# Unmanned Aerial Systems: Networking Applications, Challenges and Issues

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Washington University in Saint Louis

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These slides and recording of this talk are available on-line at:

**http://www.cse.wustl.edu/~jain/talks/unmanned.htm**

**or http://bit.ly/jain_unmanned**

# Range of UAVs

- Micro-UAVs: Innovative applications of current wireless technologies. Far away from national air space and manned aircrafts
- Large UAVs: New wireless technologies required to integrate them in national air space. Landing and take-offs from the same airports as manned aircrafts.


1. Micro-UAVs:
   1. Networking Applications
   2. Challenges and Issues
2. Larger UAVs:
   1. Aeronautical Datalinks: Challenges
   2. UAS Datalink Design Decisions

# Cell Service During Disasters

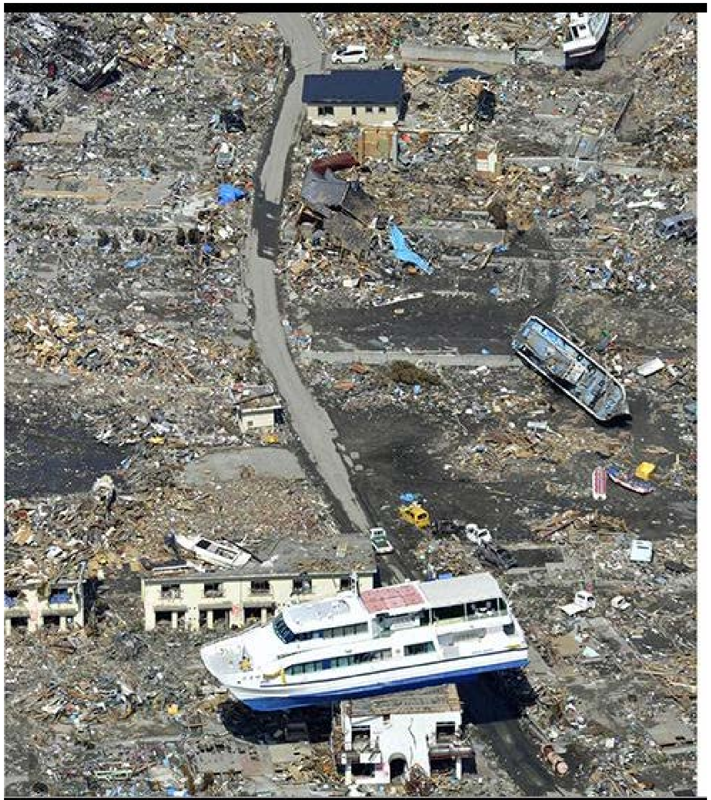
- Tsunamis, floods, cyclones, hurricanes, tornadoes, earthquakes, landslides, wild fires, etc. are common around the globe
- In 2012, there were 905 natural disasters worldwide with a cost of $170 Billion and heavy human casualties
- Ground communication infrastructure is often destroyed during such disasters making it difficult for safety personnel to give early warnings and for victims to reach emergency workers



Ref: http://en.wikipedia.org/wiki/Natural_disasters

# Japan Tohoku Earthquake and Tsunami

- Japan has a cellular Early Earthquake Warning (EEW) system
- March 11, 2011: Cellular and landline phone service suffered major disruptions leading to congestion across much of Japan
- Three times the normal call volume
- National Public Radio could not reach any one in Sendai on the cell phone
- Government had to use loudspeaker alerts and television broadcasts



Ref: http://en.wikipedia.org/wiki/2004_Indian_Ocean_earthquake_and_tsunami
Ref: http://www.weather.com/news/japan-earthquake-tsunami-3-years-later-photos-20140310

# New Orleans Hurricane Katrina

- *"Up to 2000 cell towers were also knocked out and responder Land Mobile Radio communications were significantly degraded. Emergency 911 service was severely damaged, and surviving stations were soon overwhelmed by spiking call volumes as desperate people tried to get help or check on those at risk."*

Ref: R. Miller, "Hurricane Katrina: Communications & Infrastructure Impacts," National Defense Univ, http://tinyurl.com/mhtdfy3

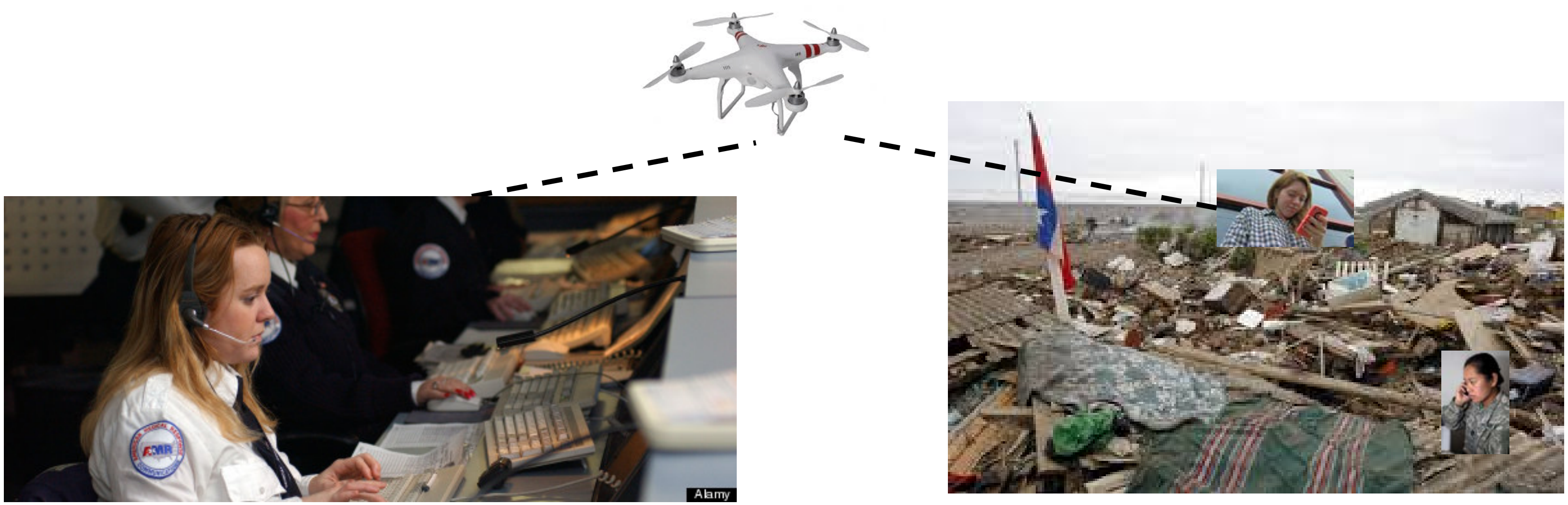
# Indian Ocean Earthquake and Tsunami

- December 26, 2004, Sumatra, Indonesia
- Several hours between the earthquake and tsunami but there was no warning system in Indonesia
  ⇒ Killed 230,000 people in 14 countries

Ref: http://en.wikipedia.org/wiki/2004_Indian_Ocean_earthquake

# Solution: Instant Cell Tower

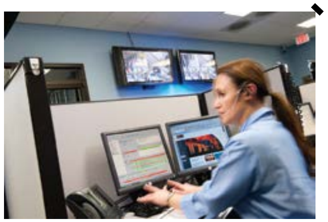
- Instant **cellular tower in the sky** using micro unmanned air vehicles (UAVs)
- Anyone with a **regular cell phone** can call anyone in the world
- Emergency personnel can send evacuation instructions to victims via cell phone messages
- Number of cell phones = 96% of world population

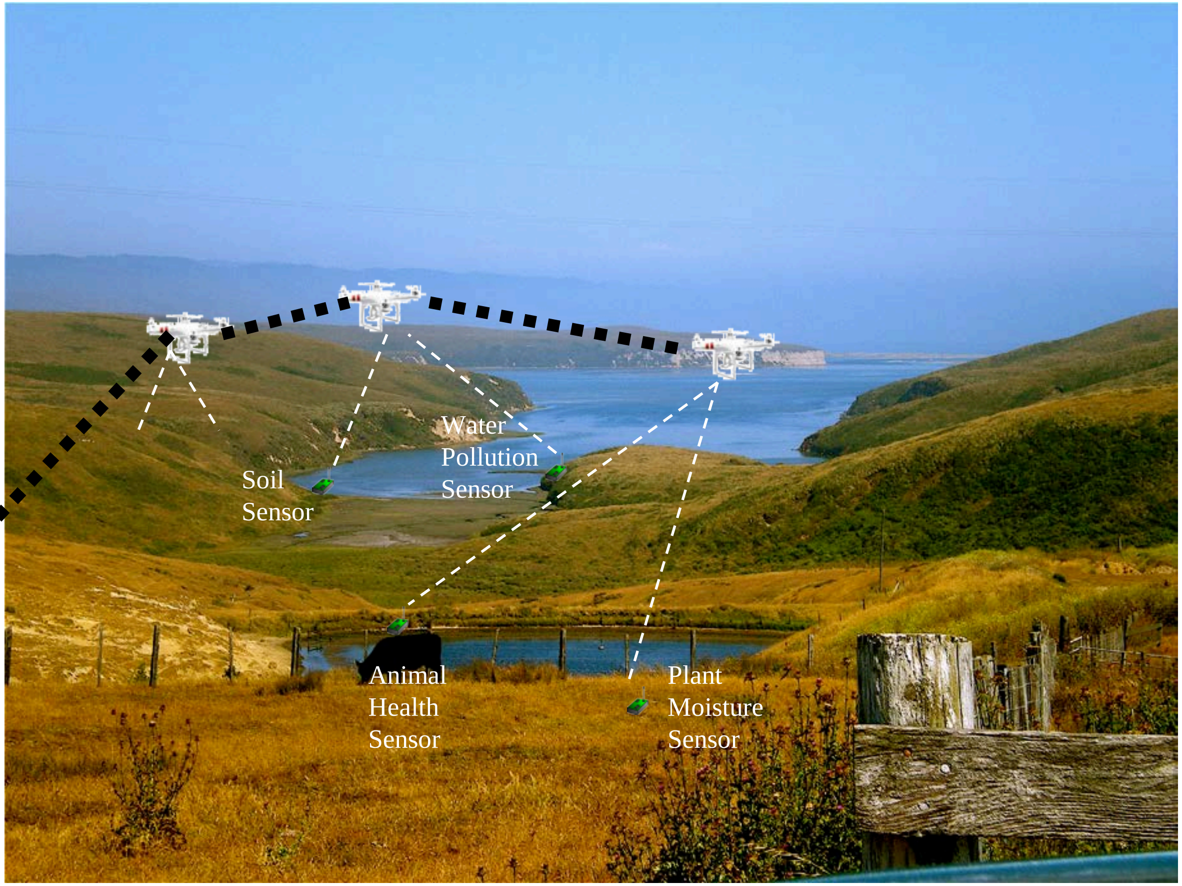



Ref: ITU, "The world in 2013: ICT Facts and Figures," http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx

# Environmental Sensing

- Easiest method to collect sensor data

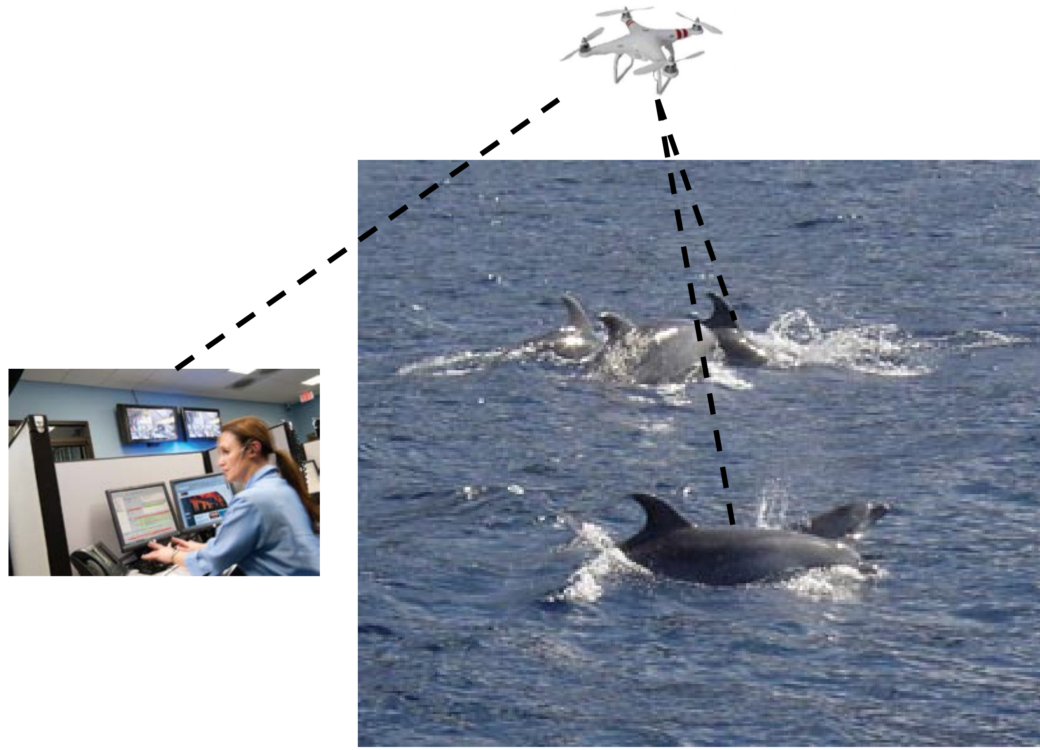




# Wild-Life Monitoring

- Not this

- But this



# Forest Fires

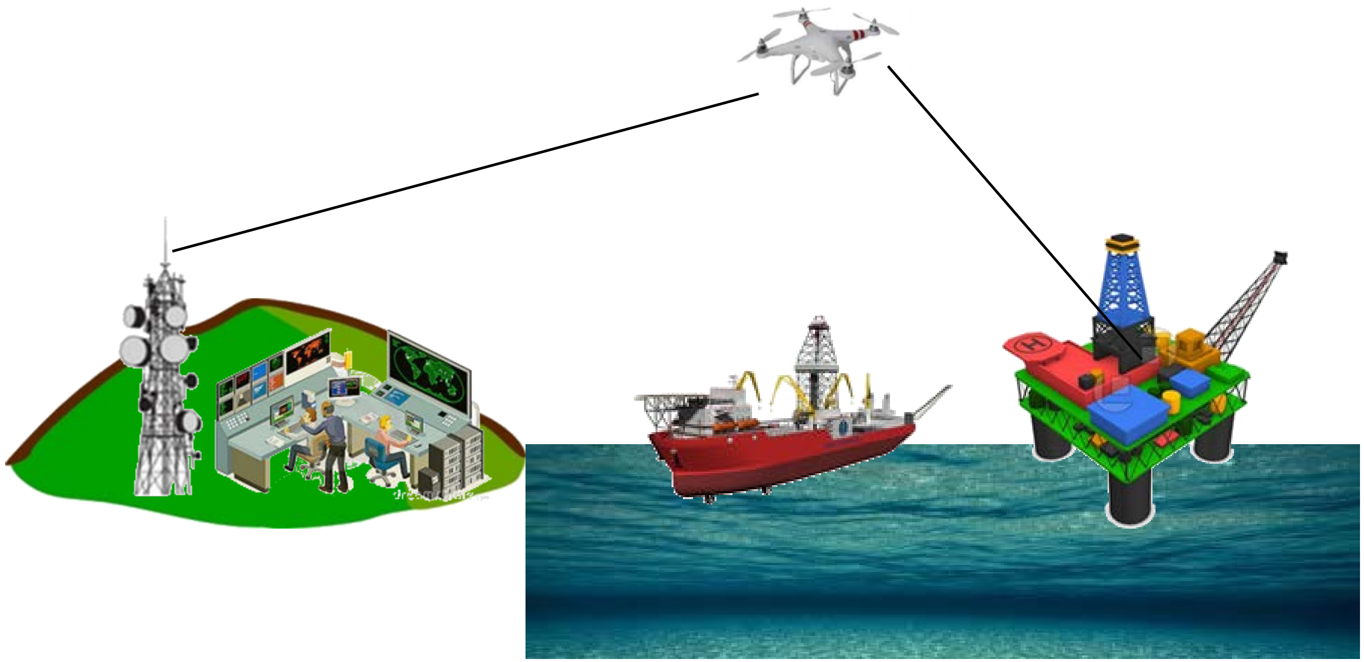
- Sense $CO_2$ or temperature before the fire spreads

# Smart Grid

- Meter reading

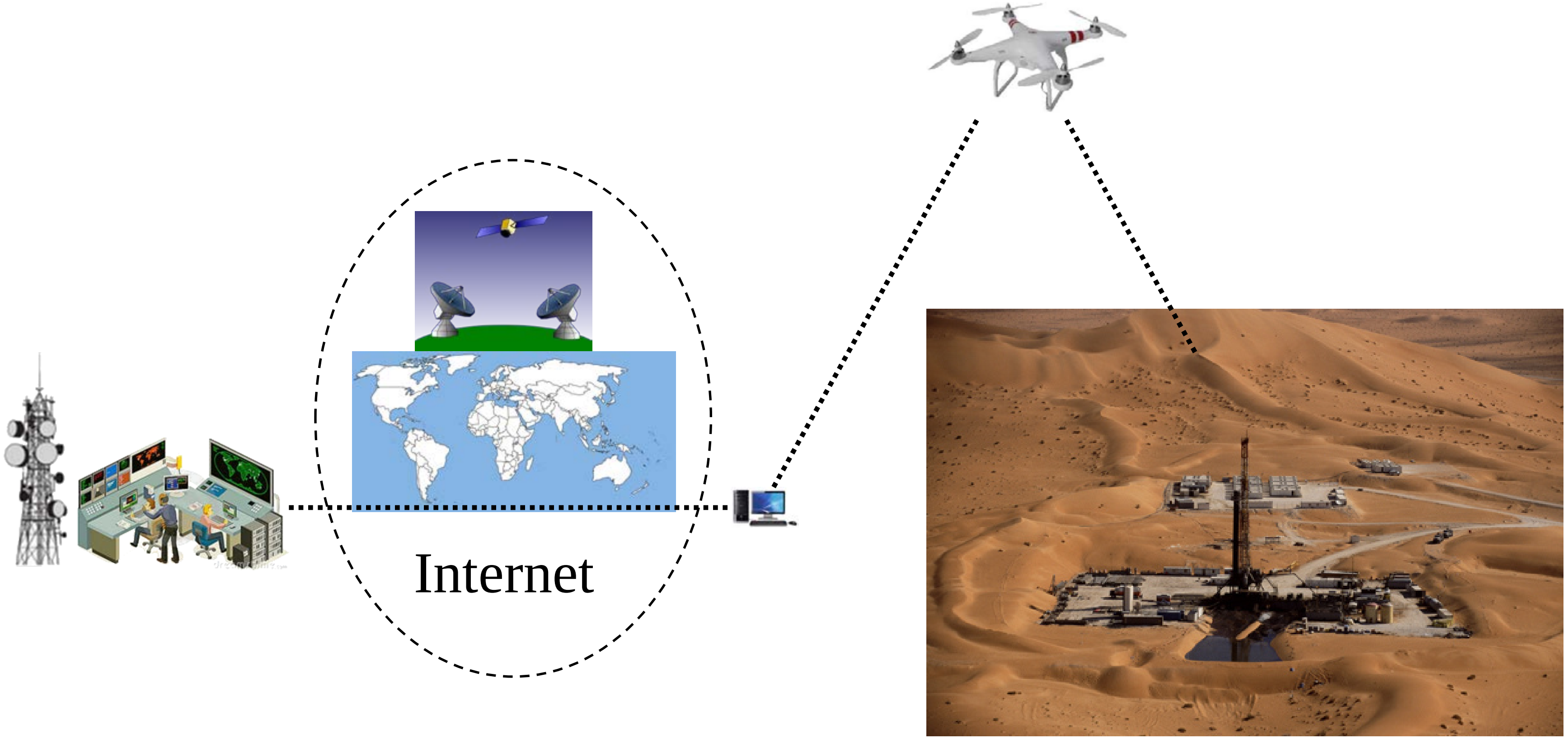
# Oil/Gas Exploration

- Big data analytics in a cloud data center
  ⇒ Significantly reduce exploration time and costs



# Internet to Remote Areas

- Nearest Internet point to the best cloud computing center in the **world** using satellite, fiber, …







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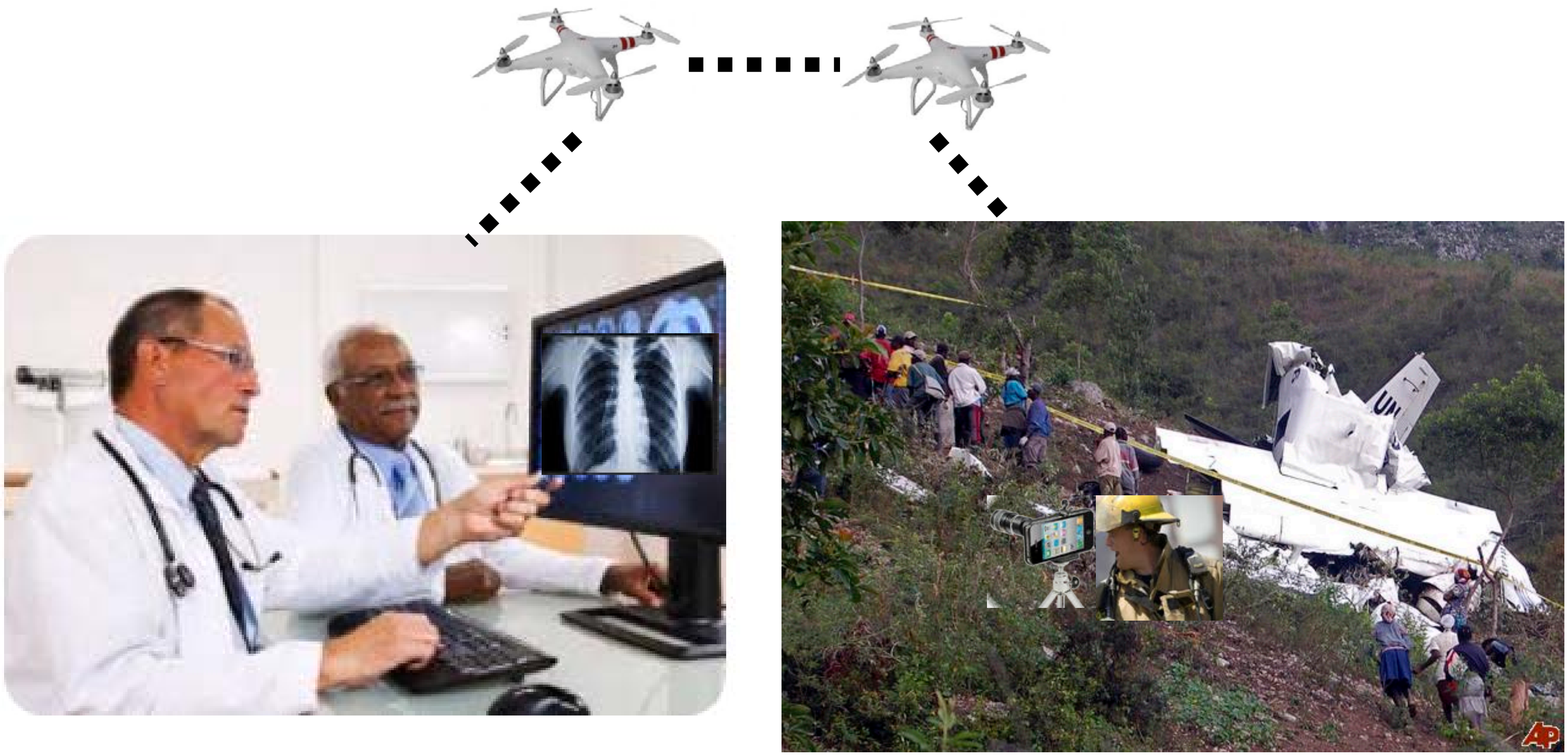
# Remote Health Care

- Accidents



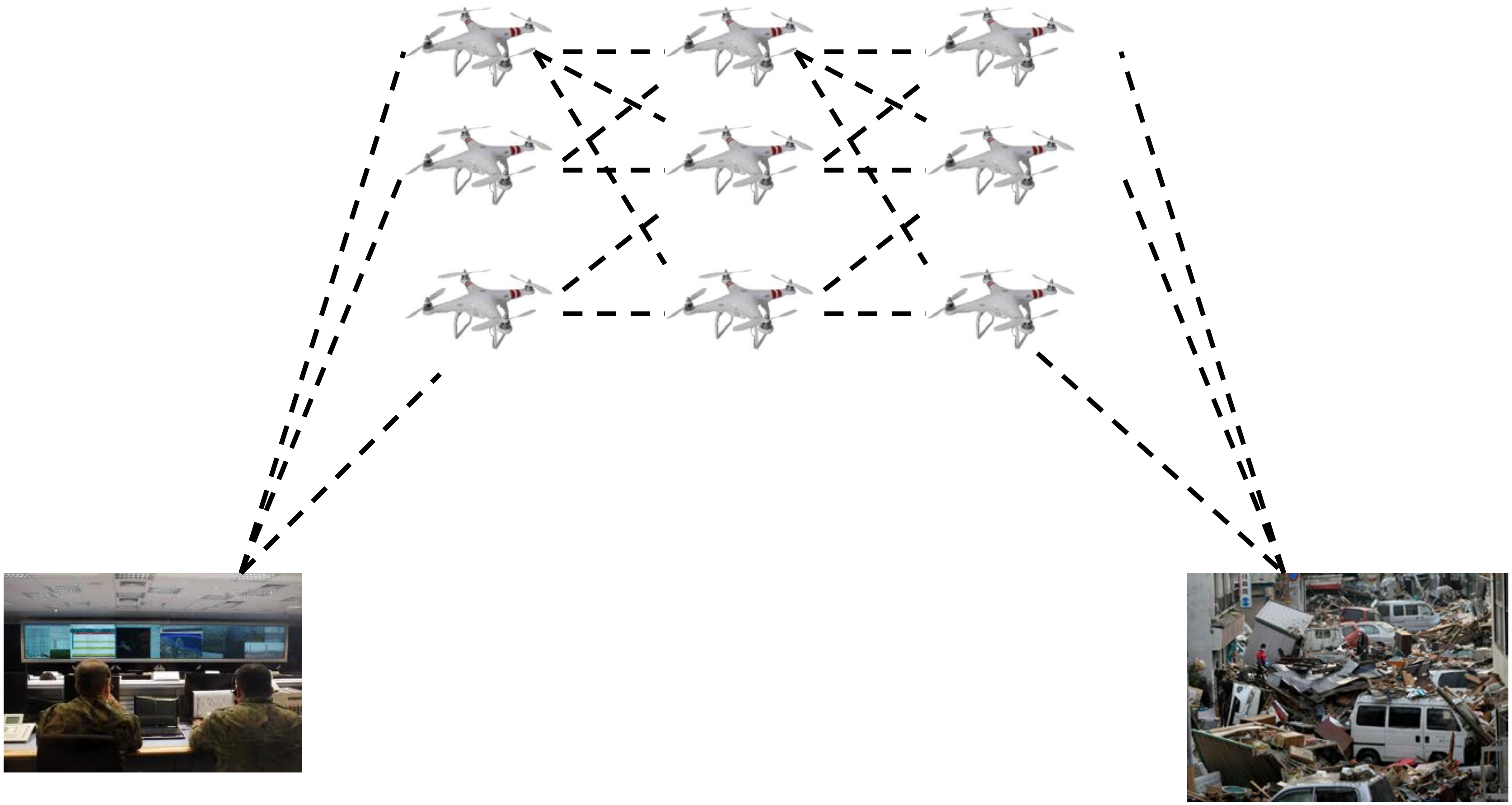
# Networking Challenges

- Seamless Handover
- Drone Networks in the Sky
- Throughput Enhancements
- Fault Tolerance

# Seamless handover

- **Proactive replacement**: New UAV is launched before battery depletion
- **Seamless**: Communication continues with no interruptions

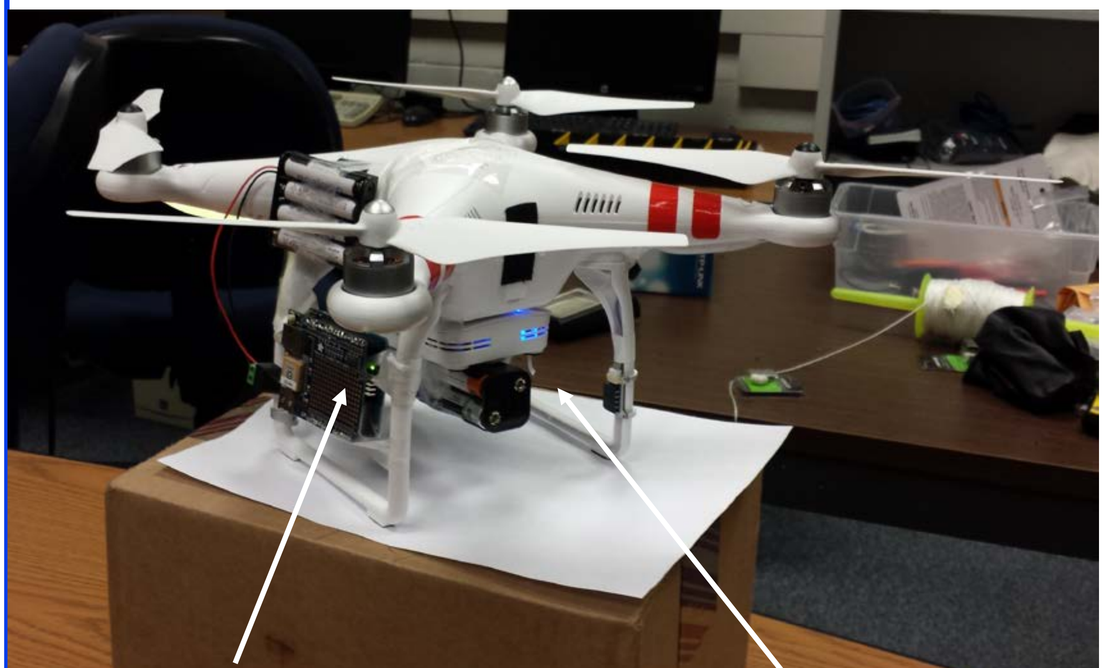
# Drone Network in the Sky



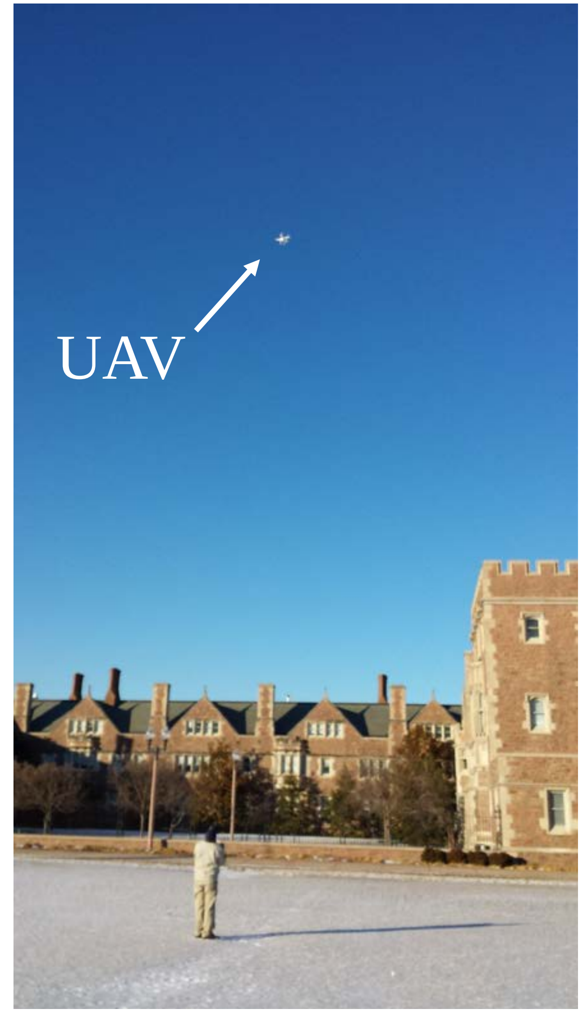
# Drone Spy

# Feasibility and Sustainability

- Current Status: Proof of concept
- Instrumented a UAV



Controller with GPS   Base Station

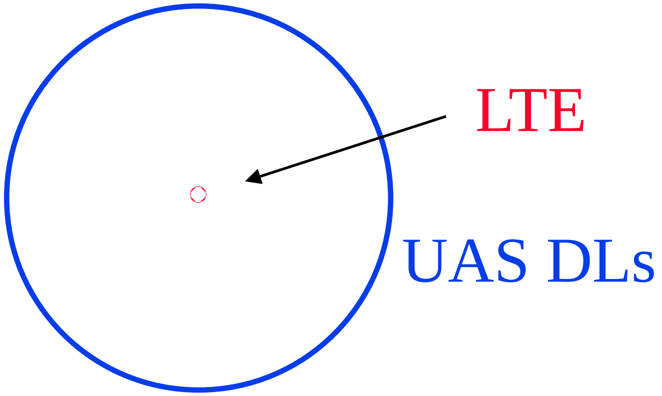


# Large UAS Networking Issues

- Satellite, Cellular, and several new standards are competing
- These may or may not meet the requirements

# Aeronautical Datalinks: Challenges

- Very long distances:
  - WiFi covers 100 m
  - LTE cells are 1km in urban and 3 km in suburban areas
  - UAS DLs needs to cover 360 km (200 nautical miles)
    - Limited Power ⇒ High bit error rate or very low data rate ⇒ Low Spectral efficiency (2 bps/Hz is a challenge)
    - Long turn-around times ⇒ Large guard times (360 km = 1.2 ms one-way at speed of light)



# Datalinks Challenges (Cont)

- Very High Mobility:
  - WiFi isn't designed for mobility
    (200m at 60km/h = 12s between handovers)
  - LTE is optimized for 0-10 km/h, operates up to 120 km/h
  - UAS DLs have to operate up to 600 nm/h (1080



# Frequency Spectrum

- Lower frequencies are more crowded.
  HF (3-30MHz) is more crowded than VHF (30-300MHz).
  VHF is more crowded than L-band.
- Higher frequencies have more bandwidth and higher data rate
  $\Rightarrow$ Trend: Move up in Frequency
- Effect of Frequency on signal:

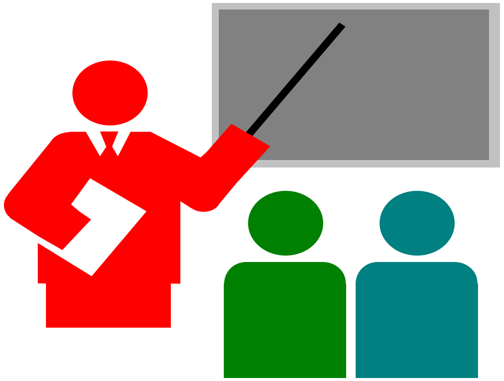
$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

- Attenuation $\propto$ (frequency)$^2$(distance)$^2$
  $\Rightarrow$ Lower Frequencies have lower attenuation,
  e.g., 100 MHz has 20 dB less attenuation than 1GHz
  $\Rightarrow$ Lower frequencies propagate farther
  $\Rightarrow$ Cover longer distances

# Spectrum (Cont)

- Doppler Shift = velocity/wavelength
  ⇒ Lower frequencies have lower Doppler shift
  Higher Frequencies not good for high-speed mobility
  Mobility ⇒ Below 10 GHz
- Higher frequencies need smaller antenna
  Antenna ≥ Wavelength/2, 800 MHz ⇒ 6”
- Higher frequencies are affected more by weather
  Higher than 10 GHz affected by rainfall
  60 GHz affected by absorption of oxygen molecules

# Summary



1. Drones have several networking and sensing applications
2. Key issues for micro-drones are related to smooth handover and throughput enhancements
3. Larger UAS need wireless data links. Designing these  is challenging because of long distances, high-velocity, and spectrum availability issues

# Related Papers

- Raj Jain and F. Templin, "**Requirements, Challenges and Analysis of Alternatives for Wireless Datalinks for Unmanned Aircraft Systems**," IEEE Journal on Selected Areas in Communications (JSAC) Special Issue on Communications Challenges and Dynamics for Unmanned Autonomous Vehicles, Vol. 30, No. 5, June 2012, pp. 852-860
- Raj Jain, Fred L. Templin, Kwong-Sang Yin, "**Analysis of L-Band Digital Aeronautical Communication Systems: L-DACS1 and L-DACS2**," 2011 IEEE Aerospace Conference, Big Sky, Montana, March 5-12, 2011, pp. 1-10
- Raj Jain, Fred L. Templin, "**Datalink for Unmanned Aircraft Systems: Requirements, Challenges and Design Ideas**," AIAA Infotec@Aerospace Conference, Saint Louis, MO, March 2011.

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