Future Broadband Aeronautical Communication – Opportunities and Challenges for SatCom

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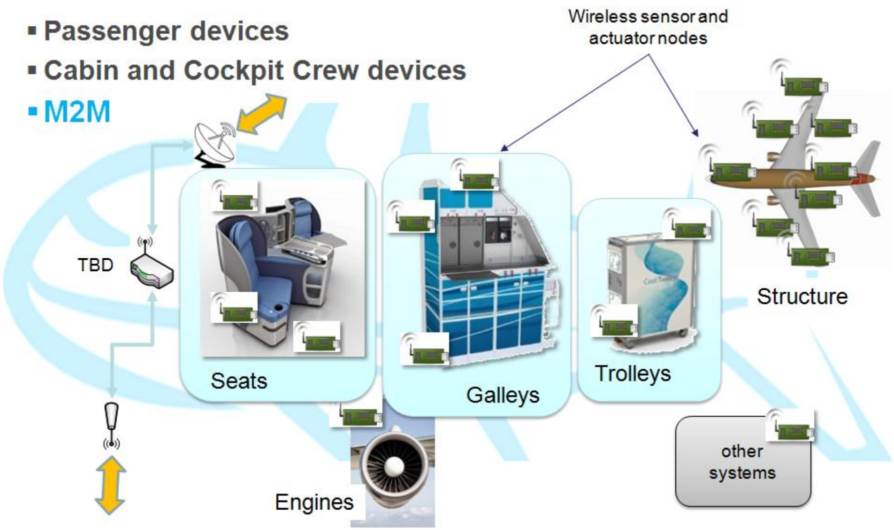
Outline

- **Future broadband aeronautical communication**
  - Connected Cabin & Connected Aircraft



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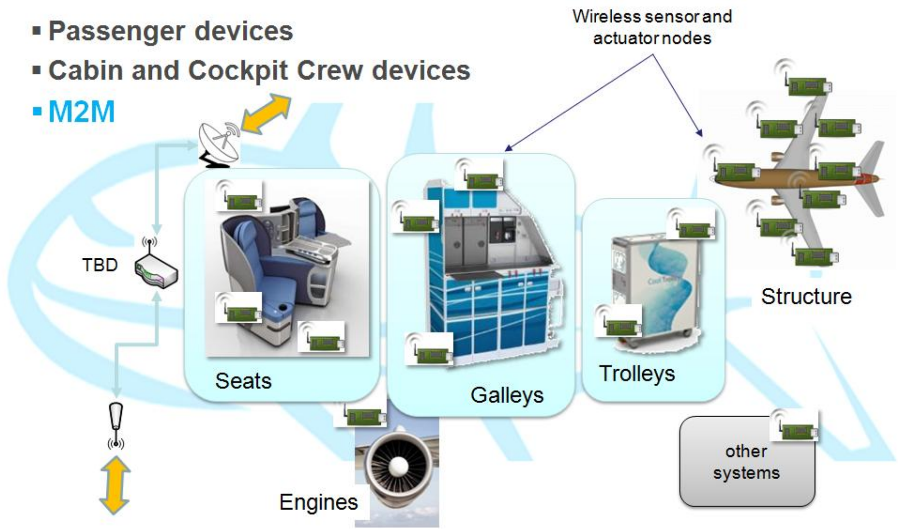
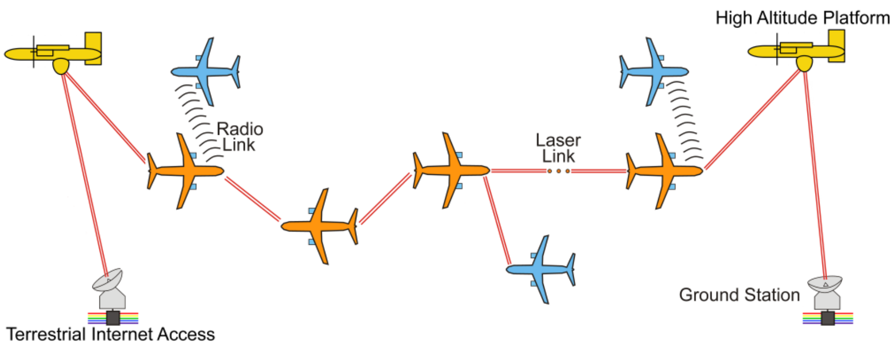
- **Aircraft-aircraft-network**
  - link to ground networks via satellite, optical or mm-wave ground link





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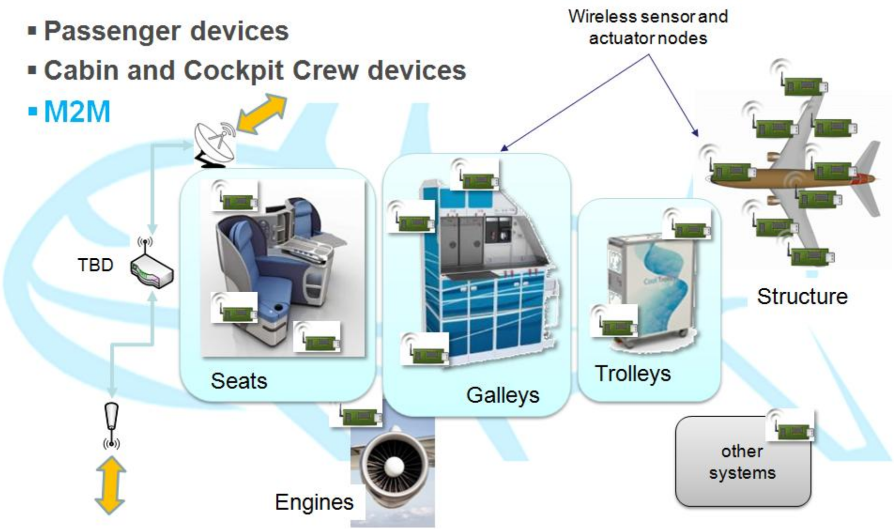

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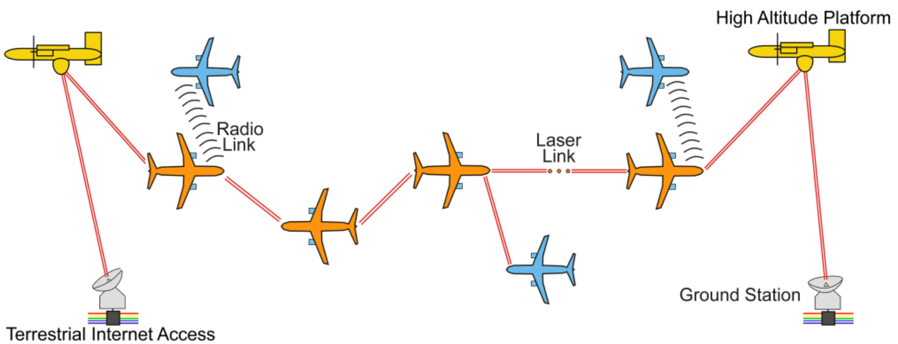
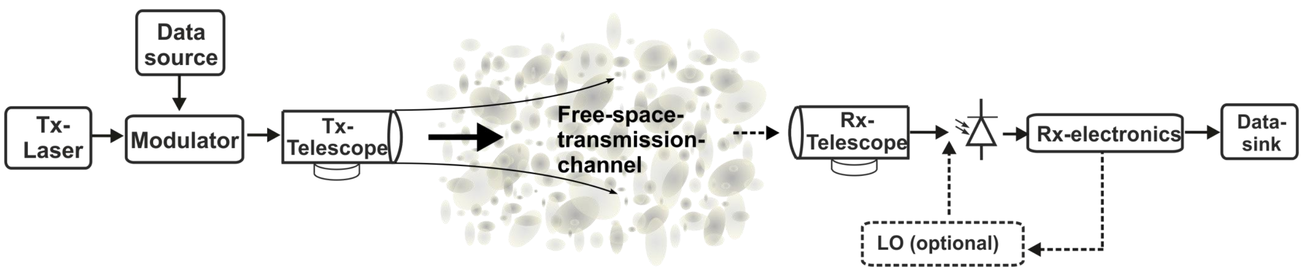


- **Free-Space Optical Links**
  - aircraft-aircraft, aircraft-ground, aircraft-satellite



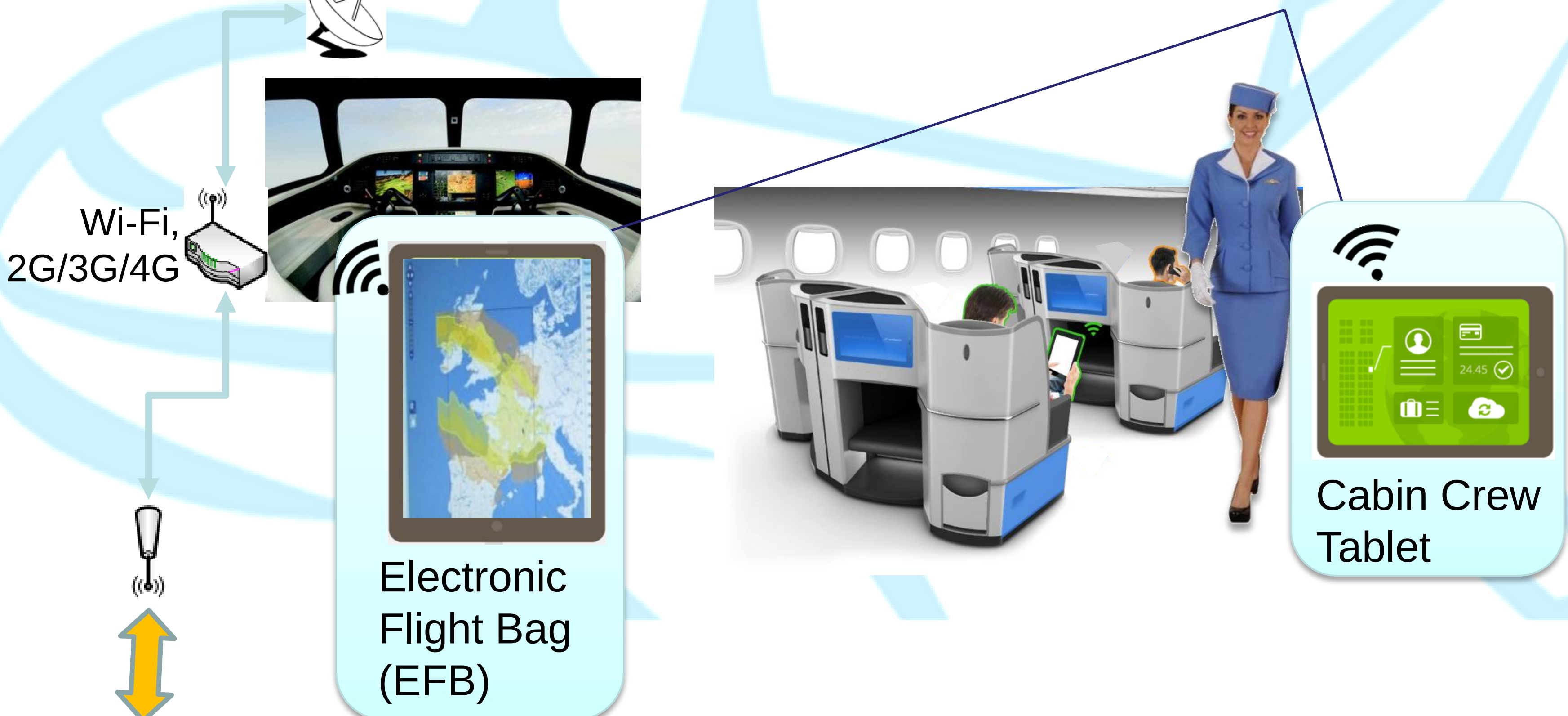
The Connected Cabin, Overview (1/3)

- **Passenger devices**
- **Cabin and Cockpit Crew devices**
- **M2M**

The Connected Cabin, Overview (2/3)

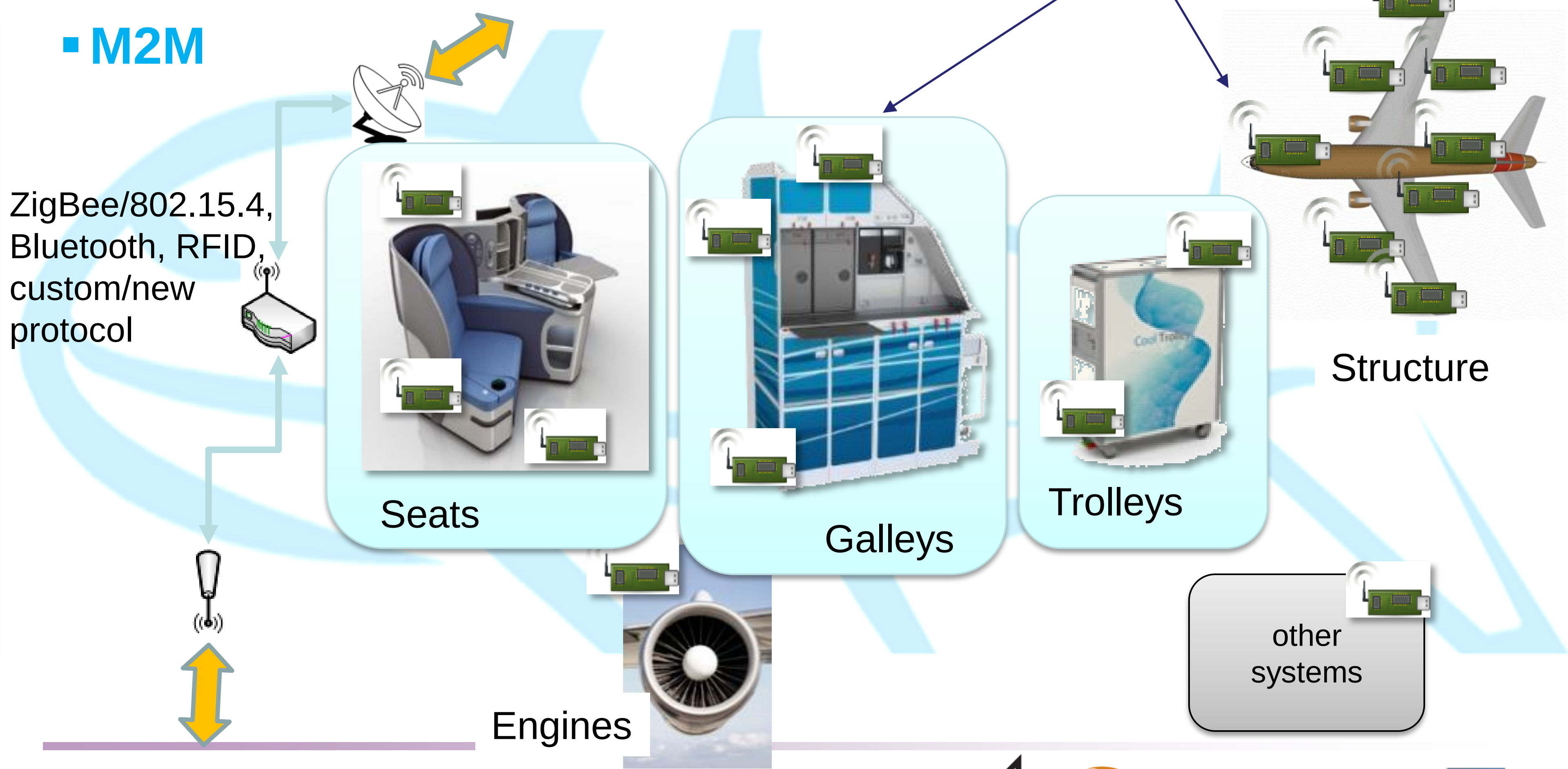
- **Passenger devices**
- **Cabin and Cockpit Crew devices**
- **M2M**

for access to information within the aircraft and from ground

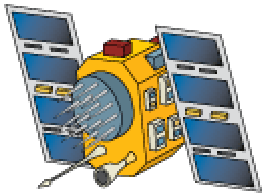


The Connected Cabin, Overview (3/3)

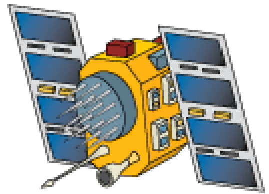
- **Passenger devices**
- **Cabin and Cockpit Crew devices**
- **M2M**



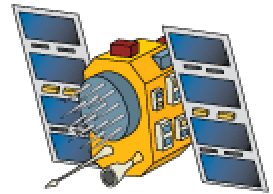
The Connected Aircraft – Market (1/3)



L-band

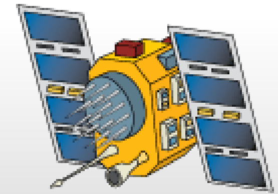


FSS Ku



GEO-HTS
Ku, Ka

planned



non-GEO-HTS
Ku, Ka

Wide-body
(A380, B747, A340, ...)

Narrow-body
(A320, B757, ...)

Bizjets
(Dassault, Bombardier, ...)

General aviation
(Cessna, Diamond, ...)

Direct Air-to-Ground

GoGo (US)

planned

SmartSky (US)

Inmarsat (EU)

The Connected Aircraft – Market (2/3)

2014: ~4900
2024: ~7600*

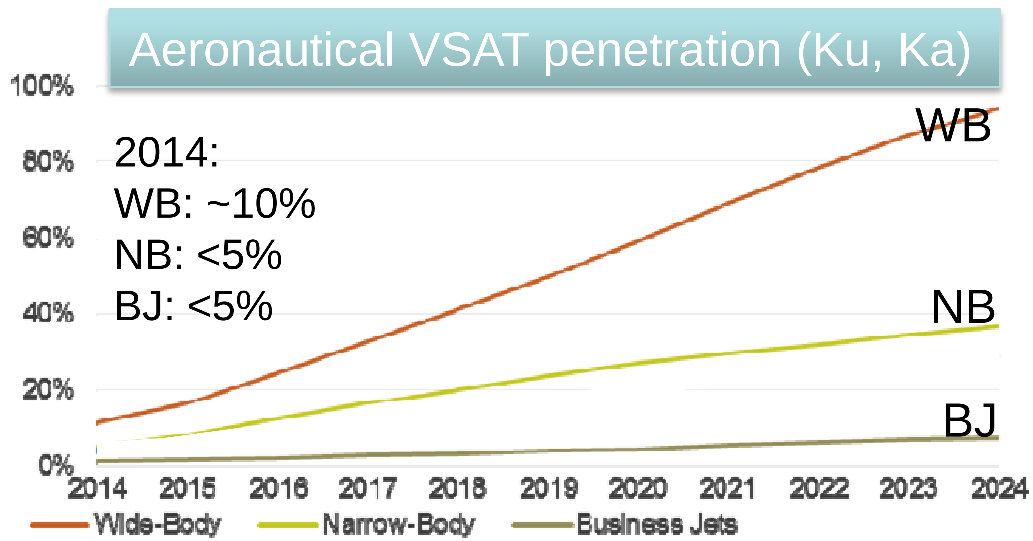
Wide-body
(A380, B747, A340, ...)

2014: ~14000
2024: ~22000*

Narrow-body (w/o regional; A320, B757, ...)

Bizjets (Dassault, Bombardier, ...)

2014: ~16000
2024: ~23000**
(w/o very light BJs)



2024:
WB: ~90%
NB: ~35%
BJ: <10%

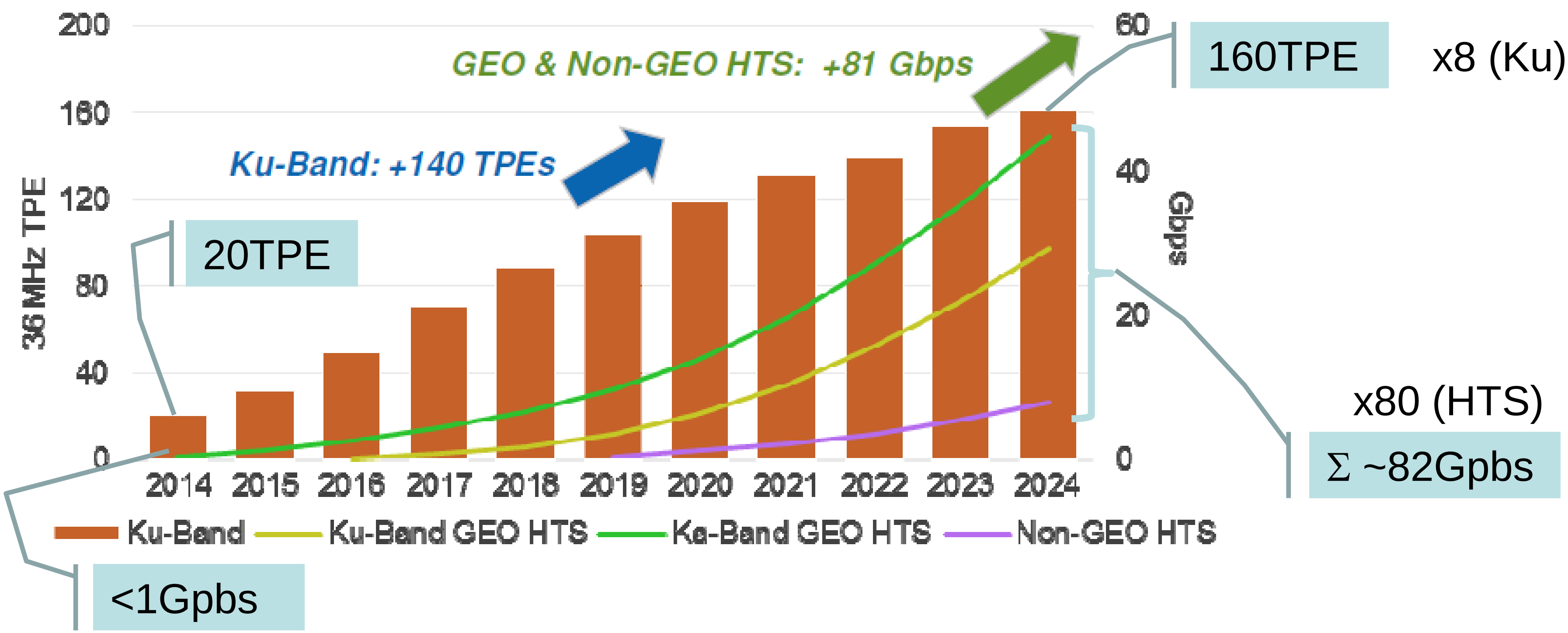
[source: NSR]

*[source: Boeing Market Forecast 2015-2034]

**[source: Bombardier Market Forecast 2015-2024]

The Connected Aircraft – Market (3/3)

- Aeronautical SatCom Capacity Demand (without L-band)

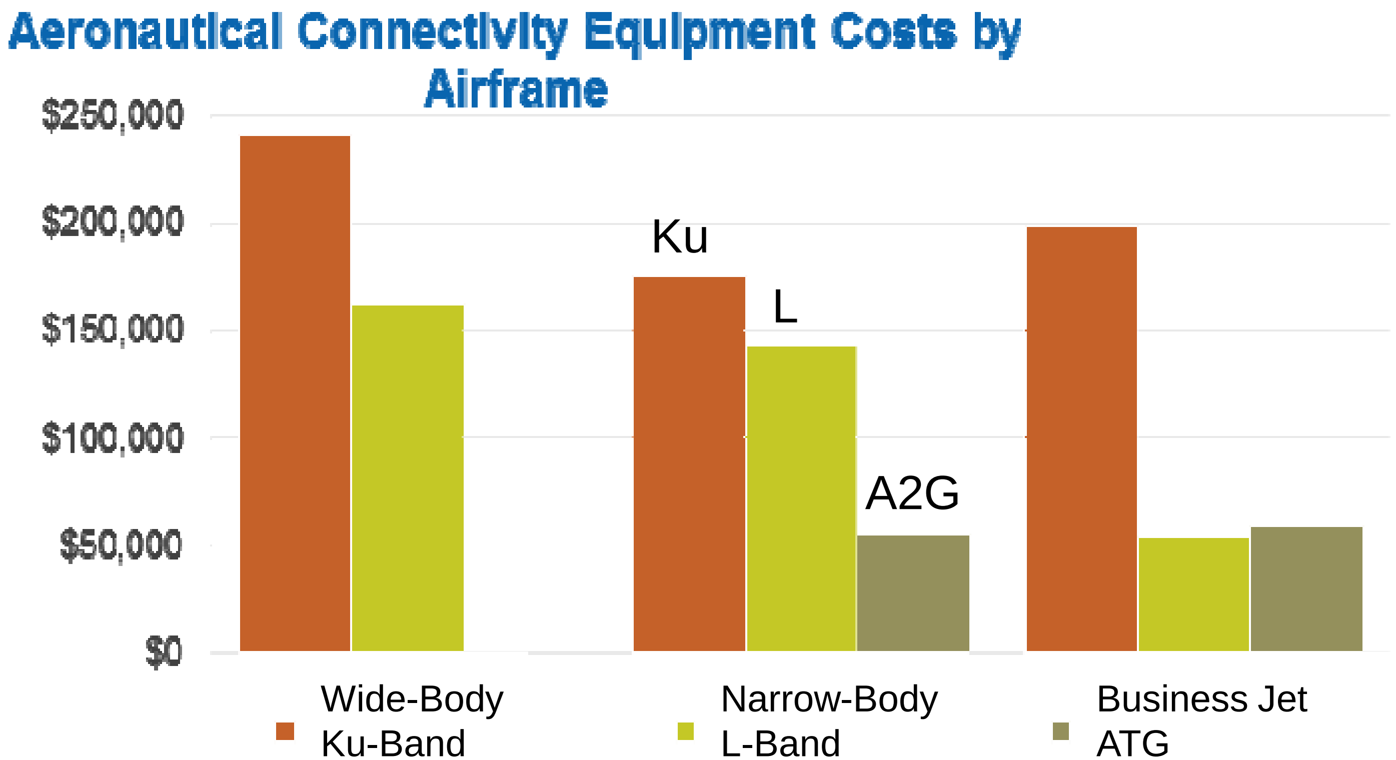


- ~5000 ATG aeronautical units in-service in 2014 (GoGo, US only) => estimated ~11000 in 2024

[source: NSR]

The Connected Aircraft – SatCom (1/2)

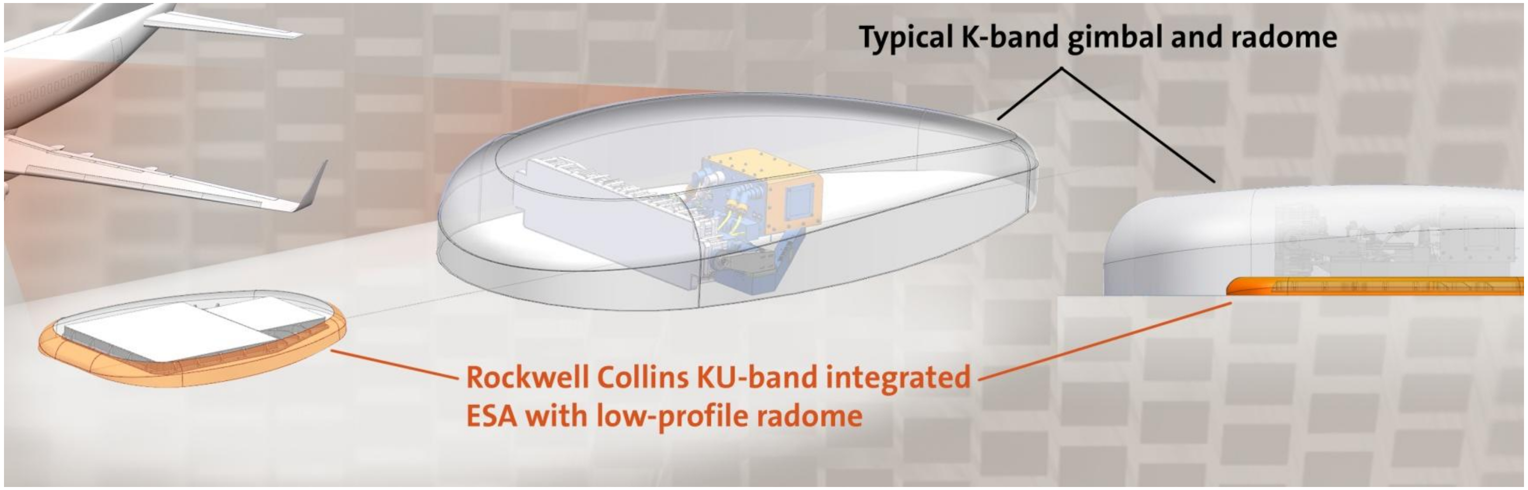
- **Ku, Ka GEO SatCom terminals**
  - too bulky, expensive for new aviation markets
  - competition from ATG



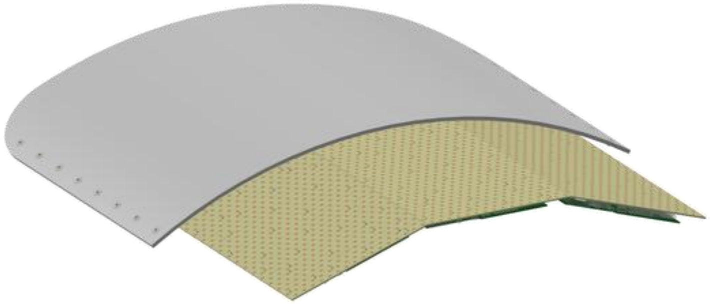
[source: NSR]

The Connected Aircraft – SatCom (2/2)

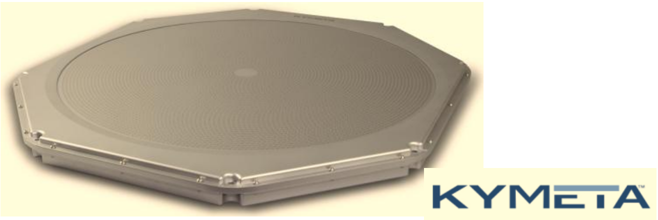
- **New flat antenna technologies for new markets**
  - for Ku, Ka GEO
  - for future non-GEO SatCom (OneWeb)



[source: Rockwell Collins for OneWeb]



[source: Phasor solutions]



[source: Kymeta]

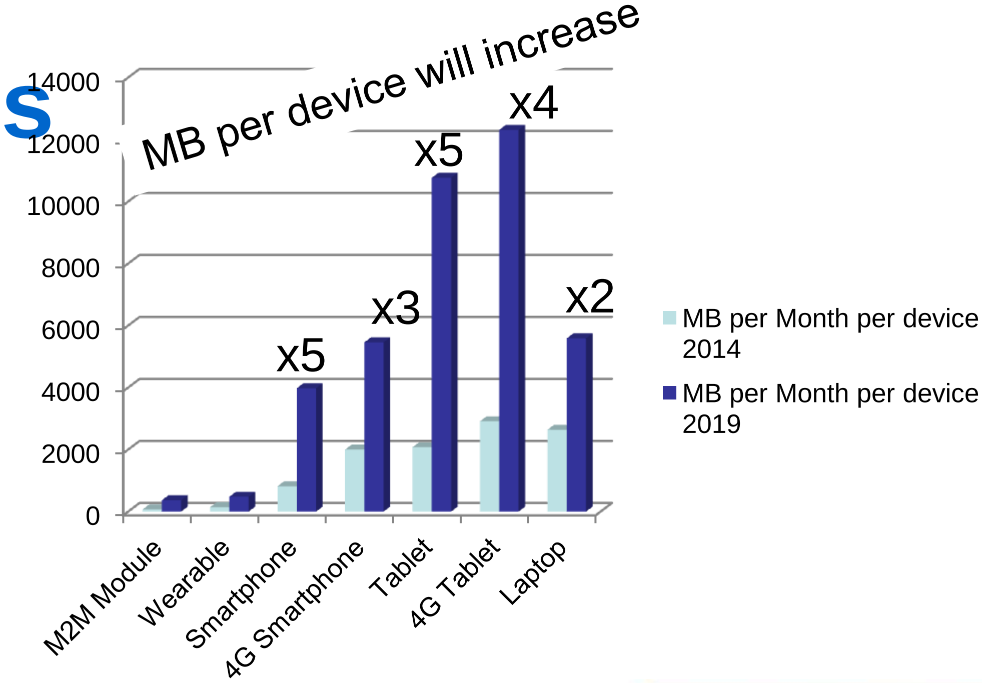
PAX Comm. Trends (1/2)

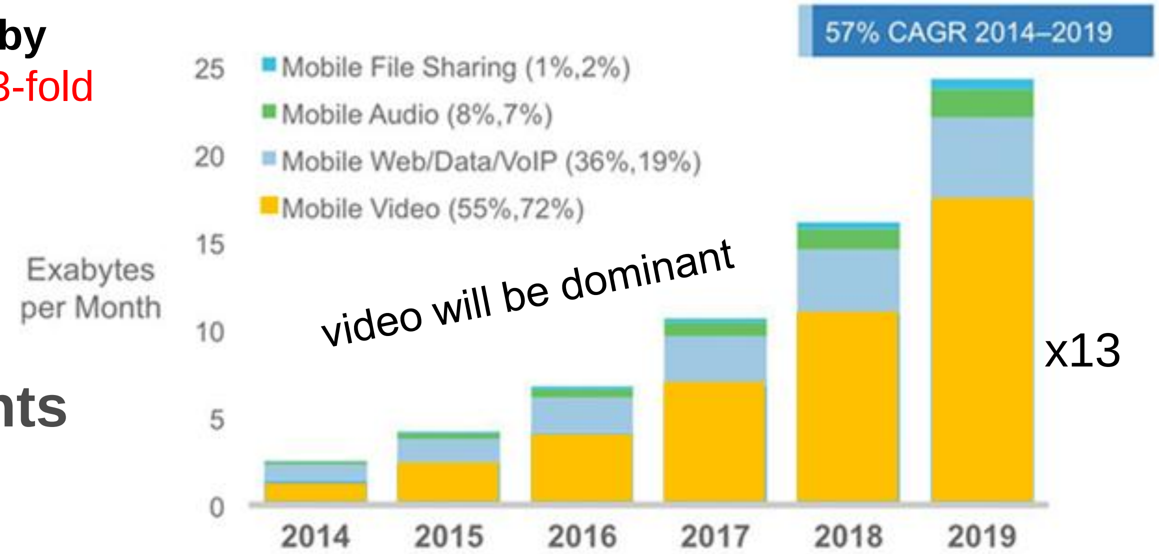
Global Mobile Internet trends

"The average smartphone will generate 4.0 GB of traffic per month by 2019, a fivefold increase over the 2014 average of 819 MB per month."

"Nearly three-fourths of the world's mobile data traffic will be video by 2019. Mobile video will increase 13-fold between 2014 and 2019."

- **Higher bit rates**
- **Higher QoS requirements**
- **Lower costs per bit**





[Source: Cisco VNI Mobile, 2015]

PAX Comm. Trends (2/2)

- **Passengers expectations and pressure on airlines are high!**
  - Connectivity on all flights, including continental
  - Gate-to-gate service
  - Similar performance and pricing*

Passengers want to stay connected: send and receive text/emails (60%), stream live content (56%).

[SITA Passenger IT Trends Survey 2015]

37% would be upset without Wi-Fi access on their next flight.

[Honeywell 2014 Connectivity Survey]

17% have switched carriers due to a better Internet offering.

[Honeywell 2014 Connectivity Survey]

*"Connectivity! But for **free…**"

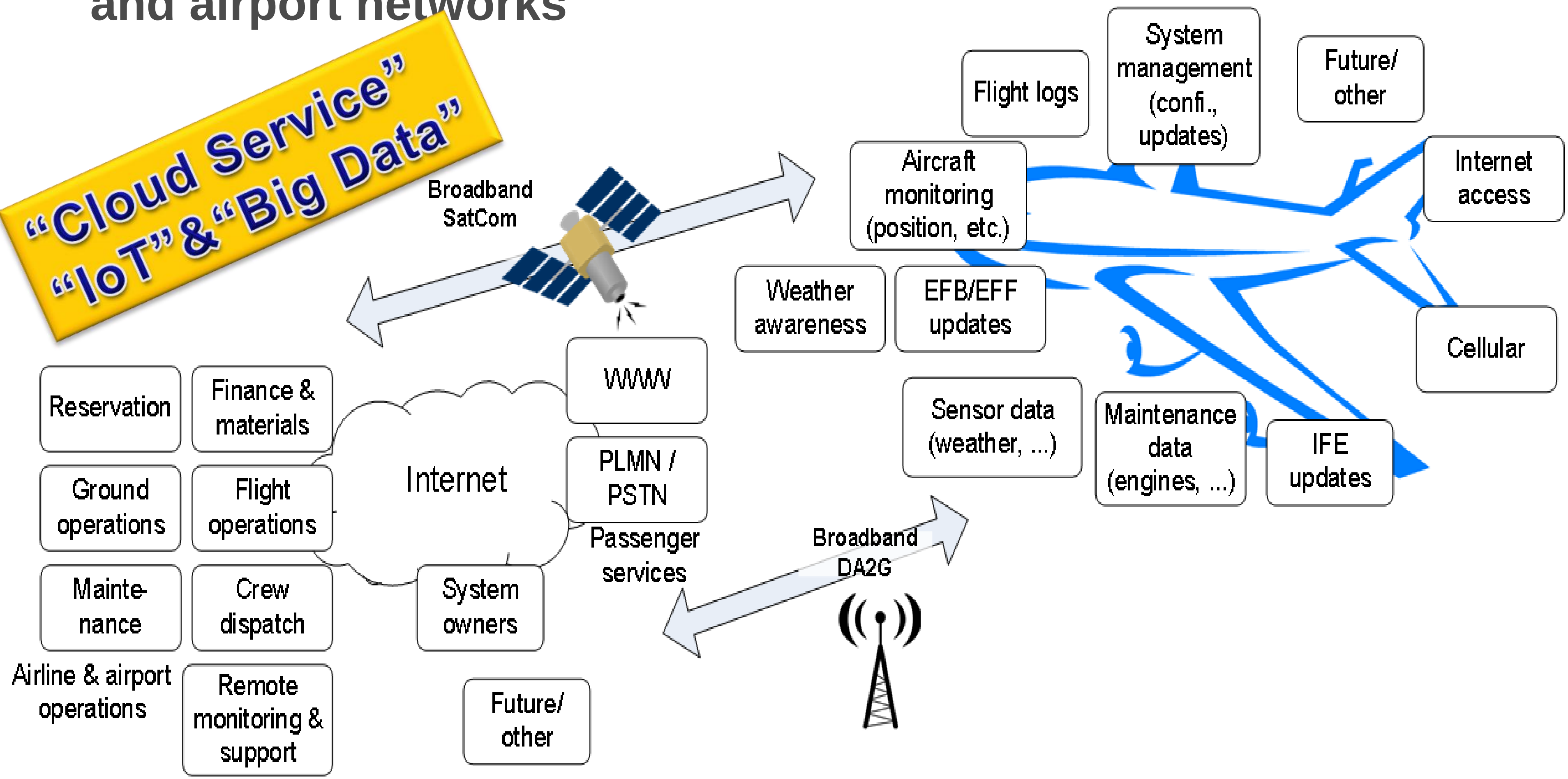
Airline Communication (1/2)

- **Today:**
  - often inefficient data handling with a lot of paper work, lack of process integration
    - e.g. leading to longer turn-around times
  - possibilities of in-flight connectivity not yet exploited
    - e.g. leading to flight inefficiencies

- **In-flight weather updates**
  - increase safety and flight efficiency
- **Predictive/proactive maintenance**
  - from engine and airframe monitoring to "any system" monitoring
  - "Boeing 787s to create half a terabyte of data per flight"
- **On demand real-time monitoring**
  - "black box" data; position, system statuses
- **IT integration cabin-airport-processes**
  - reduce turn-around times
- **... and many other applications**

Airline Communication (2/2)

- **Full IT integration of aircraft in airline and airport networks**



Airline Communication (2/2)

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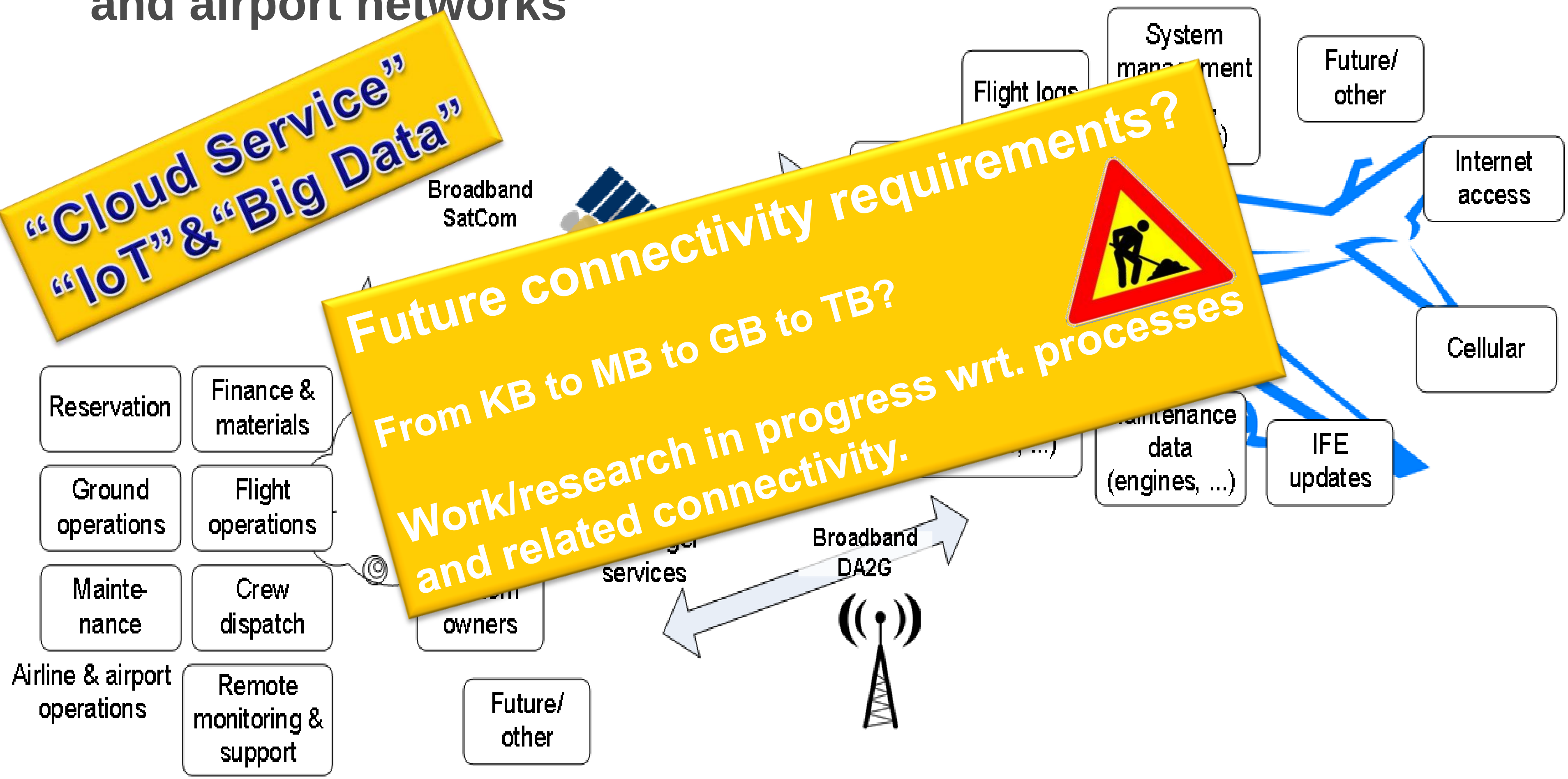


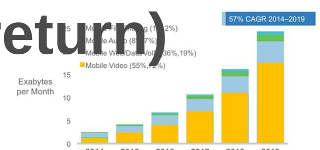
Opportunities and Challenges

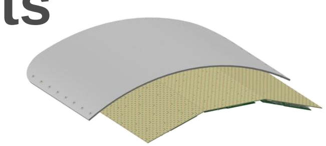
Opportunities

- Connectivity essential for PAX services and future airline operations
- Connectivity for new markets, incl. continental fleets and business jets

Challenges

- Increasing data volumes (forward&return)
- Increasing QoS requirements
- PAX expect low cost / free of cost connectivity $$$ -> $
- SatCom terminal size and cost for new markets



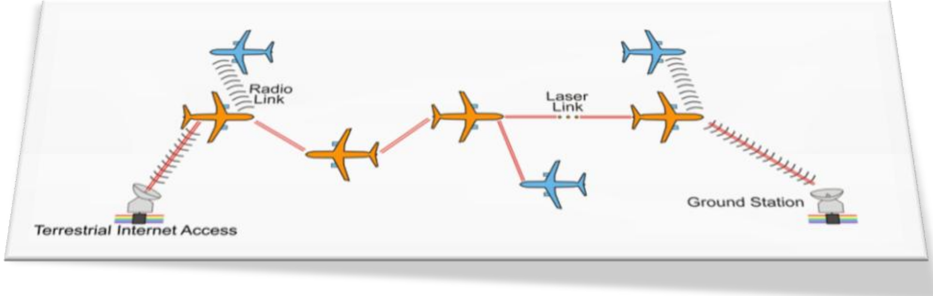


Aircraft-Aircraft Network

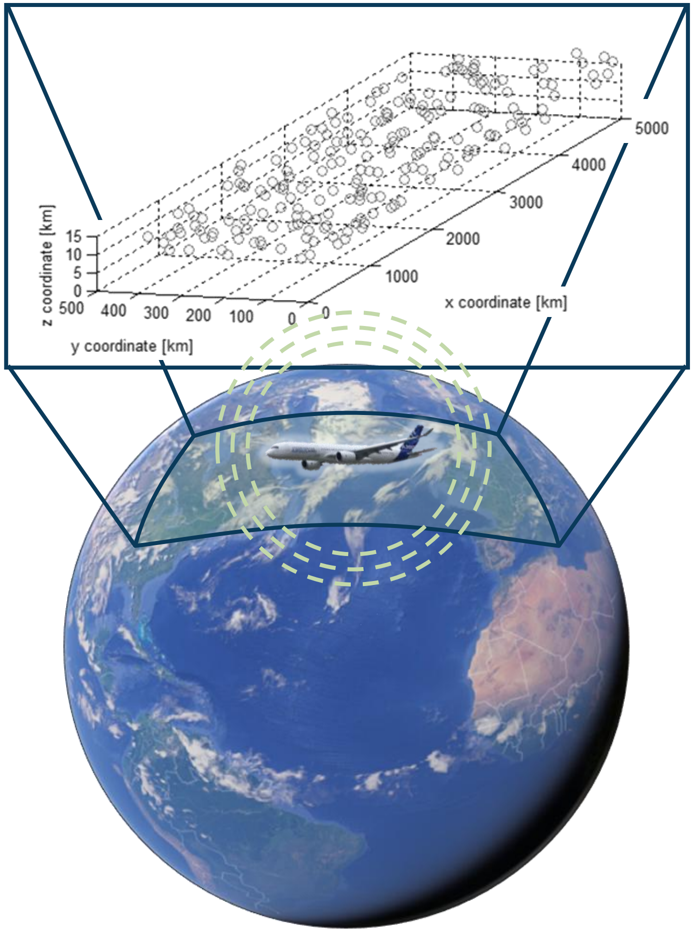
- **SatCom as "stand-alone" service may in the future face capacity boundaries**
  - growing customer base
  - increasing capacity per customer
- **Broadband, "Airborne net-works" may emerge to cope with aeronautical communi-cation requirements**
- **SatCom may become an integral element of such networks in the future**

"It appears that the race to develop a large-scale civilian airborne network is on […] it is clear that much more work must be done on the networking front before the race can be won."

B. Newton, J. Aikat, and K. Jeffay, *Concise Paper: Analysis of Topology Algorithms for Commercial Airborne Networks,* 2014 IEEE 22nd International Conference on Network Protocols

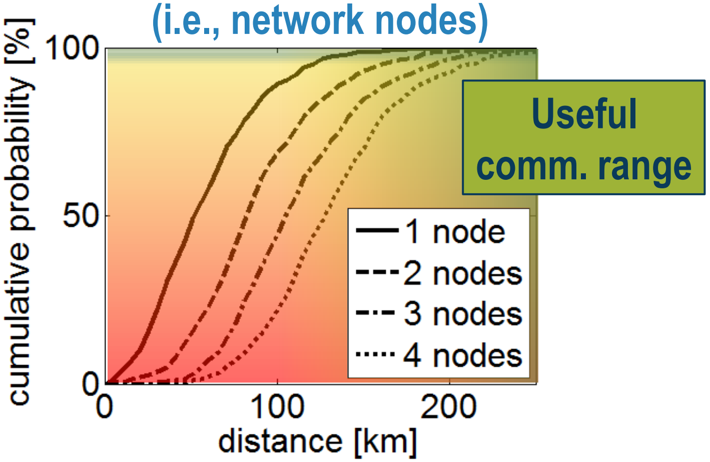


Feasibility Study

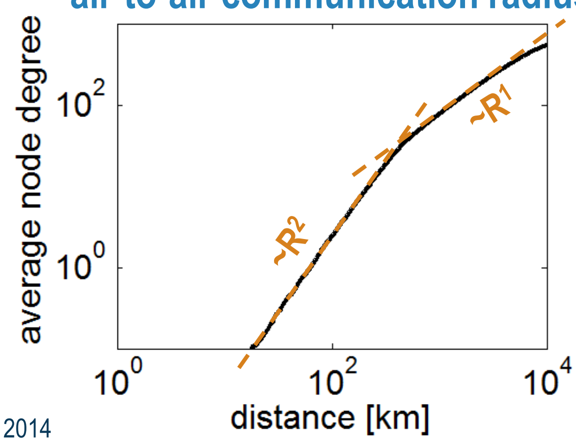


© Google/NASA/Terrametrics

Cumulative probability to find nearby aircraft (i.e., network nodes)

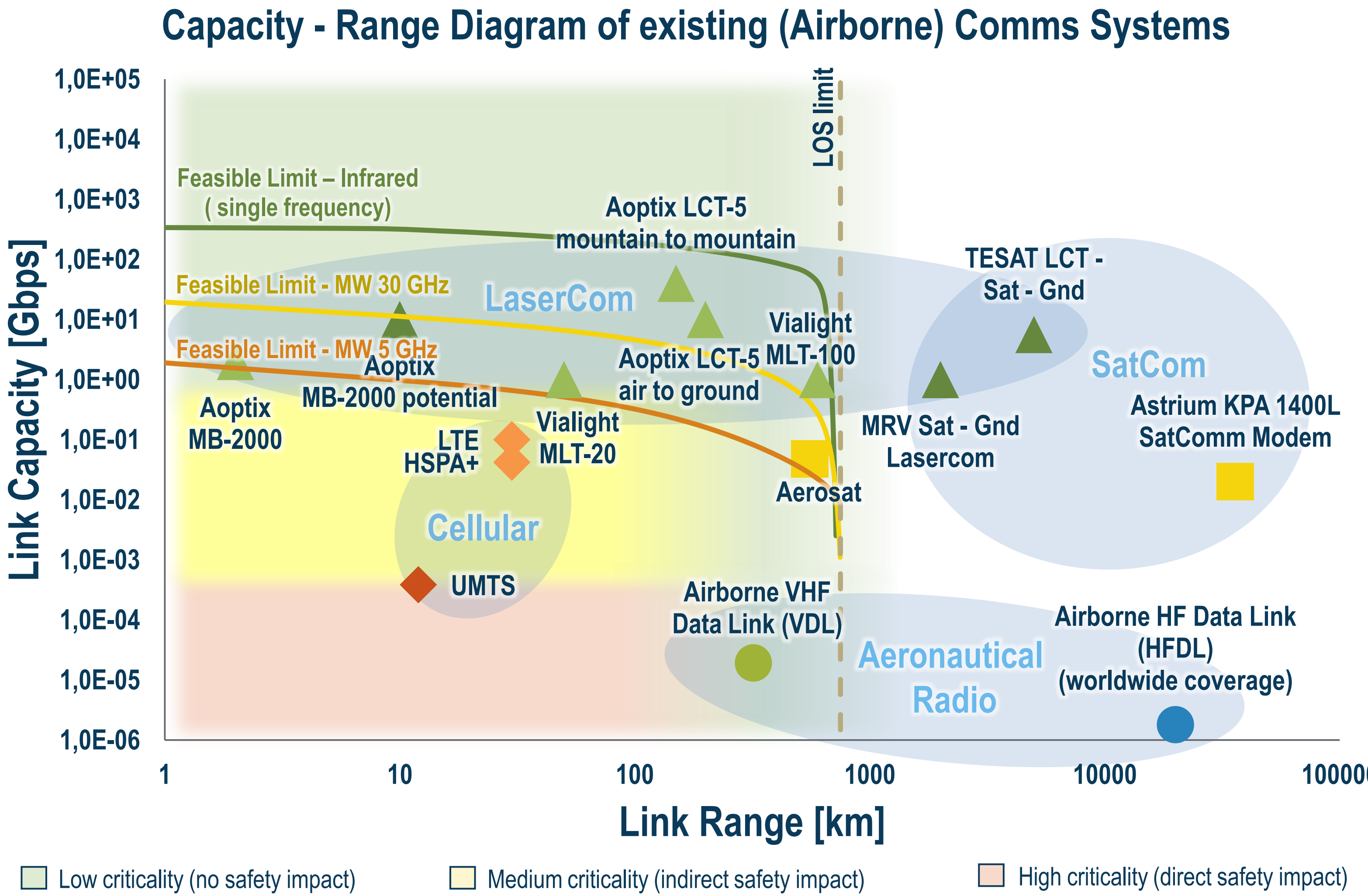


Average number of nodes within air-to-air communication radius



K.-D. Büchter, A. Sizmann, DLRK 2014

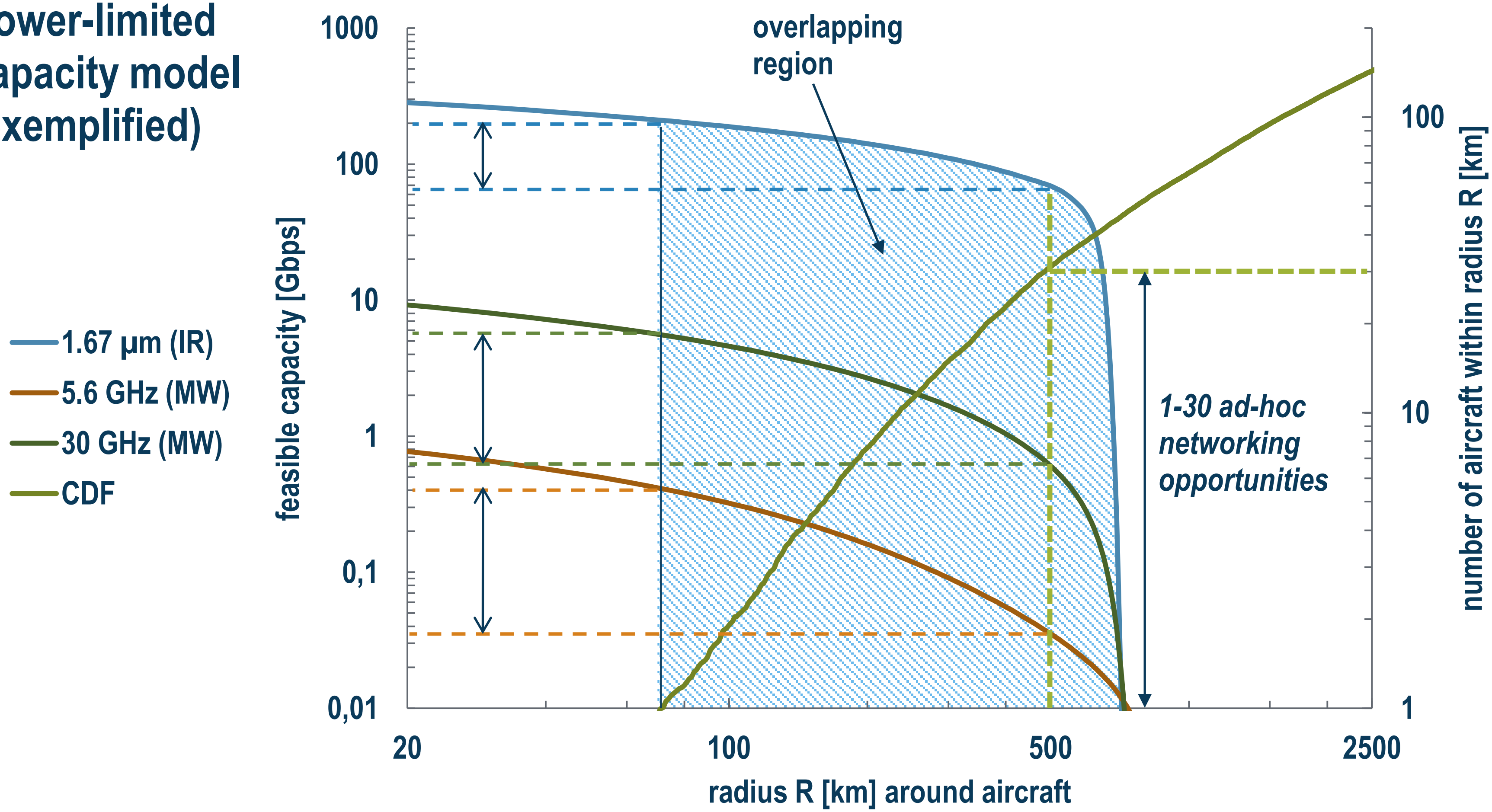
Transmission System Performance



K.D. Büchter, A. Reinhold, G. Stenz, A. Sizmann, “Drivers and Elements of Future Airborne Communication Networks,” DLRK 2012, Berlin, Germany

Matching: Requirements/Performance

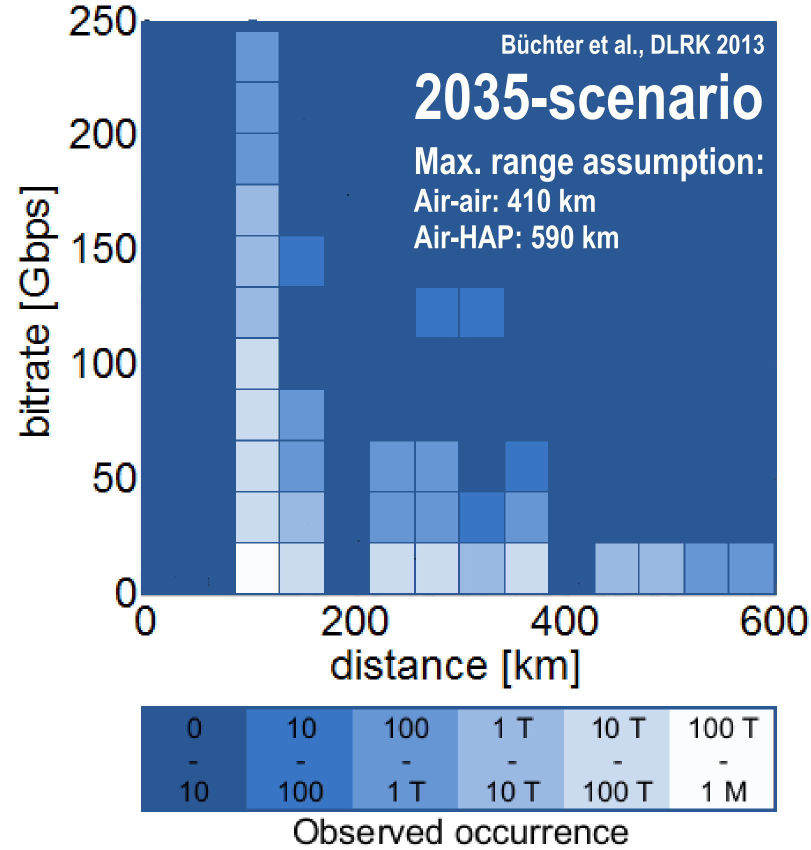
Power-limited capacity model (exemplified)

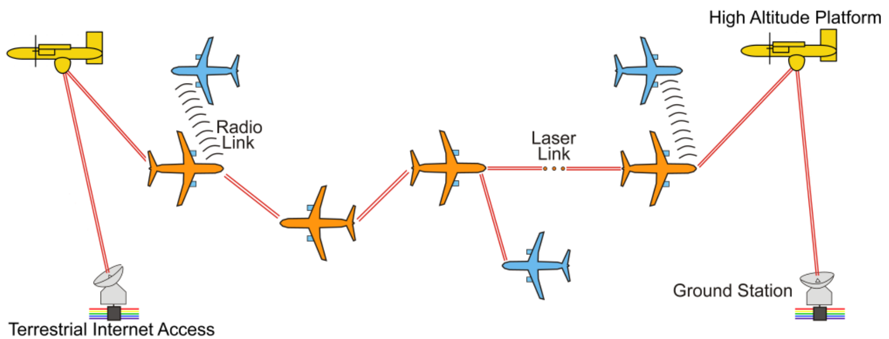


Aircraft-Aircraft Network Simulation

- **Simulated scenario**
  - Airborne network over North Atlantic Corridor
  - Internet access via High-Alt. Platforms/HAP
    - Weather mitigation
    - Better range Air-to-HAP compared to Air-to-Ground

Bitrate – Distance Statistics
cf. Capacity – Range





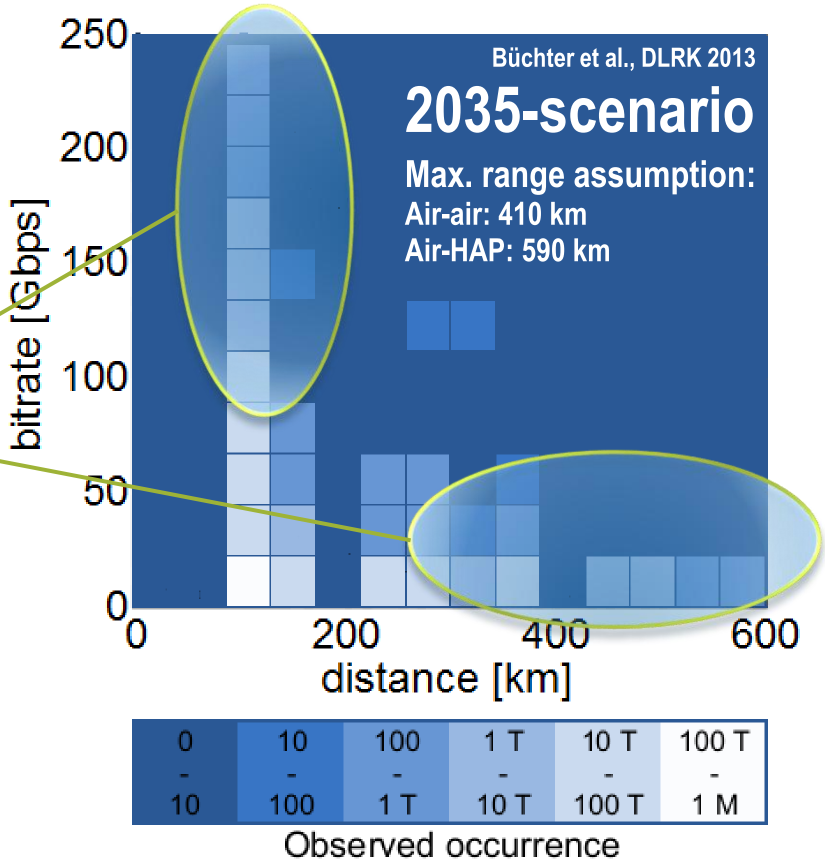
Aircraft-Aircraft Network Simulation

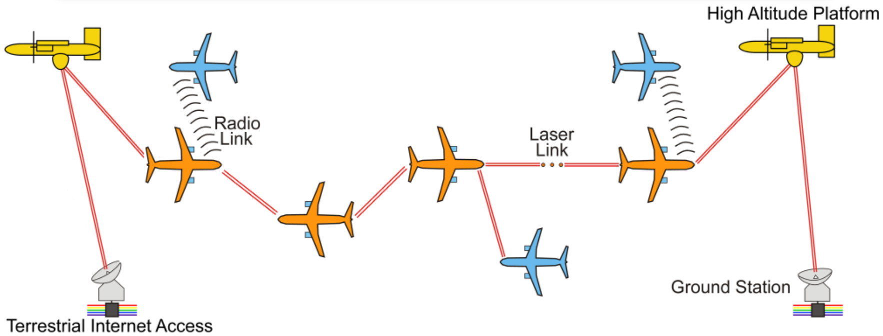
- **Simulated scenario**
  - Airborne network over North Atlantic Corridor
  - Internet access via High-Alt. Platforms/HAP

Satellite access:

- **Alleviate loads for single aircraft and network clusters**
- **Absorb long-range (air-to-air) links**

Bitrate – Distance Statistics
cf. Capacity – Range

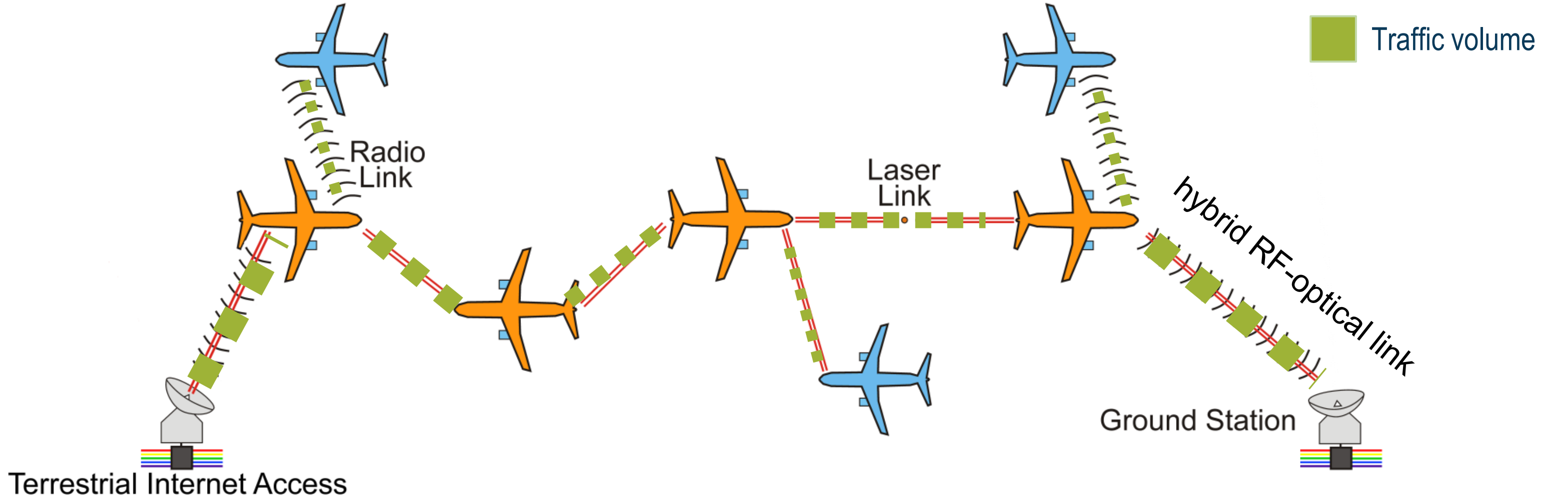




Aircraft-Aircraft-Sat Networking

Airborne network with aircraft-ground links:

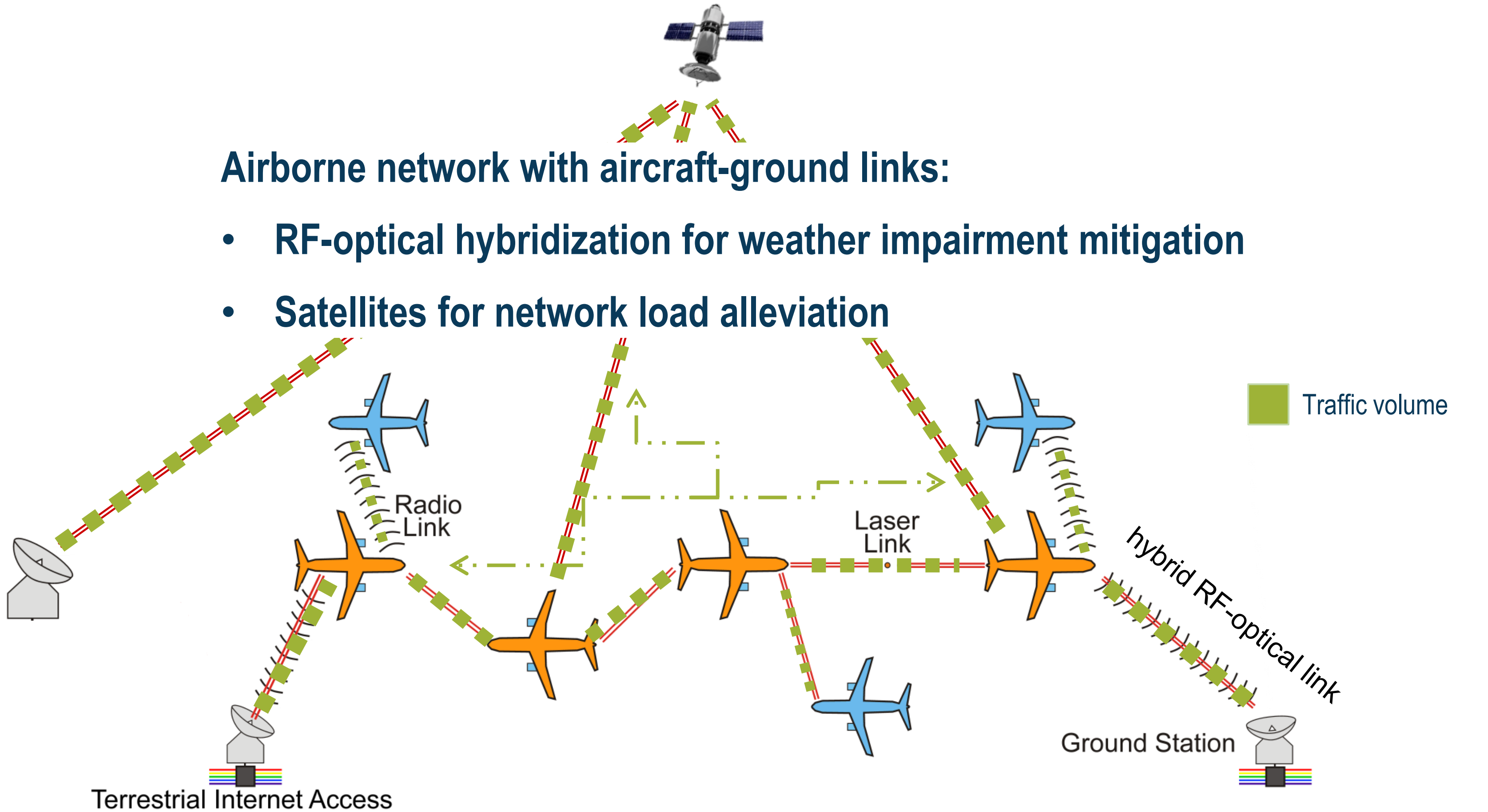
- **RF-optical hybridization for weather impairment mitigation**



Aircraft-Aircraft-Sat Networking

Airborne network with aircraft-ground links:

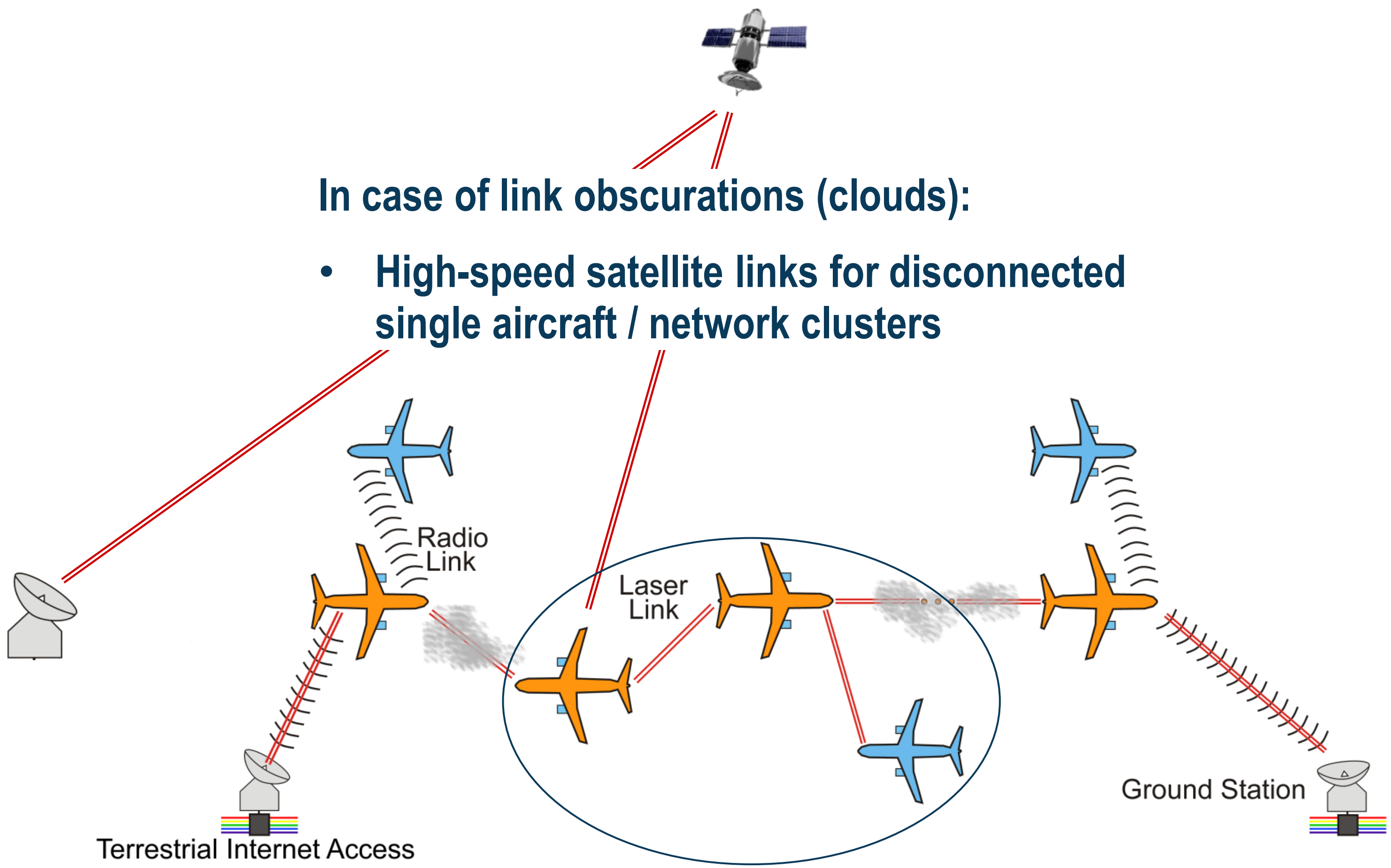
- **RF-optical hybridization for weather impairment mitigation**
- **Satellites for network load alleviation**



Aircraft-Aircraft-Sat Networking

In case of link obscurations (clouds):

- High-speed satellite links for disconnected single aircraft / network clusters



Outlook: Aircraft-aircraft Network

- **Airborne communication networks are conceptually interesting and may offer "fiber-like" broadband in the cabin**

- **Implementation is challenging due to**
  - Weather susceptibility of free-space optical laser communication
  - Frequency allocation and performance limitations of complementary RF technologies (long range / high bandwidth)

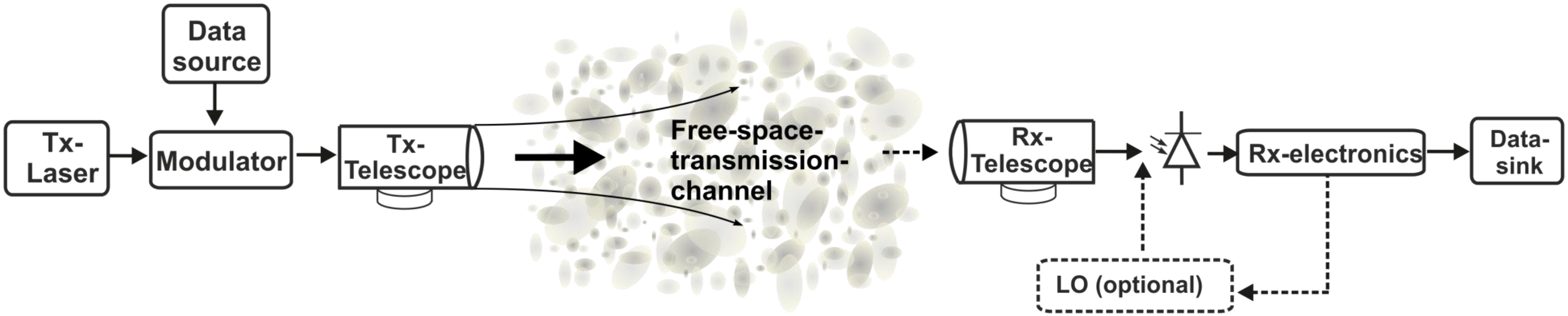
- **SatCom may play an important role to make the concept "fly"**

Free-space Optical Communications

- **FSO vs RF**
  - Carrier frequencies in optical spectrum — high data rates (>Tbit/s), good EMC properties
  - Small beam divergence — low free-space loss, high resistance against interference and interception
  - No spectrum regulation — lower cost and management effort
  - Smaller wavelengths — smaller antennas, terminals

Free-space Optical Communications

- **FSO vs RF**
  - Carrier frequencies in optical spectrum — Absorption and scattering by molecules and aerosoles
  - Small beam divergence — High beam steering accuracy
  - Atmospheric turbulence — phase distortions and intensity fluctuations
  - Hazardous risks — laser safety must be regarded



Types of Aeronautical FSO Links

- **General link parameters**

Link type	Distance	Extinction	Turbulence
Air-ground	low	high	moderate/high
Air-air	low/moderate	Moderate	low/moderate
Air-LEO	moderate	Low/moderate	low/moderate
Air-GEO	high	Low	low/moderate

- **Wavelengths to date: 850/1064/1550 nm**
- **Data rates: several Gbps (to date) / Tbps**
- **Modulation schemes to date: OOK/PPM/BPSK/DPSK**

Examples of FSO Terminals

- **Air-ground link**
  - Vabene / DODfast (Germany), Foenix (USA) → 10 Gpbs
- **Air-air link**
  - Minervaa / Capanina (Europe), Foenix (USA) → 10 Gpbs
- **Air-sat link**
  - LOLA (Europe), ALCOS (USA+Europe) → 1.8 Gpbs

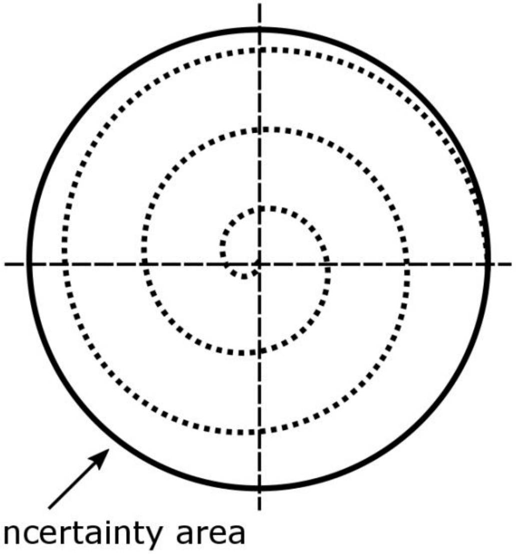
Transportable Optical Ground Station
Source: DLR

Alphasat Laser Communication Terminal
Source: DLR

Aircraft downlink terminal
Source: Vialight Communications

Terminal Operations

- **Pointing, acquisition and tracking (PAT)**
- **P**ointing → beam steering based on a priori information (GPS, orbit, ADS-B)
- **A**cquisition → beam detection and redirection → link lock
- **T**racking → Maintaining link lock
- Actuators: Coarse Pointing and Fine Pointing assembly
- Beacon laser (optional)
  - Broad divergence → beam covers uncertainty area → easy acquision, but high power needed
  - Narrow divergence → beam does not cover uncertainty area → scanning algorithm necessary, less power required
- Uncertainty area depends on attitude & ephemeris and gimbal pointing (gimbal accuracy, jitter and reference calibration)



Terminal Operations

- **Availability based on cloud obscuration**

Link type	impact	Countermeasure
Air-ground	significant	spatial diversity / rerouting / hybridization
Air-air	moderate	rerouting / hybridization
Air-space	low	rerouting / hybridization

- **Scheduling based on satellite ephemeris, visible aircraft and cloud situation (weather monitoring necessary)**
- **Signaling link necessary**

Laser Safety

- Laser safety treatment according to applicable norm (ISO, DIN, or other)
- Preferred operation: eye/skin safe
- Alternatively: definition of non hazardous distances and appropriate operation procedures (minimum height of laser operation, mission radiation switch, appropriate shielding)

$NOHD$ Non Ocular Hazardous Distance

MPE Maximum Permissible Exposure

θ Divergence angle

d Beam size

P Optical power

$$NOHD = \frac{1}{\theta}\sqrt{\frac{4P}{\pi \cdot MPE}} - \frac{d}{\theta}$$

Wavelength	MPE (t_{exp} > 10 s)
635 nm	10 W/m^2
850 nm	20 W/m^2
1064 nm	53 W/m^2
1550 nm	1000 W/m^2
10.6 µm	1000 W/m^2

Outlook: FSO

- **FSO is …**
  - on the verge from R&D to commercialization
  - capable of highest transmission rates (fiber in the air) → Tbps
  - complementary to RF systems
- **Main things to work on**
  - Operational concept of FSO/RF links (availability, link planning)
  - Robust channel coding and interleaving schemes with low latency
  - Accurate channel models
  - Maturation of terminal technology (robustness, miniaturization, link acquisition)

?!

Contacts

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