The Integral Distribution Function of the Kilometric Attenuation of Infrared Radiation in the Atmosphere Fergana Region of the Republic of Uzbekistan

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Abstract

The ever-increasing need for the provision of a wide range of services to the end user requires the organization of high-speed communication channels at the "last mile". One of the obvious solutions to this problem is the use of FTTH (fiber-to-the-home) technology, which has all the capabilities to transfer large amounts of information over long distances. However, this solution does not always satisfy the end user. This is due to the high cost and the need to obtain permission to lay an optical cable, long time for installation and connection. An alternative to this solution is the use of open optical transmission systems (OOTS) technology, also known as Free Space Optics (FSO). The article is devoted to the organization of high-speed communication channels at the "last mile" using the "Free Space Optics - FSO" technology. Advantages and disadvantages of the FSO are given. It is noted that when designing FSO systems by matching the integral distribution function of the kilometer attenuation (IDFKA) of infrared (IR) radiation in the atmosphere of a given geographical region (GR) with the energy resource of the FSO equipment used, the coefficient of readiness of the interval of the atmospheric communication channel (ACCR) is determined. In its turn, the IDFKA depends on the climatic features of the given geographical region where the AC route will take place. In determining the IDFKA, it is proposed to use measurements of the meteorological visibility range (MVR) made at all airports in the world. As an example, the MVR data measured at airports in the Fergana region and IDFKA values obtained on their basis are recommended. It is recommended to use the results obtained in the design and calculation of distances for optimal reception quality using FSO.

Keywords

Atmospheric Communication Channel, Integral Distribution Function, Infrared Radiation, Geographical Region, Kilometric Attenuation.

Introduction

Increasing needs to provide the end user with a wide range of services require the organization of high-speed communication channels on the "last mile". One of the obvious solutions to this problem is the use of FTTH (fiber - to - the - home) technology, which has all the capabilities to transmit large amounts of information over long distances. However, this solution does not always satisfy the end user. This is due to the high cost and the need to obtain permission for the installation of optical cable, long installation time and connection. An alternative to this solution is the use of open optical transmission systems (OOTS) technology, also known as Free Space Optics (FSO).

OOTS technology is analogous to fiber-optic communication lines (FOCL), but unlike it, the atmosphere is the propagation medium of radio waves. This fact is also essential, allowing you to avoid the costs associated with the purchase, obtaining permission to lay the cable, etc (Efanov, 2012), (Muradova & Khujamatov, 2019). The most significant advantage is the use of an unlicensed frequency range, which makes it one of the less expensive methods of organizing point-to-point communication.

Currently, all over the world, OOTS are at the stage of mass introduction into commercial operation. OOTS, in contrast to radio communication systems, have some features of constructing a linear path, including a propagation medium and technical means that ensure the formation, transmission, conversion and processing of optical signals. The main elements of the terminal equipment of the optical line path are transmitting and receiving modules. As a transmitter in OOTS, most often used are semiconductor, solid-state (mainly with the use of a neodymium-doped yttrium-aluminum garnet laser (Nd-YAG), gas (for example, CO_2). The detectors are usually photoelectric semiconductor radiation detectors. To receive signals in the wavelength range ($1<\lambda<2$) μm, p-i-n or avalanche photodiodes are used. At wavelengths $\lambda<1$ μm, it is advisable to use a photomultiplier tube, and at longer wavelengths, heterodyne detection can be used. (Dumin & Akhrnedov, 2018).

Due to the fact that in the OOTS the propagation medium is the atmosphere, then its state imposes certain restrictions on the communication range. The factors that have a negative impact on the operation of these systems include fluctuations due to heterogeneities in the air density and the attenuation of the radiation power when scattered by aerosol particles (Arsheen et al., 2020), (Osharin & Troitsky, 2000). The wavelengths at which the OOTS operates are commensurate with the wavelengths of atmospheric precipitation, and fog has a particularly significant effect on the communication range (Liu et al., 2005), (Khujamatov et al., 2021).

The prospect of OOTS technology, as shown in (Galati et al., 2006), (Shi et al., 2010), due to a number of advantages over radio communication and allows you to solve the above problems.

Material and Method

The factors that have a negative impact on the operation of OOTS systems include fluctuations due to heterogeneities in the air density and the attenuation of the radiation power when scattered by aerosol particles (Ibraimov & Sultonova, 2020), (Khujamatov, Reypnazarov et al., 2019). Due to the complex structure of aerosols in the atmosphere, the calculation of radiation losses in the optical range, with maximum accuracy, is rather difficult.

In practice, for these purposes, they use the meteorological visibility range (MVR, Sm), which is the greatest distance at which a black object of angular dimensions more than 15 'becomes invisible during daylight hours, projected against the background of the sky near the horizon or against the background of air haze. MVR is a characteristic of the transparency of the atmosphere and represents the range of visibility of a black object during the day against the sky near the horizon. MVR has a different meaning during the day and at night with the same transparency of the atmosphere.

Meteorological visibility range and atmospheric transparency are related in the following way. A distant object of large angular dimensions can be observed provided that the brightness contrast between the object and the sky background at the horizon is greater than the contrast threshold value. Knowing the integral distribution function of the meteorological visibility range (IDF-MVR), over a 3-5 year period, it is possible to estimate the average availability of the OOTS channel connection, for a specific geographic region (Ulyanov et al., 2007), (Siddikov et al., 2017), (Mook-Seng Leong et al., 2000).

In turn, the IDF-MVR can be obtained from the meteorological data of the airports of each geographic region, where meteorological stations with continuous meteorological measurements of the minimum visibility range are provided. The airport has a fairly extensive territory, and therefore it can be argued that there are practically some averaged conditions for a given geographic region (GR) (Siddikov et al., 2017), (Khujamatov & Toshtemirov, 2020).

Thus, to solve this problem, it is necessary to collect and process empirical data on the statistics of the IDF-MVR from the airports of the region in which the OOTS is being designed.

The advantages of technology OOTS include:

- Low cost of equipment.
- The possibility of creating a broadband line of communication where cable laying is impossible.
- The possibility of achieving high speeds (obtained speeds above Gbit/s, and in the future, Tbit/s is also achievable).
- The frequency range used is not licensed, thereby eliminating the need for obtaining permission from the radio frequency regulator.
- The radiation pattern of the radiating device is very narrow and has practically no side lobes.
- The system does not interfere with other communication systems.
- Compliance with electromagnetic compatibility standards is not required.
- High directivity, in turn, causes high protection against unauthorized interception of transmitted information.

However, the OOTS also has a number of shortcomings, the main of which is the limited range of communication due to atmospheric phenomena, which lead to a denial of access to the atmospheric communication line.

Therefore, it is necessary to pre-calculate its reliability and, if it does not satisfy the requirements, provide for the possibility of their solution, for example, by means of redundancy, in parallel with the radio link (Mo Zhao et al., 2012), (Khujamatov, Reypnazarov et al., 2020), (Siddikov et al., 2021).

Atmospheric influences cause attenuation and scattering of IR (Infrared) radiation, and the resulting turbulence leads to consequences such as (Shevtsov & Shishkariev, 1991), (Khujamatov, Khasanov et al., 2020):

- Change of the beam trajectory (fluctuation of the angles of arrival).
- Expansion (blurring) of the beam (leads to a change in the spatial power density at the receiver input).
- Polarization fluctuations.
- Beam scintillation (leads to small-scale interference phenomena within the cross-Section of the beam).
- Image shake (causes movement of the focal point in the image plane).
- Deterioration of spatial coherence (violation of phase coherence in the cross section of the phase front of a laser beam).

When designing OOTS systems, by matching the integral distribution function of kilometric attenuation (IDFKA) of IR radiation in the atmosphere of a given geographical region (GR) with the energy resource of the OOTS equipment used, the availability ratio of the atmospheric communication channel (ACCR) is determined. In turn, the IDFKA substantially depends on the climatic features of this GR, where the AC route will pass.

The weakening of the energy of optical waves during propagation in the atmosphere is mainly due to molecular and aerosol absorption and scattering, and they significantly exceed the attenuation caused by turbulence. The radial pressure of the wave on atmospheric aerosols can also be ignored due to the relatively low power of the laser emitters used in the OOTS (Refat et al., 2016), (Khujamatov, Reypnazarov et al., 2020a).

In determining the IDFKA, the total value of all attenuating factors is important, as well as its statistical characteristics. Therefore, we can assume that the energy losses during signal propagation in AC consist of two components, a constant component and a variable, determined by changes in the transparency of the atmosphere depending on changes in meteorological conditions (Lei et al., 2009), (Khakimovich et al., 2016), (Khujamatov, Reypnazarov et al., 2020).

The magnitude of the constant component for a particular region as a rule is known and therefore the main problem in determining the IDFKA is to identify the attenuation of the wave energy caused by changes in the transparency of the atmosphere due to the presence of aerosols. To this end, experimental measurements of the attenuation of laser radiation in the atmosphere were made in various regions of the world to determine the likelihood of the occurrence of a corresponding attenuation at specific paths (Mizuno et al., 2015), (Khujamatov, Khasanov et al., 2021).

Results and Discussion

It is known that the attenuation of laser radiation in AC directly depends on the transparency of the atmosphere, which is regularly measured at a network of meteorological stations at airports (measurements are made at a wavelength of λ = 0.55 μm, corresponding to the highest sensitivity of the eye and measured for measuring meteorological visibility range at all airports around the world). In accordance with the requirements for information on MVR on the runway, measurements should be carried out with an error of no more than ± 5%. For this purpose, the measurement period is made variable and automatic. In case of constant meteorological conditions, measurements are made every 15 minutes, with a sharp change, the interval decreases up to 1 minute. The airport has a fairly long territory, and therefore it can be argued that it establishes almost some averaged conditions for a given geographical region (GR).

According to the obtained atmospheric transparency data, MVR (Sm) is determined using the Koshmider's ratio:

$$S_m = -\ln\left(\frac{\varepsilon_r}{\alpha_A}\right) = \frac{3.9}{\alpha_A\left(\frac{1}{km}\right)} = \left[\frac{16.9}{\alpha_A\left(\frac{dB}{km}\right)}\right], km \qquad (1)$$

Where $\varepsilon_r = 0.02$ is the threshold of the contrast sensitivity of the eye at λ = 0.55 μm; αA is an indicator of attenuation of the visible wave.

For visible and near infrared waves, the attenuation due to aerosol scatter is recalculated as:

$$\alpha_A(\lambda_i) = \frac{3.9}{S_m} * \left(\frac{0.55}{\lambda_i}\right)^m = 0.55 * \alpha_A * \left(\frac{0.55}{\lambda_i}\right)^m \qquad (2)$$

Where λ_i is the wave lying in the "transparency window" of the atmosphere; m is a parameter dependent on Sm (at S_m < 6 km, m=0,585•Sm1/3 for average visibility conditions -m=1.3; for very good conditions -m=1.5).

Experimental studies (Shi et al., 2009) showed that the correlation coefficient between α_A and S_m for the urban route is on average 0.76, and for the suburban route 0.8. Thus, it can be argued that the use of MVR as a criterion for the state of the AC is quite appropriate.

Statistical data on MVR collected from the meteorological stations of the Fergana region airports (airports of Andijan and Fergana) in the territory of the Republic of Uzbekistan are shown in Tables 1 and 2. The volume of data processing (total observation time) was 26,280 hours (3 years). In accordance with the recommendations of the International Civil Aviation Organization (ICAO), MVR values were selected from 11 intervals: 0-0.45; 0.45-0.7; 0.7-1.1; 1.1-1.3; 1.31.5; 1.5-2.2; 2.2-3.0; 3.0-3.5; 3.5-4.1; 4.1-7.0; 7.0-10.0. The choice of intervals is quite sufficient and the frequency of the data collected is acceptable for carrying out practical calculations for assessing the influence of atmospheric transparency on the work of the OOTS. Next, we determined the probability of Sm entering the corresponding interval during the year, and then they were averaged over the probability of hitting during the entire observation period.

According to the table. 1 and 2, the average values of IDF - MVR were calculated, broken down into average annual, summer and winter, periods of measurements (Table 3).

Table 1 Experimental values of IDF-MVR for the city of Andijan

S (km)/ F(Sm)		10	7	4,1	3,5	3	2,2	1,5	1,3	1,1	0,7	0,45
Months	I	1.00	0.95	0.86	0.76	0.69	0.56	0.43	0.31	0.31	0.22	0.12
	II	1.00	0.90	0.64	0.49	0.40	0.27	0.17	0.06	0.06	0.02	0
	III	1.00	0.72	0.24	0.13	0.09	0.06	0	0	0	0	0
	IV	1.00	0.36	0.04	0.01	0.01	0	0	0	0	0	0
	V	1.00	0.06	0	0	0	0	0	0	0	0	0
	VI	1.00	0.03	0	0	0	0	0	0	0	0	0
	VII	1.00	0.06	0.01	0.01	0.01	0	0	0	0	0	0
	VIII	1.00	0.05	0	0	0	0	0	0	0	0	0
	IX	1.00	0.37	0.02	0	0	0	0	0	0	0	0
	X	1.00	0.49	0.11	0.04	0.04	0.02	0	0	0	0	0
	XI	1.00	0.60	0.15	0.09	0.09	0.05	0.01	0	0	0	0
	XII	1.00	0.8	0.47	0.33	0.30	0.25	0.16	0	0.14	0.11	0.09
Annual average		1.00	1.00	0.44	0.21	0.15	0.13	0.10	0.06	0.04	0.04	0.03

Table 2 Experimental values of IDF-MVR for the city of Fergana

S (km)/ F(Sm)		10	7	4,1	3,5	3	2,2	1,5	1,3	1,1	0,7	0,45
Months	I	1.00	0,74	0,67	0,53	0,39	0,29	0,21	0,09	0,05	0,05	0,01
	II	1,00	0,68	0,55	0,47	0,33	0,25	0,21	0,03	0,01	0,01	-
	III	1,00	0,34	0,24	0,19	0,14	0,10	0,07	0,04	0,01	0,01	-
	IV	1,00	0,03	0,01	-	-	-	-	-	-	-	-
	V	1.00	0.03	0.03	0.03	0.03	0.03	0.02	0.01	0.01	0.01	-
	VI	1.00	0.02	0.02	-	-	-	-	-	-	-	-
	VII	1.00	0.10	0.08	-	-	-	-	-	-	-	-
	VIII	1.00	0.05	0.03	0.01	-	-	-	-	-	-	-
	IX	1.00	0.11	-	-	-	-	-	-	-	-	-
	X	1.00	0.18	0.07	0.03	0.03	-	-	-	-	-	-
	XI	1.00	0.47	0.22	0.11	0.02	-	-	-	-	-	-
	XII	1.00	0.53	0.25	0.07	0.02	-	-	-	-	-	-
Annual average		1.00	0.27	0.18	0.12	0.08	0.05	0.04	0.01	-	-	-

For the convenience of the process of computing and automating the design of the OOTS, it is desirable to present the experimentally obtained data on the IDF - MVR as analytical expressions. The MATLAB environment, as it is known, is a well-tested and reliable system of computer representation of mathematical dependencies for solving a wide range of tasks.

Using MATLAB programs, analytical expressions approximating the experimental dependencies for the interval of 0.45 - 10 km are given in Table 3, which are presented in Table 4.

Table 3 The average data of the IDF-MVR for the city of Fergana and the city of Andijan

S(km)/ F(Sm)		10	7	4.1	3.5	3	2.2	1.5	1.3	1.1	0.7	0.45
Andijan	Year.	1.00	0.44	0.21	0.15	0.13	0.10	0.06	0.04	0.04	0.03	0.02
	Summer.	1.00	0.03	-	-	-	-	-	-	-	-	-
	Winter.	1.00	0.95	0.86	0.76	0.69	0.56	0.43	0.31	0.31	0.22	0.12
Fergana	Year.	1.00	0.27	0.18	0.12	0.08	0.05	0.04	0.01	-	-	-
	Summer.	1.00	0.02	0.02	-	-	-	-	-	-	-	-
	Winter.	1.00	0,74	0,67	0,53	0,39	0,29	0,21	0,09	0,05	0,05	0,01
Average	Year.	1.00	0.35	0.19	0.13	0.10	0.07	0.04	0.01	0.01	0.01	0.01
	Summer.	1.00	0.25	0.01	-	-	-	-	-	-	-	-
	Winter.	1.00	0.85	0.77	0.65	0.54	0.43	0.32	0.20	0.18	0.14	0.7

Table 4 Analytic expressions of average values

Region	Analytical expression
Andijan	$F(S_m) = 0.000165*S_m\text{^}4 - 0.002256*S_m\text{^}3+0.01476*S_m\text{^}2+ 0.01182*S_m+0.01252$
Fergana	$F(S_m) = 0.000227*S_m\text{^}5 - 0.00452*S_m\text{^}4 + 0.02984*S_m\text{^}3 - 0.0724*S_m\text{^}2 + 0.09357*S_m - 0.03573$
Averaged value for Andijan and Fergana	$F(S_m) = 0.0004974*S_m\text{^}4 -0.008176*S_m\text{^}3 + 0.04703*S_m\text{^}2 - 0.05263*S_m+ 0.02509$

The graph of the dependencies of the average values of the IDF - MVR, built on the analytical expressions table. 4 and 5, is shown in Fig.1.

Tables 4 and 5 show the standard deviations of the average values.

Table 5 The standard deviations of the IDF-MVR from the average values for Andijan city

Andijan												**Magnitude deviations**
Distance	**0,45**	**0,7**	**1,1**	**1,3**	**1,5**	**2,2**	**3**	**3,5**	**4,1**	**7**	**10**	
F (S_m) exp.	0,02	0,03	0,04	0,04	0,06	0,10	0,13	0,15	0,21	0,44	1	
F(S_m) analit.	0,02	0,027	0,040	0,048	0,056	0,089	0,133	0,162	0,200	0,440	1	
F (S_m) averaged over Andijan and Fergana	0,01	0,008	0,013	0,019	0,026	0,061	0,11	0,141	0,176	0,351	0,999	
F (S_m) deviations	0,01	0,019	0,027	0,029	0,030	0,028	0,023	0,021	0,024	0,089	0,001	0,027

Table 6 The standard deviations of the IDF-MVR from the average values for Fergana city

Fergana												**Magnitude deviations**
Distance	**0,45**	**0,7**	**1,1**	**1,3**	**1,5**	**2,2**	**3**	**3,5**	**4,1**	**7**	**10**	
F (S_m) exp.	0	0	0	0,01	0,04	0,05	0,08	0,12	0,18	0,27	1	
F(S_m) analit.	-0,005	0,003	0,013	0,017	0,021	0,043	0,088	0,125	0,173	0,269	1	
F (S_m) averaged over Andijan and Fergana	0,01	0,008	0,013	0,019	0,026	0,061	0,11	0,141	0,176	0,351	0,999	
F (S_m) deviations	-0,015	-0,005	0,000	-0,002	-0,005	-0,018	-0,022	-0,016	-0,003	-0,082	0,001	-0,015

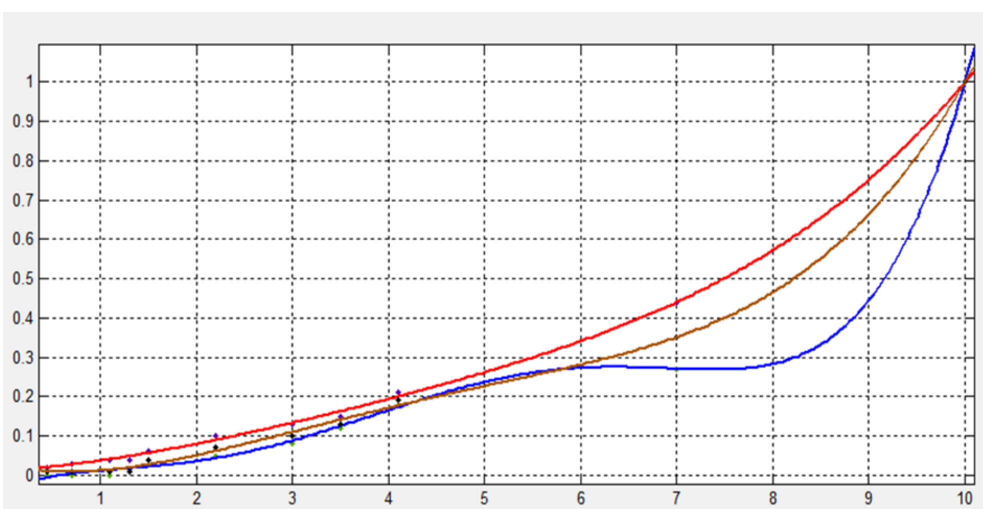

Figure 1 Graphs of average values: red - Andijan city, blue - Fergana city

As can be seen from Tables 5 and 6, the root- mean-square deviations from average values are quite acceptable when calculating the average availability of a communication channel and the energy resource of equipment.

Conclusion

Based on the above, it can be argued that all ACs for a given GR are individual, and there are no absolutely identical ones. Each AC has its own individual IDFKA, since its microclimate is everywhere, one on the sunny side, the other on a shaded one, the third on a hill, the fourth in a valley, etc. However, the differences within the same area are such that the IDF - MVR or IDFKA, obtained in this region, are close to each other and do not lead to a significant change in the size of the ACCR, unless the requirements for the selection of the OOTS route are roughly violated.

Consequently, as the initial IDFKA for determining the ACCR at the design stage of the OOTS, the averaged IDFKA for a given GR can be used. After collecting a sufficient number of IDF-MVR in the GR, the limits of IDF-MVR spread and the error of using the averaged IDFKA can be determined.

An example confirming this statement is the data on IDF-MVR for the city of Fergana and the city of Andijan of the Republic of Uzbekistan. The weather conditions in these cities of the Fergana Valley are approximately the same and, as calculations show, it is advisable, with some assumptions, to use averaged meteorological data for the entire GR, which will save time on meteorological measurements, when designing and calculating the distance for optimal reception quality.

References

Arsheen, S., Wahid, A., Ahmad, K., & Khalim, K. (2020). Flying Ad hoc network expedited by DTN scenario: reliable and cost-effective MAC protocols perspective. In *IEEE 14th International Conference on Application of Information and Communication Technologies (AICT)*, 1-6. https://doi.org/10.1109/aict50176.2020.9368575

Dumin, O., & Akhrnedov, R. (2018). Ultrashort impulse radiation from plane disk with uniform current distribution. *In 9th International Conference on Ultrawideband and Ultrashort Impulse Signals (UWBUSIS)*, 169-173. https://doi.org/10.1109/uwbusis.2018.8520223

Efanov, V.I. (2012). *Design, construction and operation of FOCL: Textbook.* Tomsk State university of control systems and radioelectronics.

Galati, G., Dalmasso, I., Pavan, G., & Brogi, G. (2006). Fog detection using airport radar. *In International Radar Symposium*, 1-4. https://doi.org/10.1109/irs.2006.4338037

Ibraimov, R.R., & Sultonova, M. O. (2020). Influence of Weather Conditions on Disconnection in Open Optical Transmission Systems. *In International Conference on Information Science and Communications Technologies (ICISCT)*, 1-5. https://doi.org/10.1109/icisct50599.2020.9351374

Khakimovich, S.I., Abdishukurovich, S.K., Ravshanovich, D.O., & Ergashevich, K.K. (2016). Modeling of the processes in magnetic circuits of electromagnetic transdusers. In *International Conference on Information Science and Communications Technologies (ICISCT)*, 1-3. https://doi.org/10.1109/icisct.2016.7777393

Khujamatov, H., Reypnazarov, E., Khasanov, D., & Akhmedov, N. (2021). IoT, IIoT, and Cyber-Physical Systems Integration. In *Emergence of Cyber Physical System and IoT in Smart Automation and Robotics*, 31-50. https://doi.org/10.1007/978-3-030-66222-6_3

Khujamatov, K., Khasanov, D., Reypnazarov, E., & Akhmedov, N. (2021). Existing Technologies and Solutions in 5G-Enabled IoT for Industrial Automation. In *Blockchain for 5G-Enabled IoT*, 181-221. https://doi.org/10.1007/978-3-030-67490-8_8

Khujamatov, K., Khasanov, D., Reypnazarov, E., & Axmedov, N. (2020). Industry Digitalization Consepts with 5G-based IoT. *In International Conference on Information Science and Communications Technologies (ICISCT)*, 1-6. https://doi.org/10.1109/icisct50599.2020.9351468

Khujamatov, K., Reypnazarov, E., Akhmedov, N., & Khasanov, D. (2020). Blockchain for 5G Healthcare architecture. *In International Conference on Information Science and Communications Technologies (ICISCT)*, 1-5. https://doi.org/10.1109/icisct50599.2020.9351398

Khujamatov, K., Reypnazarov, E., Akhmedov, N., & Khasanov, D. (2020, November). IoT based centralized double stage education. *In International Conference on Information Science and Communications Technologies (ICISCT)*, 1-5. https://doi.org/10.1109/icisct50599.2020.9351410

Khujamatov, K., Reypnazarov, E., Khasanov, D., & Akhmedov, N. (2020). Networking and computing in Internet of Things and cyber-physical systems. *In IEEE 14th International Conference on Application of Information and Communication Technologies (AICT)*, 1-6. https://doi.org/10.1109/aict50176.2020.9368793

Khujamatov, K.E., & Toshtemirov, T.K. (2020). Wireless sensor networks based Agriculture 4.0: challenges and apportions. *In International Conference on Information Science and Communications Technologies (ICISCT)*, 1-5. https://doi.org/10.1109/icisct50599.2020.9351411

Lei, F., Hands, A., Truscott, P., & Dyer, C. (2009). Cosmic-ray heavy ions contributions to the atmospheric radiation field. *In European Conference on Radiation and Its Effects on Components and Systems*, 375-376. https://doi.org/10.1109/radecs.2009.5994679

Wen Qing, L., TianShu, Z., & MinGuang, G. (2005). The measurement of infrared radiation of Earth and atmosphere by airborne FTIR spectrometer. *In IEEE International Conference on Information Acquisition*, 4-pp. https://doi.org/10.1109/icia.2005.1635103

Mizuno, Y., Kishikawa, T., Hinata, H., Kiyoyama, K., Shimojima, M., Oyama, K., & Tanaka, Y. (2015). Improvement of solar radiation model based on physical parametrization.

In International Conference on Renewable Energy Research and Applications (ICRERA), 789-792. https://doi.org/10.1109/icrera.2015.7418519

Mo Zhao, Minrui Yu, & Blick, R.H. (2012). Wavenumber-Domain Theory of Terahertz Single-Walled Carbon Nanotube Antenna. *IEEE Journal of Selected Topics in Quantum Electronics, 18*(1), 166–175. https://doi.org/10.1109/jstqe.2011.2111361

Mook, S.L., Pang-Shyan, K., Tat-Soon, Y., & Le-Wei, L. (2000). An efficient calculational approach to evaluation of microwave specific attenuation. *IEEE Transactions on Antennas and Propagation, 48*(8), 1220–1229. https://doi.org/10.1109/8.884490

Muradova, A., & Khujamatov, K. (2019). Results of calculations of parameters of reliability of restored devices of the multiservice communication network. *In International Conference on Information Science and Communications Technologies (ICISCT)*, 1-4. https://doi.org/10.1109/icisct47635.2019.9011932

Osharin, A.M., & Troitsky, A.V. (2000). Polarization of the thermal radiation of the cloudy atmosphere in millimeter wavelength band. *In Conference Proceedings 2000 International Conference on Mathematical Methods in Electromagnetic Theory (Cat. No. 00EX413)*, 244-246. https://doi.org/10.1109/mmet.2000.888570

Refat, I.R., Muazzam, K.Z., & Nurbek, D.D. (2016). Review of open optical transmission systems and their possible use in Urgench city. *In International Conference on Information Science and Communications Technologies (ICISCT)*, 1-4. https://doi.org/10.1109/icisct.2016.7777401

Shevtsov, B.M., & Shishkariev, A.A. (1991). Radio-thermal radiation of the atmosphere in the presence of the waveguide propagation. *In Antennas and Propagation Society Symposium 1991 Digest*, 1259-1262. https://doi.org/10.1109/aps.1991.175077

Shi, X., Li, X., Huang, W., Zheng, C., & Luo, Q. (2009). The study of atmospheric path radiation for inhomogenous atmosphere on MODIS remote sensing images. *In Joint Urban Remote Sensing Event*, 1-7. https://doi.org/10.1109/urs.2009.5137684

Shi, X., Li, X., & Zhu, R. (2010). A new approach of generating atmospheric path radiation images based on atmospheric radiation transmittance theory. *In International Conference on Computer Application and System Modeling (ICCASM 2010)*, 4, V4-559. https://doi.org/10.1109/iccasm.2010.5620598

Siddikov, I.K., Sattarov, K.A., & Khujamatov, K.E. (2017). Modeling of the transformation elements of power sources control. *In International Conference on Information Science and Communications Technologies (ICISCT)*, 1-5. https://doi.org/10.1109/icisct.2017.8188581

Siddikov, I., Khujamatov, K., Khasanov, D., & Reypnazarov, E. (2020). IoT and intelligent wireless sensor network for remote monitoring systems of solar power stations. *In World Conference Intelligent System for Industrial Automation*, 186-195. https://doi.org/10.1007/978-3-030-68004-6_24

Ulyanov, Y.N., Maksimova, N.G., & Shifrin, Y.S. (2007). Combined acousto-electromagnetic antennas for radioacoustic sounding of the atmosphere. *6th International Conference on Antenna Theory and Techniques*, 344-347. https://doi.org/10.1109/icatt.2007.4425206

Malhotra, M., & Chhabra, J.K. (2018). Micro level source code summarization of optimal set of object oriented classes. *Webology, 15*(2), 113-132.