Feasibility of an Aeronautical Mobile Ad Hoc Network Over the North Atlantic Corridor

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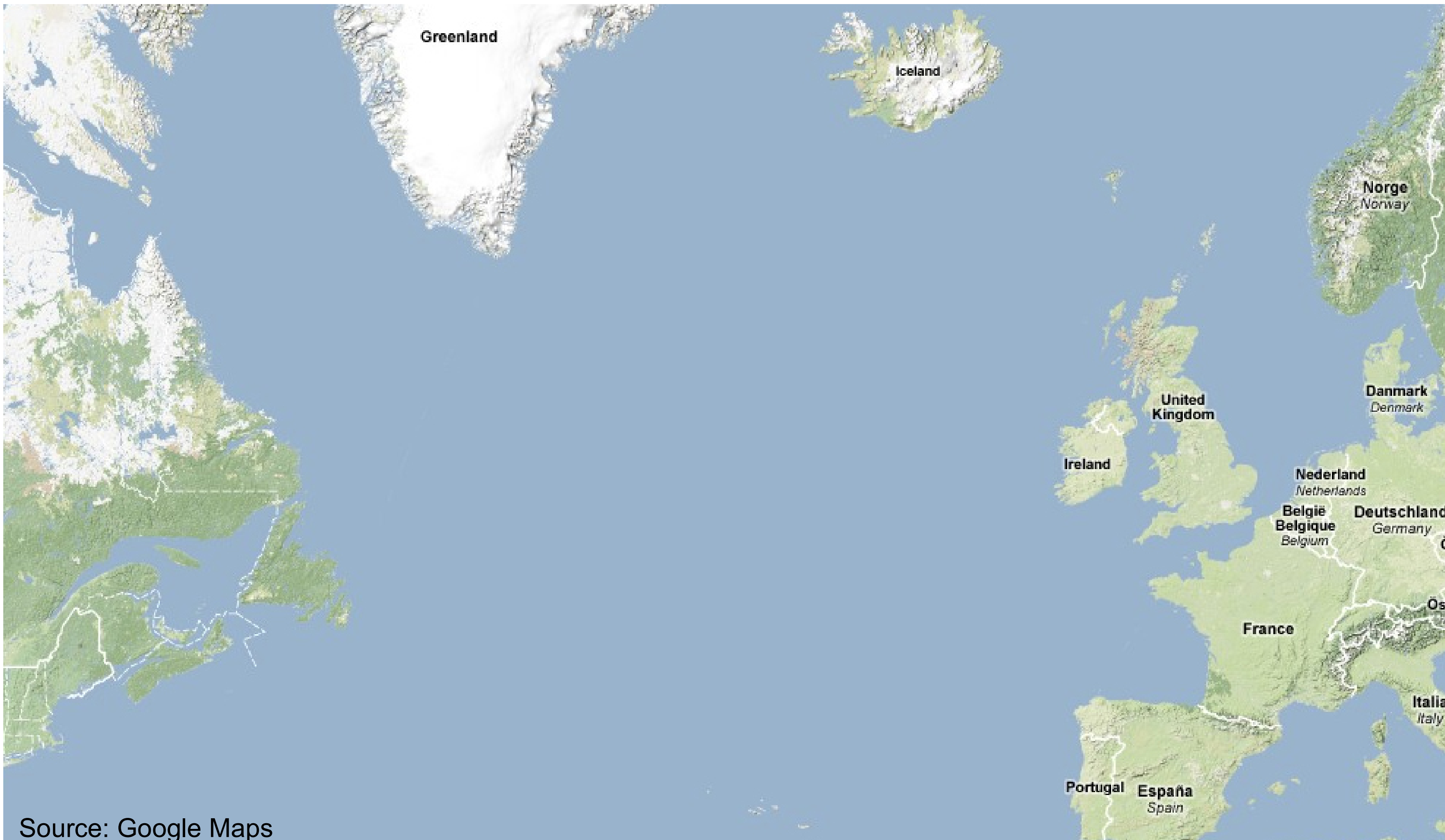
Overview

1. Introduction
   - basic idea / motivation
2. Setup
   - network model
   - greedy forwarding
   - link model
3. Analysis of the Network
4. Conclusion and Review

1. What is the idea?

Aircraft Ad Hoc Network in the North Atlantic Corridor



Source: Google Maps

1. Motivation

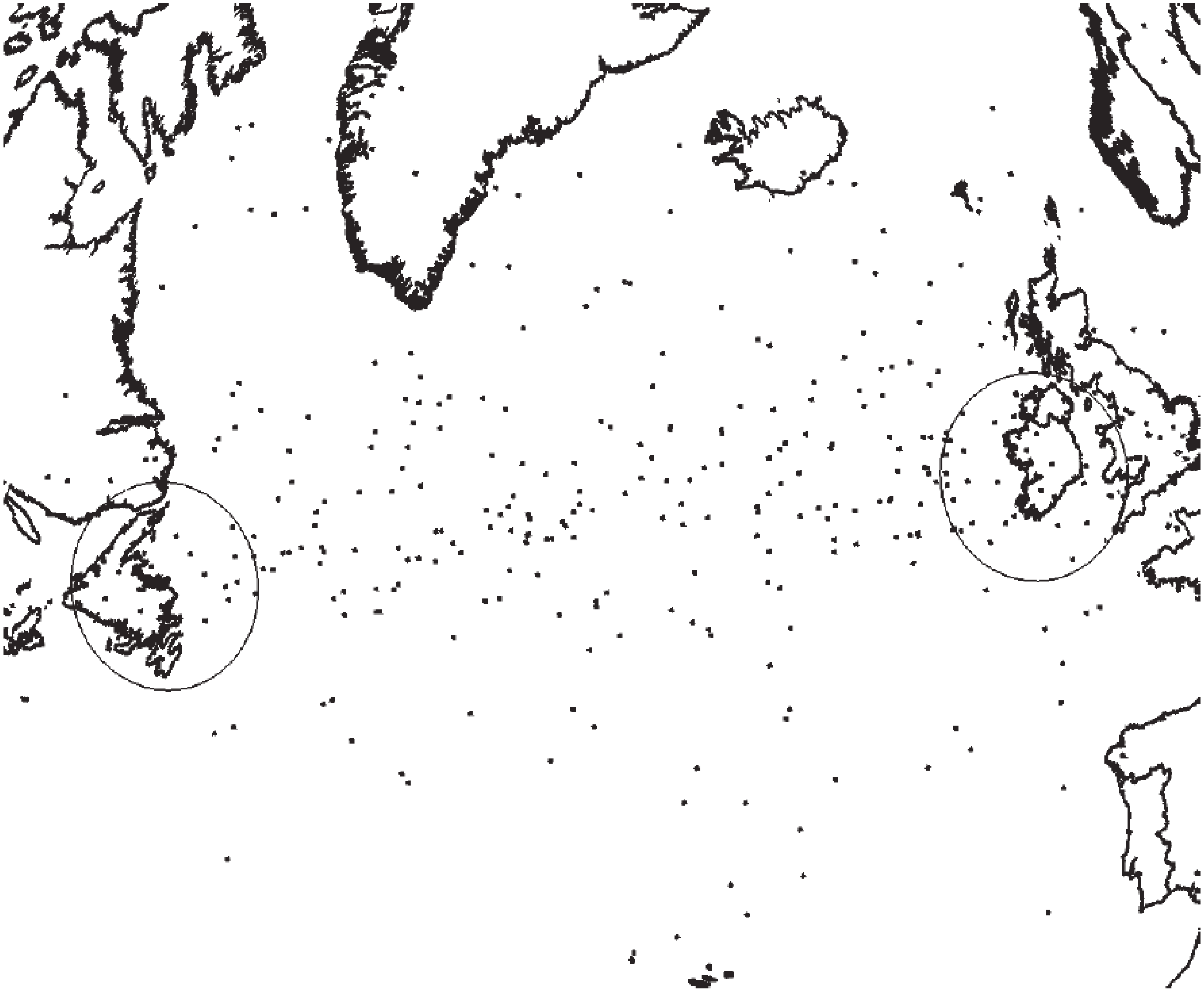
- need for communication
  - information about the aircrafts
    - e.g. delay, connecting flights, fuel consumption
  - Internet access for passengers
  - phone calls
- today: possible only over a satellite link
  - expensive, high delay

Is an Ad Hoc Network between aircrafts possible?

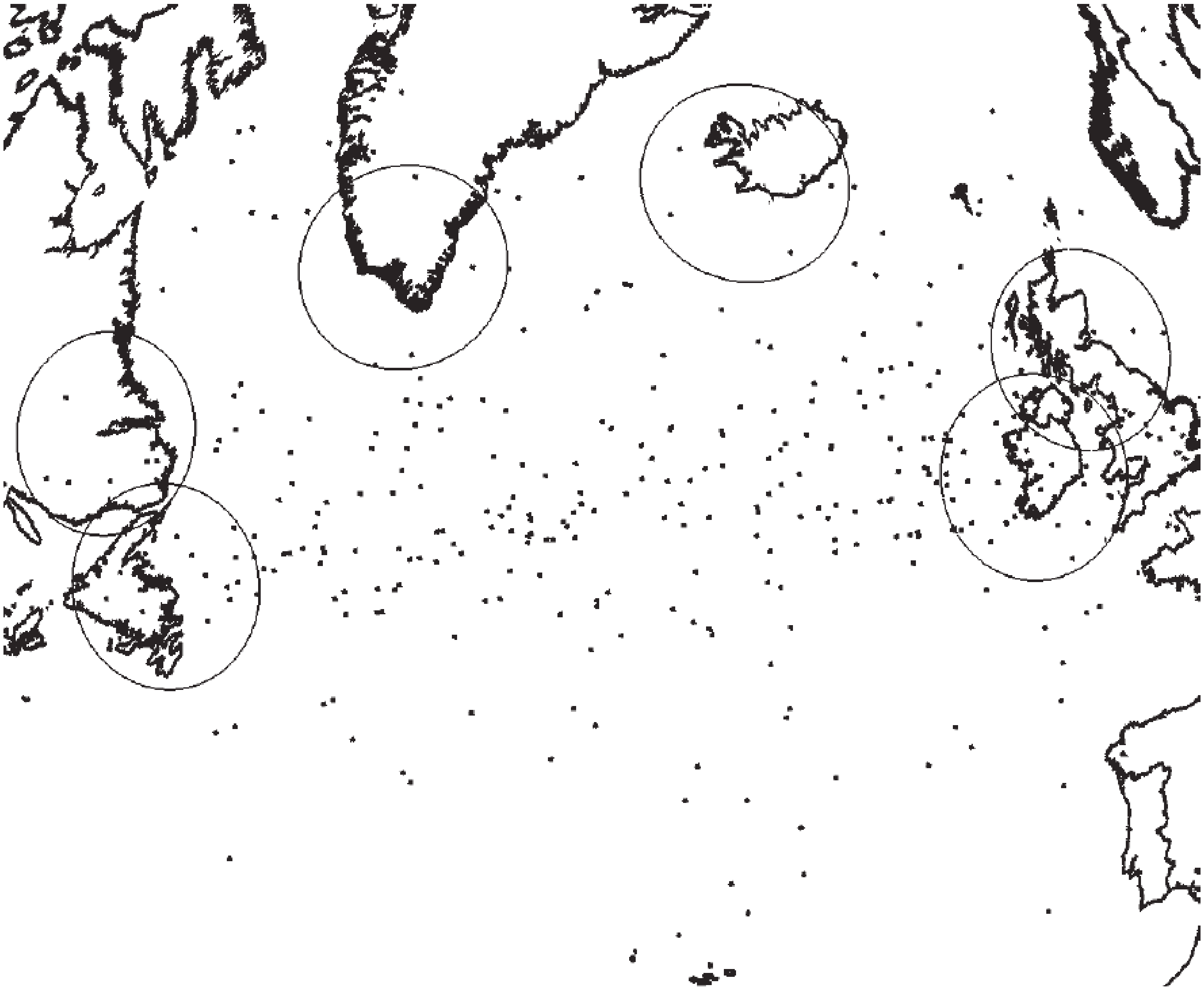
2. Setup

- two elements in the network:
  - aircrafts and ground stations
- ground stations (IGWs) operate as gateways
- 2 scenarios
  - scenario A with two IGWs
  - scenario B with six IGWs

Scenario A



Scenario B



2. Setup

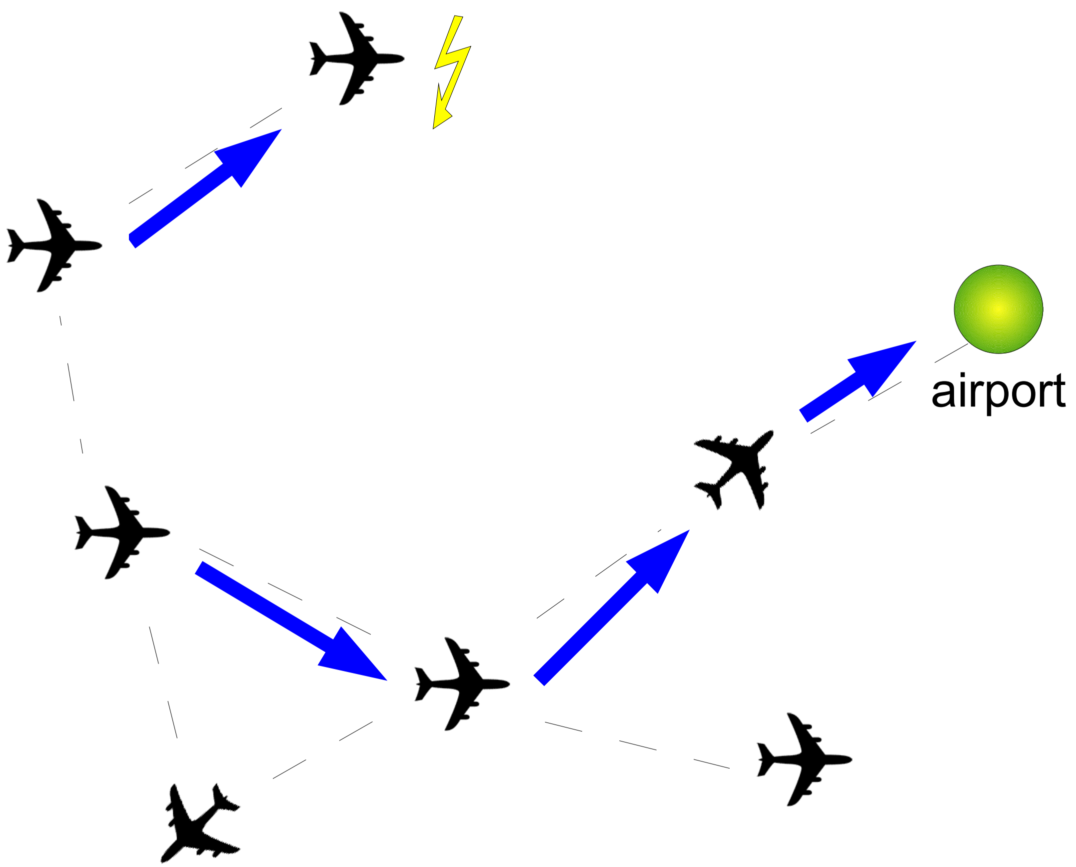
- IGW periodically sends advertisements (IGWADVs)
  - IP of IGW, Hop Count field
- aircraft creates a table from IGWADVs for routing
  - nearest IGW = lowest Hop Count
  - entries have limited lifetimes
- Routing via "Greedy Forwarding"
  - chooses the local optimum for the next hop
  - forwards a packet to the next hop which is closest to the target (IGW)

→ problem: local maximum

2. Setup

- local maximum
  - packet is dropped
  - situation may stay the same
  - ➤ connection problem
- solution exists
  - not considered in this paper
  - Greedy Perimeter Stateless Routing (GPSR)[1]

- Example



2. Setup

- requirements for greedy forwarding
  - positions: own, neighbors and IGW
    - own position: GPS (already on board)
    - neighbors: Automatic Dependent Surveillance Broadcast (ADS-B) planned be on board until 2012
    - IGW: updated and stored at the airport or included in the IGWADVs
  - IGW needs position of the aircraft
    - aircraft sends position updates
    - current position is interpolated by IGW

2. Setup

- transmission ranges are limited

$$t = \sqrt{(r+h)^2 - r^2} = \sqrt{2\mathrm{rh} + h^2}$$

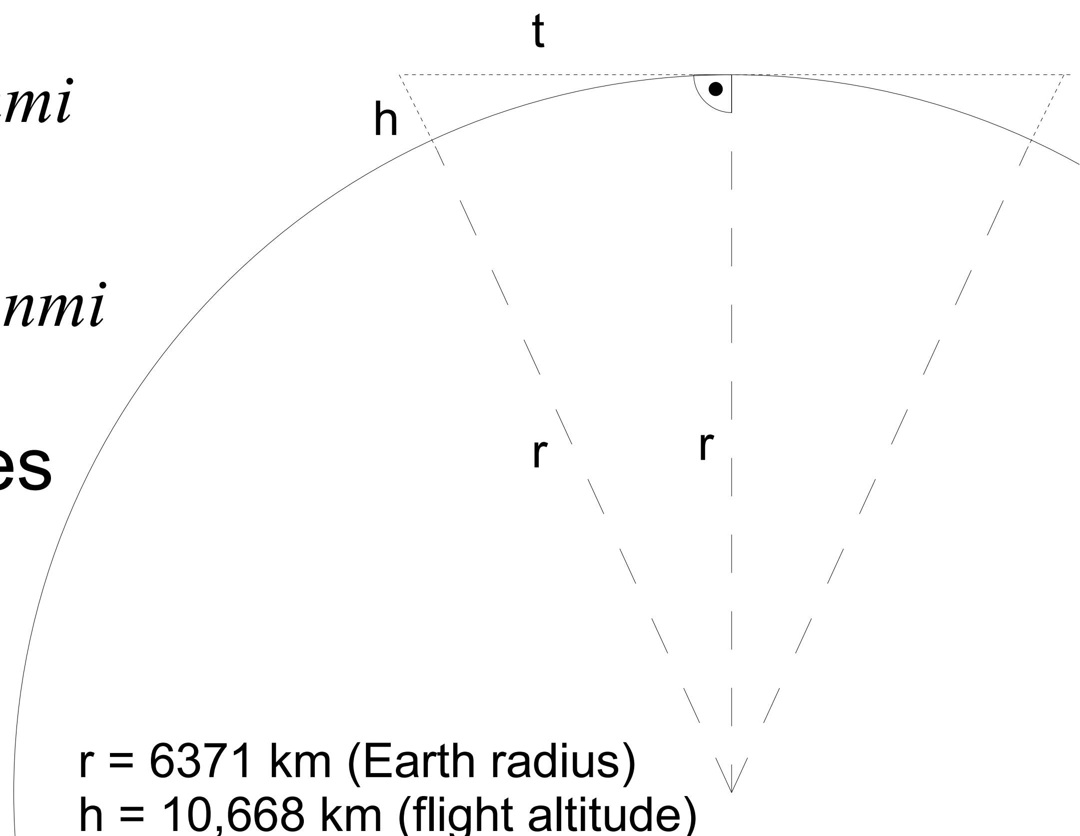
  - ground to air:

$$t \approx 368{,}85\,km = 199{,}1\,nmi$$

  - air to air:

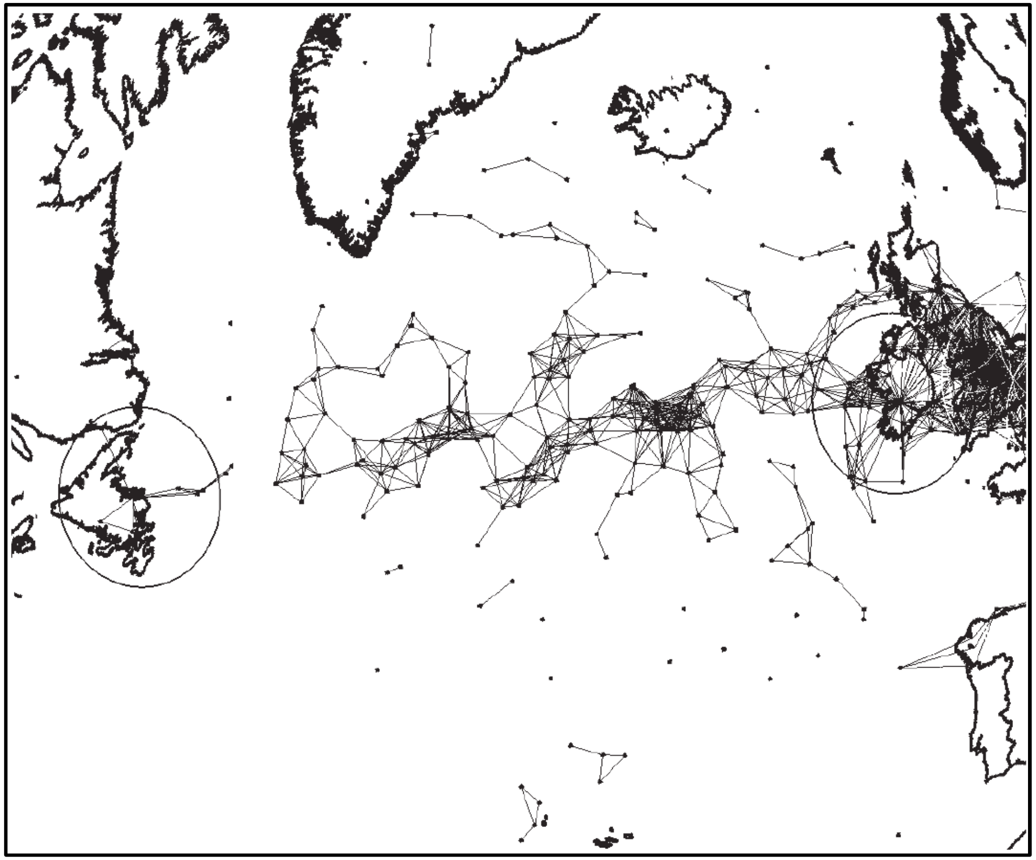
$$2 * t \approx 737{,}7\,km = 398{,}2\,nmi$$

- tested transmission ranges
  - 100 nmi
  - 200 nmi

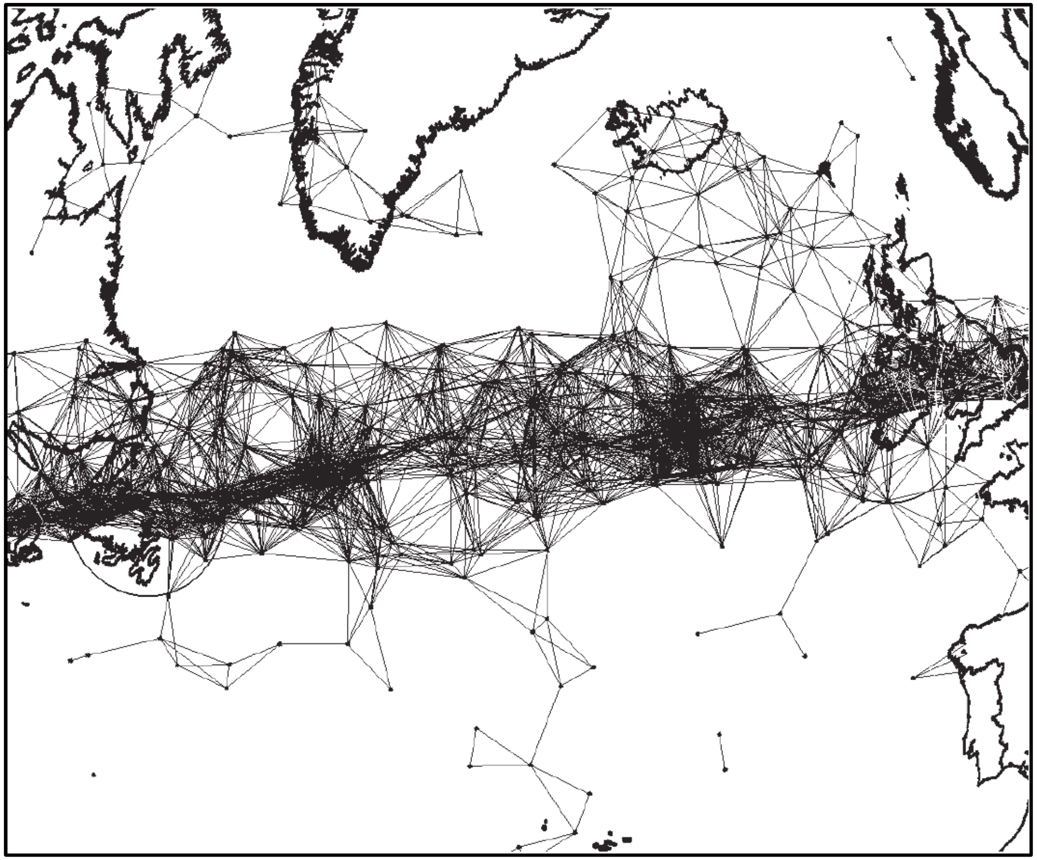


3. Analysis of the Network

- realistic flight-data for simulation



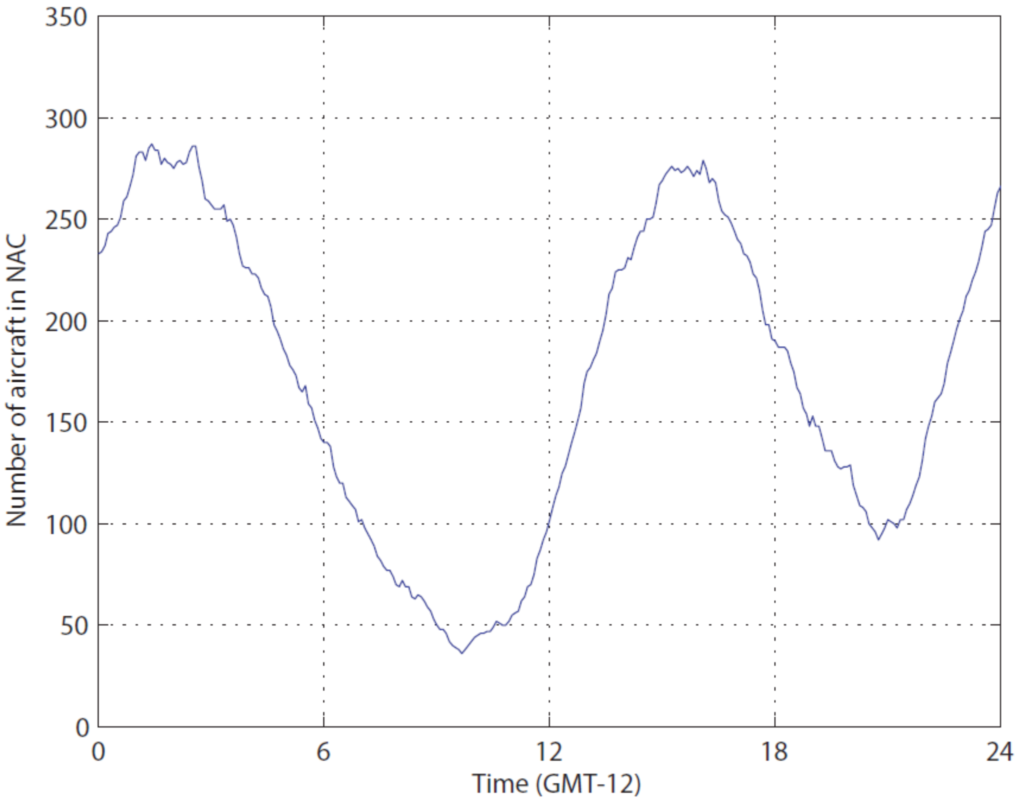
r = 100 nmi



r = 200 nmi

3. Analysis of the Network

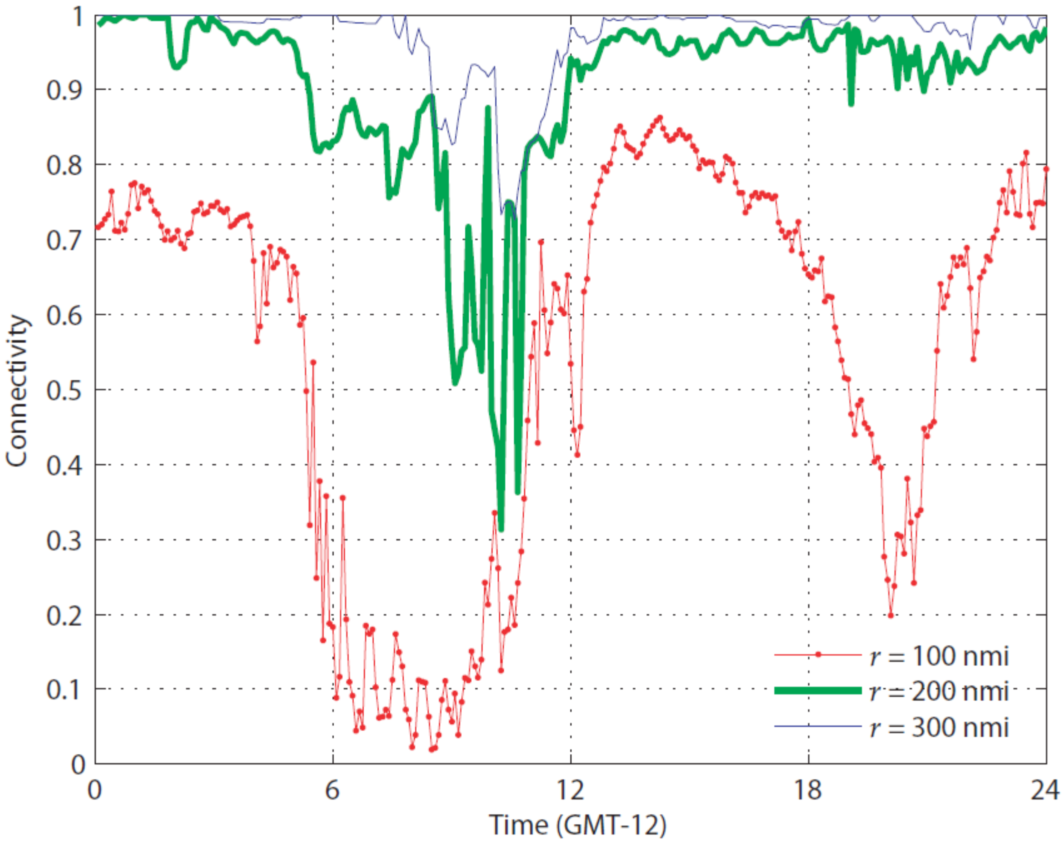
- number of aircrafts in the NAC



  - number changes during the day
  - peak while rush hour
  - low point when the last aircrafts arrive in America or Europe

3. Analysis of the Network

- connectivity in the NAC



$100\, nmi = 185{,}2\, km$

- 100 nmi is not sufficient
- 200 nmi provides connectivity to nearly all aircrafts
- Scenario B is slightly better
  - additional IGWs are to far away

$$C(t) = \frac{\textit{number of connected aircrafts}}{\textit{total number of aircrafts}}$$

3. Analysis of the Network

- connectivity in the NAC (2)

r	100 nmi	200 nmi
p	36%	63%

p = percentage of flights with permanent connection to IGW

- Link Stability:
  - short-time links between eastbound and westbound aircrafts
  - long-lasting links between aircrafts flying in the same direction

r	100 nmi	200 nmi
d	25,8 min	42,6 min

d = average value of link duration

3. Analysis of the Network

- Relay Traffic Load
  - Aircrafts near the coast are often chosen as forwarders.
    - up to 5 times the traffic load
    - bottleneck of the network
  - Scenario B slightly reduces the traffic at the coast.
- Greedy Forwarding
  - Performance is measured by
    - packet delivery ratio
    - average path length

3. Analysis of the Network

- Greedy Forwarding (2)
  - Packet Delivery Ratio
    - Defined as percentage of transmitted packets which were successfully delivered.
    - Why do packets get lost?
      - old information in the routing table
      - path to destination exists, but packet is delivered to a local maximum
    - average percentage of delivered packets from all flights:

100 nmi	200 nmi
68%	89%

3. Analysis of the Network

- Greedy Forwarding (3)
  - Average Path Length

		100 nmi	200 nmi
Scenario A	SP	5.92 hops	3.91 hops
	GF	6.00 hops	3.93 hops
Scenario B	SP	5.74 hops	3.61 hops
	GF	5.82 hops	3.63 hops

- Greedy forwarding is on average only 0.1 hops longer.
- Scenario B reduces the average path length only by a small amount.

4. Conclusion and Review

- With a communication range of 200 nmi most of the flights have permanent connectivity.
  - but: there are flights with weak or no connectivity
- Greedy forwarding doesn't delivers all packets
  - is to be improved in future research
- Bottleneck at the coast
  - is to be improved in future research
- Average number of hops is smaller than 4.
- today: separation of westbound and eastbound aircrafts[2]; therefore the simulation is not realistic.

4. Conclusion and Review

- Many questions are still open :
  - which frequencies will be used
    - different laws worldwide
    - higher frequencies are absorbed by clouds
  - aircrafts can't be all equipped at the same time.

    → poor or not connected network
  - unlikely that every aircraft will be equipped
    - lots of different companies.

Thank you for your attention!

Questions?

References

[1] B. Karp and H. T. Kung, *GPSR: Greedy Perimeter Stateless Routing for Wireless Networks. In Proceedings of the Sixth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom 2000).*

[2] Eurocontrol/FAA, *Communications Operating Concept and Requirements for the Future Radio System (COCR), version 2.0, May 2007.*