Aeronautical Ad Hoc Networks

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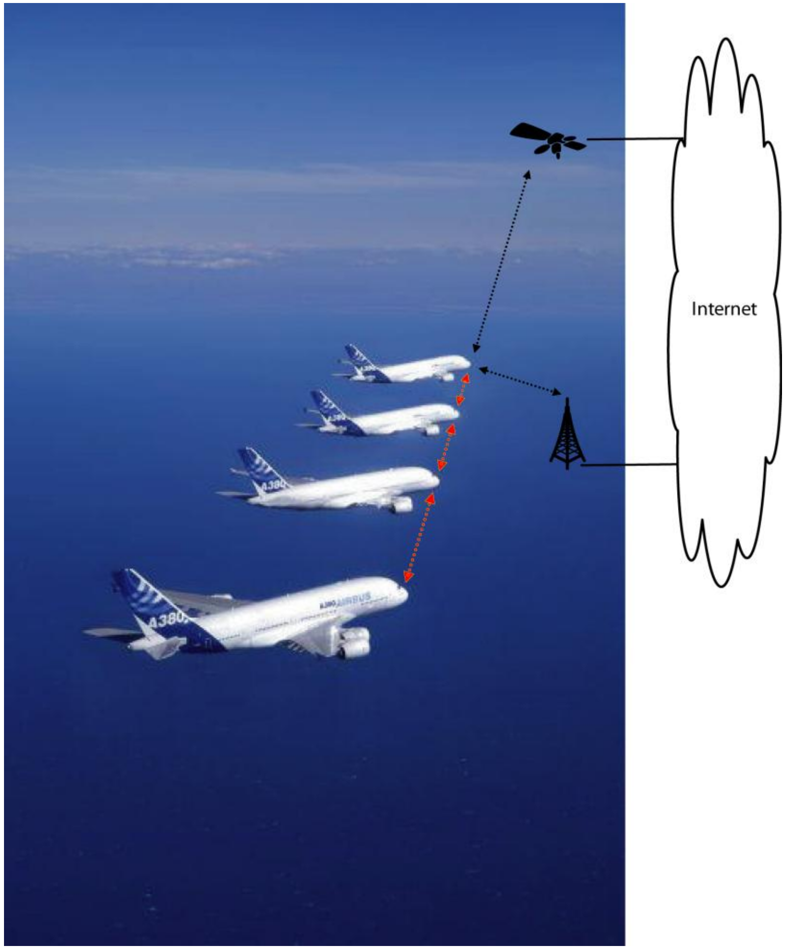
Outline

- Concept
- Internet connectivity
- A2A NET/MAC/PHY



Scenario 1: Continental Airspace

- Uncoordinated aircraft movement
- Highly dynamic topology
- Very dense topology
  - Up to 30 000 flights per day
  - Ca. 2 000 simultaneous flights

- Application:
- Extension of coverage via multi-hop relays beyond coverage of terrestrial base stations

Scenario 2: Oceanic/Remote Airspace

- Coordinated aircraft movement
- Very stable (quasi-static) topology
- Lower connectivity
  - Ca. 1 500 flights per day
  - Max. 300 simultaneous flights

- Application:
- Extension of terrestrial coverage
  - Ad hoc network as alternative to satellite communications
- Sharing of satellite links among aircraft

Node characteristics

- Limited battery power
- GPS not always available
- Short transmission range
- Random motion
- One user per node

- ‚Unlimited' battery power
- GPS always available
- Huge transmission range (over 200 nautical miles)
- Linear uniform motion
- Many users (e.g. passengers) per node

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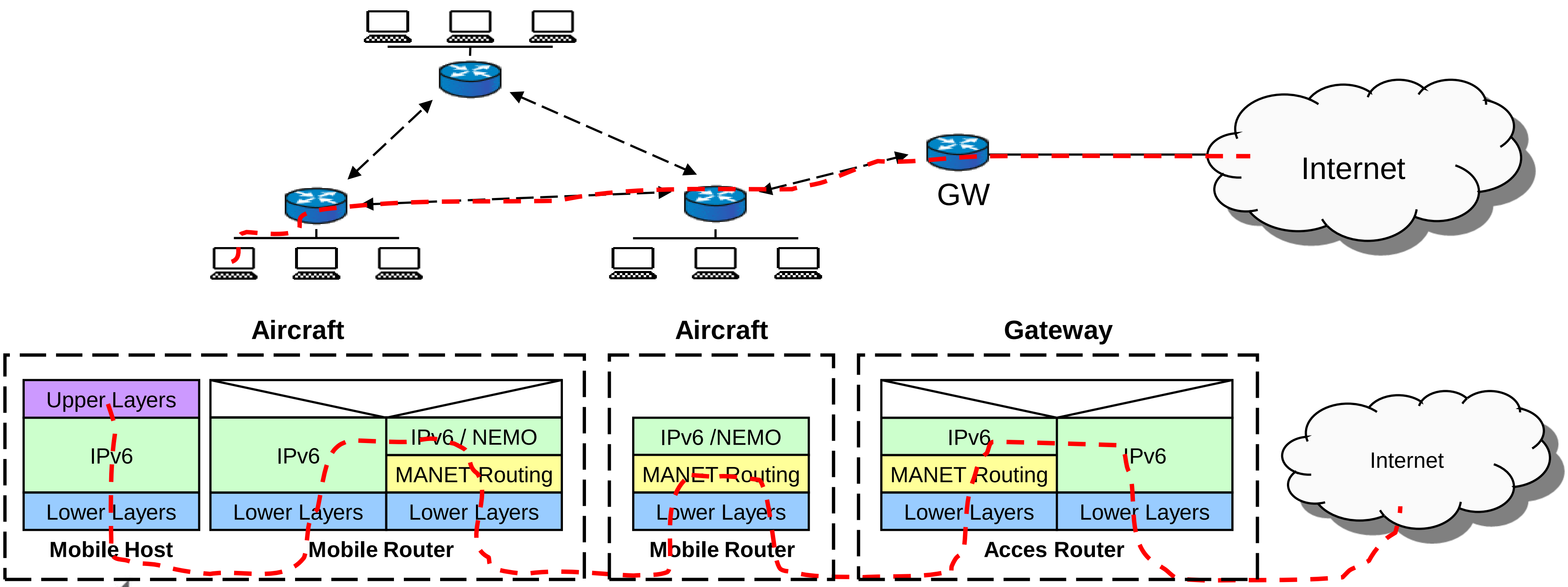
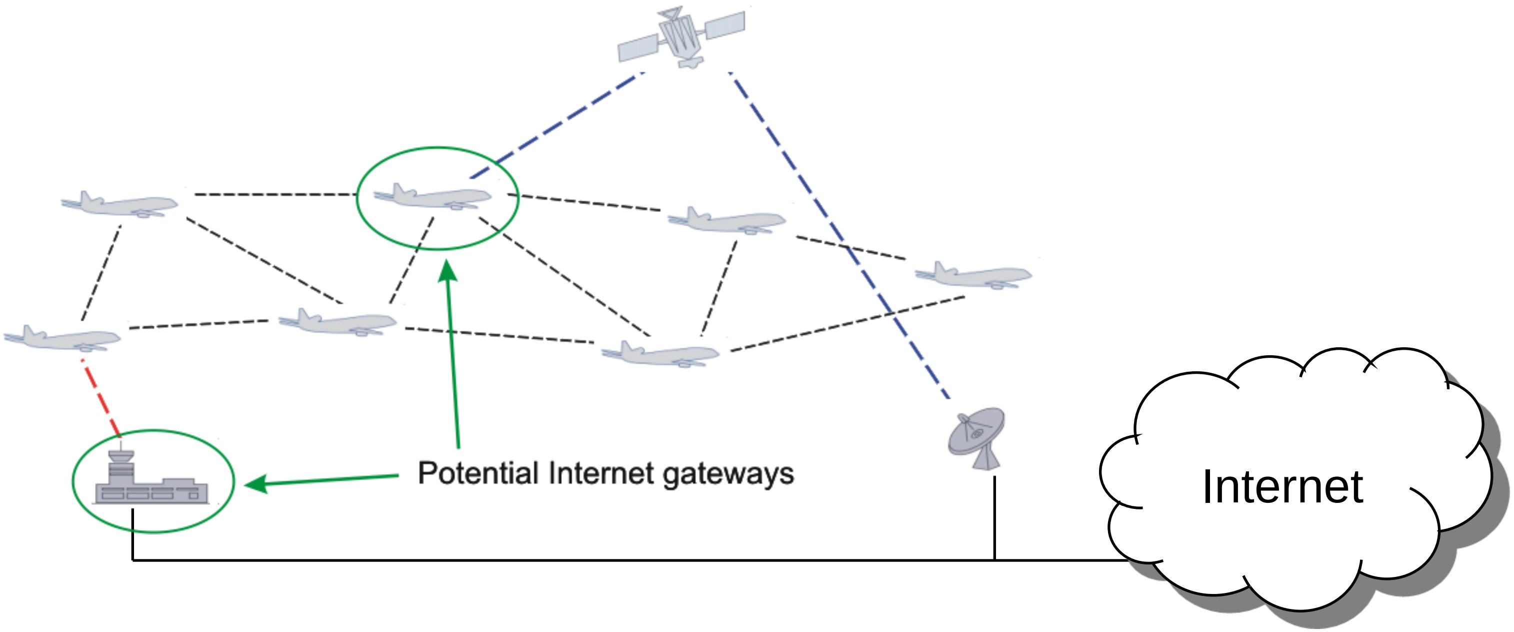
Aircraft as Mobile Networks

- ***Internet Gateways*** (IGWs) connect MANETs to Internet
- Multi-hop communication between aircraft and GW is performed by a MANET routing protocol below IP
- Transparent to IP mobility protocol (NEMO)



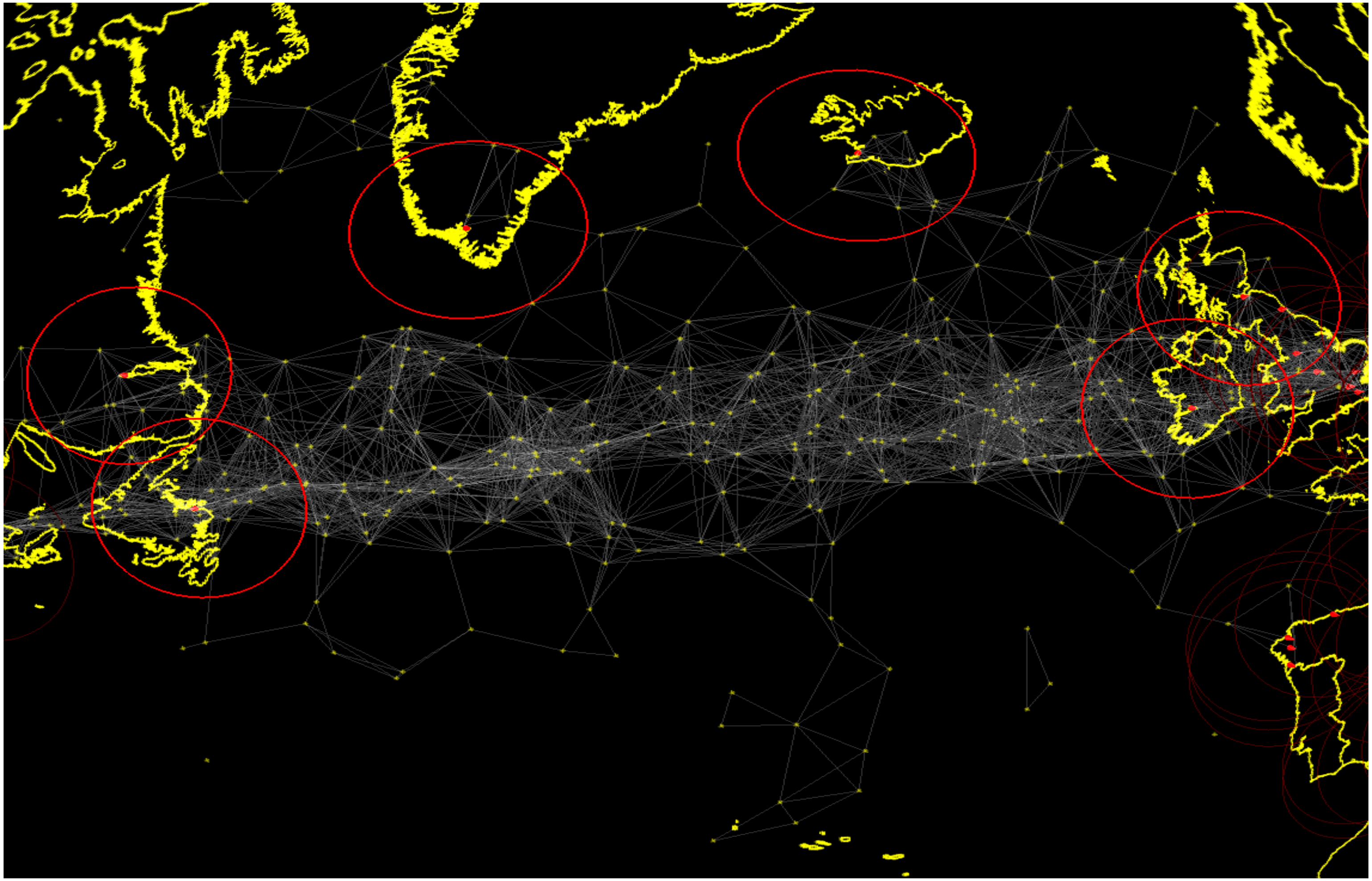
Internet Gateways



- GWs may exhibit significantly different characteristics concerning bandwidth, delay, reliability
- Traffic is concentrated around the GWs

→ IGW selection crucial for overall network performance!

Internet Gateway Deployment Example



Internet Connectivity: Key Questions

1. What GWs are reachable?
   - ↗ GW Discovery

2. What is the best GW?
   - ↗ GW Selection

3. What aircraft should act as opportunistic GW?
   - ↗ GW Election

Internet Gateway Discovery

- Proactive
  - Based on periodic flooding of IGW advertisements (ADVs)
  - Constant overhead
  - Suited to highly mobile environments
- Reactive
  - Based on on-demand IGW solicitations
  - Overhead scales with no. of sources
  - More suitable for less mobile networks
- Hybrid
  - Flooding of ADVs limited to region around GW
- **Here**: Exploitation of *position information* for efficient flooding of ADVs

Internet Gateway Selection

- What is the best GW (regarding throughput, delay, etc.) ?
- Approaches proposed so far mainly based on
  - Hop Count
  - Gateway Utilization
  - Compound Metrics
    - e.g. $\alpha \cdot$ HopCount + $\beta \cdot$ GWUtilization
- **But:** Cannot adapt to different traffic situations

→ Improvement of GW selection by
  - Use of ***delay*** as selection metric: natural combination of hop count and traffic load
  - Cooperation between gateways

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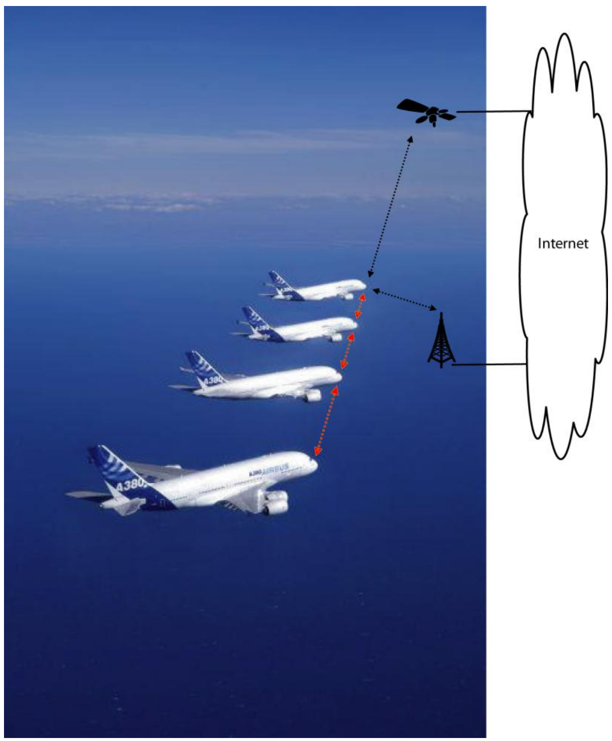
NET/MAC/PHY Design for Aircraft-to-Aircraft (A2A) Communication

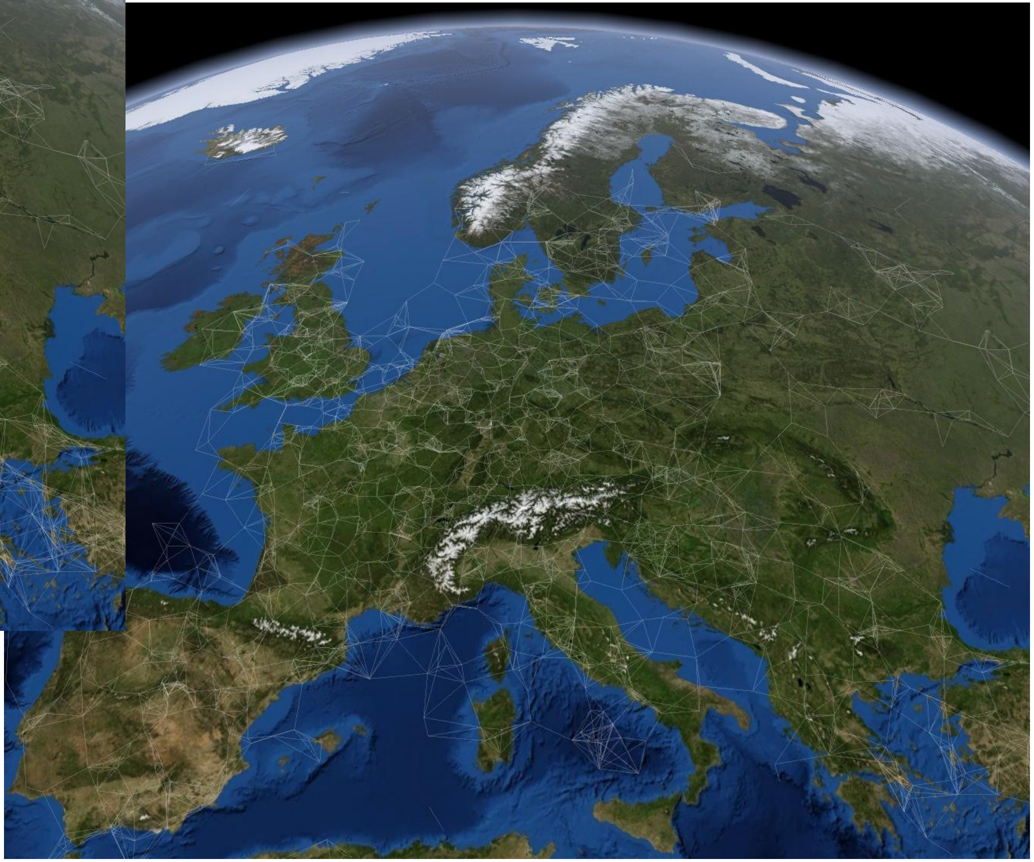


Crosslayer A2A Protocol Stack

NET	Geographic Routing Topology Control
MAC	TDMA Scheduling
PHY	OFDM MIMO (Beamforming) Power Control, Rate Control, etc.

Adapt **802.16 Mesh** for A2A?

Topology Control



Topology control algorithms

- Precursor works:
  - In the context of Slotted ALOHA (Kleinrock, Hou, Zander)
  - **Tradeoff** between spatial reuse and forward progress
  - Goal: Optimize **expected forward progress** of packets
- Structures from computational geometry…
  - Planar subgraphs for geographic routing (e.g. Gabriel graph)
  - Yao Graph
- In the context of TDMA:
  - Moscribroda et al. [MobiHoc'06] obtained scaling laws for the „scheduling complexity of an arbitrary topology" (schedule length) as the network grows
- Our approach: „Back to the roots"
  - Apply the **tradeoff** concept to TDMA multihop wireless networks

TDMA algorithms

- Desirable features of a TDMA algorithm [Grönkvist]
  - **Distributed**
    - No central controller
    - Only local information required
  - **Traffic sensitive**
    - Each link has a different traffic demand
  - **Density adaptive**
  - **SINR based**
    - Protocol interference model does not reflect reality well
  - **Exploits directional antennas**

- Examples:
  - USAP [Young]
  - ROMA [Bao and Garcia Luna Aceves]

Topology Control in TDMA Multihop Wireless Networks

- Objective:

  Control the routing topology to maximize the ***end-to-end*** throughput-delay performance of TDMA
- Existing TC algorithms, e.g. Cone-based Topology Control (CBTC)
  - are based on ***geometrical*** considerations
  - ignore the tradeoff btw spatial reuse and forward progress
- Basic idea:
  - Use feedback from the TDMA layer to adapt the routing topology, based on some scheduling complexity metric
  - e.g. control the ***neighborhood*** (knowledge range) of each node so that all links can be scheduled within a given fixed-size frame

Some notes…

- With TDMA-based Topology Control…
  - Topology may change frequently (on a frame by frame basis!)
  - Maybe only appropriate when using ***localized*** routing (geographic routing)

- In particular with ***directional antennas***, TDMA-based TC is expected to significantly outperform geometry-based TC

Questions?