Mobile Optical Communication projects at DLR and prospects on future developments

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Content

- Introduction of DLR's OCG, their fields of work and methodology

- Projects
  - HAP-Downlinks: CAPANINA
  - LEO-Downlinks: KIODO

- Technological options for future optical space communications with emphasis on EO-downlink
Optical Communications Group (OCG) at IKN
- Fields of Works:

- Atmospheric Optical Freespace Communications with OOK- and Phase-Modulation, at 850nm / 1064nm / 1550nm
- Mobile Links between Ground / HAP / UAV / Balloon / Aircraft / Satellite / Ground Vehicle
- Optical Space Communications with LEOs and Studies on GEO- and Deep-Space-Links
- Simulation and Analysis of the Propagation through the turbulent Atmosphere -> Index-of-Refraction Turbulence, Pressure Turbulence around AC
- Methods for Fading-Mitigation:
  - Diversity (Space, Wavelengths, Time)
  - asynchronous Transmission with FEC and Interleaving
- Pointing, Acquisition and Tracking (PAT): Optical / GPS / INS / Orbit
- System Demonstrations, Field Trials, and System Tests
The Three Principals to Investigate IRT Propagation

Analytical theory

theory inherent restrictions apply
(The Rytov theory is valid only under weak fluctuations (the multiple scattering effect is ignored)

$$\nabla^2 U(P) + k^2 \sigma^2 \left( P' \right) \cdot U \left( P \right) = 0$$

$$\sigma_R^2 = 1.23 \; C^2 \; k^{7/6} \; L^{11/6}$$

Numerical simulation

PILab

split-step Fresnel propagation

Field trials and measurement campaigns

results only valid for one specific scenario

- Verification by measurements is indispensable
Measurements of IRT:
The Atmospheric Transmission Monitor (ATM)

- **Pupil Camera**
  - Estimates $C_n^2$-profiles
  - Calculates scintillation indices
  - Calculates intensity correlation

- **DIMM** (Differential Image Motion Monitor)
  - Measures parameters of the wave-front distortion
  - 2b replaced by Shack-Hartm.
Projects:

- CAPANINA: Stratospheric Optical Downlink
- KIODO: LEO Downlink from Japanese OICETS
CAPANINA - Trial: Stratospheric tests "STROPEX", Optical Downlink at 1.25Gbps (IM/DD)

Weight: 17.54 kg

Pointing Acquisition and Tracking Computer
Gyroscopes
Optical Amplifier
Laser Driver Electronics and beacons
Pointing Assembly

CAPANINA - Trial: Stratospheric tests "STROPEX", Optical Downlink at 1.25Gbps (IM/DD)
Measurement campaign at Site “ESRANGE” (Sweden)

- Downlink from a stratospheric test-bed
- Nacelle with Backup systems for Acquisition
- Turning mechanism for secure landing
- Transportable ground station

![Image of measurement equipment at Site “ESRANGE”](image-url)
Acquisition of ground station from balloon terminal

- Typical acquisition time
  30 s (with no heading information available!)

- Tracking accuracy of HAP-terminal was better than 142 µrad (0.0081deg)

STROPEX Control room

Video: Acquisition sequence
1.25 Gbps Signal received at Optical Ground Station
distance 64km, from 22km altitude, 100mW Tx-power
Details of the Stratospheric Downlink Terminal

View onto Optics:

- D: 30mm, cl. Ap.: 22mm, Tracking
- 977.8nm redund.
- 978.6nm redund.
- 1550nm & 986nm

- Fibres
- Filter 808nm
- Periscope
- 1550nm & 9xxnm Tx-Beams
- f=75mm
- 810nm incoming Tracking-Beam
- Tracking Camera
**KIODO - LEO-Downlink**
(Kirari Optical Downlink to Oberpfaffenhofen)
- Joint Experiment with JAXA, in June 2006

**OGS-OP: Optical Ground Station Facilities at DLR-Site**
Oberpfaffenhofen (near Munich)
KIOODO - Parameters

\[ \lambda_{\text{signal}} = 847 \text{ nm (50 Mbit/s)} \]

5-\text{mrad div.}

\[ \lambda_{\text{beacon}} = 808 \text{ nm} \]

5-mrad div.
Measurements in the IM/DD satellite downlink channel

- 8 Downlinks from JAXA’s Kirari to OGS-OP in June06
- Successful data-reception (50Mbps, 847nm)
- Channel-measurements
Measurement-Monitoring during KIODO-Trial 7
Downlink: $r_0$-Estimations from DIMM-data

Exposure time = 80 µs
Downlink (847nm): Intensity Correlation Length (from PROF-Data)
- Mean Rx-power was more than enough for error-free reception.
- BER was limited by Rx-electronics' spectral behaviour; electronics and algorithms were optimized between trials.
- Ongoing research in lab testbed at DLR to optimize Rx-electronics.
KIODO-Results:

- Successful optical downlink from LEO to "lowland" OGS-site
- Optical Downlink from LEOs proved feasible with low effort on ground
- Measurements of the Atmospheric Optical Index-of-Refraction-Turbulence Fading Channel during LEO-Overflight

Remark: Japan's NICT conducted similar trials in 2006 to their OGS near Tokyo
Current and future projects at DLR-OCG:

- Downlink experiments with the coherent DLR-LCT onboard TerraSAR-X, to OGS-OP (at DLR-Oberpfaffenhofen) and to Calar Alto (Spain), ongoing
- Aeronautical optical links investigations with in-flight tests (MINERVAA-project)
- Adaptive Optics and other concepts for link quality enhancement
- Stratospheric Optical Inter-Platform Links
- Optical downlinks from UAVs
Future Scenarios (1-3)
EO-Sat Downlinks over optical GEO-Relays

pros:
- real-time data connection to the EO-Sat during half of its orbit
- increased data throughput
- simple operations planning when using μwave downlink from GEO to GND: no dealing with hard-to-predict cloud blockage

cons:
- strained link-budget over long distance (40,000km)
- several link-components need to be in place in time
Future Scenarios (2-3)
Optical EO-LEO Downlinks directly to Ground

pros:
- short distance allows low power consumption with small Tx-terminals
- easy to be installed also on very small LEOs
- agile LEOs can do the pointing to the OGS – no CPA needed (this feature is mission dependent)
- low costs for Sat-Tx-Terminal and for OGS

cons:
- cloud blockages require several ground stations ("OGS-Diversity") for secured downlink-throughput
- large data storage capacity required if only few/one OGS is used, to overcome blockage periods
- atmospheric IRT reduces performance at low elevation
  -> specialized FEC required

further issues:
- special protocols to be developed for ensured data throughput (FEC, efficient retransmission, buffering) -> is a current research objective at DLR
Future Scenarios (3-3)
Optical Sat-Downlinks to Stratospheric Relays (HAP)

pros:
- cloud-blockage is no problem as HAPs are located far above cloud-ceiling
- IRT only a minor problem and only at very low/negative elevations
- enhanced contact time for downlinks by factor two (5700km footprint-diameter, as LEO-visibility starts at -2° elevation)
- also beneficial for bidirectional (communications-) links from satellites
- very low costs for simple Sat-Tx-Terminal; HAP also used for other tasks

cons:
- HAP-technology not mature ye, many problems still to be solved

further issues:
- link from HAP to ground can be done by "short-range" (~30km) μwave-links or also optical (combined with buffering onboard the HAP when clouds block the direct downlink to ground) or with re-routing to other HAPs w/o cloud blockage underneath
- one can also use unsteered stratospheric balloons which can be kept in a loose station keeping box for several weeks by altitude-control
Geometrical Relations with OGS and Stratospheric Optical Relays
Technological Considerations

- highest sensitivity is required for LEO-GEO OISLs which can be delivered by coherent BPSK better than by OOK/DD
- for shorter distances like in LEO-downlinks, larger ground-based Rx-telescopes (in the order of few dm) together with the reduced freespace-loss relax the link budget
- an open technology is desirable, which allows simple transmission schemes (e.g. OOK, DPSK) where applicable but can be upgraded to sophisticated schemes (e.g. BPSK) where necessary
- when considering transmission through (thin) clouds, inter-symbol-interference (ISI) has to be evaluated to chose the most robust modulation format
Summary – Technological Options for EO-Downlinks

- Optical downlink-terminals can provide an immense increase in operational usability of EO-sensors, but are restricted by cloud cover over the OGS.
- Direct optical downlinks can provide simple online region-of-interest access for optical sensors (e.g. forest fire detection, boarder control, …) – "when optical sensors can see the ground also the optical downlink works"
- An internationally organized OGS-Network for civil EOSat-Missions would be very beneficial for all members; could also be used for deep-space missions.
- Even geographical areas with high average cloud coverage can benefit from optical downlinks when using OGS-diversity on national territory with optimally chosen OGS-sites (e.g. optical downlinks to Germany with four OGS: 96% combined availability in summer-term and 75% in winter-term).
- International cooperation is required for coordination of wavelengths and modulation formats.