Mobile Ad-Hoc Networks in the Sky – for Civilian Applications: State of Art, Challenges and Opportunities

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Overview

- Motivation
- Vision
- Research
- Opportunities and Challenges
- Conclusions

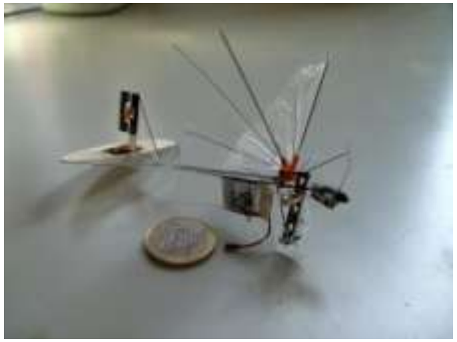
Motivation for Research

UAVs play a critical role in setting up communication infrastructure during disaster recovery operations. Scientific, engineering, technological and societal barriers exist before UAV networks can be deployed in the civilian airspace. Most important among these are enhanced safety, security and privacy of citizens.

Technology is in the very early stages. Fundamental science and engineering research is needed to take the technology to its mature levels of safety and security that are critical before UAV networks are deployed for real-world scenarios.

Researchers are demonstrating the unique capabilities of UAV networks. Real-world test-beds, proof-of-concepts, and experimental platforms are needed before deploying the technology in the real-world.

Unmanned Aerial Vehicles



The **DelFly Micro** is a 'Micro Air Vehicle' (MAV), an exceptionally small remote-controlled aircraft with camera and image recognition software. The Micro, weighing just 3 grams and measuring 10 cm (wingtip to wingtip) is the considerably smaller successor to the successful DelFly I (2005) and DelFly II (2006). (Credit: Image courtesy of TU Delft)

Parrot (AR Drone)

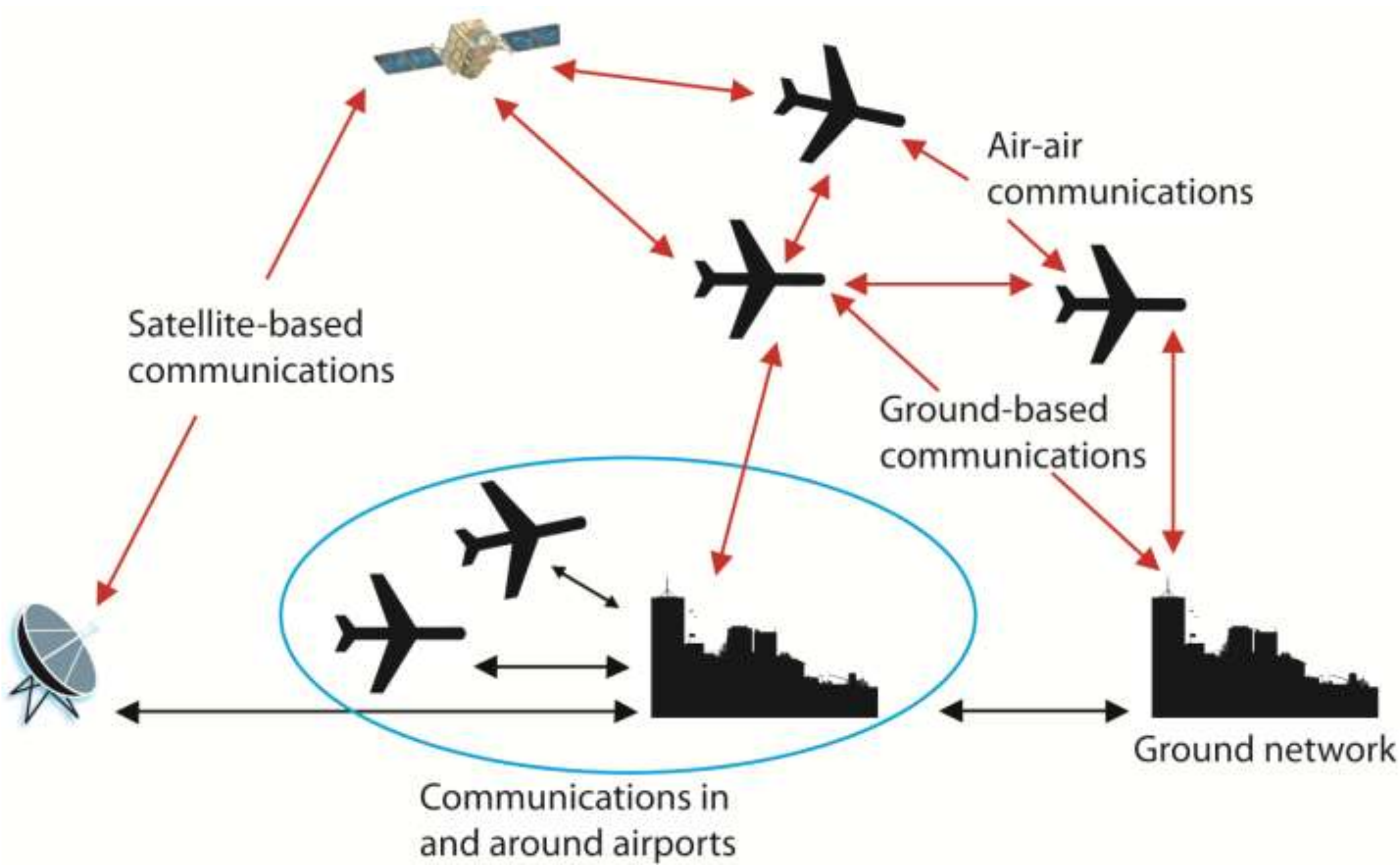
Fly up to 165 feet from your Wi-Fi device
See what the pilot sees with new front facing camera
Capture 720p HD videos and stills to share online
Fly indoors or out
Android and IPhone Applications available

Boeing's Tactical Compact Communications Relay (TCCR) allows a small UAV to function as a communications repeater for military handheld radios. It can extend the range of line-of-sight (LOS) handheld tactical radios to more than 150 nautical miles and is small enough to fit into a slot of about 5 by 5 by 1 inch in the **ScanEagle**'s payload bay.

Flying Cell Towers

- Smaller, low-flying drones could offer a more rapid means of bringing in or restoring wireless capability than construction of radio and cell towers — ideal for remote areas or for use after any kind of disaster that wipes out wireless service.
- “In one respect, you can think of it as a pseudo-satellite,” said Keith Monteith, a senior manager and business-development lead for the Phantom Eye project. “It can go up in orbit over a spot on the planet and stay there for days.”
- “You’re 13 miles up, at 65,000 feet, so you have a very good view to the horizon,” he added, explaining the wide area such aircraft payloads could oversee. This altitude could also be useful for reconnaissance uses as well as telecommunications, according to Monteith.

Airborne Network



Research Vision

- Safe and secure use of Unmanned Aerial Systems (UAS) in the civilian world
- Focus on the fundamental science, high risk/high reward research of enabling technologies that are required to enhance the situational awareness, safety and security of UAS when they fly in the National Airspace.
- Work closely with government agencies (NASA, FAA, FCC, and others) to help develop the technology, standards, policies, and guidelines needed for using UAS for emergency and disaster recovery operations.
- Speedup technology innovation in the airborne networking, control, and communication by working closely with the telecommunications and aviation industry.
- Develop university, pre-university, and K-12 programs necessary to prepare the future workforce in this emerging discipline.

Applications

- After hurricane Katrina, according to L-3 Communications, UAV (ROVER III) enabled video network feed resulted in rescuing 36 people, evacuating 148 people, identifying 9 Levee breaks, locating 26 fires and 3 sewage water main breaks, and providing critical situational awareness to response teams and route surveillance before the Presidential tour.
- On several occasions involving wildfires, UAVs provided firefighters with aerial views of the affected areas, aiding search and rescue operations.

Applications (Cont’d)

- UAV as a Communication Relay Node
  - Cell Towers in The Sky
- Micro-UAVs in Agriculture
  - Monitoring Crops
  - Spraying Pesticides
- Security During Public Events and Demonstrations
- Disaster Preparedness, Damage Assessment, and Recovery Operations
- Other Emerging Applications

Research

- Fundamental science and applied engineering aspects of deploying a network of UAVs in the air:
  - Airborne Networking and Communications
  - Situational awareness, Sense-and-avoid
  - Coordination and Control
- Experimental test-beds, proof-of-concept demonstrations for UAS applications:
  - Emergency Communications
  - Search and Rescue, and Fire Control Operations
  - Disaster Assessment, and Recovery Operations
  - Infrastructure Protection
- Policies, regulations, and standards for
  - Safety and security of people in the air and on the ground
  - Citizen’s privacy when drones fly in the civilian space

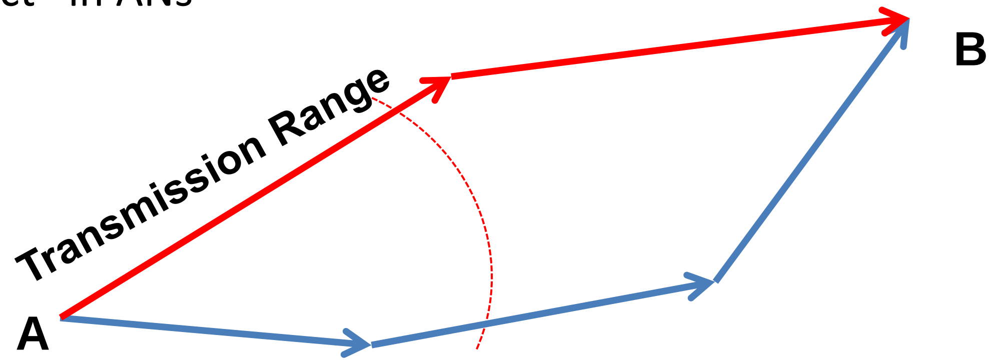
Research (cont'd)

- Integration of UAS in National Airspace
  - Air-traffic modeling and control
  - Protocols and standards for the coexistence of manned and unmanned aircrafts

- Transformative and Timely Research
  - Airborne networking is an emerging area of research
  - Fundamental science, and engineering, and technology problems need to be solved before deploying UAVs for
  - Safety, security, and privacy issues that critical for UAS operations need to be addressed
  - Significant interest from FCC, public and private sectors
  - Emerging discipline in universities around the world

Need for AN Mobility Models

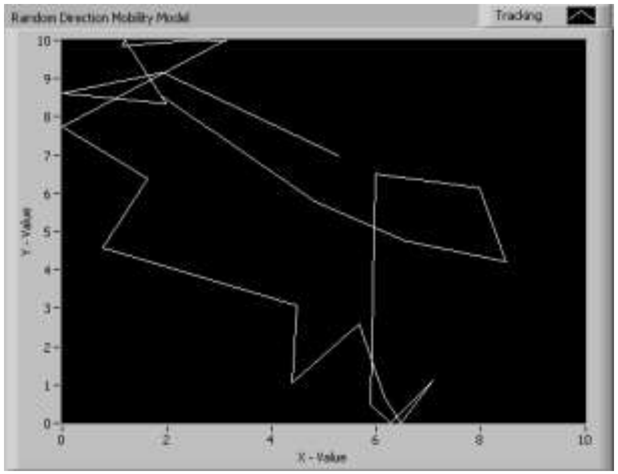
- ``Edge effect” in ANs



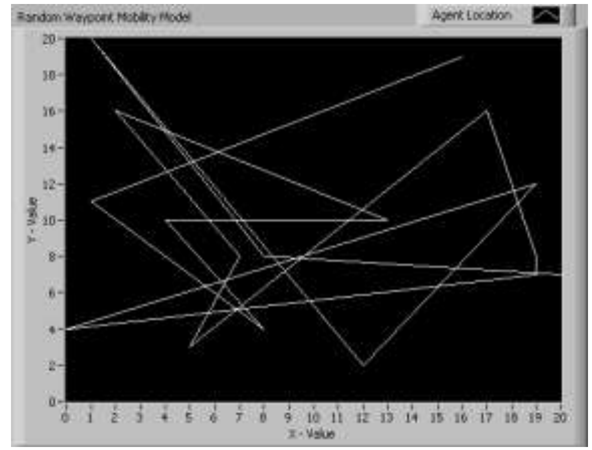
- Routing protocol design should take into account the knowledge of the dynamic structure of airborne nodes
- Mobility model captures the movement patterns of nodes
- Mobility model serves as the fundamental mathematical framework for network connectivity analysis, network performance evaluation, and eventually the design of reliable routing protocols.

Mobility Models

- Random Direction (RD)



Random Waypoint (RWP)

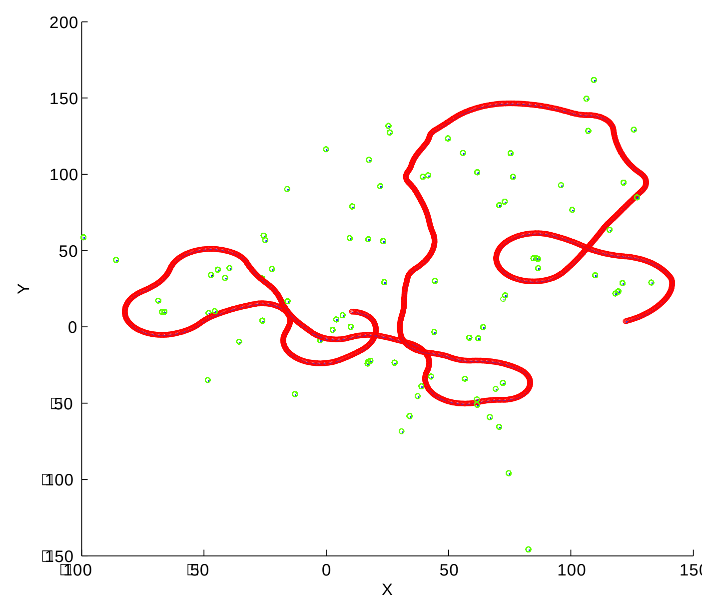


- They fail to capture unique features of airborne vehicles such as
  - smooth trajectories
  - maintaining the same heading speed
  - change direction through making large turns
  - mechanical and aero-dynamical constraints
- The correlation along temporal and spatial dimensions created by the smooth trajectory can be useful to design routing protocols.

Model: Description

- Idea of the Model
  - Select a point perpendicular to its heading direction and circle around it → smooth trajectory
  - Duration between the changes of circling centers to be memoryless → makes the analysis tractable
  - Inverse length of the circling radius to be Gaussian distributed → straight trajectories and slight turns are preferable
- Model Details

$$
\begin{aligned}
a_t(t) &= 0 \\
a_n(t) &= \frac{V^2}{r(T_i)} \\
\dot{\Phi}(t) &= -w(t) = -\frac{V}{r(T_i)} \\
\dot{l}_x(t) &= v_x(t) = V cos(\Phi(t)) \\
\dot{l}_y(t) &= v_y(t) = V sin(\Phi(t))
\end{aligned}
$$



Engineering Education

- University and Pre-College Programs
  - Curriculum design by reverse mapping of skill set needed to work with the UAS technology in real-time critical applications
  - Emphasis on depth and cross-disciplinary training
  - Ability to interact with industry professionals, government agencies, and people during emergency situations
  - Ability to work with peers from other disciplines
  - Research Experiences for Undergraduates (REU)
  - Research Experiences for Teachers (RET)
  - Internships in the industry and government
  - Research experiences in Federal laboratories
  - Research experiences in foreign university laboratories
  - Outreach programs in STEM for K-12 students

Industry Partnerships

- Telecommunications Industry
  - Airborne networking and communications
  - Disruption tolerant communications
- Aviation Industry
  - Resilience and survivability
  - Navigation and Control
  - Control and coordination
  - Air traffic modeling
  - Unmanned cargo delivery
  - Micro and Nano air vehicles
- Information Security Industry
  - Surveillance
  - Information Assurance
  - Privacy

University Partnerships

University Partners	Expertise	Contributions	Deliverables
University of North Texas	Mobility Models Connectivity	Network Science Air-traffic Modeling	Mobility Models for Airborne Networks
The University of Kansas	Communications and Networking	Resilience, Survivability, and Disruption Tolerance	Technologies for highly Dynamic Airborne Networks
Air Force Institute of Technology	Navigation, Control, and Security	Flight-tests and Experiments	Proof of Concepts and Demonstrations
Clark Atlanta University	Security, Controls, and Data Management	Security, Privacy, and Data Analytics	Security and Privacy Strategies in Airborne Networks
Massachusetts Institute of Technology	Navigation, Control, and Situational Awareness	Controls and Coordination in Airborne Networks	Sense-and-avoid Situational Awareness in Airborne Networks

Conclusions

- UAV Networks for civilian use is an emerging engineering discipline
- Technology will significantly benefit people during critical times
- Research in Science and Engineering is transformative and timely
- Before critical applications involving UAS are deployed for real world applications, there is an urgency to
  - solve fundamental science and applied engineering problems involved in airborne networks and communications
  - enhance situational awareness, safety, security, and privacy of people

Conclusions

- Significant interest from the Government, Industry, and Academic researchers worldwide
- Need for developing future workforce with the capabilities to work in real-world applications involving UAS
- Need for building the innovation eco-system in this emerging discipline