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GENERAL OVERVIEW OF WIRELESS COMMUNICATION TECHNOLOGY

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Abstract- Wireless communication technology has gained enormous importance in the application of signal transmission. It is named as free space optical (FSO) communication. Signal attenuation due to atmospheric conditions affect the performance of signal quality of the FSO communication. In this paper, fundamental of optical wireless communication, application, and challenges from mainly atmospheric conditions are discussed. The effects of different atmospheric conditions over wireless signal transfer are evaluated. The evaluation shows that attenuation of signal results from atmospheric scattering effects, which mainly depend on the wavelength. The technological improvements of the optical communication systems are promising for efficiently transferring data in future because of the advancement in the photonic and semiconductor technologies. Wireless communication technology will definitely find extensive applications for high speed data communication in near future. Advantages and challenges of the wireless communication have been discussed in the paper. The atmospheric effect on the signal transfer has been simulated as a function of the wavelength, and suitable wavelength range has been determined for better signal transfer.

Keywords: Wireless Communication, Free Space Optical Communication, Atmospheric Signal Attenuation, Laser, Optical Communication.

I. INTRODUCTION

Signal transmission through optical fibers allows the data to reach a relatively large distance without much signal losses. A perfect alignment between the sender and the receiver is a must to keep the communication unobstructed [3]. Wireless signal transmission provides an alternative solution to keep communication unobstructed for places like terrestrial areas, where fiber optic connection is unable to reach. In addition, there is advantage of the wireless communication due to high data rates compared the traditional signal transfer.

The operating frequency of 4G wireless technology is around 1.8-2.5 GHz, and it can reach up to data rate up to 20 Mbps (having bandwidth around 5-20 MHz).

Moreover, the 5G technology has 15 GHz bandwidth, and allows much higher data rate. The advantage of the 5G technology is due to its broad bandwidth and high reliability. Such wireless communication technologies are required for reliable wireless signal transmission in future because the 5G plays an important role for high speed and high capacity data transfer. In addition to high speed and high data rate, this technology would expand its application to more dimensions, which provide new sense of technology. For example, the 5G technology has potential to be used for daily life from autonomous cars to remote medical care, and from tactile communication (communication through the sense of touch) to agricultural sensors, to name just a few [4].

There are many challenges faced in achieving the wireless transmission system because the medium for the transmission of wireless communication is free space. They are atmospheric challenges because of different weather condition and are beam divergence due to large propagation distances. Overcoming of this physical problems for free space optical communication is important to have good beam quality so the optic lenses can be used to obtain small beam divergence. Small beam divergence provides spatial isolation from the possible interferer on the beam path and brings additional security of the transmitted signal. Thus, the minimum loss of the transmitted signal at the receiver is essential to gather enough information from the transmitter (Figure 1).

Wireless transmission systems with high bandwidth capacity are favorable candidate for efficient wireless signal communication. For an example, data transferring of 26 terabits per second has achieved with fiber optic technology [5, 6], and even more advancement has extend this record to 43 terabits per second [7]. Data transferring systems will be improved with accelerated speed for day by day, and the type of the information would expand ranging from text to speech, and from pictures to high definition videos. This expansion of information content requires high bandwidth communication technology, which is needed to support increasing future bandwidth demands. This new FSO communication system is an alternative to traditional telecom demands.

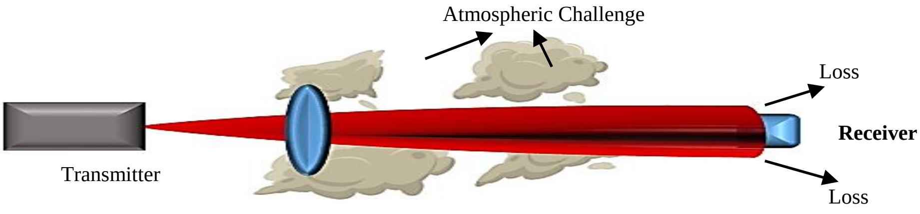

Figure 1. Schematic demonstration of wireless communication system [1]

Technological achievements in the nano photonic area leads to improve the quality of the transmitted signal. Such improvements in the technology would provide much larger bandwidth than the current systems. For example, generation of short pulses from semiconductor lasers (such as femtosecond lasers) would be candidate because of their stability and applicability to information and communication systems [8]. Also, transferring information through laser has advantage in terms of the data security because it is difficult to dig collimated laser beam. Moreover, the reliability of the wireless signal transmission could be improved to higher level in different ways such as reaching large beam power, and the information security can be even much more improved with quantum cryptography.

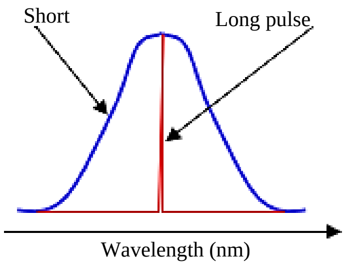

Figure 2. Comparison of the bandwidth of the short and long laser pulses [2]

II. BANDWIDTH OF THE WIRELESS SIGNAL COMMUNICATION

The optical bandwidth is used for determining the data rate in wireless communication system, which shows how much information can be transported over a channel (in bits per second). Lasers having short optical pulses are promising candidate for wireless data transmission because of their broad optical bandwidth, which is the full width at half maximum (FWHM) of the spectrum (Figure 2). The bandwidth is given as $\Delta\lambda \approx \lambda^2 / (c\Delta\tau)$ [9] here $\Delta\lambda$ is the bandwidth, λ is the central wavelength, and $\Delta\tau$ is the pulse duration. For an example, the bandwidth is ~21 nm (~10 THz) for 100 fs pulses at 800 nm central wavelength while it is 42 nm (~20 THz) for 50 fs pulses at 800 nm, here 1 fs corresponds to 10^{-15} s. Thus, ultra-short pulses have enormous potential for signal transmission with very high data rate compared to the longer pulses and of course traditional copper cable, which has bandwidth of ~1 GHz. Also, different beam shapes such as Gaussian vortex beam can beneficial to optical links and can be used as an alternative for wireless signal communication [10]

To have high quality optical signal several parameters need to be optimized. Accumulating much of the sender signal with less power loss is important to reach high quality signal transmission (Figure 1). Another important thing is to reduce the disturbing influences such as background light, i.e. noise, which effect the data transmission capacity. Moreover, wireless signal communication can be affected by several challenges from atmospheric conditions such as rain, fog, clouds or strong wind. Such disturbances cause remarkable signal attenuation, and they need to be minimized for efficient signal transfer.

III. ATMOSPHERIC CHALLENGES IN WIRELESS SIGNAL COMMUNICATION

There are many challenges faced while achieving high quality of the wireless signal communication. In this paper, one of the important challenges, which is due to atmospheric conditions such as rain, fog, and pollution etc. causing signal attenuation has been studied. They cause the attenuation of the transmitted signal. Attenuation of the atmospheric challenge is described by Beer-Lambert law [11];

$$\tau(\lambda, L) = e^{-\gamma L} \tag{1}$$

where, L is the distance between the transmitter and the receiver, and γ is total attenuation coefficient, which is sum of the absorption and the scattering due to atmospheric particle [12];

$$\gamma = \alpha + \beta \tag{2}$$

where, α and β represent the absorption and the scattering coefficient, respectively. The typical communication wavelength falls in the atmospheric transmission window (Figure 3) [13]. So the atmospheric loss due to absorption is neglected in the calculation [13].

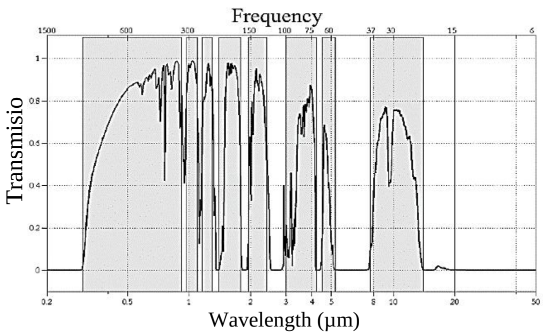

Figure 3. Atmospheric transmission as a function of the wavelength [3]

Figure 3 shows the atmospheric transmission window (grey color rectangles). In this paper, scattering of the signal due to different weather conditions is studied in wireless communication system. The scattering is defined the change of the direction of the beam. It depends on the particle size that encounters during the propagation, and results from Rayleigh scattering, Mie scattering and Geometrical scattering. If the particle size is much smaller than the beam wavelength, it is called Rayleigh scattering [14], which is negligible on the IR band of the spectrum. So factors affecting wireless signal come from the Mie scattering and Geometrical scattering, and the total scattering is given as [15];

$$\beta_{total} = \beta_{Mie} + \beta_{Geo} \quad (3)$$

The first term of Equation (3) is due to Mie scattering, which is the interaction of the beam with atmospheric particle having radius close to the beam wavelength, and it is given as [15];

$$\beta_{Mie} = \frac{3.91}{V}\left(\frac{550\text{ nm}}{\lambda}\right)^{q} \quad (4)$$

where, V is the visual range of the atmosphere, and λ is the wavelength.

The second term of Equation (3) results from the Geometrical scattering, which is due to the larger particle size than the wavelength of the beam, and it mainly depends on the weather conditions such as rain. The geometrical scattering due to raindrop is given as [15];

$$\beta_{Geo} = \pi a^2 N_a Q_{scat}\left(\frac{a}{\lambda}\right) \quad (5)$$

where, a and N_a are the radius of the raindrop (cm) and the raindrop distribution (cm^{-3}), respectively, Q_{scat} is scattering coefficient $(Q_{scat} = 2)$ [16], and N_a depends on the rain fall rate and the speed of the rain drop.

In this section, the total loss due to scattering in four different atmospheric conditions are analyzed: (i) only Mie scattering (Non-rainy weather), (ii) light rain, (iii) medium rain, and (iv) heavy rain conditions. Total scattering (β_{total}) factor in Equation (3) is analyzed for different particle size (a), different rain distribution (N_a) and different visual range (V). The visual range (V) is chosen between 2 km to 20 km depending on the weather condition.

Particle size (a) is chosen 0.002 cm, and rain distribution (N_a) is chosen for different rain type from Ref. [15, 16]. The total scattering for different weather condition is presented in Figure 4. The difference of the scattering from the clear sky to the light rain conditions are relatively small. However, there is a notable increase in the scattering coefficient for the heavy weather conditions, which most attenuate the wireless signal. Increase of the wavelength decreased the scattering (Figure 4). Figure 4 presents the Mie scattering blue solid line, the light rainy day red dashed line, medium rainy day yellow dotted line, and heavy rainy day purple dashed-dotted line, respectively.

Table 1. Data for different scattering parametersScattering Coefficients (10^{-4}/km)

Wavelength (μm)	Mie Scattering	Light Rain	Medium Rain	Heavy Rain
0.5	23.29	3.01	22	30
0.7	15.04	2.14	16	22
0.9	10.84	1.70	13	18
1.1	8.35	1.44	12	15
1.3	6.72	1.27	11	14
1.5	5.58	1.15	9.86	12
1.7	4.74	1.06	9.29	12
1.9	4.10	0.943	8.86	11
2.1	3.60	0.941	8.52	10
2.3	3.20	0.899	8.25	10
2.5	2.87	0.864	8.02	9.71
2.7	2.60	0.835	7.84	9.43
2.9	2.37	0.811	7.68	9.20

IV. THE PROS AND CONS OF WIRELESS COMMUNICATION SYSTEM

The amount of data transferred in the optical communication system is directly related to the bandwidth of the carrier field. Optical frequency permits data transfer at THz (1 THz = 10^{12} Hz) bandwidth. Wireless technology provides improved data communications leading to faster transfer of signal between the transmitter and the receiver.

Wireless communication system also provides very narrow beam, providing the transmitted signal to focus very small area. This focusing provides spatial isolation from the possible interferer during the propagation and enhancing the security of the information. However, the beam divergence leads to size of the beam larger at the receiver so the only some fraction of the beam is collected by the receiver. Moreover, the atmospheric conditions such as fog and rain cause the signal loss at the receiver, Figure 1. The diffraction limited beam should be used to eliminate the power losses due to diffraction. In addition, elimination of the optic loss from the transmitter and from the receiver increases the signal quality of the wireless communication system.

Table 1 shows varying scattering parameters for different wavelength. Mie scattering is higher for smaller wavelength, and it is relatively small at the wavelength around 2 μm. For the light rain condition, the scattering parameters are small, but it goes below 1 after 2 μm. For the medium rain and heavy rain conditions it starts with higher scattering coefficient at smaller wavelength, and both scatterings get smaller after 2 μm. From the result of the Table 1, it has been concluded that the optical source of around 1.5 to 2 μm is suitable to have better signal quality for wireless data transmission.

After improving the challenges in wireless communication, it will definitely be an alternative to conventional communication system. It will find extensive application in equipment monitoring, climate control, earth quake sensing, remote data collection, satellite system for vehicle tracking, and wireless transmission in power engineering. Among the applications of the wireless signal transfer, the transmission of electrical power wirelessly has been an important aim and underdeveloped technology since the time of Tesla. The application of the power transmission wirelessly could be that the wireless technology can transfer power by converting electricity into light, i.e. laser beam, and then sending the beam on the receiving detector, such as solar cell, converting the beam back into the electricity. The power transmission without wires would reduce to transmission and distribution cost. In future, solar power satellites in high earth orbit would be the main part of supplying energy from the sun with high efficiency [17].

Besides the improvements of the FSO communication in the world, FSO communication technology in Turkey has been advancing on the account of weapon data link, technical data links, satellite communication and technical communication. These improvements have potential applications on the development of the current signal processing system not only in security but also in communications. Among them satellite communication is vital role for improving high data transfer in high reliability. Thus, Turkey has been making investment heavily in those technologies, and it is on the same track with leading economies in terms of communication and information investments.

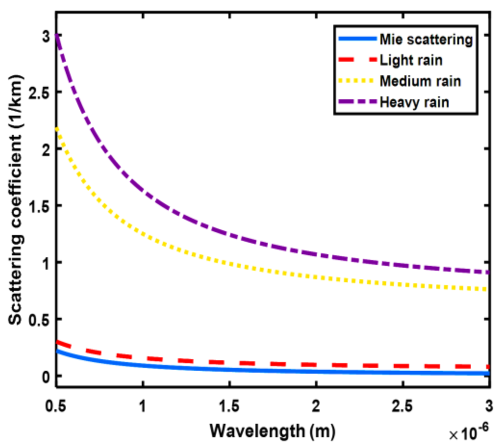

Figure 4. Scattering coefficient for varying atmospheric conditions as a function of the laser wavelength from 0.5 to 3 µm

V. RESULTS AND DISCUSSION

In this paper, we present a detailed study of atmospheric condition for the wireless communication system. We mentioned applications, advantages and challenges of the FSO communications. With different atmospheric condition, the parameters are varied and optimized. This paper targets to present advances and challenges of the wireless communication system. First of all, the advantages of the wireless communication are mentioned in the section of the introduction part, and then importance of bandwidth for the high signal transfer rate is presented. It is studied the effect of the atmospheric condition on the wireless communication system. The transmitted signal is attenuated due to obstacles that the signal encounters while traveling. To analyze the challenges on the wireless communication the attenuation has only been assumed due to the absorption and the scattering effects. The theoretical calculation of signal attenuation has been performed with the MATLAB program.

The absorption has neglected in the used spectral range since the absorption falls into transmission window of the spectrum, Figure 3. Moreover, the scattering which is caused from much smaller particle size than the laser wavelength (Rayleigh scattering) has been neglected. The theoretical calculation for wireless communication has been performed for only Mie scattering and the Geometrical scattering. Both scatterings factors have been considered as the main atmospheric attenuation factor in the calculation.

The scattering of the signal has been plotted four different weather conditions that mainly affect the signal quality as in Figure 4. The atmospheric conditions for the clear sky and the light rain do not have much effects on the signal attenuation. But, when the atmospheric conditions become worse, the signal scatterings are significantly increased, which leads the signal attenuation. In addition, the increase of the wavelength leads to improvement of the signal attenuation. Thus, the longer wavelength around 2 µm range is good candidate for wireless optical communication.

VI. CONCLUSIONS

In this work, the advantages and the challenges of the wireless communication are discussed. The atmospheric factor of scattering has been taken into account to calculate the signal attenuation for varying atmospheric conditions. The theoretical calculation demonstrates that the suitable wavelength for signal transmission of around 2µm results less scattering effects. In next future, high quality communication networks would be required from each aspect of the life, and would need to be efficient, secure, and high capacity data transmission. Optical wireless communication through laser pulses is an alternative if fiber optic communication is absent or difficult to access. Development of wireless communication technology would find extensive application in many areas such as radar, remote sensing from unmanned aircraft systems, spectroscopic sensing and imaging for defense and security screening, biological sensing (disease or cancer diagnostic), telecom and wireless data transfer. The advantage of this technology provides a wide range of applications bringing significant benefit to society with user friendly and secure. We thus conclude that with relatively intense atmospheric conditions, the longer wavelength is preferable to decrease the scattering affects.

NOMENCLATURES

A. Acronyms

FSO Free Space Optical
FWHM Full Width at Half Maximum
GPS Global Positioning System

B. Symbols / Parameters

λ : Central wavelength
$\Delta\tau$: Pulse duration
c : Speed of light

$\Delta\lambda$: Optical bandwidth
$\tau(\lambda, L)$: Attenuation factor
γ : Total attenuation coefficient
α : Attenuation due to absorption
β : Attenuation due to scattering
β_{Mie} : Mie scattering
β_{Geo} : Geometrical scattering
N_a : Rain drop distribution
a : Rain drop size
Q_{scat} : Scattering coefficient

REFERENCES

[1] R. Paschotta, "Free-Space Optical Communications, Encyclopedia of Laser Physics and Technology", Wiley-VCH, 2018-07-07.
[2] G. Toesko, C. Dehnert, "Ultrafast Laser Optics: Femtosecond Laser Optics Combat Pulse Dispersion, Color Errors, and Reflections", Laser Focus World, 2016.
[3] S. Koenig, et al., "Wireless Sub-THz Communication System with High Data Rate", Nature Photonics, 7, 977, 2013.
[4] T. Nakamura, S. Nagata, "5G Standards Frontline Report - High Speeds and High Capacity or Ultra High Confidence and Low Latency, Which Should Come First: Two Sides of a Debate at the 3GPP", 5th Generation Mobile Communication Promotion Forum (5GMF), 2016.
[5] D. Hillerkuss, et al., "26 Tbit s−1 Line-Rate Super-Channel Transmission Utilizing All-Optical Fast Fourier Transform Processing", Nature Photonics, No. 5, 2011.
[6] L.K. Oxenlowe, "Single-Laser Super-Channel", Nature Photonics, No. 5, 2011.
[7] H. Hu, et al., "Single Source 5-Dimensional (Space-, Wavelength-, Time-, Polarization-, Quadrature-) 43Tbit/s Data Transmission of 6SDM x 6WDM x 1.2Tbit/s Nyquist-OTDM-PDM-QPSK", Lasers and Electro-Optics (CLEO), 2014.
[8] K.A. Ahmed, C. Kai Choong, L. Hai-Feng, "Femtosecond Pulse Generation from Semiconductor Lasers Using the Soliton-Effect Compression Technique", IEEE Journal of Selected Topics in Quantum Electronics, No. 1, 1995.
[9] R. Paschotta, "Bandwidth, Encyclopedia of Laser Physics and Technology", Wiley-VCH, 2018-03-14.
[10] H.T. Eyyuboglu, M. Ari, M.C. Taplamacioglu, H. Gozde, "Probability of Error Estimation for an Optical Link Using Phase Distribution of Gaussian Vortex Beam", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 37, Vol. 10, No. 4, pp. 31-35, December 2018.
[11] R.M. Gagliardi, S. Karp, "Optical Communications", New York, 1995.
[12] H. Willebrand, B. Ghuman, "Free Space Optics: Enabling Optical Connectivity in Today's Networks", Sams Publishing, Indianapolis, 2002.
[13] H. Henniger, O. Wilfert, "An Introduction to Free-Space Optical Communications", Radio Engineering, No. 19, 2010.
[14] D.R. Bates, "Rayleigh Scattering by Air", Planetary and Space Science, No. 32, 1984.
[15] K.M. Shahiduzzaman, M. Hassan, B.K. Karmaker, L.K. Biswas, "Scattering Effect on Terrestrial Free Space Optical Signal in Tropical Weather Condition", IOSR Journal of Electronics and Communication Engineering, No. 10, 2015.
[16] H.A. Fadhil, et al., "Optimization of Free Space Optics Parameters: An Optimum Solution for Bad Weather Conditions", International Journal for Light and Electron Optics, No. 124, 2013.
[17] S.K. Singh, T.S. Hasarmani, R.M. Holmukhe, "Wireless Transmission of Electrical Power Overview of Recent Research & Development", International Journal of Computer and Electrical Engineering, No. 4, 2012.

BIOGRAPHIES

Muhammed Sayrac received bachelor's degree in physics from Cumhuriyet University, Sivas, Turkey. In August 2011, he started his master degree program, which included extensive experimental research in optics and laser physics at Texas A&M University, College Station, Texas. The master research has been about high harmonic generation (HHG) by using amplified femtosecond laser systems, which generates pulse duration at around 50 fs with repetition rate of 1 kHz or 10 Hz. After completion his master degree in August 2013, he began his PhD program in physics at the Texas A&M University. His PhD research has included a variety of experimental topics such as high harmonic generation, laser spectroscopy, mass spectroscopy, white light generation, and Bessel-Gaussian beams. Specifically, he focused on the improving the efficiency of HHG yield. He performed research on pressure optimization of HH yield, HHG from pump-probe fields, molecular alignment, and two-color laser field, diffractive imaging from a micron sized mesh using optimized harmonic source. He has experience in low light detection system, e.g., photomultipliers and related electronics as well as spectroscopic data acquisition LabVIEW codes, Matlab, Mathematica, Origin and SolidWorks programs. He completed his Ph.D. degree in May 2017. He is a faculty member of Physics Department at Cankiri Karatekin University, Cankiri, Turkey since November 2017. His research interests include ultrafast lasers and laser spectroscopy, nonlinear optics, high harmonic generation, attosecond science, and femtosecond lasers.

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