Research Article

Application of Single-Mode Fiber-Coupled Receivers in Optical Satellite to High-Altitude Platform Communications

Franz Fidler and Oswald Wallner

Institute of Communications and Radio-Frequency Engineering, Vienna University of Technology, Gusshausstrasse 25/389, 1040 Vienna, Austria

Correspondence should be addressed to Franz Fidler, ffidler@nt.tuwien.ac.at

In a free-space optical communication system employing fiber-optic components, the phasefront distortions induced by atmospheric turbulence limit the efficiency with which the laser beam is coupled into a single-mode fiber. We analyze different link scenarios including a geostationary (GEO) satellite, a high-altitude platform (HAP), and an optical ground station (OGS). Single-mode coupled optically preamplified receivers allow for efficient suppression of background noise and highly sensitive detection. While GEO-to-OGS communication suffers from atmospheric turbulence, we demonstrate that GEO-to-HAP communication allows for close to diffraction-limited performance when applying tip-tilt correction.

1. INTRODUCTION

Free-space laser communications—with its ability to transmit information via a collimated laser beam at high data rates using compact, low-mass terminals, while avoiding interference problems and without exhausting the radio-frequency bandwidths—are a promising candidate to satisfy the ever increasing bandwidth demand associated with new communication services. While optical intersatellite links are already operable [1], laser communication from ground suffers from cloud coverage, harsh weather conditions, and atmospheric turbulence [2]. To find a remedy, current research concentrates on optical communications from or to high-altitude platforms (HAPs)—aircrafts which are situated well above the clouds at typical heights of 17 to 22 km—where the atmospheric impact on a laser beam is less severe than directly above ground [3, 4]. An optical link between satellite and HAP could serve as a broadband communication channel if data from several sensors or RF communication terminals onboard the HAP is to be transmitted to a satellite, or if the HAP works as a data relay station, receiving information from a satellite.

While existing satellite laser communication terminals use AlGaAs semiconductor lasers with wavelengths around 830 nm [1], recent research activities focus on communication wavelengths around $\lambda = 1550$ nm. At this wavelength, highly sensitive receivers incorporating Erbium-doped fiber amplifiers (EDFAs) for optical preamplification are available [5, 6]. When using such fiber-based technology, coupling into a single-mode fiber (SMF) is required and the reduction of the fiber coupling efficiency due to atmospheric turbulence is an important issue.

The Earth's atmosphere extends approximately 700 km above the surface and consists of several distinct layers [7]. Pronounced density is found within the lowest 20 km, still influencing satellite-to-HAP links. When a laser beam propagates through a turbulent medium like the atmosphere, one observes absorption, scattering, additional beam spreading and beam wander, scintillation, and phasefront distortions. The latter results in a loss of power when the light is coupled into a single-mode fiber and—in the worst case—may lead to a link failure. Knowledge of the efficiency with which random light (i.e., light that produces speckle patterns) can be coupled into optical fibers is therefore important, for example, to assess the feasibility of using single-mode coupled, optically preamplified receivers onboard of HAPs. Other effects of atmospheric turbulence than phasefront distortions are not addressed here as they influence all types of optical

Table 1: Typical parameter set for the satellite-to-HAP communication scenario.

Parameter	Symbol	Default value
HAP altitude	h_{HAP}	20 km
Satellite altitude	h_{SAT}	35786 km (GEO)
Telescope diameter	D	13.5 cm
Zenith angle	ζ	50°
Communication wavelength	λ	1550 nm

Figure 1: Setup of an optically preamplified receiver (G: preamplifier gain, F: preamplifier noise figure, S: photodiode responsivity, R_T: transimpedance).

receivers in the same way (i.e., causing additional loss in power and intensity fluctuations).

The effect of aberrations and misalignments of optical components [8, 9], angular jitter [10], or atmospheric turbulence [11–13] on the single-mode fiber coupling efficiency has been analyzed in the field of optical communications, lidar, or astronomy. In most cases, a Gaussian approximation has been used for the fundamental fiber mode. We calculate the degradation of the mean power coupling efficiency into single-mode fiber coupled devices caused by atmospheric turbulence using the exact field of the fiber's fundamental mode. We analyze different link scenarios, as GEO-to-HAP and GEO-to-OGS, and verify the applicability of fiber coupled receivers onboard HAPs due to the reduced impact of atmospheric turbulence at high altitudes. Additional tip-tilt correction even allows for close to diffraction limited performance. By comparing our calculations with analytical models for the Strehl ratio (a standard indicator of the performance of classical imaging systems), we show that the Strehl ratio is a good approximation for the coupling efficiency into a single-mode fiber.

2. COMMUNICATION SCENARIO

Optical satellite-to-HAP connections allow establishing broadband (backhaul) links, which are required to globally receive from and distribute data to HAPs. The satellite is located at a height h_{SAT} above ground, which may range from 400 km for a low Earth orbiting satellite (LEO) to 35786 km for a geostationary satellite (GEO). The HAP altitude h_{HAP} gives the height above ground for the high-altitude platform. The telescope diameter D denotes the transmit telescope diameter in the uplink case and the receive telescope diameter in the downlink. Typically, the telescope diameters of optical antennas onboard of HAPs and satellites may vary between 0.05 m and 0.2 m. The zenith angle ζ is defined as the angle between the direction to zenith and the direction of the laser beam towards the satellite. Typical system parameter values used for the calculations in the following sections (assuming the HAP to be positioned in Central Europe) are given in Table 1.

Using a single-mode coupled optical preamplifier (cf., Figure 1) onboard the HAP allows for high sensitivity detection and is of advantage with respect to the suppression of background noise. Like in heterodyning, single-mode coupled receivers are less vulnerable to background light than,
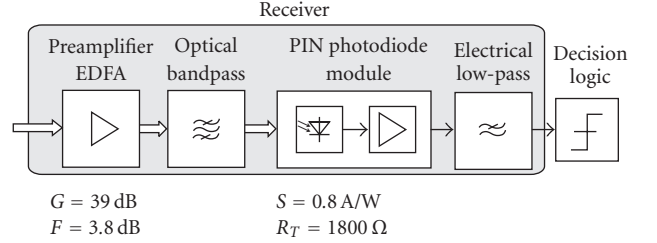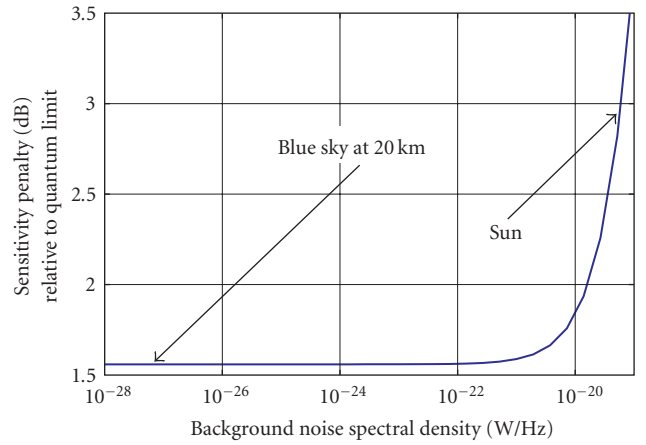

Figure 2: Calculated receiver sensitivity penalty of an optically preamplified receiver using RZ intensity modulation at a bit error probability of 10^{-9} as a function of background noise power spectral density.

for example, avalanche photodiode (APD) based receivers because the fiber provides an excellent spatial filter function and only one spatial mode (in two orthogonal directions of polarization) is detected [14] .

Figure 2 shows the calculated receiver sensitivity penalty as a function of the background noise power spectral density. The sensitivity penalty is defined as the required number of received photons per bit at a bit error probability (BEP) of 10^{-9} relative to the quantum limit of 41 photons per bit [15, 16]. For the computation, we assumed return-to-zero (RZ) intensity modulation (with a duty cycle of 33%) using an external modulator with 20-dB extinction and no polarization control at the optically preamplified receiver. Beside an EDFA (gain $G = 39$ dB and noise figure $F = 3.8$ dB), the receiver incorporates an optical fiber Bragg grating bandpass filter, a PIN-photodiode module with a sensitivity of $S = 0.8$ A/W, a transimpedance amplifier with $R_T = 1800\,\Omega$, and an electrical fifth-order Bessel lowpass filter (cf., Figure 1).

When optimizing the optical and electrical filter bandwidths, the calculated receiver sensitivity is only 1.6 dB above the quantum limit in the absence of background noise. In the case of blue sky as background source, that is, with the receiver onboard the HAP, no degradation of receiver

performance is found when compared to the case where there is no background light at all. Even when directly looking into the Sun (with a background noise power spectral density of $4.1 \cdot 10^{-20}$ W/Hz) only an additional deterioration of 1.4 dB has to be expected.

In a HAP-to-satellite uplink, the turbulent eddies forming the atmosphere are right in front of the transmitter and comparatively large relative to the optical beam (cf., Figure 3(a)). The resulting large beam spreading causes the phasefront disturbance to be negligible within the small receiving aperture at the satellite [7]. In the downlink, the turbulent eddies are relatively small when compared to the beam diameter, thus leading to noticeable phasefront distortions (cf., Figure 3(b)).

3. SINGLE-MODE FIBER COUPLING EFFICIENCY

We model the coupling as shown in Figure 4. The optical input field E—which is collected by the receive telescope of diameter D—is focussed by a thin diffraction limited lens to the bare end of a single-mode fiber, whose field distribution of the fundamental mode F as a function of the radial coordinate r is given by the Bessel function of the first kind and of zero order within the core and by the modified Bessel function of the second kind and of zero order in the cladding [17].

The power coupling efficiency η is defined as the ratio of the average power carried by the fiber mode and the average power available in the focal plane. It is possible—and often more convenient—to calculate the coupling efficiency in the aperture plane $\mathcal{A}$, that is, just in front of the coupling lens (cf., Figure 4). The mean coupling efficiency is given by

$$\langle \eta \rangle = \left\langle \left| \iint_A F(r)E(r)\exp(j\phi(r))\,dA \right|^2 \right\rangle, \qquad (1)$$

where the angled brackets represent the ensemble-average operator, $E(r)$ is the incident optical field within plane $\mathcal{A}$ normalized to a power of unity within the input aperture, and $F(r)$ is the deterministic fiber mode backpropagated into the aperture plane by means of an inverse spatial Fourier transform. A phase function $\Phi(r)$ covers any deviations from an ideal plane wavefront of the input field E. The coupling efficiency depends also on the lens-to-fiber coupling geometry, which can be taken into account via an additional coupling design parameter $\chi = \rho/r_S$, with ρ being the core radius of the fiber and r_S being the Airy radius. The parameter χ takes into account the properties of the incoming beam and of the coupling optics, while the normalized frequency $V = 2\pi\rho/\lambda(n_{co}^2 - n_{cl}^2)^{1/2}$, with core and cladding refractive indices, n_{co} and n_{cl}, determine the characteristics (e.g., the numerical aperture) of the optical fiber. Without loss of generality, we assume for the calculations to follow the fiber to be operated at single-mode cutoff ($V = 2.405$) and the lens-to-fiber geometry to be optimized for maximum coupling efficiency ($\chi = 0.5345$). In the case of a perfect phasefront, $\Phi(r) = $ const., and when approximating the fiber's eigenmode by a Gaussian field distribution a maximum coupling efficiency of $\eta_{max} = 81.5\%$ can be achieved [9]. When using
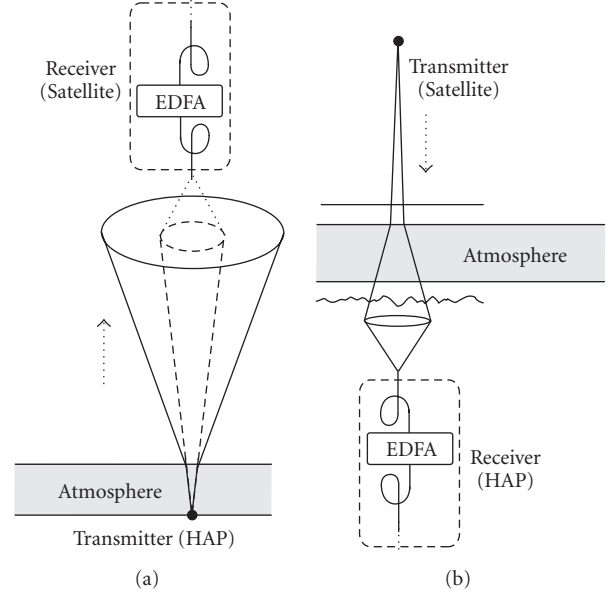

FIGURE 3: (a) Uplink: Negligible phasefront disturbance, large beam spreading. (b) Downlink: Negligible beam spread, large phasefront disturbance over receiving aperture.
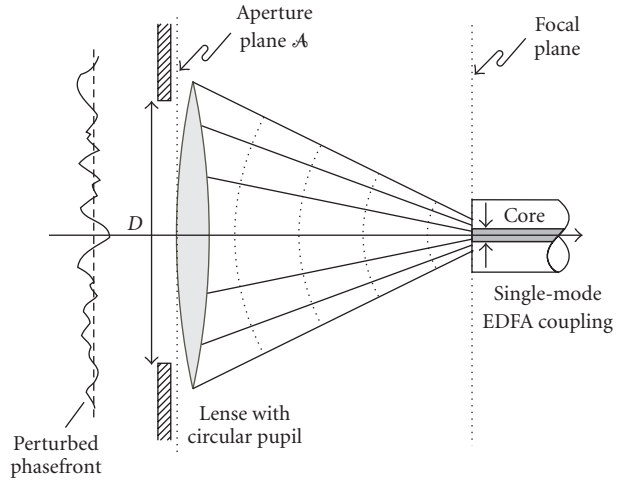

FIGURE 4: Coupling geometry: A thin lens focuses the incident field E, which is assumed to have constant amplitude but a statistically disturbed phase, onto the bare end of a single-mode fiber.

the exact field of the fiber's fundamental mode the maximum coupling efficiency amounts to $\eta_{max} = 78.6\%$, corresponding to a minimum power coupling loss of 1.05 dB.

4. TURBULENCE-INDUCED PHASEFRONT DISTORTIONS

To evaluate the influence of a phasefront disturbance on the fiber coupling efficiency, the phase function $\Phi(r)$ is modeled as a normal distribution with zero mean ($\mu_\varphi = 0$) and standard deviation σ_φ. Using (1), the resulting coupling efficiency

is calculated by means of a Monte Carlo simulation. Based on the Zernike representation of the Kolmogorov spectrum of turbulence, σ_φ can be derived depending on the receiving aperture diameter D and the Fried parameter r_0 as [7, 18, 19]

$$\sigma_\varphi = \sqrt{1.0299 (D/r_0)^{5/3}}. \tag{2}$$

The Fried parameter can be interpreted as the diameter of an aperture over which there is approximately 1 rad of rms phase distortion σ_φ^2. In accordance with [7], we calculate the Fried parameter as

$$r_0 = \left[0.423 k^2 \sec(\zeta) \int_{h_{\text{HAP}}}^{h_{\text{SAT}}} C_n^2(h) dh \right]^{-3/5}, \tag{3}$$

using the optical wave number $k = 2\pi/\lambda$ in rad/m and the structure parameter $C_n^2(h)$ in $m^{-2/3}$ at height h. The structure parameter is a measure of turbulence strength and represents the total amount of energy contained in the stochastic field of the refractive index fluctuations. It can be approximated according to the Hufnagle-Valley model [20],

$$C_n^2(h) = 5.94 \cdot 10^{-3} \, \text{m}^{-8/3} s^2 \left(\frac{\nu_{\text{RMS}}}{27} \right)^2 \left(\frac{h}{10^5 \, \text{m}} \right)^{10} \exp\left\{ \frac{-h}{1000 \, \text{m}} \right\}$$
$$+ 2.7 \cdot 10^{-16} \exp\left\{ \frac{-h}{1500 \, \text{m}} \right\} + C_n^2(0) \exp\left\{ \frac{-h}{100 \, \text{m}} \right\}. \tag{4}$$

The structure constant on ground, $C_n^2(0)$, ranges from $10^{-17} \, m^{-2/3}$ (during night and weak turbulence conditions) to $10^{-13} \, m^{-2/3}$ (during day and strong turbulence conditions). The required rms wind speed ν_{RMS} is calculated using the Bufton wind model [7, 20]:

$$\nu_{\text{RMS}} = \left[\frac{1}{15 \cdot 10^3} \int_{5 \cdot 10^3}^{20 \cdot 10^3} \left\{ \nu_{\text{wind}} + \nu_T \exp\left[-\left(\frac{h - h_T}{d_T} \right)^2 \right] \right\}^2 dh \right]^{1/2}. \tag{5}$$

The quantity ν_{wind} is the ground wind speed, ν_T is the wind speed at the tropopause, h_T is the height of the tropopause, and d_T is its thickness. For our calculations, we assume $\nu_{\text{wind}} = 3$ m/s, $\nu_T = 30$ m/s, $h_T = 9.4$ km, $d_T = 4.8$ km, and a structure constant on ground of $C_n^2(0) = 1.7 \cdot 10^{-14} \, m^{-2/3}$, which are typical values for clear sky and weak turbulence conditions.

5. COMPARISON OF LINK SCENARIOS

A comparison between the single-mode fiber coupling efficiency in a satellite-to-ground communication link and a satellite-to-HAP scenario shows the feasibility of using fiber coupled receivers onboard HAPs due to the reduced impact of atmospheric turbulence at high altitudes. Figure 5 gives the coupling efficiency as a function of the rms phasefront perturbation, RMS_λ, expressed in fractions of the wavelength λ. For the calculations (using the methods as described in Sections 3 and 4), we assumed a wavelength of 1550 nm and a standard (telecommunications) single-mode fiber with a
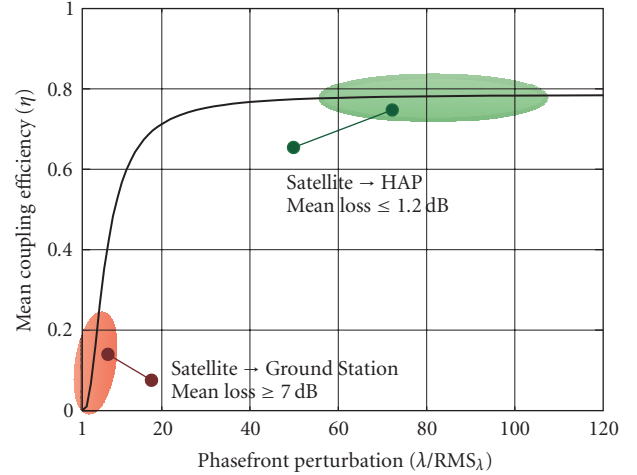

FIGURE 5: Mean coupling efficiency $\langle \eta \rangle$ for a standard single-mode fiber as a function of the rms phasefront perturbation RMS_λ given in fractions of the wavelength λ.

core diameter of $10 \, \mu m$ a core refractive index of 1.46, and a core/cladding refractive indices difference of 0.3%. As expected, the characteristic shown in Figure 5 is rather flat for small perturbations, but drops dramatically to very small values for large disturbances. For typical satellite-to-HAP communication links (i.e., with $h_{\text{HAP}} > 17$ km and $D < 20$ cm), the mean coupling loss is always less than 1.2 dB, while for communication links to a ground station it significantly increases to values larger than 7 dB.

The mean value of the coupling efficiency into a SMF as a function of the zenith angle according to (1) is shown in Figure 6(a) for the following three scenarios: (i) a GEO-to-HAP link with the HAP at $h_{\text{HAP}} = 20$ km and a receive telescope diameter of $D = 0.135$ m, (ii) a GEO-to-HAP link with $D = 0.135$ m and $h_{\text{HAP}} = 2400$ m, and (iii) a GEO-to-ground link with a telescope diameter $D = 1$ m at an optical ground station.

At high altitudes, $\langle \eta \rangle$ is roughly invariant with zenith angle and very close to the maximum possible coupling efficiency of 78.6%. With decreasing height also the coupling efficiency decreases due to increasing turbulence leading to noticeable phasefront perturbations especially at zenith angles $\zeta > 50°$. The phasefront perturbation over a large aperture like at the OGS is more severe than at a HAP, leading to a poor coupling efficiency which, in practice, excludes the use of a single-mode coupled receiver within a ground station.

If the spatial period of the phasefront perturbation is clearly smaller than the pupil diameter, the normalized mean power coupling efficiency is sometimes estimated by the Strehl ratio SR [13], which is defined as the ratio of peak power in the center of the image plane compared to that of an equivalent unaberrated (diffraction-limited) system. It is useful to have an approximate predictor for the coupling efficiency based on the SR which is also a standard indicator of the performance of classical and adaptive (astronomical) imaging systems. Under general conditions, not limited to
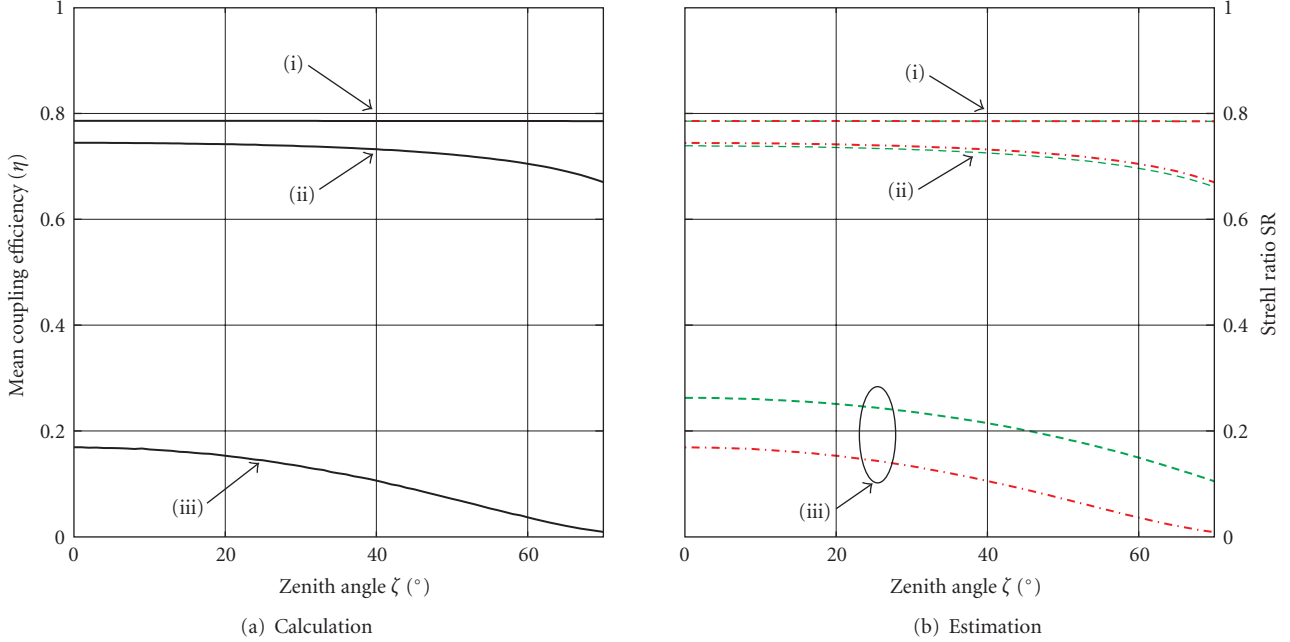
FIGURE 6: (a) Calculated coupling efficiency (1) and (b) estimation of coupling efficiency using the Strehl ratio (dashed line: (6), dashed-dotted line: (7)) versus zenith angle for three different link scenarios: (i) GEO-to-HAP with $h_{HAP} = 20$ km and $D = 0.135$ m, (ii) GEO-to-HAP with $h_{HAP} = 2400$ m and $D = 0.135$ m, and (iii) GEO-to-ground with $h_{ground} = 2400$ m and $D = 1$ m at the OGS.

weak fluctuations, the Strehl ratio for an untracked beam can be approximated by the expression [7]

$$SR_1 = \left[1 + \left(\frac{D}{r_0}\right)^{5/3}\right]^{-6/5}. \quad (6)$$

Another widely used empirical formula is the Marechal approximation [13, 19],

$$SR_2 = \exp(-\sigma_\varphi^2), \quad (7)$$

where σ_φ^2 is the variance of the phase aberration across the receiving aperture D. An estimation of the coupling efficiency using these approximations is given in Figure 6(b), showing good agreement with the computationally more intensive calculation of Figure 6(a) in the communication scenarios where HAPs are involved, that is, at high altitudes and when using small telescope diameters.

The phase variance averaged over a circular aperture of diameter D as given in (2) drops to

$$\sigma_{\varphi,\text{track}} = \sqrt{0.134(D/r_0)^{5/3}}, \quad (8)$$

if the tip and tilt components of the atmospheric perturbations are removed by means of active target tracking [18, 19]. Thus applying tip-tilt correction reduces the phase variance by a factor of $1.0299/0.134 = 7.7$, independent of the diameter of the telescope. Figure 7 compares the coupling loss into an SMF for an untracked beam and for a tip-tilt corrected system in a GEO-to-HAP downlink (at different turbulence conditions and using the parameters as given in Table 1). The

coupling loss is normalized to the maximum mean coupling efficiency of 78.6%. When tracking is performed by means of a tiltable mirror, the coupling loss is noticeably reduced compared to the untracked case. The advantage of using large wavelengths and HAP altitudes of more than 15 km, leading to negligible coupling loss, is also shown in Figure 7.

Figures 6 and 7 illustrate that using a telescope with D less than a few times r_0 as it is the case in a typical satellite-to-HAP communication scenario, will, after tip-tilt correction, lead to a residual phase variance which is small compared to unity and therefore results in close-to-diffraction-limited performance.

6. SUMMARY

We have analyzed the effect of atmospheric turbulence on a free-space optical communication system employing fiber-optic components for different link scenarios including a geostationary satellite, a high-altitude platform, and an optical ground station. We show that single-mode coupled optically preamplified receivers allow for efficient suppression of background noise and highly sensitive detection. While the phase perturbations in a downlink from GEO-to-OGS prevent the use of optically preamplified receivers because of the low achievable coupling efficiency, the perturbations are small in typical GEO-to-HAP links, thus allowing for efficient single-mode fiber coupling. Active tip-tilt correction reduces phasefront perturbations and allows for achieving close to diffraction limited performance. We showed that the Strehl ratio is a good approximation for the coupling efficiency into a single-mode coupled receiver.
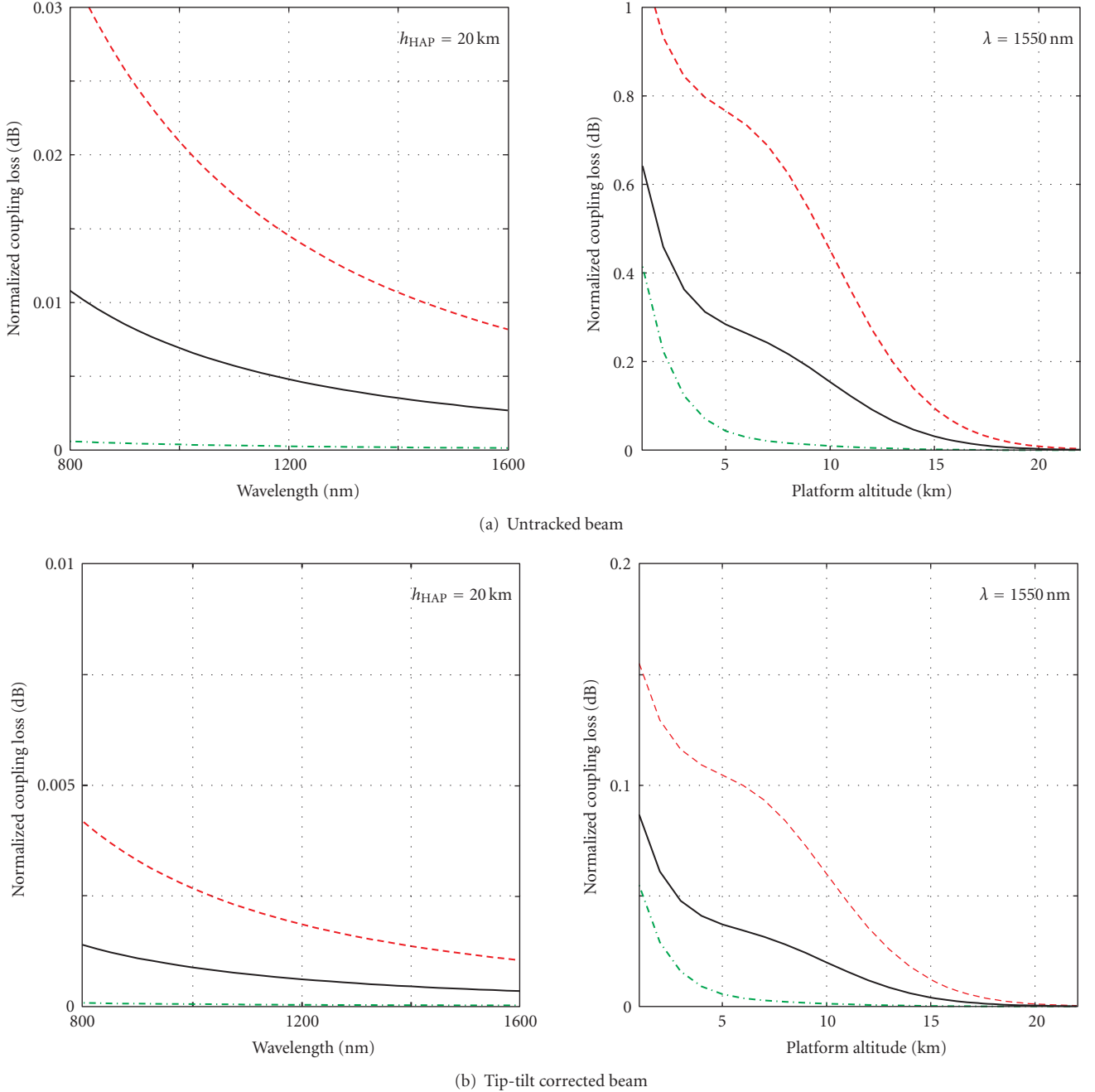
(a) Untracked beam

(b) Tip-tilt corrected beam

FIGURE 7: Normalized coupling loss into a standard single-mode fiber for a GEO-to-HAP downlink versus wavelength λ, and platform altitude h_{HAP} in the case of (a) an untracked beam and (b) a tip-tilt corrected beam. (dashed-dotted line: $v_{\mathrm{wind}} = 0\,\mathrm{m/s}$, $C_n^2(0) = 10^{-17}\,\mathrm{m}^{-2/3}$, solid line: $v_{\mathrm{wind}} = 3\,\mathrm{m/s}$, $C_n^2(0) = 1.7 \cdot 10^{-14}\,\mathrm{m}^{-2/3}$, dashed line: $v_{\mathrm{wind}} = 20\,\mathrm{m/s}$, $C_n^2(0) = 10^{-13}\,\mathrm{m}^{-2/3}$).

ACKNOWLEDGMENTS

REFERENCES

[1] G. Planche and V. Chorvalli, "SILEX in-orbit performances," in *Proceedings of the 5th International Conference on Space Op-* tics (ICSO '04), pp. 403–410, Toulouse, France, March -April 2004.

[2] S. Arnon, N. S. Kopeika, D. Kedar, et al., "Performance limitation of laser satellite communication due to vibrations and atmospheric turbulence: down-link scenario," *International Journal of Satellite Communications and Networking*, vol. 21, no. 6, pp. 561–573, 2003.

[3] J. Horwath, M. Knapek, B. Epple, M. Brechtelsbauer, and B. Wilkerson, "Broadband backhaul communication for stratospheric platforms: the stratospheric optical payload experiment (STROPEX)," in *Free-Space Laser Communications VI*,

vol. 6304 of *Proceedings of the SPIE*, pp. 1–12, San Diego, Calif, USA, August 2006.

[4] COST 297, "HAPCOS—High Altitude Platforms for Communications and Other Services," October 2007, www.hapcos.org.

[5] A. Polishuk and S. Arnon, "Optimization of a laser satellite communication system with an optical preamplifier," *Journal of the Optical Society of America A*, vol. 21, no. 7, pp. 1307–1315, 2004.

[6] M. Pfennigbauer, M. M. Strasser, M. Pauer, and P. J. Winzer, "Dependence of optically preamplified receiver sensitivity on optical and electrical filter bandwidths-measurement and simulation," *IEEE Photonics Technology Letters*, vol. 14, no. 6, pp. 831–833, 2002.

[7] L. C. Andrews and R. L. Phillips, *Laser Beam Propagation through Random Media*, SPIE, Bellingham, Wash, USA, 2nd edition, 2005.

[8] R. E. Wagner and W. J. Tomlinson, "Coupling efficiency of optics in single-mode fiber components," *Applied Optics*, vol. 21, no. 15, pp. 2671–2688, 1982.

[9] O. Wallner, P. J. Winzer, and W. R. Leeb, "Alignment tolerances for plane-wave to single-mode fiber coupling and their mitigation by use of pigtailed collimators," *Applied Optics*, vol. 41, no. 4, pp. 637–643, 2002.

[10] M. Toyoshima, "Maximum fiber coupling efficiency and optimum beam size in the presence of random angular jitter for free-space laser systems and their applications," *Journal of the Optical Society of America A*, vol. 23, no. 9, pp. 2246–2250, 2006.

[11] P. J. Winzer and W. R. Leeb, "Fiber coupling efficiency for random light and its applications to lidar," *Optics Letters*, vol. 23, no. 13, pp. 986–988, 1998.

[12] Y. Dikmelik and F. M. Davidson, "Fiber-coupling efficiency for free-space optical communication through atmospheric turbulence," *Applied Optics*, vol. 44, no. 23, pp. 4946–4952, 2005.

[13] C. Ruilier and F. Cassaing, "Coupling of large telescopes and single-mode waveguides: application to stellar interferometry," *Journal of the Optical Society of America A*, vol. 18, no. 1, pp. 143–149, 2001.

[14] W. R. Leeb, "Degradation of signal to noise ratio in optical free space data links due to background illumination," *Applied Optics*, vol. 28, no. 15, pp. 3443–3449, 1989.

[15] G. Jacobsen, *Noise in Digital Optical Transmission Systems*, Artech House, Boston, Mass, USA, 1st edition, 1994.

[16] P. J. Winzer, M. Pfennigbauer, M. M. Strasser, and W. R. Leeb, "Optimum filter bandwidths for optically preamplified NRZ receivers," *Journal of Lightwave Technology*, vol. 19, no. 9, pp. 1263–1273, 2001.

[17] A. W. Snyder and J. D. Love, *Optical Waveguide Theory*, Chapman & Hall, Boca Raton, Fla, USA, 1st edition, 1991.

[18] R. J. Noll, "Zernike polynomials and atmospheric turbulence," *Journal of the Optical Society of America*, vol. 66, no. 3, pp. 207–211, 1976.

[19] R. K. Tyson, *Principles of Adaptive Optics*, Academic Press, San Diego, Calif, USA, 2nd edition, 1997.

[20] R. E. Hufnagel, "Variations of atmospheric turbulence," in *Digest of Technical Papers, Optical Propagation through Turbulence: Topical Meeting*, pp. Wa1-1–Wa1-4, Boulder, Colo, USA, July 1974.

Special Issue on
Formal Techniques for Embedded Systems
Design and Validation

Call for Papers

Computing platforms that are embedded within larger systems they control, called embedded systems, are inherently very complex as they are responsible for controlling and regulating multiple system functionalities. Often embedded systems are also safety-critical requiring high degree of reliability and fault tolerance. Examples include distributed microprocessors controlling the modern cars or aircrafts and airport baggage handling system that track and trace unsafe baggage. To address this growing need for safety and reliability, formal techniques are increasingly being adapted to suit embedded platforms. There has been widespread use of synchronous languages such as Esterel for the design of automotive and flight control software that requires stronger guarantees. Languages like Esterel not only provide nice features for high-level specification but also enable model checking-based verification due to their formal semantics. Other semiformal notations are also being proposed as standards to specify industrial embedded systems using, for example, the newly developed IEC61499 standard for process control. This standard primarily focuses on component-oriented description of embedded control systems. The goal of this special issue is to bring together a set of high-quality research articles looking at different applications of formal or semiformal techniques in specification, verification, and synthesis of embedded systems.

Topics of interest are (but not limited to):

- Verification of system-level languages
- Verification of embedded processors
- Models of computation and verification
- Models of computation for heterogeneous embedded systems
- IP verification issues
- Open system verification techniques such as module checking and applications of module checking
- Formal techniques for protocol matching and interface process generation
- Applications of DES control theory in open system verification

- Adaptive techniques for open system verification
- Verification techniques for automatic debugging of embedded systems
- Formal approaches for secure embedded systems
- Hardware-software coverification of embedded systems
- Compositional approaches for SOC verification
- Verification of distributed embedded system

Before submission authors should carefully read over the journal's Author Guidelines, which are located at http://www.hindawi.com/journals/es/guidelines.html. Authors should follow the EURASIP Journal on Embedded Systems manuscript format described at the journal's site http://www.hindawi.com/journals/es/. Prospective authors should submit an electronic copy of their complete manuscript through the journal's Manuscript Tracking System at http://mts.hindawi.com/, according to the following timetable:

Manuscript Due	August 1, 2008
First Round of Reviews	November 1, 2008
Publication Date	February 1, 2009

Guest Editors

Partha S. Roop, Department of Electrical & Computer Engineering, University of Auckland, Auckland 1142, New Zealand; p.roop@auckland.ac.nz

Samik Basu, Department of Computer Science, Iowa State University, Ames, IA 50011, USA; sbasu@cs.iastate.edu

Chong-Min Kyung, Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Daejeon 305-701, South Korea; kyung@ee.kaist.ac.kr

Gregor Goessler, INRIA Grenoble-Rhône-Alpes, 38334 Saint Ismier Cedex, France; gregor.goessler@inrialpes.fr

Special Issue on
Active Antennas for Space Applications

Call for Papers

Over the last years, many journal articles appeared on the principles, analysis, and design of active and active integrated antennas (AAs and AIAs). An AA is a single system comprising both a radiating element and one or more active components which are tightly integrated. This gives clear advantages in terms of costs, dimensions, and efficiency. In the case of an AIA, both the active device and the radiator are integrated on the same substrate. Both options lead to very compact, low-loss, flexible antennas, and this is very important especially at high frequencies, such as those typical of a satellite link. As microwave integrated-circuit and the microwave monolithic integrated-circuit technologies have ripened, AA and AIA applications have become more and more interesting, not only at a scientific level but also from a commercial point of view, up to the point that they have recently been applied to phased array antennas on board moving vehicles for satellite broadband communication systems.

The goal of this special issue it to present the most recent developments and researches in this field, with particular attention to space-borne applications, as well as to enhance the state of the art and show how AAs and AIAs can meet the challenge of the XXI century telecommunications applications.

Topics of interest include, but are not limited to:

- Active (integrated) antenna design, analysis, and simulation techniques
- Active (integrated) antenna applications in arrays, retrodirective arrays and discrete lenses
- Millimeter-wave active (integrated) antennas

Authors should follow International Journal of Antennas and Propagation manuscript format described at the journal site http://www.hindawi.com/journals/ijap/. Prospective authors should submit an electronic copy of their complete manuscript through th journal Manuscript Tracking System at http://mts.hindawi.com/, according to the following timetable:

Manuscript Due	September 1, 2008
First Round of Reviews	December 1, 2008
Publication Date	March 1, 2009

Guest Editors

Stefano Selleri, Department of Electronics and Telecommunications, University of Florence, Via C. Lombroso 6/17, 50137 Florence, Italy; stefano.selleri@unifi.it

Giovanni Toso, European Space Rechearch and Technology Center (ESTEC), European Space Agency (ESA), Keplerlaan 1, PB 299, 2200 AG Noordwijk, The Netherlands; giovanni.toso@esa.int

Special Issue on

FPGA Supercomputing Platforms, Architectures, and Techniques for Accelerating Computationally Complex Algorithms

Call for Papers

Field-programmable gate arrays (FPGAs) provide an alternative route to high-performance computing where fine-grained synchronisation and parallelism are achieved with lower power consumption and higher performance than just microprocessor clusters. With microprocessors facing the "processor power wall problem" and application specific integrated circuits (ASICs) requiring expensive VLSI masks for each algorithm realisation, FPGAs bridge the gap by offering flexibility as well as performance. FPGAs at 65 nm and below have enough resources to accelerate many computationally complex algorithms used in simulations. Moreover, recent times have witnessed an increased interest in design of FPGA-based supercomputers.

This special issue is intended to present current state-of-the-art and most recent developments in FPGA-based supercomputing platforms and in using FPGAs to accelerate computationally complex simulations. Topics of interest include, but are not limited to, FPGA-based supercomputing platforms, design of high-throughput area time-efficient FPGA implementations of algorithms, programming languages, and tool support for FPGA supercomputing. Together these topics will highlight cutting-edge research in these areas and provide an excellent insight into emerging challenges in this research perspective. Papers are solicited in any of (but not limited to) the following areas:

- Architectures of FPGA-based supercomputers
  - History and surveys of FPGA-based supercomputers architectures
  - Novel architectures of supercomputers, including coprocessors, attached processors, and hybrid architectures
  - Roadmap of FPGA-based supercomputing
  - Example of acceleration of large applications/simulations using FPGA-based supercomputers
- FPGA implementations of computationally complex algorithms
  - Developing high throughput FPGA implementations of algorithms
  - Developing area time-efficient FPGA implementations of algorithms

  - Precision analysis for algorithms to be implemented on FPGAs
- Compilers, languages, and systems
  - High-level languages for FPGA application development
  - Design of cluster middleware for FPGA-based supercomputing platforms
  - Operating systems for FPGA-based supercomputing platforms

Prospective authors should follow the EURASIP Journal on Embedded Systems manuscript format described at the journal site http://www.hindawi.com/journals/es/. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/, according to the following timetable:

Manuscript Due	July 1, 2008
First Round of Reviews	October 1, 2008
Publication Date	January 1, 2009

Guest Editors

Vinay Sriram, Defence and Systems Institute, University of South Australia, Adelaide, South Australia 5001, Australia; vinay.sriram@unisa.edu.au

David Kearney, School of Computer and Information Science, University of South Australia, Adelaide, South Australia 5001, Australia; david.kearney@unisa.edu.au

Lakhmi Jain, School of Electrical and Information Engineering, University of South Australia, Adelaide, South Australia 5001, Australia; lakhmi.jain@unisa.edu.au

Miriam Leeser, School of Electrical and Computer Engineering, Northeastern University, Boston, MA 02115, USA; mel@coe.neu.edu

Special Issue on
Network Structure and Biological Function: Reconstruction, Modelling, and Statistical Approaches

Call for Papers

We are particularly interested in contributions, which elucidate the relationship between structure or dynamics of biological networks and biological function. This relationship may be observed on different scales, for example, on a global scale, or on the level of subnetworks or motifs.

Several levels exist on which to relate biological function to network structure. Given molecular biological interactions, networks may be analysed with respect to their structural and dynamical patterns, which are associated with phenotypes of interest. On the other hand, experimental profiles (e.g., time series, disturbances) can be used to reverse engineer network structures based on a model of the underlying functional network.

Is it possible to detect the interesting features with the current methods? And how is our picture of the relationsship between network structure and biological function affected by the choice of methods?

Perspectives both from simulation approaches as well as the evaluation of experimental data and combinations thereof are welcome and will be integrated within this special issue.

Authors should follow the EURASIP Journal on Bioinformatics and Systems Biology manuscript format described at the journal site http://www.hindawi.com/journals/bsb/. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/, according to the following timetable:

Manuscript Due	June 1, 2008
First Round of Reviews	September 1, 2008
Publication Date	December 1, 2008

Guest Editors

J. Selbig, Bioinformatics Chair, Institute for Biochemistry and Biology, University of Potsdam, Germany; selbig@mpimp-golm.mpg.de

M. Steinfath, Institute for Biochemistry and Biology, University of Potsdam, Germany; steinfath@mpimp-golm.mpg.de

D. Repsilber, AG Biomathematics & Bioinformatics, Genetics and Biometry and Genetics Section, Research Institute for the Biology of Farm Animals, Dummerstorf, Germany; repsilber@fbn-dummerstorf.de

Special Issue on
OFDMA Architectures, Protocols, and Applications

Call for Papers

Orthogonal frequency-division multiple access (OFDMA) technologies are currently attracting intensive attention in wireless communications to meet the ever-increasing demands arising from the explosive growth of Internet, multimedia, and broadband services. OFDMA-based systems are able to deliver high data rate, operate in the hostile multipath radio environment, and allow efficient sharing of limited resources such as spectrum and transmit power between multiple users. OFDMA has been used in the mobility mode of IEEE 802.16 WiMAX, is currently a working specification in 3GPP Long Term Evolution downlink, and is the candidate access method for the IEEE 802.22 "wireless regional area networks." Clearly, recent advances in wireless communication technology have led to significant innovations that enable OFDMA-based wireless access networks to provide better quality-of-service (QoS) than ever with convenient and inexpensive deployment and mobility.

However, regardless of the technology used, OFDMA networks must not only be able to provide reliable and high quality broadband services, but also be implemented cost-effectively and be operated efficiently. OFDMA presents many of the advantages and challenges of OFDM systems for single users, and the extension to multiple users introduces many further challenges and opportunities, both on the physical layer and at higher layers. These requirements present many challenges in the design of network architectures and protocols, which have motivated a significant amount of research in the area. Also, many critical problems associated with the applications of OFDMA technologies in future wireless systems are still looking for efficient solutions. The aim of this special issue is to present a collection of high-quality research papers that report the latest research advances in this field from physical and network layers to practical applications. Original papers are solicited in all aspects of OFDMA techniques including physical layer issues, architectures, protocol designs, enabling technologies, theoretical studies, practical applications, and experimental prototypes. Topics of interest include, but are not limited to:

- Adaptive coding and modulation
- Signal processing for OFDMA
- Interference control techniques
- Bandwidth and resources allocation
- Efficient MAC protocol development
- Routing algorithms and congestion control schemes
- MAC and network layer management
- Cross-layer design and optimization
- Cooperative and game theoretic analysis
- Quality of service provisioning
- Network modeling and performance analysis
- Security and privacy management
- Broadband Wireless Access
- Testbed, experiment, implementation, standards, and practical applications

Authors should follow the EURASIP Journal on Wireless Communications and Networking manuscript format described at the journal site http://www.hindawi.com/journals/wcn/. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/, according to the following timetable.

Manuscript Due	August 1, 2008
First Round of Reviews	November 1, 2008
Publication Date	February 1, 2009

Guest Editors

Victor C.M. Leung, The University of British Columbia, 2329 West Mall Vancouver, BC, Canada, V6T 1Z4; vleung@ece.ubc.ca

Alister G. Burr, Department of Electronics, University of York, York, YO10-5DD, UK; alister@ohm.york.ac.uk

Lingyang Song, Wireless Group, Philips Research Laboratories, Cross Oak Lane, Redhill, Surrey RH1 5HA, UK; lingyang.song@philips.com

Yan Zhang, Simula Research Laboratory, 1325 Lysaker, Norway; yanzhang@ieee.org

Thomas Michael Bohnert, Siemens AG, 80312 Munich, Germany; thomas.bohnert@siemens.com

Research Letters in
Communications

Why publish in this journal?

Research Letters in Communications is devoted to very fast publication of short, high-quality manuscripts in the broad field of communications. The journal aims for a publication speed of 60 days from submission until final publication. Articles will be limited to a maximum of four published pages, and they should convey important results that have not been previously published.

Why publish in this journal?

Wide Dissemination

All articles published in the journal are freely available online with no subscription or registration barriers. Every interested reader can download, print, read, and cite your article

Quick Publication

The journal employs an online «Manuscript Tracking System» which helps streamline and speed the peer review so all manuscripts receive fast and rigorous peer review. Accepted articles appear online as soon as they are accepted, and shortly after, the final published version is released online following a thorough in-house production process.

Professional Publishing Services

The journal provides professional copyediting, typesetting, graphics, editing, and reference validation to all accepted manuscripts.

Keeping Your Copyright

Authors retain the copyright of their manuscript, which are published using the "Creative Commons Attribution License," which permits unrestricted use of all published material provided that it is properly cited.
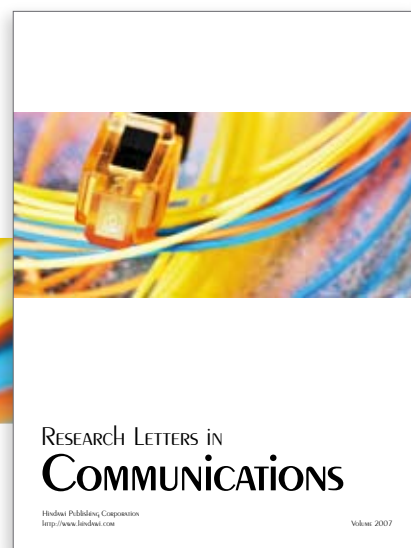
Extensive Indexing

Articles published in this journal will be indexed in several major indexing databases to ensure the maximum possible visibility of each published article.

Submit your Manuscript Now...

Please visit the journal's website found at **http://www.hindawi.com/journals/rlc/** in order to submit your manuscript and click on the "Manuscript Submission" link in the navigational bar.

Should you need help or have any questions, please drop an email to the journal's editorial office at **rlc@hindawi.com**