High-rate Free-Space Optical Communications for Terrestrial Platforms

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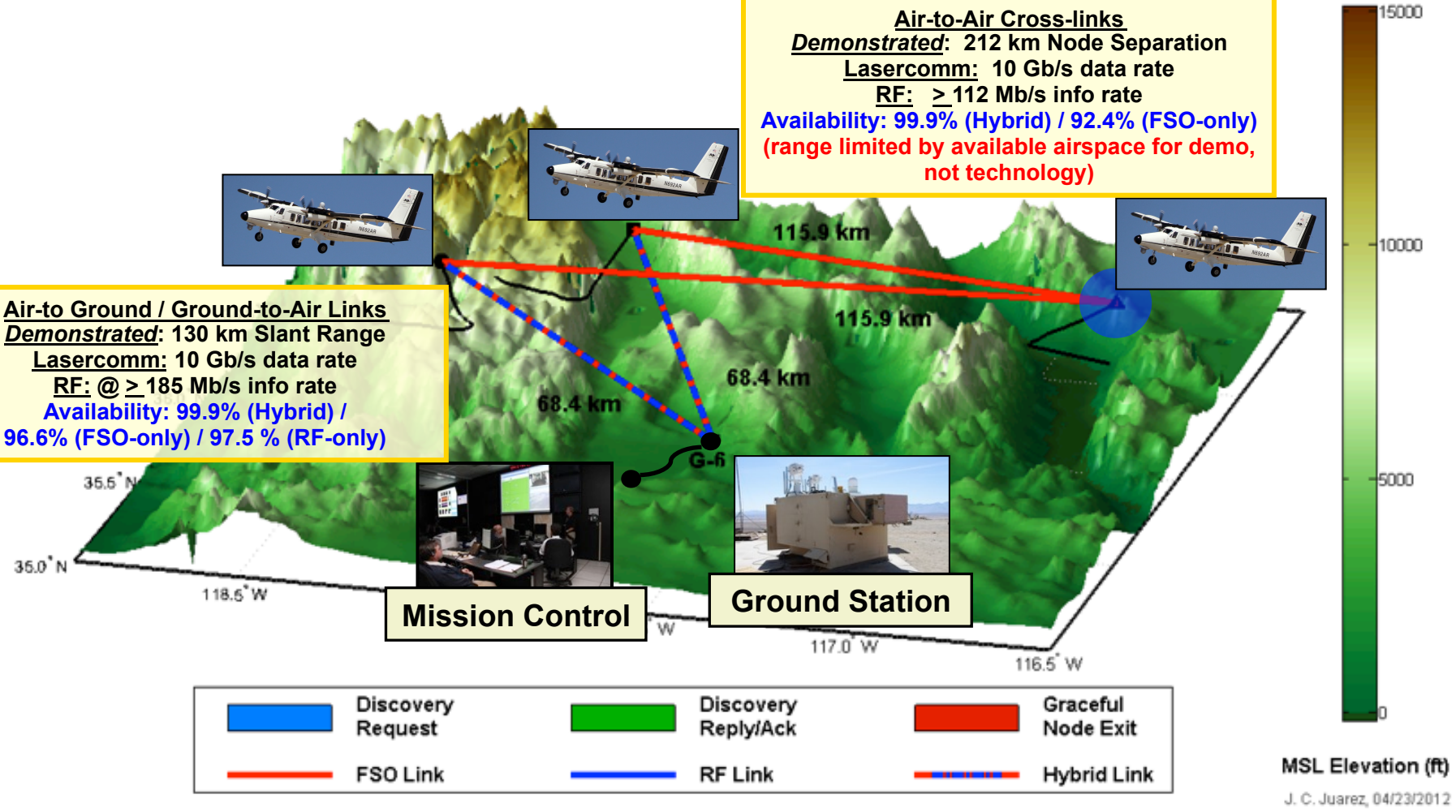
DARPA FOENEX Demonstrated Capabilities - 2012

Air-to-Air Cross-links
Demonstrated: 212 km Node Separation
Lasercomm: 10 Gb/s data rate
RF: > 112 Mb/s info rate
Availability: 99.9% (Hybrid) / 92.4% (FSO-only)
(range limited by available airspace for demo, not technology)

Air-to Ground / Ground-to-Air Links
Demonstrated: 130 km Slant Range
Lasercomm: 10 Gb/s data rate
RF: @ > 185 Mb/s info rate
Availability: 99.9% (Hybrid) / 96.6% (FSO-only) / 97.5 % (RF-only)

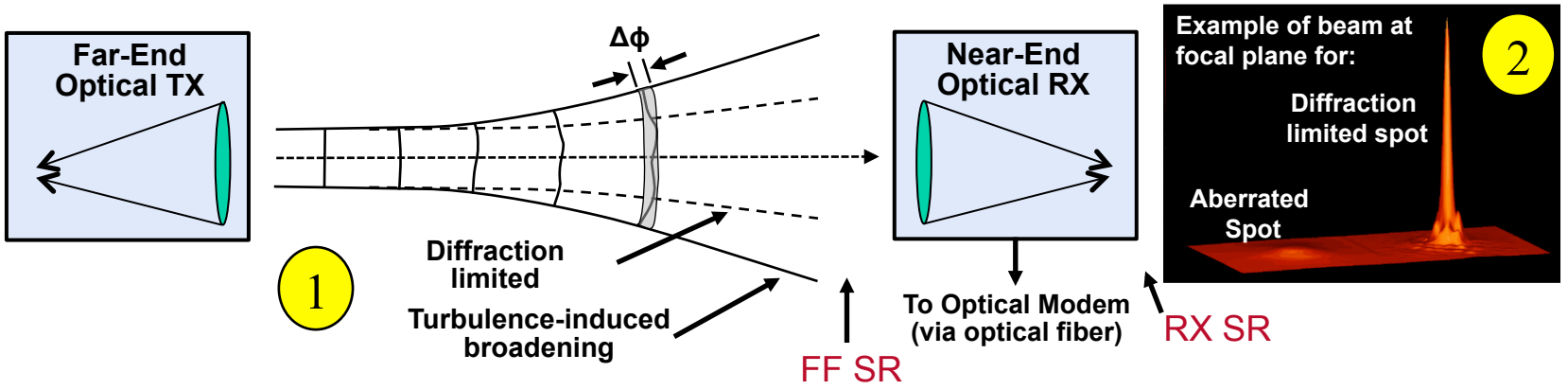


Demonstrated a four-node hybrid Lasercomm/RF airborne mesh network with high availability, high bandwidth, end-to-end connectivity at TRL 6

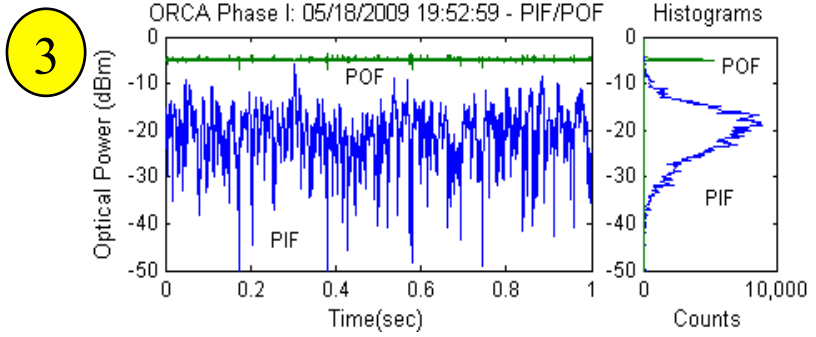
* Over 200 flight hours of testing. Final report and data available upon request

Background: Impact of Optical Turbulence on Terrestrial FSO

- **For FSO link, beyond attenuation effects and line-of-sight limitations, performance is primarily driven by optical turbulence**



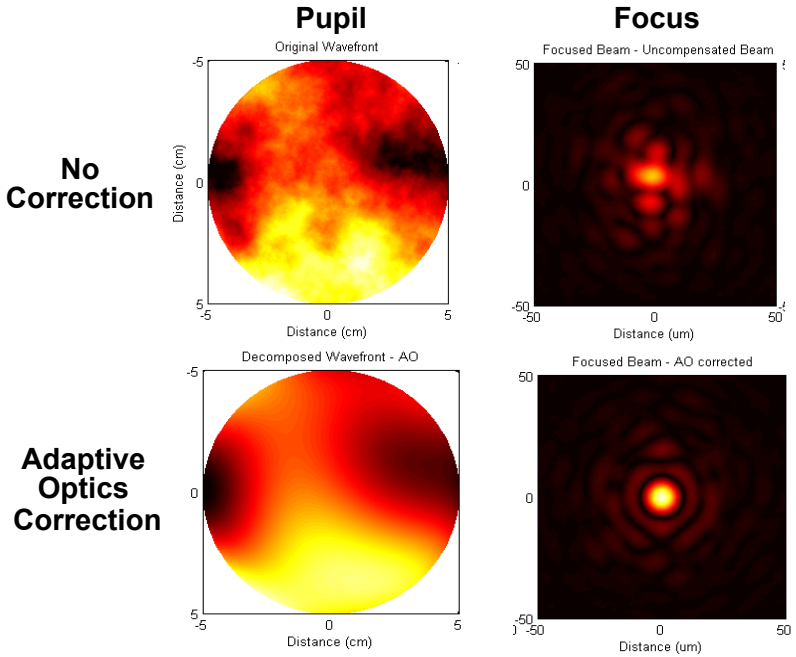
1. **Beam broadening of transmitted beam**
   → **Decreased average power at RX**
2. **Broadening of focused spot at RX**
   → **Degraded average fiber coupling**
3. **Intensity fluctuations at the receiver**
   → **Degraded beam tracking performance**
   → **Burst errors in data link**



Data from ground receiver of an air-to-ground, 183-km link during the ORCA program testing in May 2009 [1].

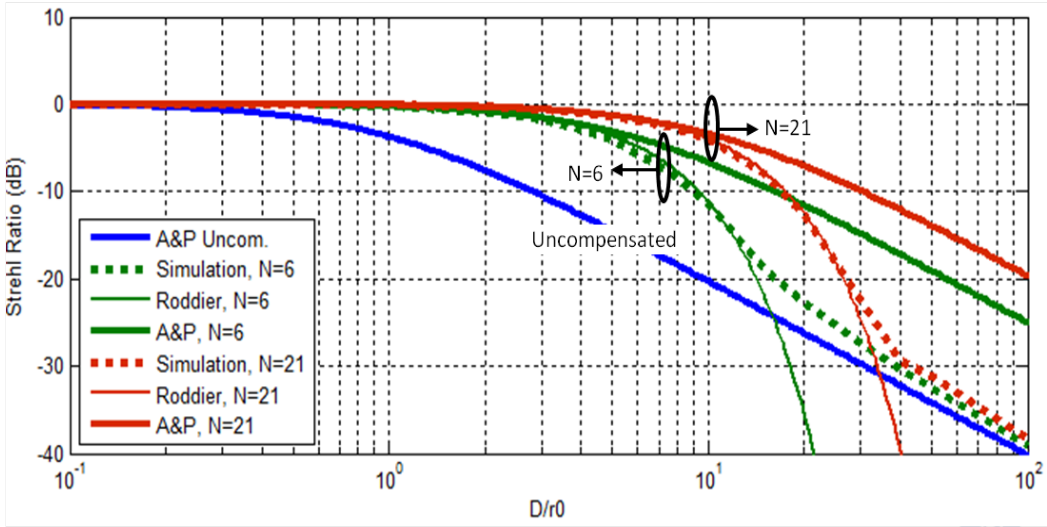
L. B. Stotts, et al, "Hybrid optical RF airborne communications," Proc. IEEE **97**,(2009).

Adaptive Optics Terminal Characterization and Modeling



- **Receive Strehl Ratio (RX SR)**
  - SR at focal plane of receive terminal
  - Measure of performance for coupling light into fiber
  - (i.e. RX performance)
- **Far-field Strehl Ratio (FF SR)**
  - SR at aperture plane of remote terminal
  - Measure of performance at concentrating beam on remote terminal
  - (i.e. TX performance)

Solid lines: theoretical models
Dashed lines: simulation results



- **Strehl ratios in FSOC are very useful for:**
  - Developing link budgets for systems under different turbulence conditions
  - Evaluating different levels of compensation that may be required for applications of interest
- **Current Strehl ratio models**
  - Development based on weak turbulence theory
  - Found to not accurately predict system performance under strong turbulence conditions

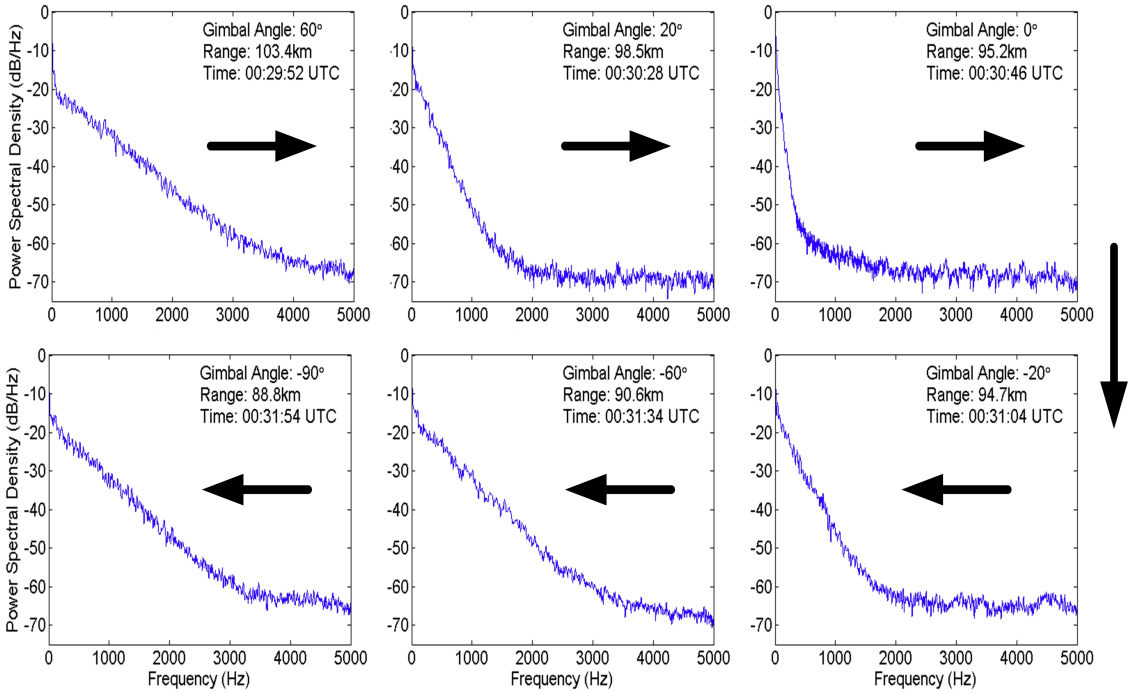
FSO Terminal Bandwidth Requirements

- **Greenwood frequency, f_G, gives the frequency scale over which the wavefront aberrations evolve**
  - **f_G = 20-100's Hz for static links and several kHz for airborne links**
  - **Determines *bandwidth requirements of AO system***

$$f_G = 2.31\lambda^{-6/5}\left[\sec\beta \int C_n^2(z)V^{5/3}dz\right]^{3/5}$$

$$\tau_o = \frac{0.32r_o}{V_\perp}$$

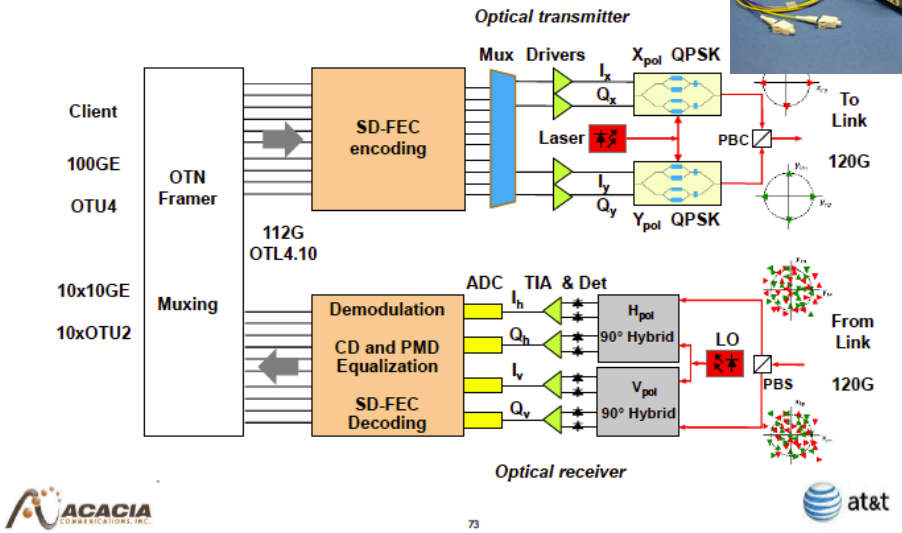
- **DARPA ORCA results**
- **Spectral content of beacon as a function of gimbal angle on aircraft**
- **Airborne systems introduce much higher frequency spectral content**
- **New AO systems must support higher compensation**

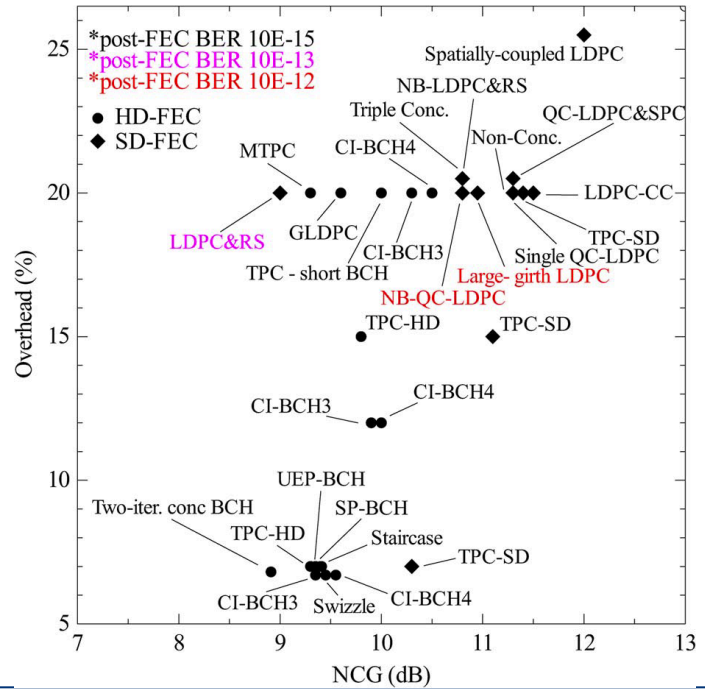


D. T. Wayne, et. al., "Observation and Analysis of Aero-Optic Effects on the ORCA Laser Communication System," SPIE 8038 (2011).

Coherent Transceivers for 100G and Beyond

- Commercially available for 40G, 100G, 200G, and 400G
- Integrated TX and coherent RX with SD-FEC, CD/PMD equalization, and demodulation
- Can approach Shannon limits
- Designed for stable OSNRs





- FSO fades can cause loss of multiple frames, frame alignment, polarization tracking and LO tracking
  - Can take multiple seconds to restart
- Require FECs, interleavers, and synchronization algorithms be adapted to FSO channel