Robotics Facilitate Communications: Laser-Powered Drones with QoS Awareness

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Wireless Communications Systems Group (WSCG)

- Aristotle University of Thessaloniki (34 departments, about 80.000 students), www.auth.gr
- Electrical & Computer Engineering Dept. (2000 undergraduate, 400 MSc and 100PhD), www.ee.auth.gr
- Wireless Communications Systems Group (WSCG)
  - Head: George K. Karagiannidis
  - 5 PhD students
  - 2 Postdocs
  - Research Areas
    - Wireless Communications
    - Wireless Power Transfer and Applications
    - Optical Wireless Communications
    - Molecular Communications
    - Communications and Robotics
    - Wireless Security
  - About 400 papers in prestigious journals and conferences
  - Seven (7) patents
  - http://geokarag.webpages.auth.gr/

Outline

- Drones for good
- Energy sustainability and Laser-powered drones
- Challenges in drones-enabled communication networks
- Ongoing research
- Future research challenges

What are drones?

- Drones are small unmanned aerial vehicles, i.e. small aircrafts without human pilots.
- They are usually equipped with embedded inertial sensors, such as gyroscopes, accelerometers, and sonar altitude sensors.
- The flight can be controlled autonomously by computer.
- They can move freely through the air in any conditions, e.g. non-graded areas.
- They are appropriate for surveillance, monitoring, and communication (?).
- They are not constrained in three dimensions or by ground obstacles.

.........all in all, they are small flying robots.

Drones for good

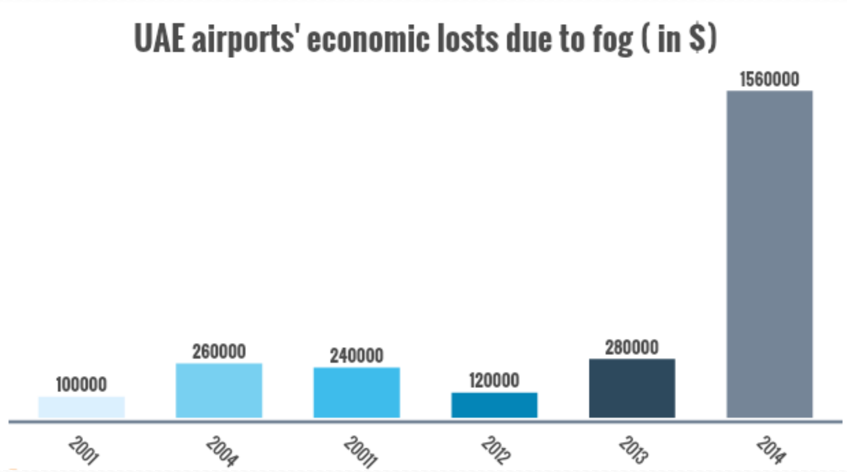
Drones have become a viable sensor platform due to the advances in communication, computation, and energy storage technology, as well as the *development in lightweight and resistant materials*.

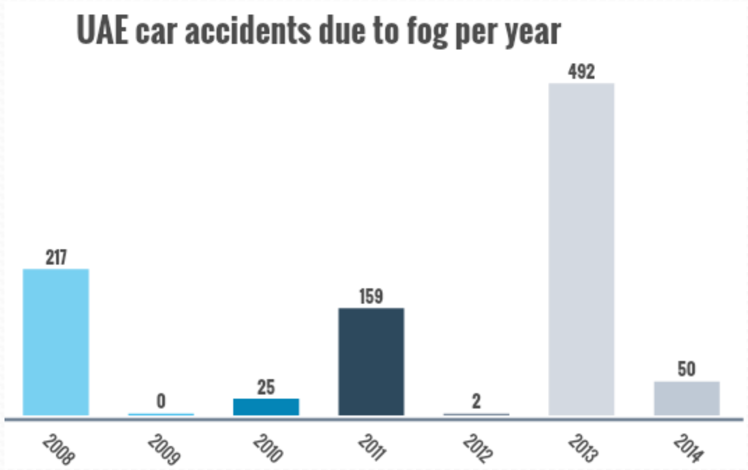
- Environmental incidents and disasters, when aerial measurements need to be carried out [Daniel et al., ISWCS 2010].
- As a swarm of sensors for target localization on the ground [Gade et al., ICCC 2013].
- For communication purposes in cases of emergency, e.g. when the established networks experience damage [Yanmaz et al., WCNC 2014].

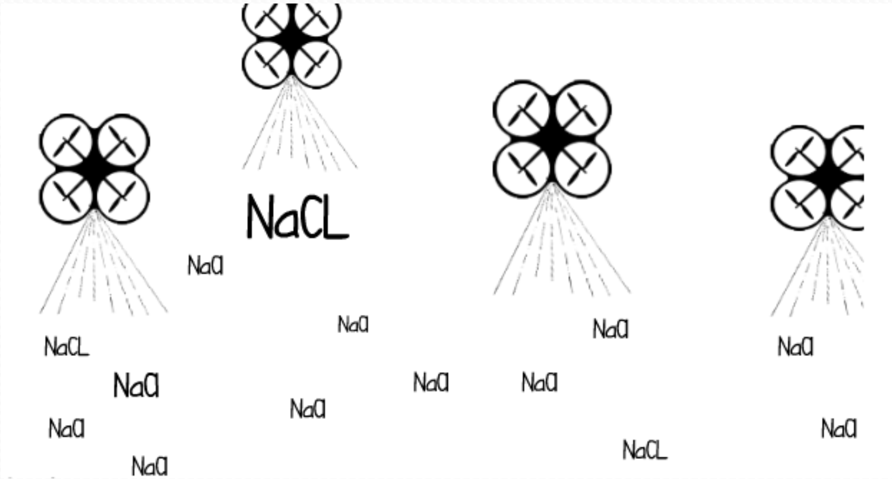
- When the Tohoku-Pacific Ocean Earthquake occurred, human-controlled drones were used to survey the damage at the Fukushima Dai-1 nuclear plant.
- In a recent study, drones were used to capture 3D reconstructed images of indoor and outdoor environments using mounted cameras.

Drones for good-Another example

- Fog dissipation drones used to clear airport runways and other areas from fog [Source: www.dronesforgood.ae, Accessed: 2016].







Ongoing Research on Drones for good

- Development of routing algorithms, which enable a swarm of drones to forward the information to the intended recipients, considering
  - Self-organization of the nodes
  - Positioning and movement
- Characterization of the drone-to-ground and drone-to-drone wireless channel.
- Algorithms for the efficient coverage of 3D space by a swarm of drones sensors, while maintaining their interconnectivity and connectivity with the ground.

.....and energy sustainability

Energy Sustainability

- Drones are energy and, thus, battery constrained.
  - They require energy for:
    - Supporting their routines
    - Communication purposes
    - Other purposes, e.g. video capturing, mechanical movement of their parts, etc.
  - A typical drone can fly for only 10 minutes, so, it is difficult to perform tasks that require longer flying periods.
  - The power supply of the drones should:
    - be monitored and scheduled in real time,
    - be self organized,
    - be reliable, in order to ensure that the drones remain intact.

Energy Sustainability

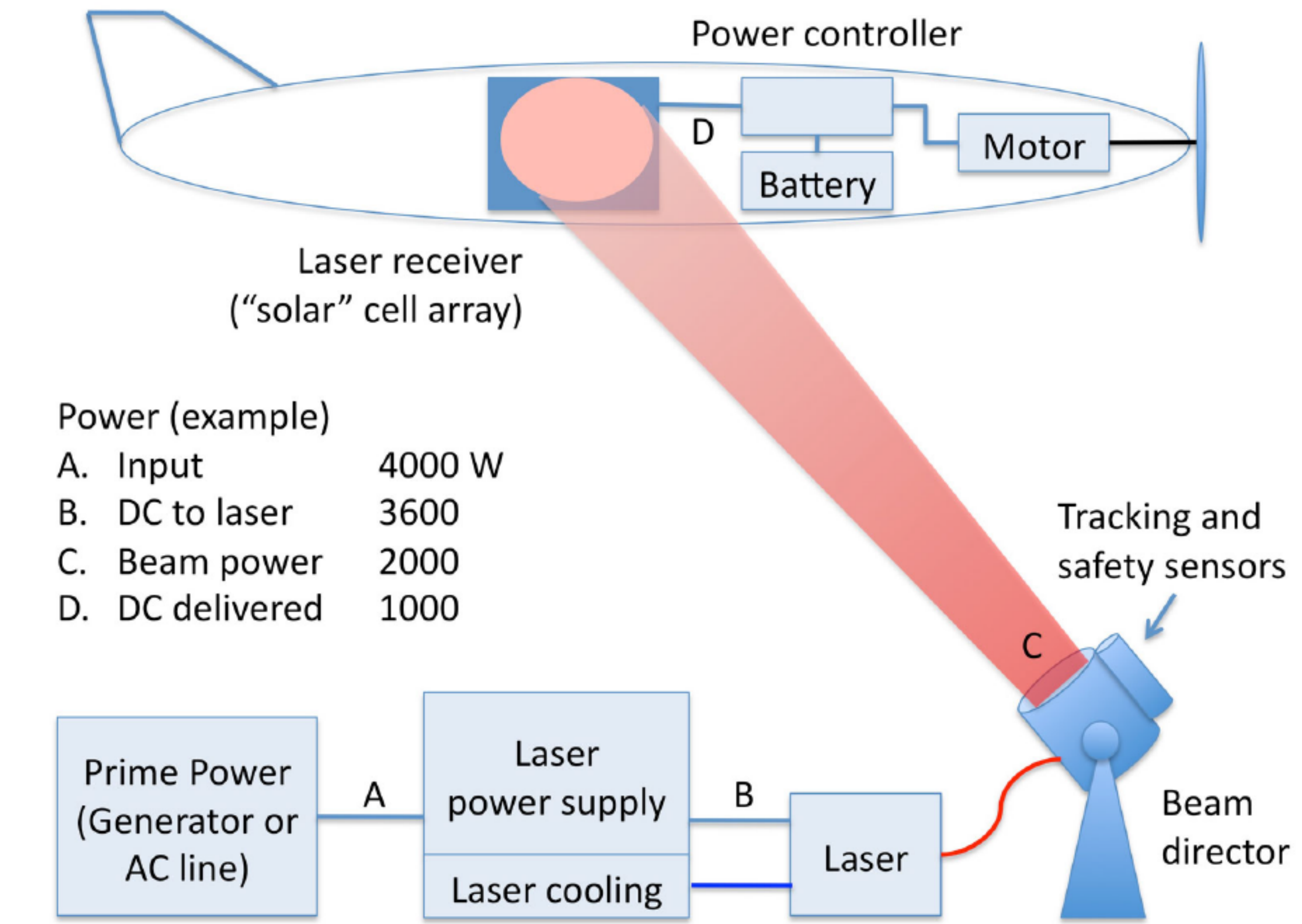
- Reduction of energy consumption
  - Construction of lightweight drones, which consume less energy.
    - A tiny remote-control helicopter developed by Prox Dynamics is being used for surveillance on the front line by the Norwegian and British Army [Source: proxdynamics, Accessed: 2016].
      - ✓ It measures about 10cm by 2.5cm and weighs 16g (including cameras).
      - ✓ It is equipped with GPS.
      - ✓ It is capable of autonomous flights.
      - ✓ Endurance up to 25 minutes.
  - Reduction of the power consumption after the positioning of the nodes (e.g. landing on specific sites).
  - Max of the energy efficiency of the communication between users/devices and the drones, but also for drone-to-drone and drone-to-backbone links.

Energy Sustainability

- Power supply for drones:
  - Solar panels
  - Development of continuously flying drone with automatic battery replacement [Source: Fujii et al., ICUIC/ICATC 2013]
  - **Laser power beaming**
    - Wireless power delivery systems based on laser beams have also been developed by Laser Motive [Source: lasermotive].
    - Lasers can transmit power to drones in flight, giving them potentially unlimited endurance aloft.

Energy Sustainability

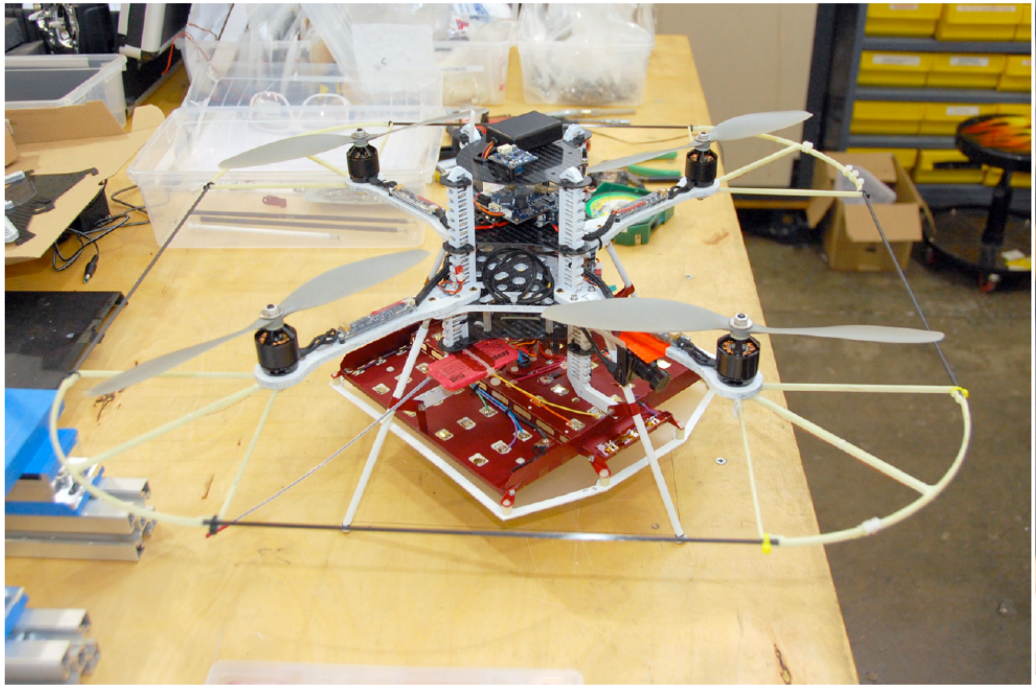
- Laser power beaming (LPB) by Laser Motive



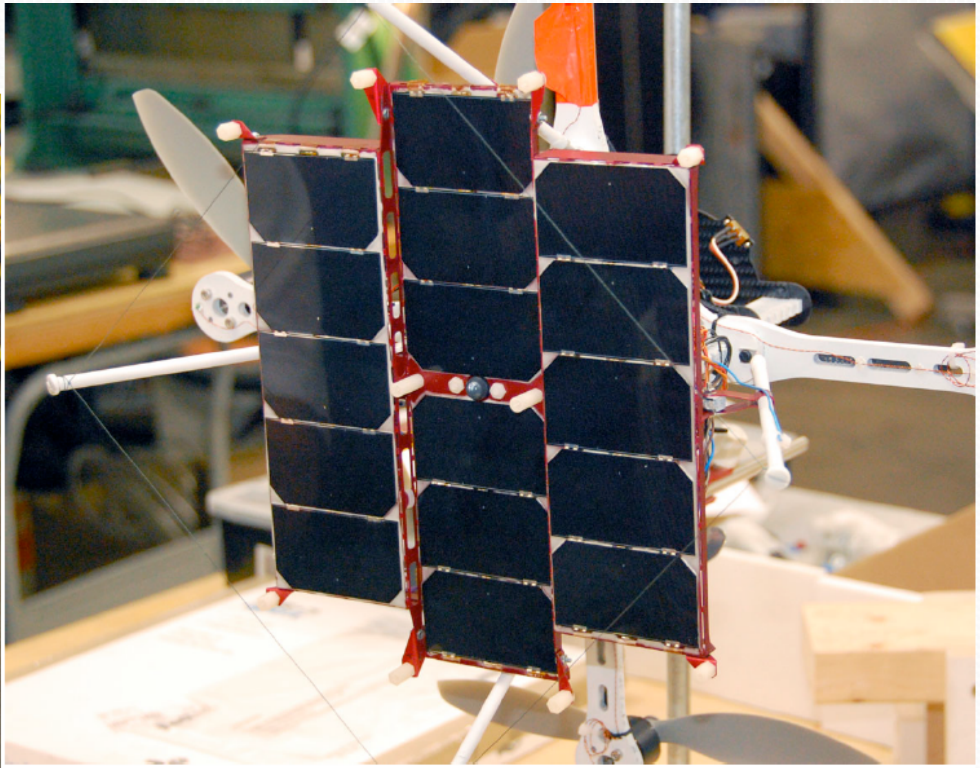
Energy Sustainability

- Laser power beaming (LPB)
  - Drones carry photovoltaic cells that are optimized to the laser wavelength, and they convert about half of the laser power to generate a few watts of electricity, which is sufficient to power the motors of a small quadcopter
  - The benefits of this new technology include:
    - Great energy concentration
    - The same optical link be used for simultaneous information and wireless power transfer (SWIPT)
    - Secure control of the drones

Energy Sustainability



•photovoltaic receiver mounted to the underside



•The laser receiving side of the PV array

Energy Sustainability

- Simultaneous information and wireless power transfer (SWIPT)
  - SWIPT is a well-explored technology in radio frequency communications [Ding et al., IEEE COMMAG 2014].
  - In optical wireless communications, SWIPT is a completely new topic.
    - [Wang et al., JSAC 2015], proposes a novel design of an optical wireless communications (OWC) receiver using a solar panel as a photodetector. The generated energy can potentially be used to power a user terminal or at least to prolong its operation time.
    - [Fakidis et al., PIMRC 2014] investigates the application of optical links at the same time for high-capacity backhaul and wireless power supply.

What else can drones do?

- Provide internet access

- Facebook

VS

- Google

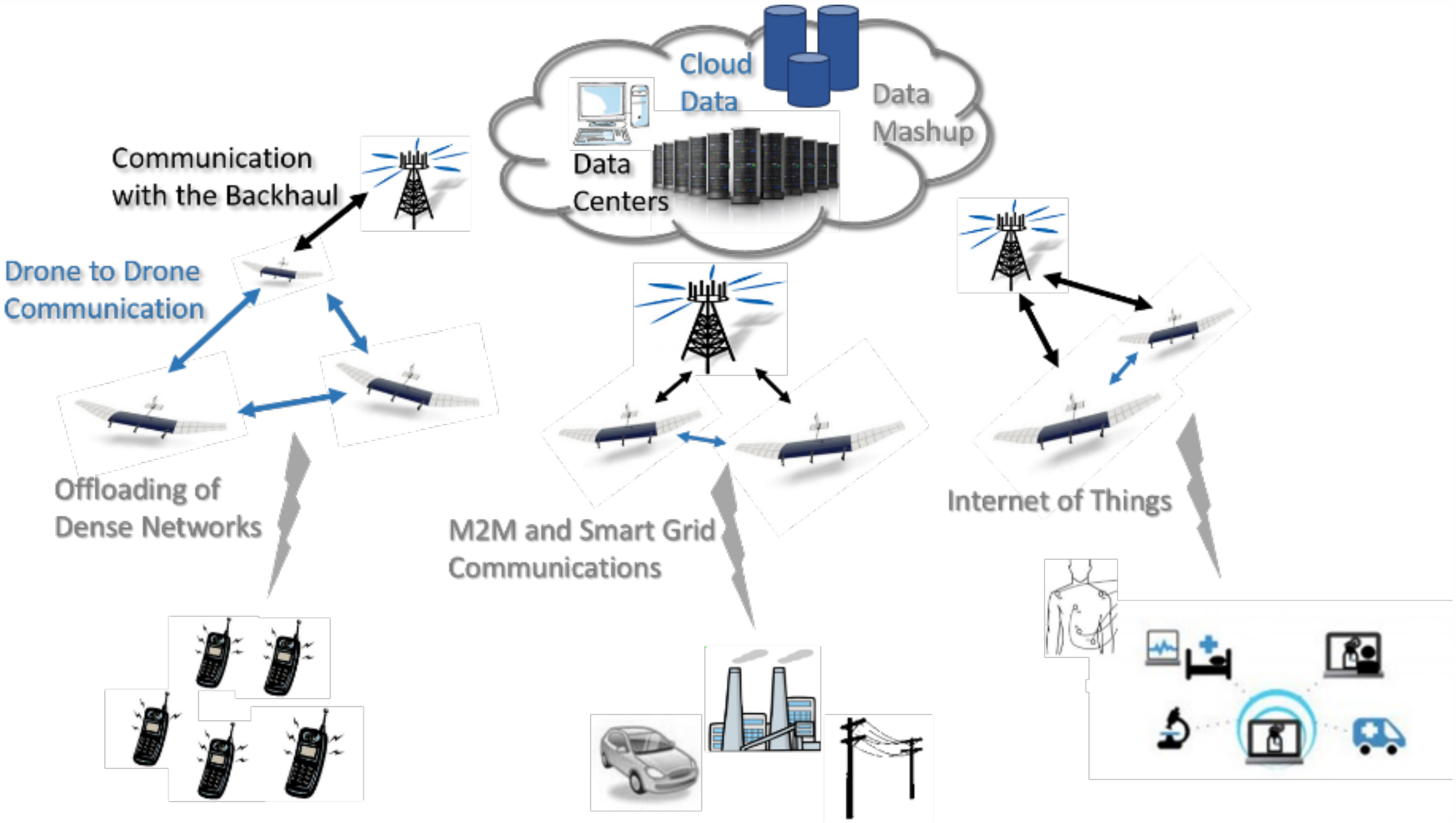
What else can drones do?

- Compared to terrestrial communications or those based on high-altitude platforms (HAPs), on-demand wireless systems with low-altitude UAVs are in general [Zeng et al., To appear in IEEE Communications Magazine 2016].
  - faster to deploy
  - more flexibly re-configured.
- Three typical use cases of UAV-aided wireless communications are:
  - UAVs are deployed to assist the existing communication infrastructure, if any, in providing seamless wireless coverage within the serving area.
  - UAV-aided relaying, where UAVs are deployed to provide wireless connectivity between two or more distant users or user groups without reliable direct communication links.
  - UAV-aided information dissemination and data collection, where UAVs are dispatched to disseminate (or collect) delay-tolerant information to (from) a large number of distributed wireless devices.

Recent Research

- A power-efficient deployment for UAVs by exploiting the optimal transport theory and facility location frameworks has been proposed in [Mozaffari et al., ICC 2016].
  - The total required transmit power is minimized by finding jointly the optimal locations of the UAVs and their associated cell boundaries.
- A decode-store-and-forward (DSF) strategy relaying has been explored in [Zeng at al., arXiv 2016].
  - The proposed mobile relaying in fact pro-actively constructs favorable channel conditions via careful mobility control, and thus introduces an additional degree of freedom for performance enhancement.
- The problem of user demand based UAV assignment over geographical areas subject to high traffic demands has been investigated in [Sharma et al., IEEE Communication Letters 2016]
  - A neural based cost function approach is formulated in which UAVs are matched to a particular geographical area.

A Look in the Future



Communication with the Backbone

- Free Space Optical (FSO)
  - Achievability of line-of-sight links
  - Utilization of optical wireless spectrum, which is orthogonal to the cellular frequencies.
  - Interference-free network
  - License free (no extra costs)
  - Very high available bandwidth (similar to fiber), Very high data rates
  - Very high directivity: Energy-efficiency (great energy concentration at the receiver), Information security, Proper for energy transfer

Communication with the users/devices

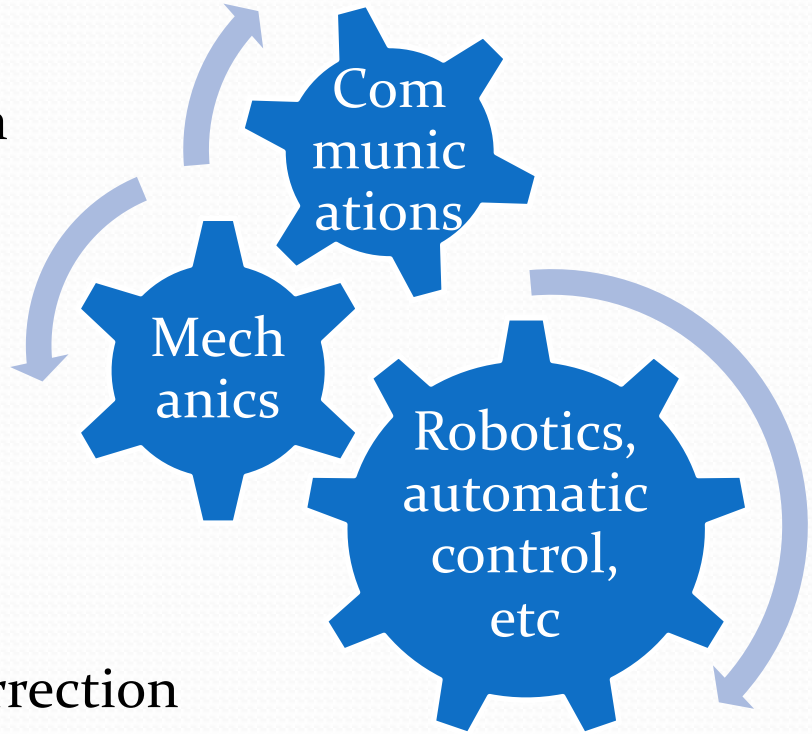
- Radio Frequency
  - Line-of-sight is not required.
  - Ensures compatibility with existing applications and devises.
  - Conventional, well-established multiple access schemes for interconnection of the users/devices can be still used.

Cross-Technology Optimization

- **Layer 1: Drones-Enabled Communications**
  - Misalignment
  - Energy efficient resource allocation
  - QoS aware resource allocation

Joint optimization

- **Layer 2: Drones Mechanics**
  - Self-positioning, and automatic correction
  - Lightweight construction and energy plan
  - Place and context-aware flight



What are the challenges from the communication perspective?

- **Energy Sustainability:** Energy constraints the system's performance, rendering energy sustainability the most important challenge of the utilization of drones for regular communication purposes.
- **Compatibility:** Drones-enabled communications must be compatible with conventional, well-established multiple access schemes for interconnection of the users/devices.
- **Communication with the Backbone:** Capacity and spectral efficient communication with the backbone of existing networks is required.
- **Provide QoS:** Fairness issues must be considered.