High Throughput Ku-band for Aero Applications

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Introduction

• Wide band Aeronautical Mobile Satellite Systems (AMSS) have been using Ku-band wide beams for number of years
• The dominance of Ku-band wide beam systems is being challenged by Ka-band multi-spot beam systems
• Ka-band spot beams often perform better than Ku-band wide beams
  – We show that the performance difference is primarily due to spot beam size rather than frequency
  – Similar size beam Ku-band perform equivalent or better than Ka-band
• Intelsat and Panasonic are partnering to introduce high throughput aero services using Ku-band multi-spot satellites
Overview

• Available Services on Aircraft
• Satellite Beam Today and Evolution
• Link Performance – Downlink
• Link Performance – Uplink
• System Architecture
• Intelsat Epic\textsuperscript{NG}
• Panasonic High Throughput Aero Service
• Conclusion
Connectivity on Aircraft

- Services
  - Live Television
  - Cellular Service
  - Internet
  - Transaction
- eXConnect, Row 44, Global Xpress, Connexion by Boeing / BBSN
- Satellite Backhaul
- Global Satellite Coverage
- Beam Switching
Wide Beam

- Easy accessibility of Ku-band wide beam capacity
- Beams are designed to cover landmass and ocean regions
- Beam design is targeted for fixed services (VSAT and TV Broadcast) and more recently mobile services

- Wide beams have relatively low EIRP and G/T
- Spot beams offer higher EIRP and G/T
Satellite Beam Today & Evolution

Spot Beam

- Performance of satellite can be improved by shrinking beam size
- Multiple spots used to cover the desired service are
- Improves EIRP and G/T
- Single spots have a long history before but multi-spot coverage for mobility is relatively new
- We show that it is not the frequency but the size of the beam that matters
Examples of multi-spot systems:

- **Viasat-1**
  - Around 60 service beams
  - Covers only the densely populated portions of the US
  - Would require 400+ equivalent beams to cover the North Atlantic flight corridor
  - Very high performance

- **Inmarsat-5 Global Xpress**
  - Around 70 beams per sat
  - 3 Satellites
  - Near global coverage
  - Beams are around 25 larger area than Viasat-1 beams
  - More modest performance
Downlink Performance

- Carrier to Thermal Noise Ratio relation is derived from
  - Gain of the Satellite
  - Gain of the Terminal Antenna
  - Space Loss

\[
\frac{C}{N_{Therm}} \approx \frac{P_{sat} \cdot 4\pi \cdot A_{eff}}{HPBW^2 \cdot d \cdot L_{atm} \cdot T_{term} \cdot k \cdot B}
\]

- Where
  - \(P_{sat}\) = satellite amplifier power
  - \(A_{eff}\) = effective terminal antenna area
  - \(HPBW\) = half power beam-width of the satellite
  - \(d\) = slant range from satellite to terminal
  - \(L_{atm}\) = rain and atmospheric loss
  - \(T_{term}\) = receiver noise temperature
  - \(k\) = Boltzmann's constant
  - \(B\) = bandwidth
Link Performance – Downlink

Downlink Performance

\[
\frac{C}{N_{Therm}} \approx \frac{P_{sat} \cdot 4\pi \cdot A_{eff}}{HPBW^2 \cdot d \cdot L_{atm} \cdot T_{term} \cdot k \cdot B}
\]

- Primary frequency terms cancel out
- Frequency independent variables are: \(A_{eff}, B, P_{sat}, HPBW^2, d, B\)
- Secondary frequency dependent variables are: \(L_{atm}, T_{term}\)
  - Higher frequencies generally reduce performance
- Beam-width dominates the final downlink performance
- Ku-band has equal or better performance over Ka-band for same beam size beam
Link Performance – Uplink

Power Limited Uplink Performance

\[
\frac{C}{N_{Therm}} \approx \frac{P_{term} \cdot 4\pi \cdot A_{eff}}{HPBW^2 \cdot d \cdot L_{atm} \cdot T_{sat} \cdot k \cdot B}
\]

- Uplink equation is similar as downlink performance
- Primary frequency terms cancel out
- Beam-width dominates the final uplink performance
- Ku-band has equal or better performance over Ka-band for same beam size beam and power limited terminals
- Small terminals are often regulatory limited rather than power limited
Link Performance – Uplink

Regulatory Limited Uplink Performance

- International Telecommunication Union (ITU) has different off-axis EIRP spectral density (ESD) limits for different bands
- Off-axis ESD mask for Ku-band is significantly higher than for Ka-band (+6 to +14 dB)
- Lower directivity of Ku-band antenna offsets the advantage on regulatory constraints (-6 dB)
- Ku-band still has advantage on uplink performance over Ka-band
Link Performance – Uplink

Regulatory Constraints

\[
\frac{C}{N_{Therm}} \approx \frac{ESD \cdot C^2}{HPBW^2 \cdot d \cdot f^2 \cdot L_{atm} \cdot T_{sat} \cdot k}
\]

- Where
  - \( c \) = speed of light
  - \( f \) = frequency
  - \( ESD \) = EIRP spectral density, derived from terminal power, gain, and bandwidth

- Frequency term no longer cancels in the derived equation
- Higher frequency has disadvantage – 6 dB at Ka-band
Link Performance

Systems with similar:
- Satellite powers
- Spot beam sizes
- Terminal Antenna Size

Will have similar:
- Data throughputs
- Costs/Mbps

Ku can equal Ka economics by:
- Using similar size spots
- Using similar size antennas

Small (iPad) size Ka antennas will have inferior economics
System Architecture

- Performance is inversely proportional to the spot beam area
- High throughput satellites can support 70 to 80 spot beams
- Beam size, coverage area, and desired performance are the variables on system design
- Right spot beam size should be large enough for optimum utilization
  - High density flight routes should be captured by smaller beams
  - Low density flight routes can be captured by large beams
- Combination of wide and spot beam can help load share the traffic
System Architecture

- Cellular network analogy
  - Macrocells – Cover larger region but smaller number of users
  - Microcells – Cover larger number of users but in a smaller region
  - Cell size matched to traffic density

- Satellite networks
  - Beam size would ideally be matched to underlying traffic density
  - Not one size fits all
Epic\textsuperscript{NG} is Intelsat’s next generation high performance satellite. Satellite consists of C-, Ku-, and Ka-Band (Wide and Spot). North Atlantic and North America will be covered by Intelsat-29e. Asia, Europe, and Africa will be covered by Intelsat-33e. IS-29e planned for Year 2015, IS-33e is planned for 2016.
Panasonic collaborated with Intelsat to bring Intelsat’s Epic\textsuperscript{NP} in aero market. Epic\textsuperscript{NP} is designed to meet the demand in aviation routes. Intelsat-29e will cover the North Atlantic and North American flight routes:
- Spot beams for high density flight routes
- Wide beams for low density flight routes and video re-broadcast.
Ku-Band Spot Beam and Panasonic

- Combination of wide beam and spot beam allows Panasonic to load balance the traffic, seamless handover, and video re-broadcast
- 1 Gbps of capacity is contracted on Intelsat-29e
- Currently working with Intelsat on the development of Intelsat-33e

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<thead>
<tr>
<th></th>
<th>Intelsat-29e</th>
<th>Global Xpress</th>
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<tbody>
<tr>
<td>Beam Size</td>
<td>&lt; 2°</td>
<td>2.1°</td>
</tr>
<tr>
<td>Spot Beam Down</td>
<td>160 Mbps</td>
<td>42-84 Mbps</td>
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<tr>
<td>Aircraft Down</td>
<td>80 Mbps</td>
<td>42 Mbps</td>
</tr>
<tr>
<td>Wide Beam Down</td>
<td>40 Mbps</td>
<td>N/A</td>
</tr>
<tr>
<td>Upload</td>
<td>4 Mbps</td>
<td>4 Mbps</td>
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Objective:
• 80% of flight routes will be overage by spot beams
• Remaining flight routes will be covered by wide beams
• Ku-band can provide equivalent or better performance than Ka-band for similar size spot beams
• Link performance is denominated by beam size rather than frequency band
• Uplink performance is equal or better for Ku-band
• Transitioning terminals from wide beam Ku-band systems to spot beam systems does not require costly retrofit in future
• More competition in the market favors innovation and benefits consumer
THANK YOU