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ESTIMATION OF COMMUNICATION DEVICE CHARACTERISTICS FOR NON-LINE-OF-SIGHT ATMOSPHERIC OPTICAL COMMUNICATION ON SCATTERED RADIATION

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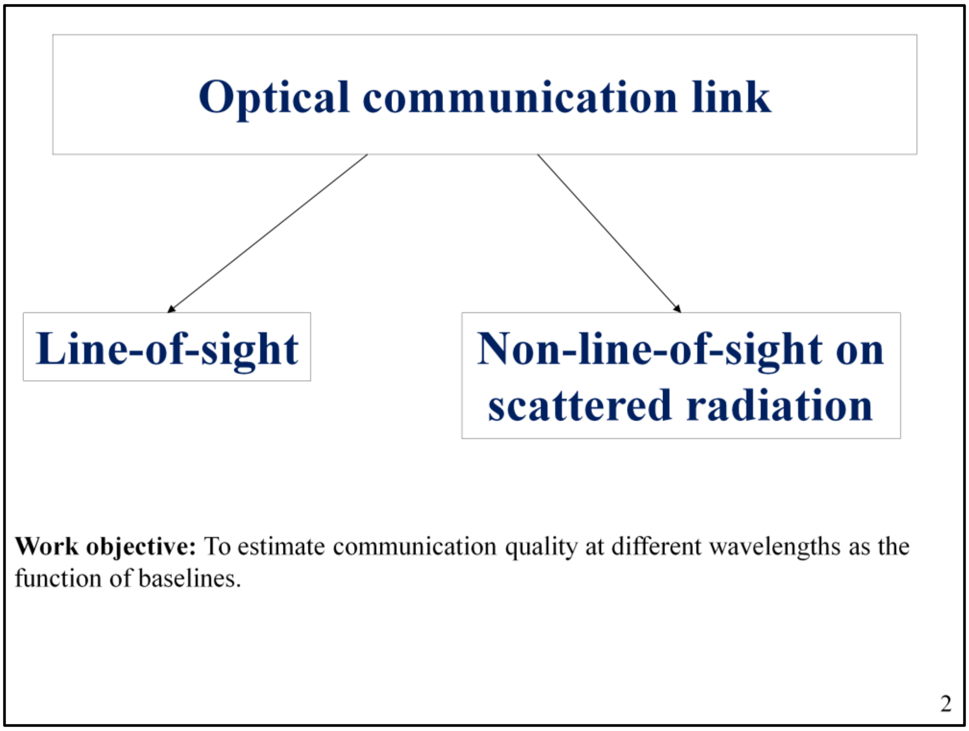
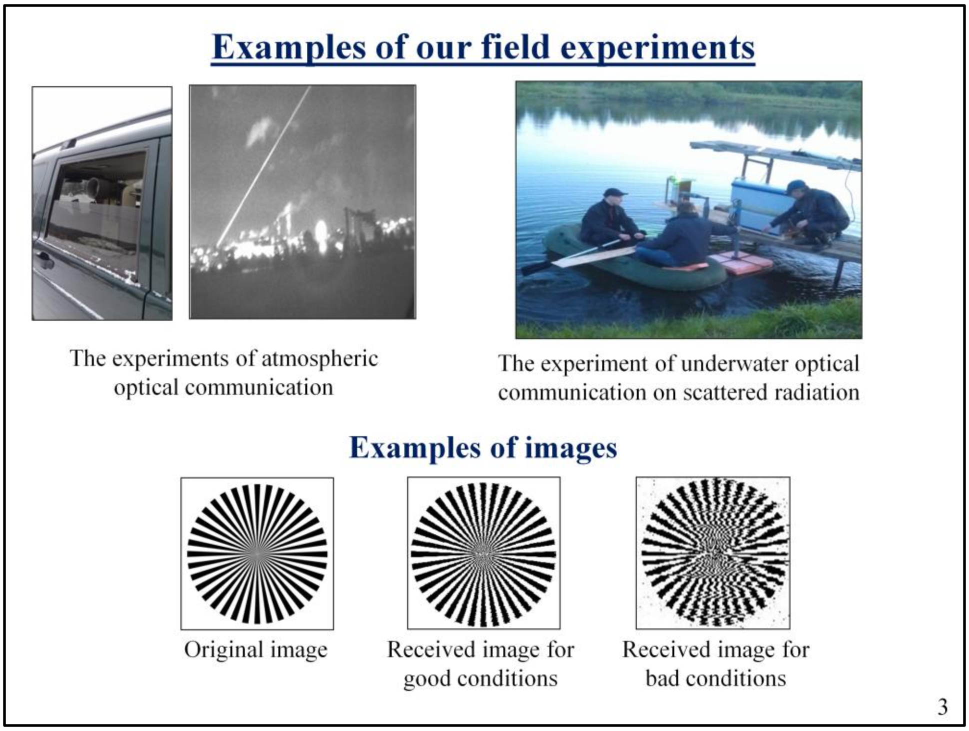
Dear colleagues, the topic of my talk today is “ESTIMATION OF COMMUNICATION DEVICE CHARACTERISTICS FOR NON-LINE-OF SIGHT ATMOSPHERIC OPTICAL COMMUNICATION ON SCATTERED RADIATION”.



In general, optical communication in atmosphere is a way to transmit information through the open atmospheric link. The following schemes of atmospheric optical communication channels can be identified:

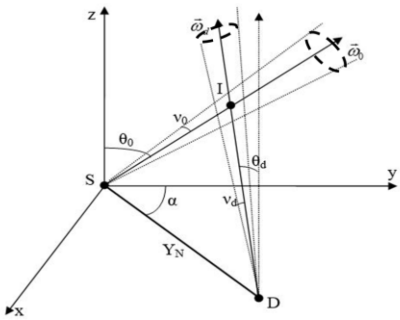
1) line-of-sight communication, and
2) multicast non-line-of-sight communication.

Optical communication on scattered radiation can be used to transfer information simultaneously to several subscribers. The use of this scheme of communication also allows us to change geometric conditions of the link for different situations. Other advantages of this type of communication are the security of the link, noise immunity and potentially high data transfer rate.



Therefore, the development of this type of communication is an important problem. To solve this problem in the institute of atmospheric optics theoretical and experimental investigations have been carried out for many years. In our field experiments we use transceiver system with small angles of divergence and field of view. In the slide you can see some photos from our field experiments, and examples of received images in one of these experiments. But in the experiment it’s impossible to find optimal schemes of communications. Only theoretical research can find these schemes. So in this talk let’s consider in details our theoretical results.

Problem description



Geometric scheme of an atmospheric communication link.

- Atmosphere - absorbing and scattering aerosol-gas medium;
- the atmosphere consists of plane-parallel homogeneous layers;
- no reflection from water or ground surface;
- source transmits a δ - pulse.
- source zenith angle θ_0, source divergence angle ν_0;
- Y_N - baseline;
- receiver zenith angle θ_d, field-of-view angle ν_d;
- angle between plane of transmitting system and plane of receiving system α
- It is required to find impulse response (IR) *h(t)*

The received signal is generally defined as [1]:

$$P(t) = S\int_0^\infty P_0(t')h(t-t')dt' = S \cdot p(t) \qquad (1)$$

1. Zuev V.E., Belov V.V., Veretennikov V.V., Theory of Systems in Optics of Disperse Media // Tomsk: Spectr, Publishing House of IAO SB RAS, 1997, 402 p.

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If the power of input signal is known then the use of this convolution integral it is possible to recover the response of the linear system to any input signal. So, it is enough to find the impulse response.
The finding of the impulse response for atmospheric link is carried out in the following conditions (Figure 1). From the origin of coordinates on ground surface a point source transmits a laser pulse in cone with the direction of axis ω_0, the zenith angle of this direction is θ_0. At the baseline Y_N at the angle α the ground surface, a receiving system is navigated in direction ω_d. The zenith angle of its axis is θ_d. The optical axis of the receiving system is navigated to the point I on the radiation axis of source. It is necessary to determine the impulse response of the link for the given conditions of its organization.
The calculation of the impulse response for the atmospheric communication channel is performed by the Monte Carlo method with modified double local estimations at each collision points of photon trajectories.

Estimation of communication quality depending on angles and baseline

Calculation conditions:

- wavelength λ=0.3, 0.5, 0.9 μm;
- meteorological range of visibility S_M=10 и 50 km ($\tau_{0.55}$=0.8 and 0.29);
- clear atmosphere;
- source zenith angle θ_0=0, 85^0;
- receiver zenith angle θ_d =85^0;
- source divergence angle ν_0=0.0034^0;
- field of view angle ν_d=2^0;
- baseline Y_N=0.5-50 km;
- angle between plane of transmitting system and plane of receiving system α=0^0,10^0,30^0,60^0,90^0;
- number of time ranges N_1=5, N_2=30, N_3=15;
- maximum path length l_{max}=200 km;

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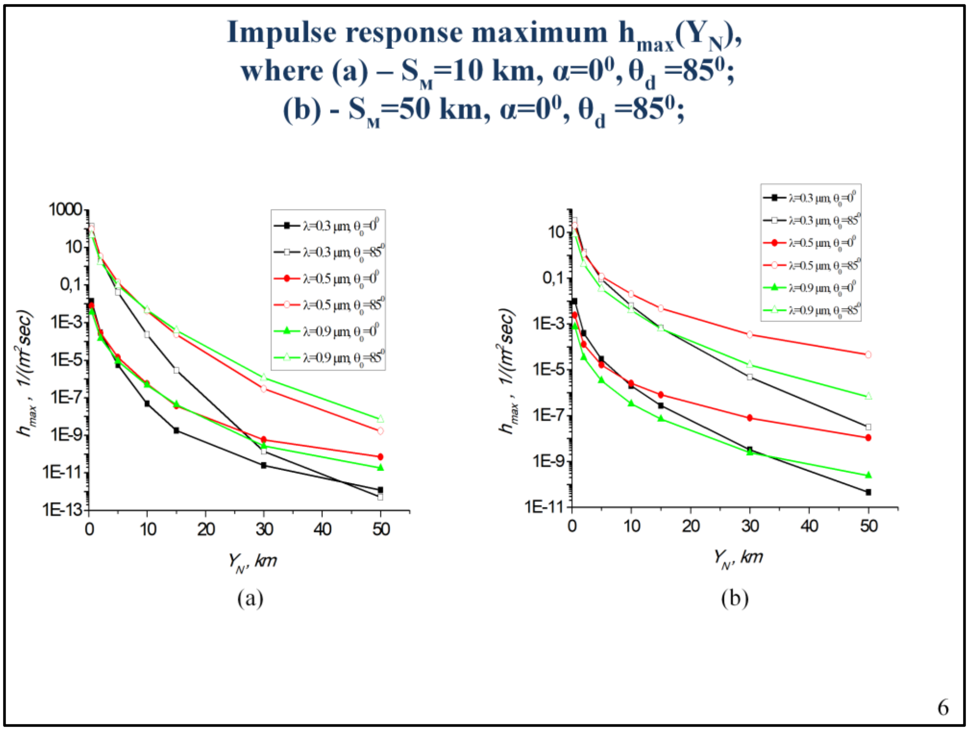
Using the developed programs the calculation of the impulse response was carried out. The first estimations were carried out for three wavelengths and this wide amount of conditions.



The performed analysis showed that the best communication scheme is in the case when θ_0 is equal to θ_d and equal to 85^0, $\alpha=0^0$. The examples of the obtained maximum values of the impulse response are shown on the slide.

Estimation of optimal wavelength under invariant characteristics of transceiver system

Calculation conditions:

- wavelength λ=0.205, 0.215, …, 2,495 μm;
- meteorological range of visibility S_M= 50 km ($\tau_{0.55}$=0.8 and 0.29);
- clear atmosphere;
- source and receiver zenith angle $\theta_0=\theta_d = 85^0$;
- source divergence angle $\nu_0=0.0034^0$;
- field of view angle $\nu_d=2^0$;
- baseline Y_N=0.5-200 km;
- angle between plane of transmitting system and plane of receiving system $\alpha=0^0$;
- number of time ranges $N_1=5$, $N_2=30$, $N_3=15$;
- maximum path length l_{max}=200 km;

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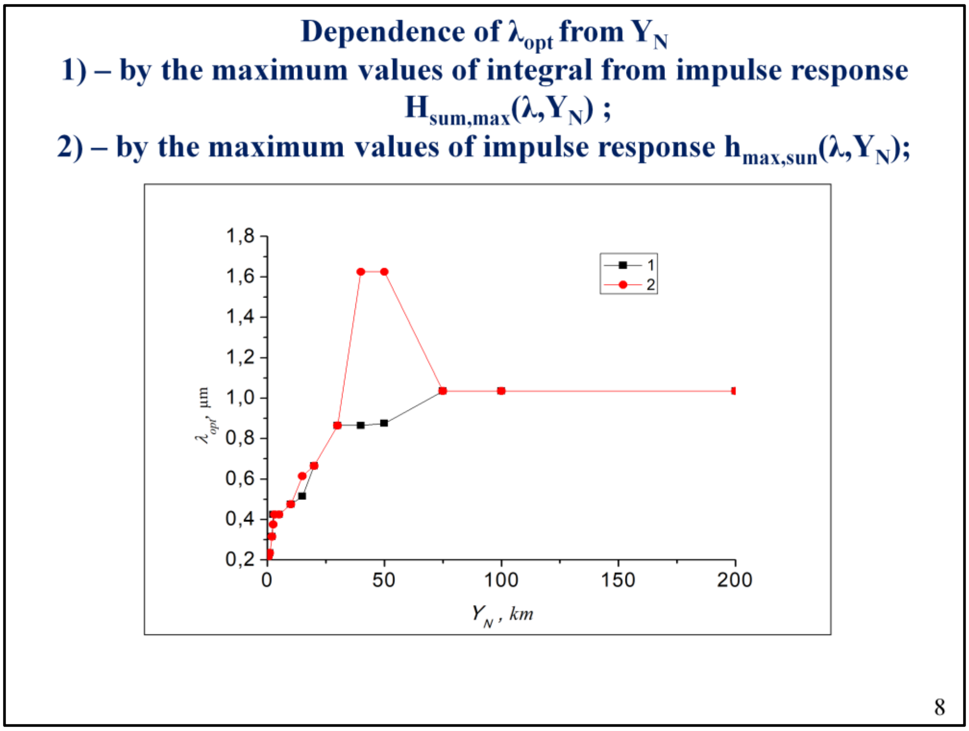
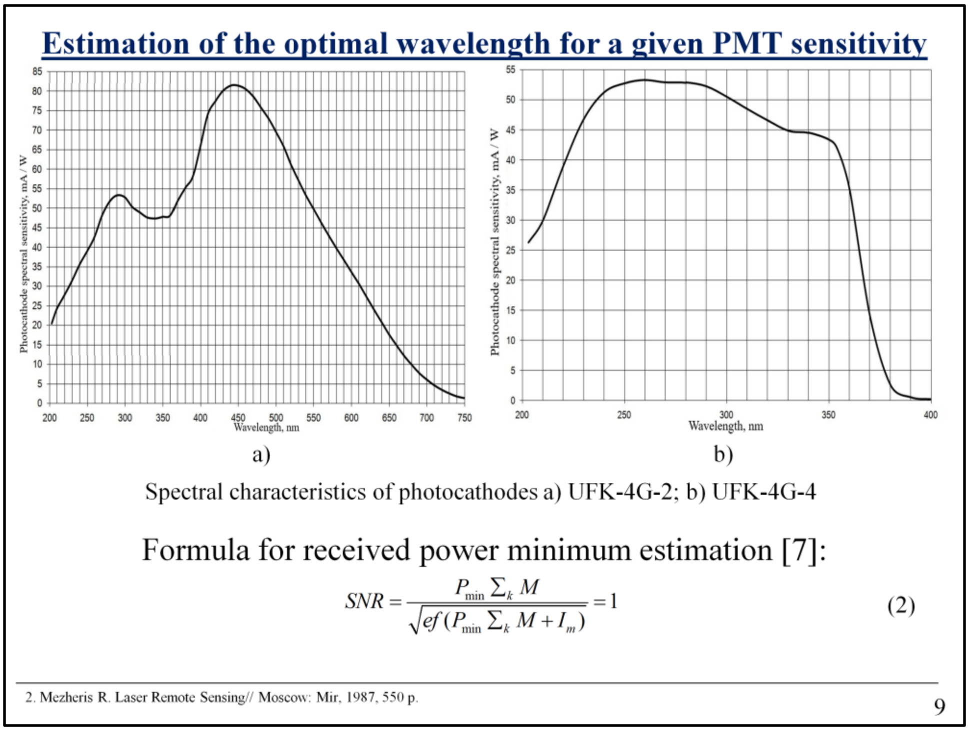
Then for these parameters of the source and receiver orientations the optimal wavelength for the same characteristics of transceiver system and night conditions were found as a function of baseline. The Wavelength range from 0.2 to 2.5 μm was considered.

On the slide you can see conditions under which the estimation was carried out. The optimal wavelengths were defined for two criteria: the wavelength under which the impulse response maximum has the largest value, or under which the integral of the impulse response has the largest value.

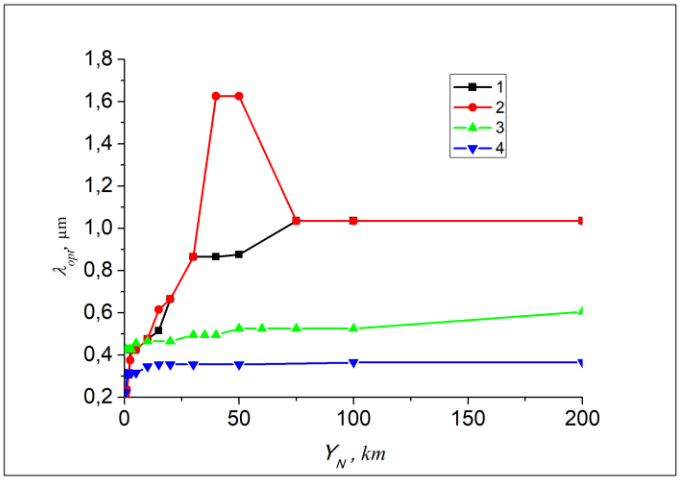


For other identical conditions, with an increase of the baseline the optimal wavelength increases up to the baseline equal to 40 km. So with the increase of the baseline, the maximum of the impulse response moves from ultraviolet to infrared region, and for the baseline of more than 75 km, the maximum of the impulse response occurs at λ=1,035 mkm.



Then, the estimation of the optimal wavelength for the given PMT sensitivity was performed. For visible and infrared ranges, the PMT-4G-2 characteristics were used, and for the UV - the PMT-4G-4 characteristics. The spectral sensitivities for photocathodes of these PMTs are shown on the slide. The minimum received power was estimated by the following formula.

Dependence of λ_{opt} from Y_N
1)–by the maximum values of integral from impulse response $H_{sum,max}(\lambda,Y_N)$;
2) – by the maximum values of impulse response $h_{max,sun}(\lambda,Y_N)$;
3) – for PMT UFK-4G-2; 4) –for PMT UFK-4G-4;



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As a result, the following optimum wavelength as a function of the baseline was obtained. For PMT UFK-4G-2, the optimal wavelength lies in the range from 0.425 to 0.605 µm, and for PMTs UFK-4G-4 from 0.225 to 0.365, depending on the baseline.

Conclusion

Table 1 - Dependence of the baselines from the wavelengths range which corresponds to the largest value of the impulse response

Baselines	Wavelengths range
up to 2-3 km	UV- range
from 3 to 20 km	visible range
more than 20 km	near IR- range
more than 75 km	IR- range

Table 2 – Optimal wavelengths for different PMT

PMT	Wavelengths range
UFK-4G-2	from 0.425 to 0.605 μm
UFK-4G-4	from 0.225 to 0.365 μm

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To sum up, for the baselines (up to 2-3 km) the largest value of the impulse response corresponds to the UV- wavelengths.
For the baselines from 3 to 20 km, the largest value of the impulse response corresponds to the visible wavelengths.
For the baselines more than 20 km, the maximum value of the impulse response corresponds to the near IR- wavelengths.
For PMT UFK-4G-2 the optimal wavelength lies in the range from 0.425 to 0.605 μm.
For PMT UFK-4G-4 the optimal wavelength lies from 0.225 to 0.365 μm, depending on the base distance.
For the baselines of more than 75 km the maximum impulse response occurs at λ_{opt} = 1.035 μm for the same other conditions.

Thank you for attention!