and Systems (RSS)*, Cambridge, MA, 2017.

Job Selection in Delivery Services

The system "intelligence"

- Which customer to serve next?
- Which vehicle to serve the next customer?
- At which depot to let vehicles load goods?
- Which paths to let vehicles follow?
- Where to let vehicles return to if no customers are waiting?

Different problem than dynamic vehicle routing

Job Selection Policies

Order of job selection

- First job first (**FJ**)
- Nearest job first (**NJ**)

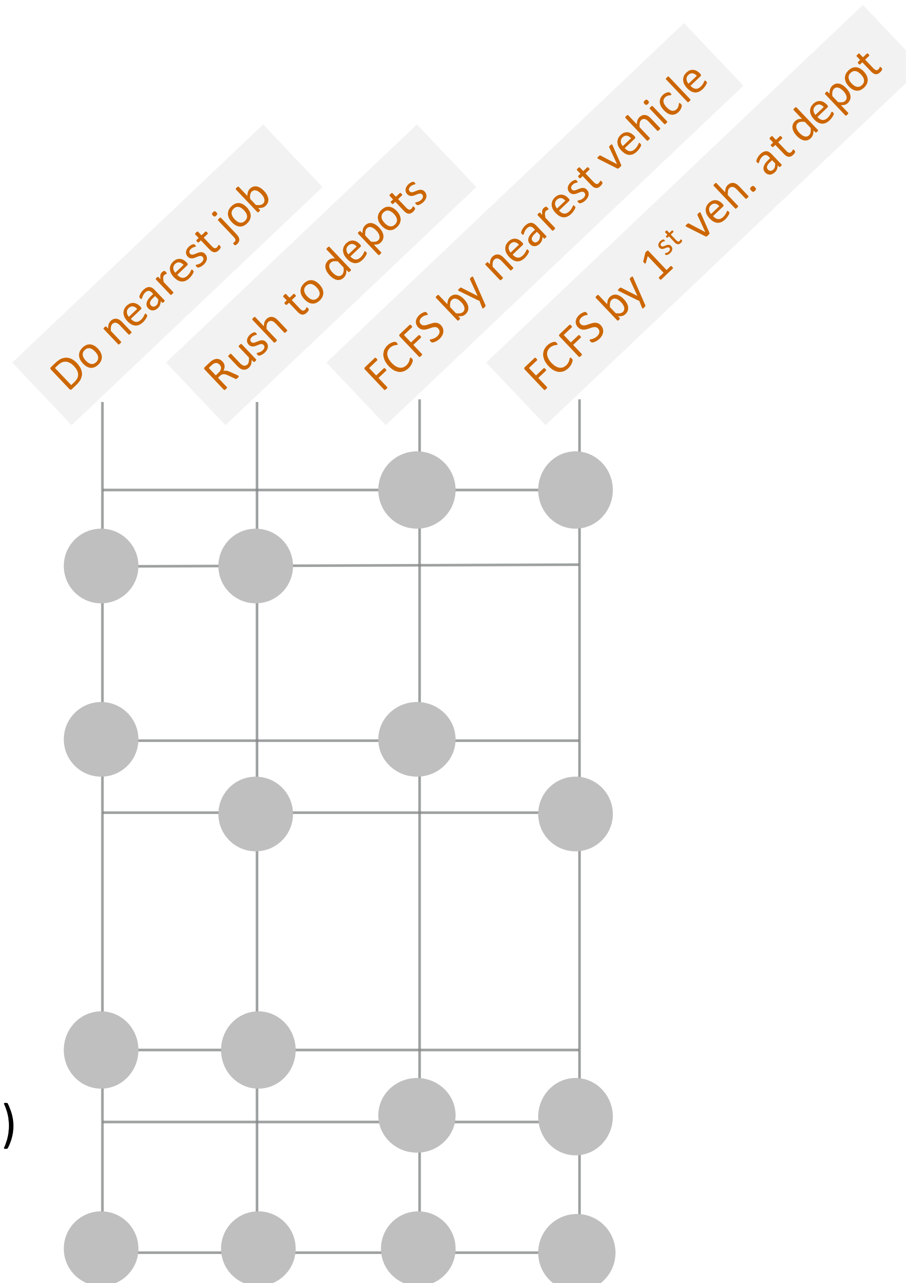
Timing of job selection

- As early as possible (**+**)
- As late as possible (–)

If >1 vehicle wants to select a job

- Random vehicles gets job (random)
- Nearest vehicle gets job (assortative)

No jobs: Vehicle goes to nearest depot



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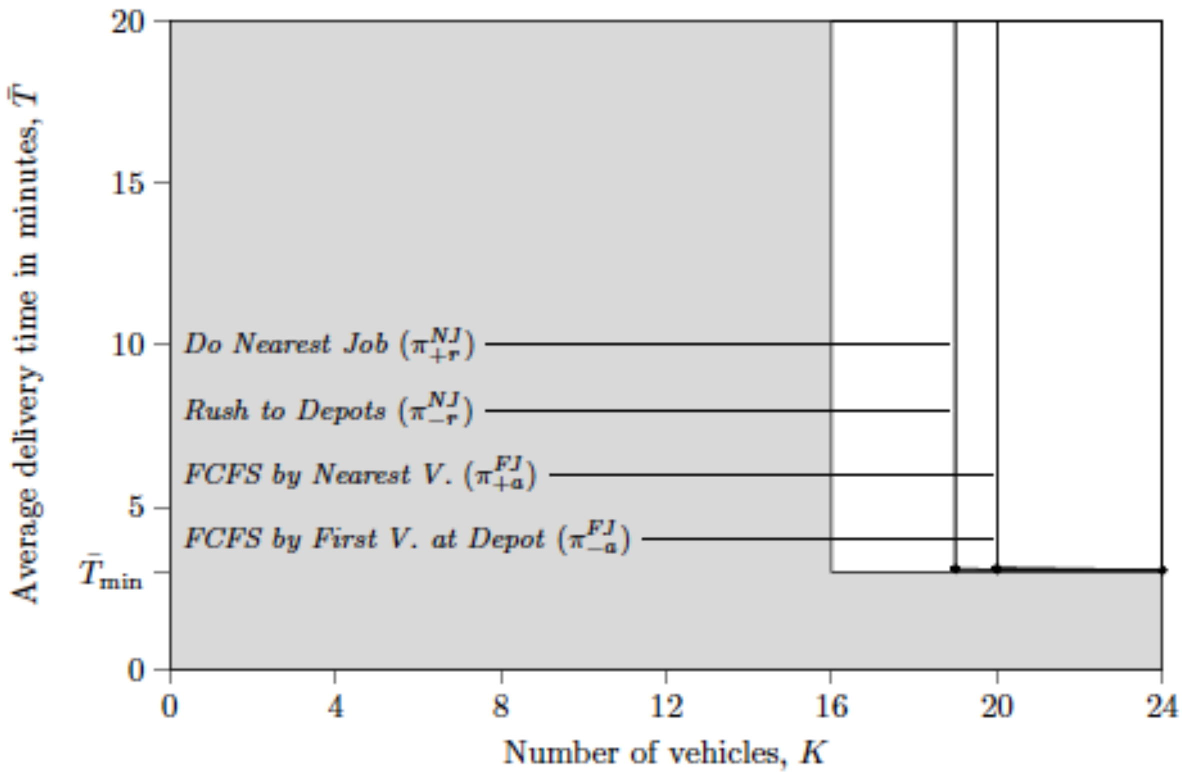
Job Selection in Delivery Services

Comparing policies in the steady phase (1/3)



Number of depots $L = 1$

P. Grippa, D. A. Behrens, C. Bettstetter, F. Wall. Job selection in a network of autonomous UAVs for delivery of goods. Accepted for *Robotics: Science and Systems (RSS)*, Cambridge, MA, 2017.

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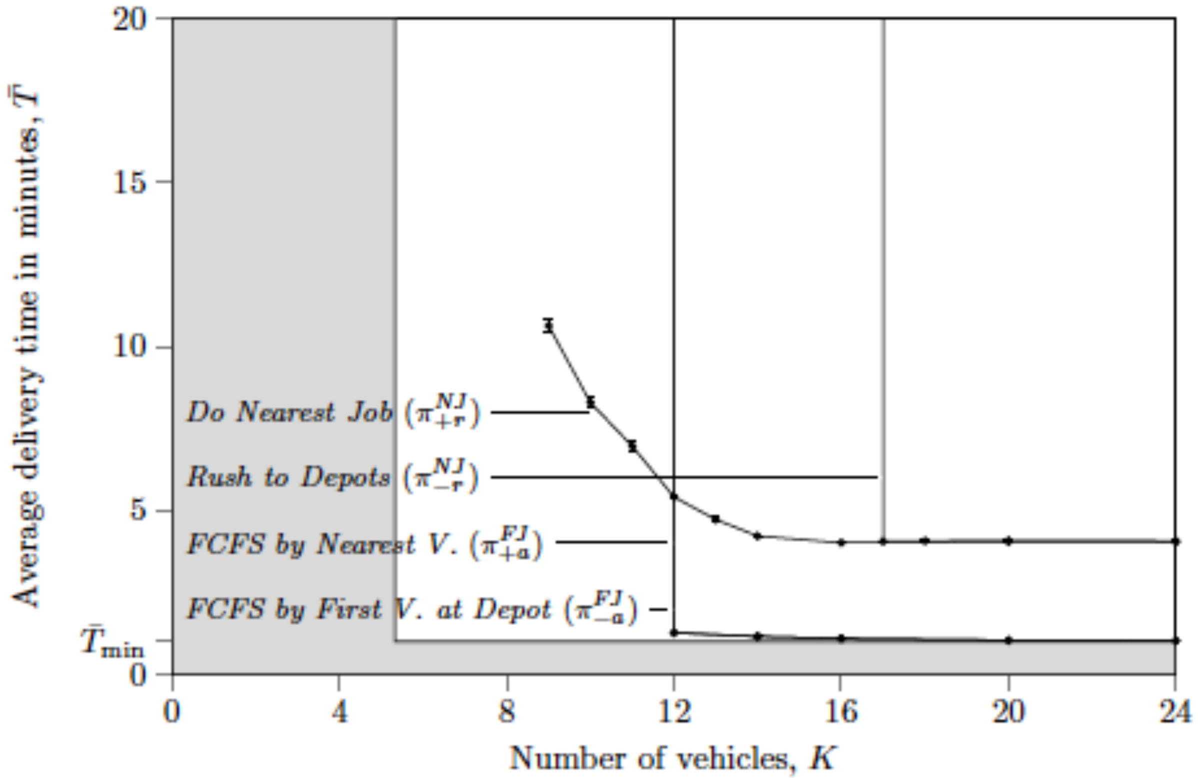
Job Selection in Delivery Services

Comparing policies in the steady phase (2/3)



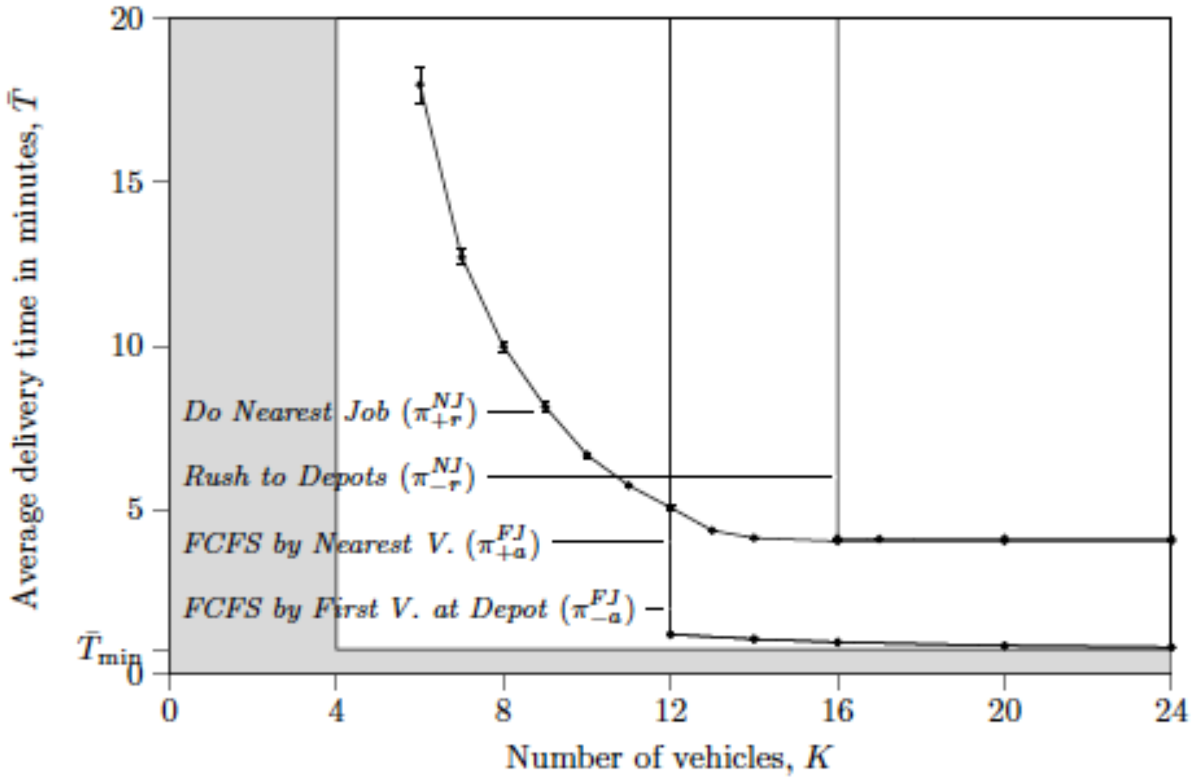
Number of depots $L = 9$

P. Grippa, D. A. Behrens, C. Bettstetter, F. Wall. Job selection in a network of autonomous UAVs for delivery of goods. Accepted for *Robotics: Science and Systems (RSS)*, Cambridge, MA, 2017.

Lakeside Labs

Job Selection in Delivery Services

Comparing policies in the steady phase (3/3)



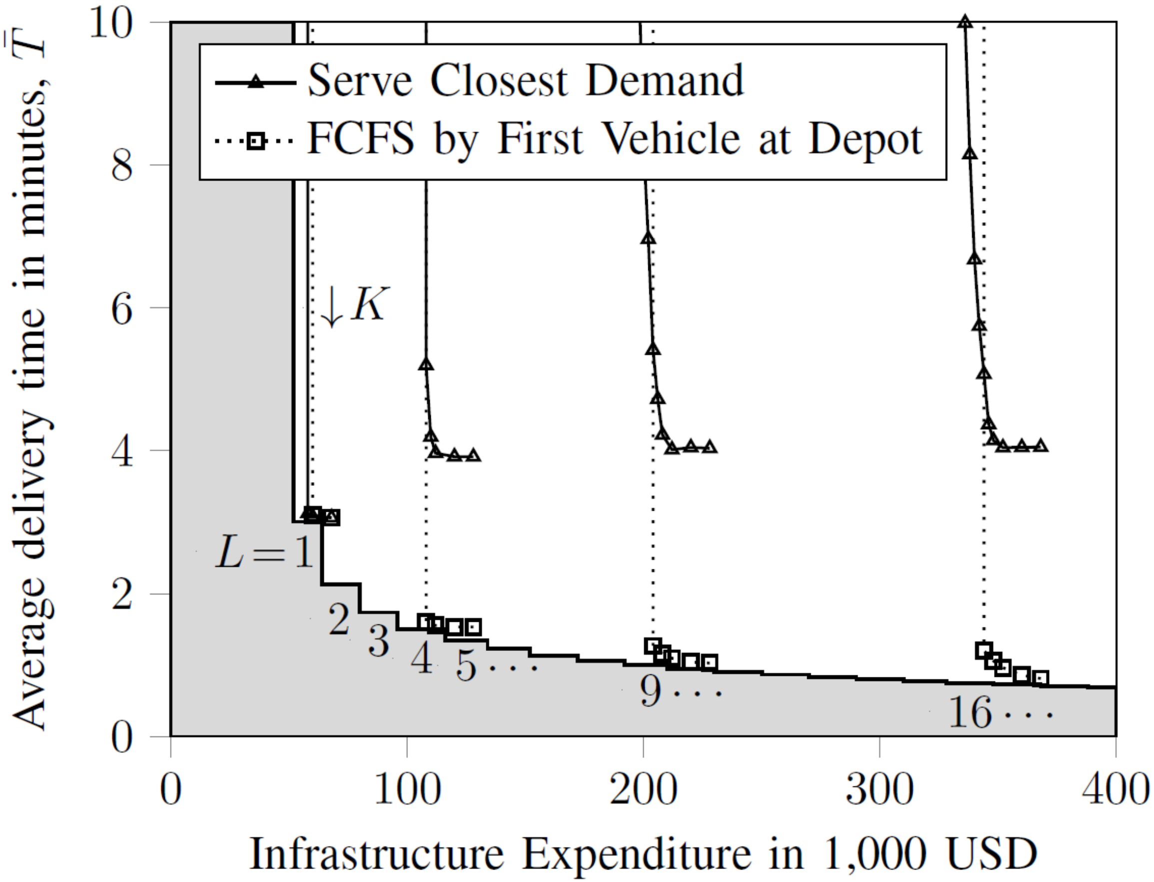
Number of depots $L = 16$

P. Grippa, D. A. Behrens, C. Bettstetter, F. Wall. Job selection in a network of autonomous UAVs for delivery of goods. Accepted for *Robotics: Science and Systems (RSS)*, Cambridge, MA, 2017.

Lakeside Labs

Job Selection in Delivery Services

Network planning: How much to invest in practice?



L depots
K drones

P. Grippa, D. A. Behrens, C. Bettstetter, F. Wall. Job selection in a network of autonomous UAVs for delivery of goods. Accepted for *Robotics: Science and Systems (RSS)*, Cambridge, MA, 2017.

Job Selection in Drone-Based Delivery Services

Take home messages

- Drone-based delivery is a reality for interesting niche applications today. There is great potential for startups.
- More complex multi-drone systems must be dimensioned on different time horizons and require some system intelligence.
- Different job selection policies show different behavior:
  - Tipping point behavior for some policies
  - Timing of decision matters for some policies

Job Selection in Drone-Based Delivery Services
Outlook

- Methods can be used for pickup-and-delivery without depots.
- Adaptive policy selection and learning to be included in the system design.
- Nontechnical issues (legal, ethical, regulatory) need to be clarified to a certain degree before large-scale drone-based delivery services will be launched in Europe.


Research Days on Self-Organization and
Swarm Intelligence in Cyber Physical Systems
Klagenfurt, July 10 – 12, 2017
Keynotes: Ayanian (USC), Di Caro (CMU)
Group work, lab sessions, and networking
researchdays.lakeside-labs.com

CPSwarm

European Commission | Horizon 2020 European Union funding for Research & Innovation

Objectives

- Tool chain for swarms of cyber-physical systems
- Algorithms for swarming and evolutionary design

Partners

- Inst. Sup. Mario Boella (lead)
- Lakeside Labs, U Klagenfurt
- Fraunhofer FIT, Search Lab
- Robotnik, Softteam, TTTech

Key facts

Duration: 2017–2020

Funding: 4.9 M€

Thanks to my team members working on drones.

Predoctoral researchers

- Torsten Andre (2010-15)
- Pasquale Grippa (2012-18)
- Samira Hayat (2012-18)
- Raheeb Muzaffar (2012-16)
- Arke Vogell (2016-)

Postdoctoral researchers

- Vladimir Vukadinovic (2014-15)
- Evsen Yanmaz (2008-)

Networked Autonomous Aerial Vehicles

New doctoral school

Collaborative 3D reconstruction

Research topics

- Multimodal sensor fusion
- Mission planning
- Time synchronization
- Multimedia communications

KARL POPPER KOLLEG

Key facts

Duration: 2017–2020

Funding: 0.5 M€

Core faculty

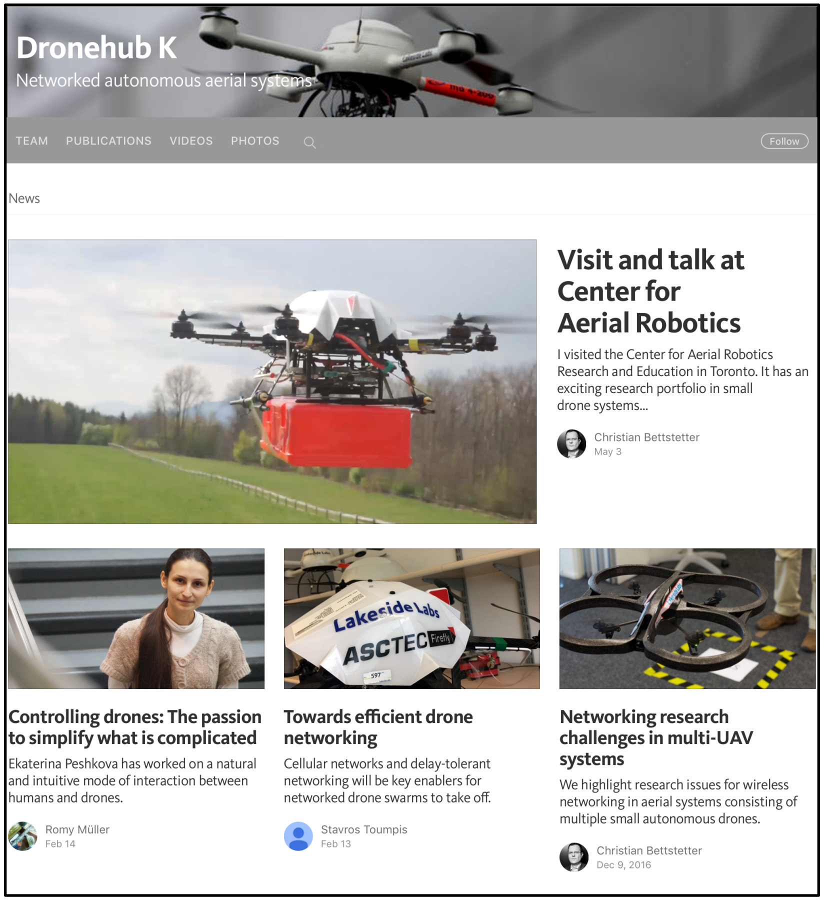
Christian Bettstetter

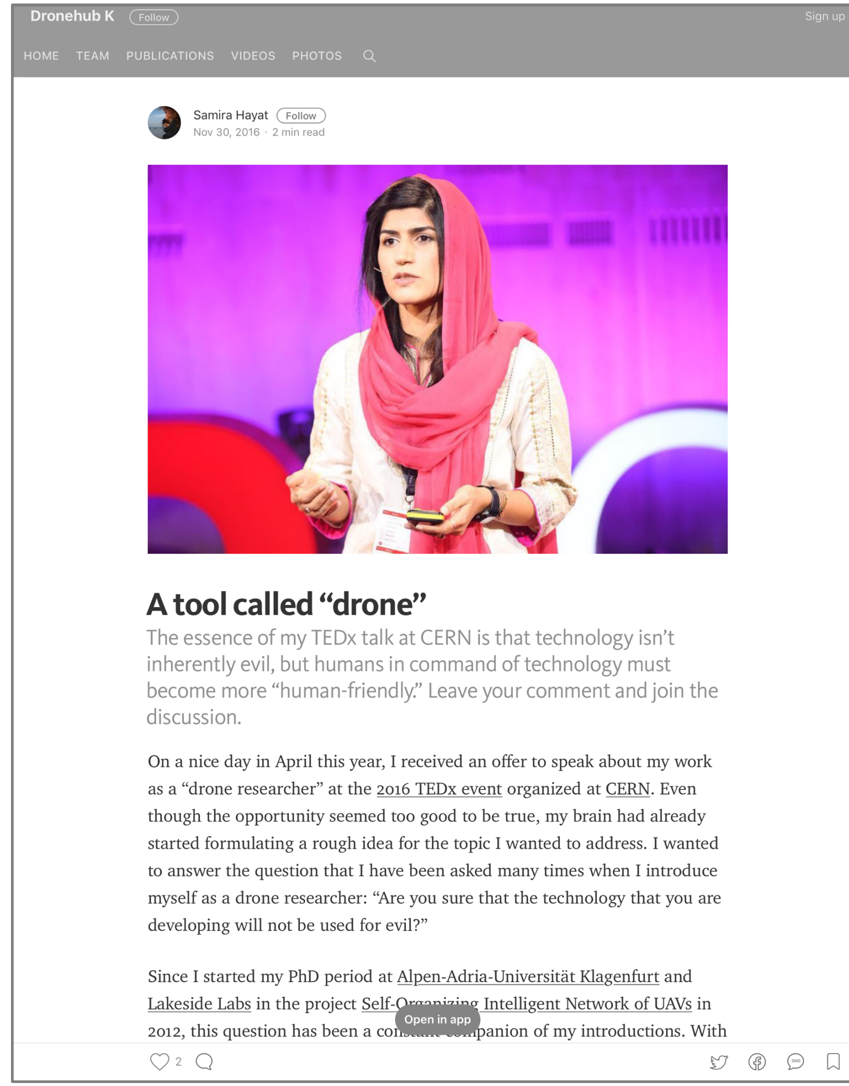
Hermann Hellwagner

Bernhard Rinner

Stephan Weiss

Dronehub K





Visit us at **uav.aau.at.**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Scientific Director, Lakeside Labs GmbH, Klagenfurt, Austria
Photo by Gert Steinthaler

Some Magazine Articles from Dronehub K

Peshkova, Hitz, Kaufmann. Natural interaction techniques for an unmanned aerial vehicle system. *IEEE Pervasive Computing*, 2017.

Hayat, Yanmaz, Muzaffar. Survey on UAV networks for civil applications: A communications viewpoint. *IEEE Communication Surveys & Tutorials*, 2016.

Andre, Hummel, Schoellig, Yanmaz, Asadpour, Bettstetter, Grippa, Hellwagner, Sand, Zhang. Application-driven design of aerial communication networks. *IEEE Communications Magazine*, 2014.

Quaritsch, Kruggl, Wischounig-Strucl, Bhattacharya, Shah, Rinner. Networked UAVs as aerial sensor network for disaster management applications. *e&i Elektrotechnik und Informationstechnik*, 2010.