Optical Satellite Downlinks to Optical Ground Stations and High-Altitude Platforms

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Introduction

Recent years have seen an immense increase in the capability of earth observation (EO) sensors flown on satellites. State-of-the-art payloads like high resolution optical or infrared cameras or SAR systems produce data at a speed of gigabits per second. This is why the conventional RF-downlink has become the bottleneck in EO-systems, as it is limited to some hundred megabits per second. The data acquired by the sensor can only be sent to the ground when it is in the reach of an according RF ground station antenna, which happens a few times per day with each downlink session lasting only around 9 minutes at maximum for a LEO (Low Earth Orbit) satellite. This limits the effective operational time fraction of such sensors to only some minutes per day. Due to limitations in the available frequency bands but also in technological feasibility the RF downlink technology is currently reaching its limits.

To solve this communications bottleneck we now have the opportunity of using free-space optical (FSO) high speed links. This technology would instantly multiply the downlink data rate by a factor of ten, while even faster links would be feasible in the near future. At the same time the mass, size, and power consumption of the satellite terminal would be cut to only a fraction of the values of conventional RF-antennas, making high speed downlinks an option even for compact- or micro-satellites (a typical Tx-aperture diameter for a LEO-downlink would be approx. 3 centimeters). Furthermore, also the size of the according Optical Ground receiving Station (OGS) remains quite compact, with only some decimeters of telescope diameter, enabling transportable or even mobile stations. This is an important benefit compared to RF ground stations which have typically antenna diameters of 5 meters and more. The inherent tap-proofness of directed optical beams due to a minimized optical signal spot beam on ground (typically between 10 and 100m) is also very appreciable in security applications.

The Institute of Communications and Navigation of the German Aerospace Center (DLR) has demonstrated together with its partner JAXA (Japan Aerospace Exploration Agency) the feasibility of direct optical LEO-Downlinks in the Project KIODO (Kirari Optical Downlink to Oberpfaffenhofen). KIODO showed a very good performance with measured bit error rates down to 10^{-6} with a transportable and inexpensive OGS [1].

Solving the Challenge of Cloud-Blockage

Reliable optical downlinks are of course limited to geographical OGS-sites with a minimum fraction of cloud coverage, as the optical signal is blocked by most clouds. Therefore, these stations should preferably be situated on mountain tops (like the classical astronomical observation site) or in countries with low occurrence of clouds, like the Mediterranean or sub tropic latitudes. In the future, also polar-located OGS will be an option with an immense downlink time fraction for polar orbiting satellites. However, this practice might still not be acceptable for applications with secure near real-time requirements. Also, for non-EO applications like communications or broadcast, a nearly hundred percent availability is required for the satellite link. Therefore the "ground" station has to be positioned above the clouds. Aircraft or aerostatic High Altitude Platforms (HAPs) provide the suitable bases, with the later having the advantage of stationarity together with lesser vibrations and position uncertainty. The final "last mile" to the ground can then be bridged by standard short-range RF point-to-point links as used today in terrestrial applications. With a buffering strategy onboard the HAP even *optical* downlinks from the HAP to a terrestrial miniature OGS could be used for the HAP-downlink, storing the data during total cloud blockage. This concept here is called *StORe* for *Stratospheric Optical Relays*. In a future scenario - with a network of HAPs in range of sight - linking the data from one HAP to an other without cloud blockage underneath would allow a purely optical downlink system [2, 3]. In a future HAP communications network, this networking functionality would be available inherently at no extra expenses.

Other benefits of the StORe-concept compared with RF and terrestrial optical ground stations are the extended visibility time of the LEO satellite (the link can already start at negative elevation angles as long as the line-of-sight stays above the maximum cloud altitude of about 13km, the top limit for European latitudes) and negligible attenuation by the atmosphere. Also the challenge of fading (caused by atmospheric index-of-refraction scintillations) is much reduced at stratospheric altitudes. Further, such HAP-relays could provide downlink capability at any place where a HAP is placed. Even reliable nomadic downlink services can thus be provided to temporary end user sites.

System comparison

Earth Observation Scenario

The system used for example calculations in this chapter consists of a satellite with a mean orbit height of 500 km and a typical near-polar orbit inclination. The satellite is equipped with a high resolution camera which during operation produces data at a rate of 6.7Gbit/s (equivalent to 26411 TByte per year at 100% usage). This high data rate illustrates that the down link bandwidth is a limiting factor for the operational time of the satellite. For simplicity in calculations and to focus on the concept of the StORe, there is only one receiving ground station for the data downlink. Here DLR's ground station at Neustrelitz, Germany, is used for calculations.

State of the Art RF Downlink

Currently used RF downlinks from LEO Satellites have effective user data rates of up to 262Mbit/s (e.g. TerraSAR-X). At Neustrelitz it is possible to start data transmission at an elevation angle of 5° of the satellite. This results in a mean daily contact time of 2360s or in a maximum transferable data volume of about 77 GByte per day. Since the ground station can be assumed to be available for downlink 100% of time, the transferable data volume per year is 28 TByte and the camera can be used during 0.1 % of the operational time of the satellite.

Proposed RF Downlink

Using modern modulation and coding (ModCod) schemes that are adaptive to the elevation angle between ground station and satellite, the downlink capacity can be strongly increased. Targeting a downlink availability of 99.9% and using three different ModCod schemes, simulations show that in the daily mean it is possible to transfer data for 898 seconds with 295 Mbit/s, for 546 seconds with 540 Mbit/s and for 927 seconds with 648 Mbit/s to the ground station in Neustrelitz. This results in a maximum daily transferable data volume of 145 GByte. Since the downlink is available for 99.9% of time this results in a downlink capacity of 53 TByte per year and a utilization of the camera of 0.2%.

Proposed Optical Downlink

Due to atmospheric effects, the availability of an optical downlink is limited to an elevation angle of 10° and more. This reduced Field-of-View results in a mean daily contact time of 1499s. Nevertheless, using an optical downlink with a data rate of 5Gbit/s, the resulting transferable data volume per day is 937GByte, when neglecting cloud blockage. These 5Gbit/s will be used in the optical link sections in further calculations.

The downlink station at Neustrelitz is in a non-optimum place for an optical ground station because it has a mean availability for optical LEO downlinks (limited by cloud cover) over the year of around 32% [4]. Even with this low availability the transferable data volume per year is at least 109 TByte and the camera could be used during 0.4 % of the operational time. A limiting factor in this case is the available data storage on the satellite for times when no data downlink is possible due to bad weather conditions.

An important note at this point is that these values are just for *one* OGS at a site far from the earth's poles and with a relatively high cloud cover probability (Neustrelitz). When using four OGSs distributed over Germany (this concept is called ground station diversity), the combined availability can be boosted to 73% during the winter half year (October to March) and 91% during the summer half year (April to September). Availability approaches 99% when using two or more ground stations in advantageous areas (outside Germany). All OGSs should be separated by several hundred km from each other to ensure uncorrelated cloud cover statistics. Ground station diversity leads not only to an increased downlink availability, but also to more downlink time slots and therefore to an increased average downlink capacity.

Proposed Combined RF-Optical Downlink

For overcoming the cases where an optical downlink is not possible due to cloud cover, one can combine an RF downlink terminal with an optical terminal on the satellite. This approach adds complexity to the data downlink management, e.g. data has to be prioritized and scheduled for downlink via RF or optical channel, but it greatly extends the downlink availability and thus the possible sensor usage. Using the values from above (proposed RF and proposed optical downlink to one ground receiving site only), the combined downlink volume per year can be increases to 162 TByte and the camera can be used during 0.6 % of the operational time.

Proposed GEO Relay

A common concept for increasing the available downlink time for a LEO satellite is the use of a GEO satellite as relay station. An example for this concept is ESA’s geostationary satellite *ARTEMIS*. Because a GEO satellite is always visible at the ground station at a high elevation angle, an RF downlink with the most efficient ModCod scheme from the previous section can be implemented. This ModCod scheme gives an available bandwidth of 648 Mbit/s with an availability of 99.9% between GEO and ground. The daily available downlink time from a GEO satellite is one day, or 86400s. The daily downlink volume is then 6998 GByte. Because of its long distance from earth (~40,000km) a GEO satellite can communicate with a LEO satellite during about half of its orbit or about 43200s per day. If the communication is done via FSO communications at 5Gbit/s the LEO satellite can transmit about 27 TByte per day to the GEO satellite. The availability of this link is 100% of geometrical visibility time because cloud blocking does not occur in space. The amount of optically transferable data is much more than the GEO satellite can relay down to earth by its RF-link, so the limiting factor in this scenario is the GEO-downlink. Buffering of the optically received data onboard the GEO is necessary to allow a constant data-flow from GEO to ground also when the LEO is not visible. With this constellation 2552 TByte per year can be transmitted from LEO to GEO to ground station and the utilization of the camera can be raised to 9.7%.

Proposed HAP Relay

The concept of a relay station above the downlink station can also be realized by using a HAP. The use of a HAP has some advantages. First, HAPs are easier to replace than GEO satellites if something fails. Second the environmental constraints for the payload are not as tough as for a GEO payload and third HAPs should be cheaper to build and launch. For the following calculations we assume a HAP placed above the downlink station in Neustrelitz at an altitude of 20 kilometers. For the downlink from HAP to ground station conventional point-to-point RF technology with a steered antenna is used (this "last-mile" link from HAP to ground has 100% availability). Due to the relatively short link distance between HAP and ground station and due to the constant high elevation angel between them, the RF downlink bandwidth can be raised to 1336 Mbit/s with an appropriate ModCod scheme and an availability of 99.9%.

The HAP holds an optical receiver terminal for data downlinks from EO-satellites, again at 5Gbit/s. Since the HAP is located 20km above the earth surface, the data link between HAP and LEO can already start at an elevation angle of -2.7°. This results in a mean daily contact time of 4759s or in a daily transferable data volume from LEO to HAP of 2974 GByte. The link availability between HAP and satellite is 100%, because of the HAP's position above the cloud layer. The HAP can downlink 14429 GByte per day, so the limiting factor in this scenario is the link time between LEO and HAP. With this system the transferable data volume per year can be increased to 1086 TByte and the camera can be used during 4.1 % of the operational time. This is less than in the GEO relay scenario, but the HAP in this scenario can theoretically serve about four LEO satellite missions in parallel (limited by contact time between LEO and HAP) while the GEO satellite can serve only one mission at a time (limited by RF-downlink capacity from GEO to ground).

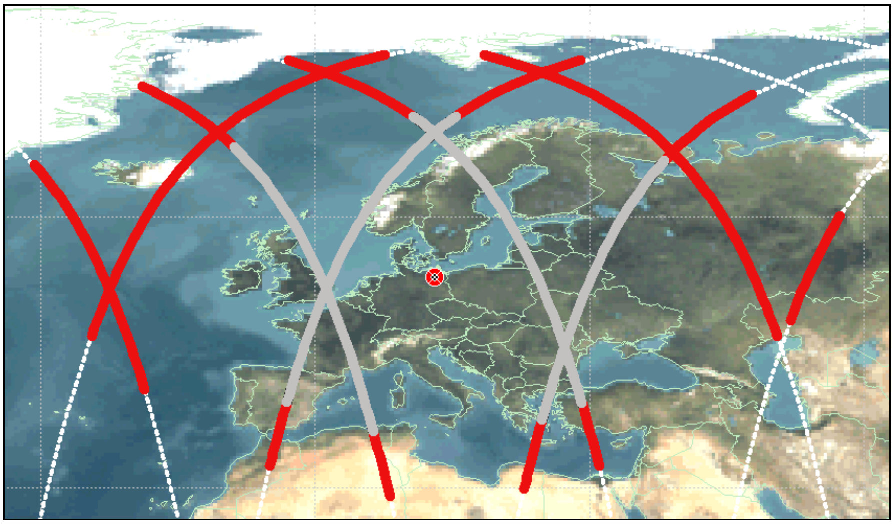

Fig. 1. Example for the improved access time by a StORe at 20 km with -2.7° minimum elevation (red and grey lines) over an RF-ground station with +5° minimum elevation (grey lines only), both stations situated at *Neustrelitz, Germany* (marker in the image center). The given orbits are the satellite passes of one day. LEO circular orbit height is 500 km with a typical near-polar inclination.

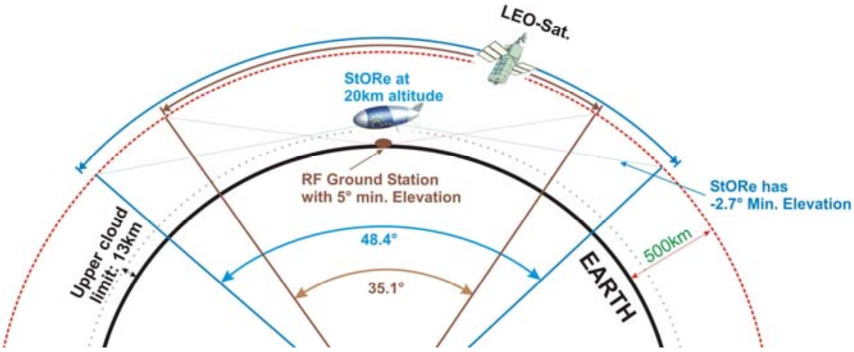

Fig. 2. Geometrical visibility constraints of a StORe with -2.7° minimum elevation and a ground station (GS) with 5° minimum elevation for a LEO in 500km orbit altitude. The StORe has a field-of-view cone with 48.4° planar angle, while the ground station has only 35.1° (angles not to scale).

Comparison of Downlink Scenarios

Table 1 compares the afore discussed downlink scenarios using only one ground receiving station. The table only presents the transferable amount of data and neglects the cost per byte for the different downlink scenarios. The cost per byte is an economical factor that should be considered if the downlink scenario for a space mission is planned.

Table 1. Comparison of the presented downlink scenarios for a ground station in Neustrelitz, Germany

Downlink Scenario	RF	Proposed RF	Proposed optical	Proposed RF-optical	Proposed GEO-relay	Proposed HAP-relay (StORE)
Effective Downlink Rate (Gbit/s)	0.262	up to 0.648	5.0	up to 5.648	0.648	1.336
Mean daily downlink time in s	2360	2360	1499	2360	86400	86400
Availability in %	100	99.9	32 - 45	100	99.9	99.9

Mean daily transferable data volume from LEO to ground (GByte/day)	77	145	300	377	6998	2974
Mean daily Camera Utilization in % of operational time	0.1	0.2	0.4	0.6	9.7	4.1

Cloud Cover Statistics and OGS-Diversity

The biggest problem for direct Free-Space Optical (FSO) downlinks from satellites or HAPs to an OGS is the changing cloud cover above the OGS which determines the availability of the downlink. For selecting favorable locations for an OGS meteorological data is needed for evaluating the cloud cover statistics. Such data is for example available from the International Satellite Cloud Climatology Project (ISCCP), World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT), European Cloud Climatology (ECC), several synoptic observation sites and others. Figure 3 gives the mean annual cloud coverage for the entire earth. Concluding from this data, favorable locations for ground stations would be in North and South of Africa, western part of the USA, Australia, the Middle East and parts of the Antarctica.

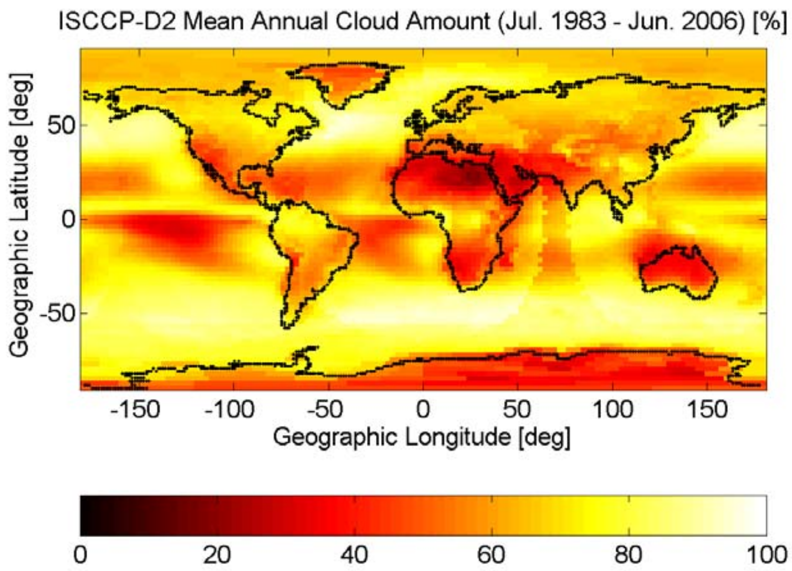

Fig. 3. Mean annual cloud coverage for the time from July 1983 to June 2006 based on data from the ISCCP. The color indicates the amount of mean cloud coverage from black = 0% over red, orange and yellow to white = 100%

In most cases the choice of the location for an OGS is not only made on base of cloud cover statistics, but influenced by factors like national interests, political stability in the region, or existing infrastructure. So sometimes it is necessary to set up an OGS in a place with a non-optimum availability. A concept that can be used to boost downlink availability up to 99% in cases where locations with low availability should be used is the concept of multiple ground station diversity. If more than one OGS is used for the downlink and the distance between the OGSs is large enough (> 1000 km) the cloud cover above these stations will be uncorrelated and while one OGS is blocked by clouds another ground station might be available. This system design will also lead to an increased downlink capacity in cases when more than one OGS is cloud free. If the distance between the OGSs is too small, the locations will all have similar weather conditions and the availability will not increase significantly. Also the effect of an increased downlink capacity is not given as the satellite will see all the OGSs at the same time and can only downlink to one of them. Another fact that has to be kept in mind is that the cloud coverage is seasonal dependant as shown by Figure 4. This requires that the data used for calculating the availability of an OGS needs enough resolution in time to reflect the change during the course of the year.

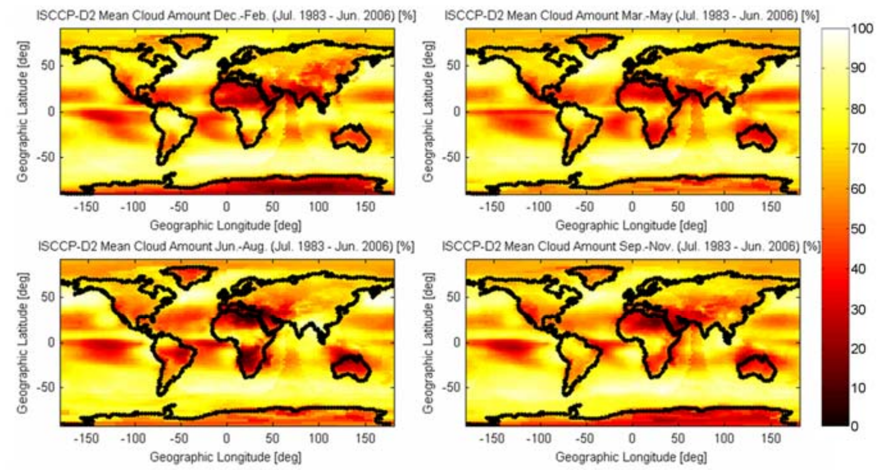

Fig. 4. Seasonal dependency of the mean cloud coverage. Based on data from the ISCCP from 7/1983 – 6/2006. The colors indicate the mean cloud coverage in the selected periods, favorable locations have darker colors. A good example for the seasonal dependency of the mean cloud coverage is Brazil which has a good availability in summer (lower left plot, around 80%) but also a bad availability during winter (upper left, around 20%).

Availability of OGS-Networks

In the following calculations of availability of OGS networks are presented. Base of these calculations is either data from ECC or ISCPP and in some cases data from synoptic observations. Because of its low resolution in time and image quality the used data can only be used for approximating of the availability. Since the cloud coverage analysis requires a lot of processing time for each desired location, a pre-selection of suitable locations has been done. The used selection criteria have been the following:

- the locations should be in political stable regions
- infrastructure should already be available
- the yearly mean availability of a location should not be below 60% (not valid within Germany)

OGS Network within Germany

Germany is not really a good place for doing direct optical LEO downlinks, because there is no location that has more than 45% mean annual availability. Since all regions have nearly the same mean cloud coverage, places have been selected to be as far away from each other as possible. If four OGSs are placed within Germany (Figure 5), the system would have an availability of about 82% in the yearly average. If the system is extended to ten OGSs the availability raises only slightly up to 87%. This slight increase in availability despite a heavy increase in the number of used OGSs shows that the weather within Germany is heavily correlated. An OGS network in Germany is also a good example for the seasonal dependency of the mean cloud coverage: During winter half the selected four-OGS-system has an availability of 73% but during summer half the availability reaches 91%.

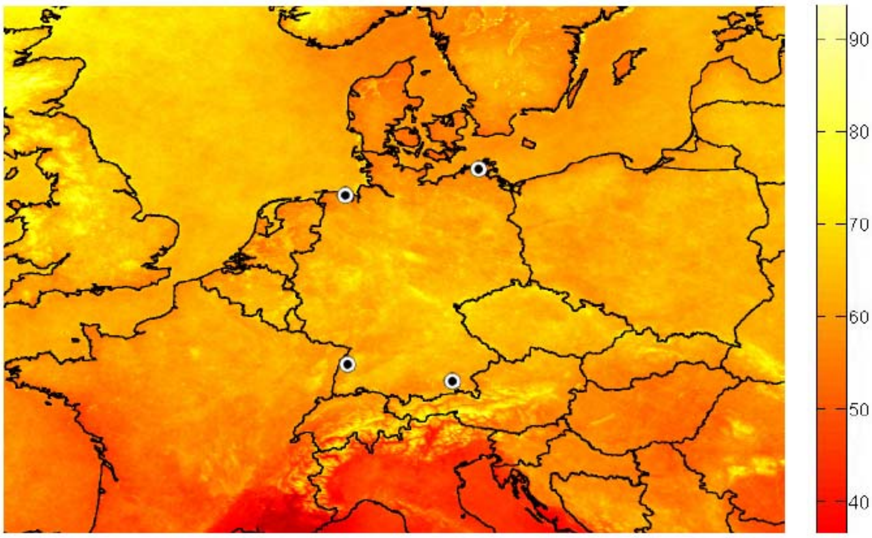

Fig. 5. An OGS network with four OGSs (black and white markers) within Germany. Although the OGSs are positioned as far away from each other as possible, there is still strong correlation in the cloud coverage of the four locations. The legend denotes the yearly mean cloud cover (darker color means less cloud probability).

OGS Network within Europe

Regions in Europe that offer mean annual availabilities higher than 45% can only be found in the southern areas, so an OGS network within Europe should be set up across the Mediterranean Sea. The preselected locations from this region are Calar Alto in the south of Spain, Marseille in the south of France, Catania on Sicily (Italy) and Skinakas on Crete (Greece). The selected sites are shown in Figure 6. The fact that there are already astronomical observatories in the chosen regions strengthens the assumption that these locations are suited for FSO. It also guarantees that there is already some existing infrastructure that can be used for setting up an OGS. Unfortunately cloud cover statistics have not been available for all of these locations. In these cases data from observation sites within a few kilometers range have been used.

Table 2. Availability of European OGS networks

OGS Location(s)	Availability in %
Skinakas, Marseille, Catania, Calar Alto	98
Skinakas, Marseille, Catania	96
Skinakas, Marseille	92
Skinakas	74
Marseille	72
Catania	69
Calar Alto	64

World Wide OGS Network

For setting up a global network also sites already containing observatories have been chosen. The selected sites are Observatorio del Teide on Tenerife (Spain), Paranal Observatory in the Atacama desert (Chile), Perth in Western Australia and again Skinakas on Crete.

Table 3. Availability of world wide OGS networks

OGS Location(s)	Availability in %
Paranal, Observatorio del Teide, Perth, Skinakas	99
Paranal, Observatorio del Teide, Skinakas	98
Paranal, Observatorio del Teide, Perth	98
Paranal, Observatorio del Teide	95
Paranal	84
Skinakas	74
Observatorio del Teide	71
Perth	60

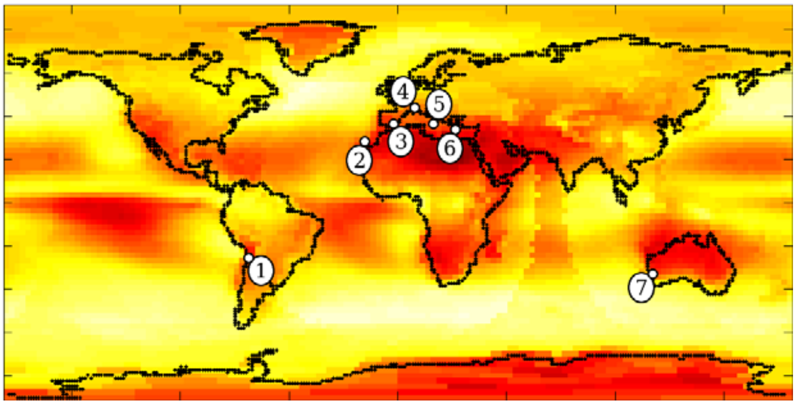

Fig. 6. Map of selected locations for a European (3, 4, 5, 6) and a world wide (1, 2, 6, 7) OGS network. 1 = Paranal Observatory, 2 = Observatorio del Teide, 3 = Calar Alto, 4 = Marseille, 5 = Catania, 6 = Skinakas, 7 = Perth.

The given networks show that it is possible to reach a direct LEO downlink availability of 99% or more when the concept of ground station diversity is used for the system setup. From the given calculations it can be seen that the number of used OGSs should be at least four OGSs in the network to reach a reasonable availability. Calculating the availability of the networks in this chapter is only done as an average statistical approximation. For a detailed evaluation of OGS locations also small scale local effects like the cloud distribution seen from the OGS and the individual satellite paths need to be taken into account. This detailed information is not available from meteorological satellite data.

Wavelength Selection and Terminal Architecture

Due to the high altitude of HAPs the effects of the atmosphere on optical beams coming from LEO satellites are much smaller compared to scenarios where the beam is received at an OGS on the ground. Due to the long horizontal propagation distance especially at low elevation angles, the wavelength has to be selected carefully because of the large variance of the absorption coefficient over the wavelength.

Generally there are two attenuation effects inside the atmosphere (besides the free-space loss which is determined by the beam divergence angle): optical absorption and scattering. These effects lead to specific transmission windows which are suitable for optical communications in the atmosphere. Beside these transmission windows it is also important that laser sources, modulators and detectors are available. The three designated wavelength regions for FSO systems are around 850nm, 1064nm and 1550nm, as shown in Figure 7.

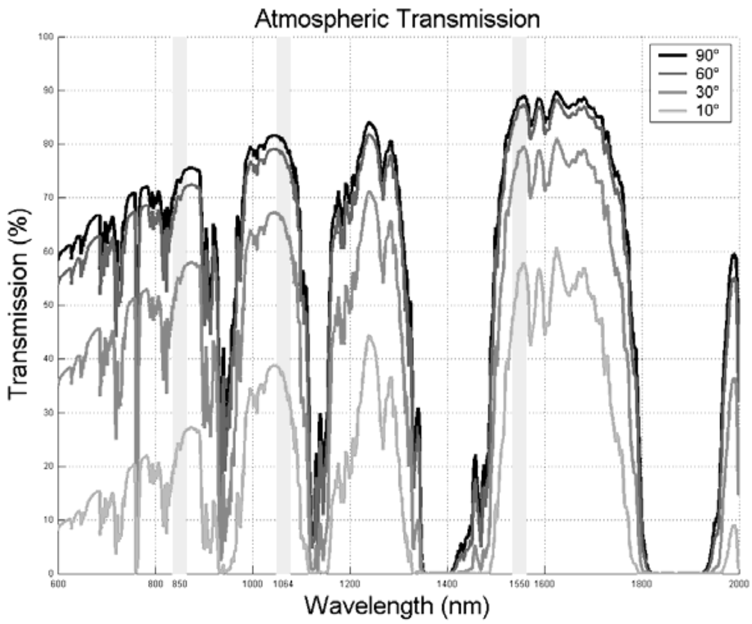

Fig. 7. Atmospheric transmission for LEO downlinks to Neustrelitz at selected elevation angles. Clear-sky atmospheric transmission windows that determine the wavelength selection for FSO and at which suitable components are available are marked by grey background coloring. The used atmosphere model is the Midlatitude Summer model combined with a rural aerosol model for the last 2km and a moderate volcanic activity model for the rest of the atmosphere.

In Figure 8 the elevation-dependence of the transmission for these three wavelengths is shown.

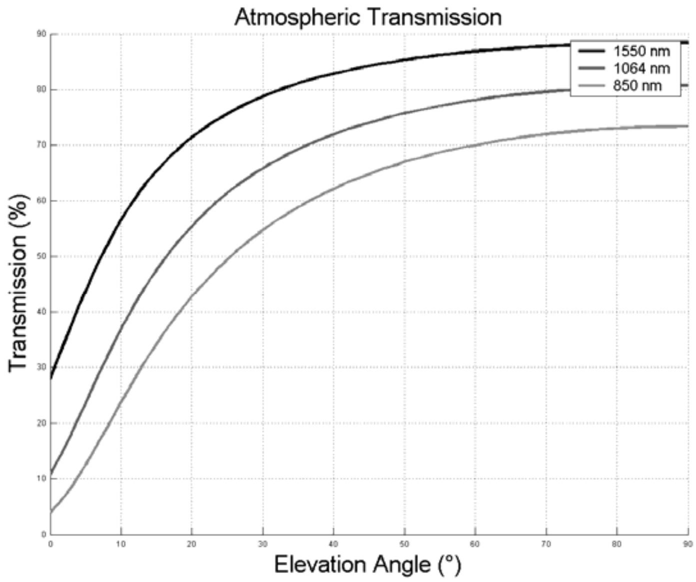

Fig. 8. Illustration of the elevation dependency of the atmospheric transmission for an optical LEO downlink to Neustrelitz at the selected wavelengths of 850nm, 1064nm and 1550nm. The atmospheric model is the same as for Fig. 7.

While sometimes also 10.6µm is considered due to its improved cloud-transmissivity, it can be shown that this improvement is more than compensated by the higher free-space loss. This wavelength lacks also available components for communications application.

800nm technology has some disadvantages: The presence of strong background light from the sun and the higher Rayleigh-scattering compared to 1064 and 1550nm. For 1064nm and 1550nm technology one of the clear advantages is the availability of high power optical fiber amplifiers to boost the transmission signal.

The wavelength of 1064nm is used for coherent systems with highly stable Nd:YAG oscillators, a laser source with very good coherence and therefore suitable for homodyne systems. This enables the implementation of homodyne binary phase-shift keying (BPSK) modulation. The advantage of these systems is the high sensitivity which leads to small aperture diameters for the optical receivers. Due to the homodyne detection scheme the communication signal is recovered at baseband, which considerably simplifies the communications electronics design compared with heterodyne or intradyne reception, but this reception technology requires diffraction limited super-positioning with the local oscillator, which is a demanding task under atmospheric index-of-refraction turbulence. Therefore, adaptive optics technologies to correct the distorted wave front might be required for its application with terrestrial OGSs. The effect of background radiation can be neglected due to the extremely small noise bandwidth of the homodyne receiver which is in the order of the data-bandwidth (e.g. 1GHz signal bandwidth corresponds to only about 3.5pm optical wavelength at 1064nm wavelength).

Optical C-Band technology around 1550nm with on/off-keying and direct detection is widely used in terrestrial fiber-optical transmission systems and has already been tested successfully in a stratospheric test-bed [3]. Current systems are not as sensitive as coherent systems but the use of fast wave-front correction systems (adaptive optics, as mentioned above) to mitigate atmospheric index of refraction turbulence would allow coupling of the received signal into a mono-mode fiber at the receiver. This is the requirement for using optical fiber pre-amplifiers. With optical pre-amplification at the receiver, the sensitivity is then comparable with current coherent systems [5].

An additional advantage of receiver concepts with wave-front correction systems for coupling into mono-mode fibers would be the enabling of Dense Wavelength Division Multiplexing (DWDM) technology. DWDM - a core technology in terrestrial fiber optical transport networks - increases the number of wavelength or channels combined onto a single fiber. Enabling this approach for free-space optics would allow the use of integrated fiber optics off the shelf components. Preference is therefore given to optical C- and L-Band technology due to the low atmospheric attenuation within this wavelength region between 1550.52nm and 1600.17 nm (more than 120 channels according to the ITU grid specification with 50 GHz channel spacing)

A possible architecture of a unidirectional DWDM-FSO system is sketched in Figure 9.

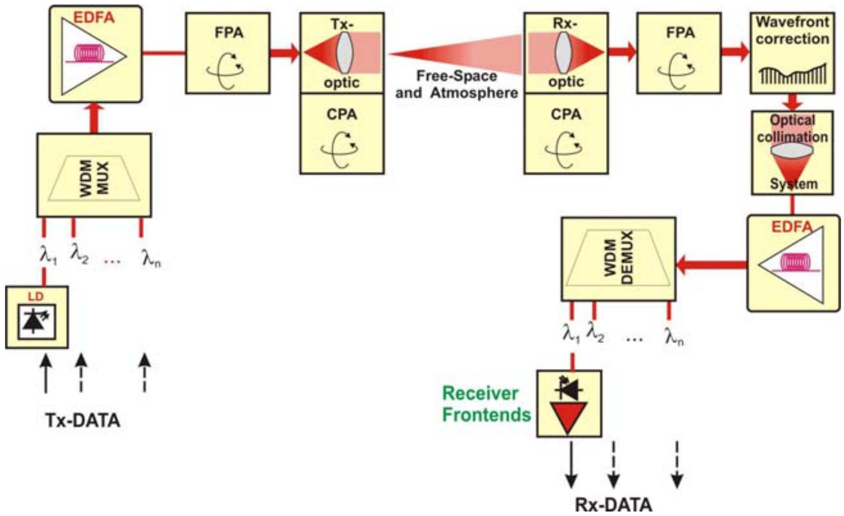

Fig. 9. Potential architecture of a future broadband free-space optical DWDM system for simplex EO-Sat downlinks

In this architecture, on the Tx-side each channel or wavelength is coupled into a single fiber by a wavelength-multiplexer and then amplified. Therefore amplifiers with erbium-doped fibers as common to terrestrial fiber communications are used (*EDFA*, Erbium Doped Fiber Amplifier). The output of the coupler is then delivered to the fine pointing assembly (FPA). The FPA is a stabilization and tracking system that removes the high frequency vibrations of the satellite in order to guarantee precise pointing. The coarse pointing assembly (CPA) is a tracking system with a wide angular range (e.g. hemispherical).

On the receiver side there exist major differences between optical terminals for satellites and optical terminals for the StORe. The spatial orientation of a satellite is usually known very precisely and the attitude changes can be controlled with similar precision (e.g. 300μrad depending on star sensors and reaction wheels). HAPs do not operate in a stable orbit but in the atmosphere. Therefore station keeping maneuvers are necessary to keep the position against the stratospheric wind. The wind can also generate oscillating movements of the payload equipment depending on the vehicle's center of gravity. Also vibrations are much stronger on HAPs compared to satellites' base motion disturbances. The high pointing and tracking requirements for optical terminals require systems that can cope with all these effects on the HAP vehicle. Therefore the control loop of the tracking system on the StORe (mainly FPA-performance) needs higher performance compared to the satellite pointing system. The FPA corrects the angle of arrival of the incoming wave front (tip/tilt correction). Changes in the angle of arrival are caused by vibrations and atmospheric turbulence. Finally the wave front correction building block corrects the higher order wave front distortions in order to reconstruct a plane wave before the signal can be coupled into the mono-mode fiber with the collimation system (this is only necessary with large Rx-apertures). In the fiber the DWDM signal is then amplified by an optical pre-amplifier. Finally the optical signal is demultiplexed and each channel is detected by a single receiver-frontend. Data rates of terminals can be 10 Gbit/s in near future and n-times this data rate by the use of the DWDM technology.

Conclusion

We have calculated the practical advantage of optical downlinks from earth observation (EO) satellites over conventional RF-downlinks in different downlink scenarios. The usability of the EO-sensor could be boosted by nearly a factor of forty with a future StORe-System (HAP-Relays) or by a factor four with simple direct downlinks to optical ground stations without RF-backup (and an OGS in a non-optimum location). This performance is offered by low-power transmit terminals with very small apertures in the range of few centimeters and according low mass.

Optical data return channels for LEO satellites using GEO relays satellites with RF-downlinks (e.g. the SILEX-system) have the advantage of higher link availability as they reliably cover nearly half of the LEO-orbit, but the system-complexity is also high. The terminal size, power consumption, and weight of optical LEO-GEO link terminals is high due to the high free-space loss and therefore this technology offers lower effective data rates and can not be carried onboard small LEO satellites. When a Ka-Band downlink from the GEO is used, this again causes a bottleneck for the data throughput. Also, the financial effort for setting up a GEO-relay scenario is much higher than for direct LEO downlinks.

It seems favorable to establish a global OGS-network (and later a StORe-Network) based on compatible technology for downlinks from LEO as well as GEO and later possibly for links from deep-space probes.

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