ASSESSING FREE SPACE OPTICAL DEVICE PERFORMANCE AS A FUNCTION OF ENVIRONMENT DEPLOYED AT THE UNIVERSITY OF WOLLONGONG IN DUBAI

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ABSTRACT

Demand for data bandwidth networks has increased enormously in the IT business industries. Free Space Optics (FSO) is gaining popularity in the telecom and network enterprises and is now accepted as a functional, wireless, high-bandwidth access tool for network and telecom engineers. However, as of today, optical fiber cable technology is still preferred by the consumers due to the high data rates and high capacities in connecting data networks. Unfortunately, fiber optic cable based connection is not applicable in all situations, especially for long distance networks, as it needs under cable trenching. The FSO, however, has a lower cost compared to fiber optics technology and has a significantly shorter installation time. FSO is now considered a viable alternative to fiber for short-haul access distances of 4 km or less.

FSO systems can be operated in a point-to-point mode to interconnect two locations or in a point-to-multipoint mode. In the past year, different types of communication system devices were deployed to connect the three UOWD buildings on its Knowledge Village campus, Dubai. The air-distance between the school buildings and the broadcast station is approximately 200 meters.

To determine the performance of FSO links, Bandwidth and link availability were observed for the entire period of 2013 (Jan 1 to Dec 31). Link availability expressed in percentage in general defines the proportion of time a system is in full operational condition. The results of our investigation reveal that there are some atmospheric disturbances. The results also reveal that fog can have a considerable impact on the reliability of the FSO link.

KEY WORDS

- Freespace Space Optics,
- Climatic factors,
- Regression

INTRODUCTION

The objective of this research is to assess the performance of FSO in relation to climatic factors. Weather factors such as temperature, humidity and wind speed limit the maximum data rate of the FSO system since the propagation of optical beam is transmitted in the air. This study needs a thorough understanding of the performance of FSO communication system as a point-to-point wireless communication including understanding how the system works and clarifying its advantages and disadvantages in the daily operation of the network services provided to the University community. This research called for the study of the network design infrastructure using FSO technology and for a comparison with other existing technologies such as Microware Radio Frequency (RF) technology.

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2. PROBLEM STATEMENT

While fiber-optic cable and FSO technology share many characteristics, they have different challenges due to the way they transmit data. Fiber-optic is subject to outside disturbance. Laying out this optic cable is sometimes not practical as it depends on the structure of the building. FSO technology has an outstanding potential solution for wireless network bridging purposes.

In the case of our University, under-cable trenching is not possible. The connectivity between these buildings is very crucial to the daily operations of the entire network infrastructure. If there is a disconnection from the FSO system, most IT services will not work. These services include internet, emails, finance applications, virtual desktop machines and wireless campus network.

For a wireless point-to-point implementation such as FSO technology, the network must be designed in such as a way to resist the severe changes in weather so that atmospheric conditions do not affect the FSO link performance in both bandwidth capacity and link availability. Since the implementation of the FSO is a line of sight technology, it relies mainly on transmitter and receiver devices as points of interconnection and must be free from physical obstruction in order for the devices to be able to see each other. Climatic factors such as humidity, temperature, wind-speed, sand-storm and fog may attenuate the signal transmitted between the two devices. Such attenuation would then degrade FSO performance in data bandwidth and network availability. Obviously, climatic factors are uncontrollable but still there is an urge to assess the effect of climatic factors on the FSO performance.

3. HISTORICAL BACKGROUND AND TECHNICAL FEATURE OF FSO

In the 19th century, Alexander Graham Bell invented a new device named photophone, which was used to transmit sound over an invisible beam light. This device as shown in figure I. did not need wire for transmission. Although this optical technology invention never became a commercial reality, it emerged as a foundation of the basic principle of optical communications (Sound Choice, 2013).

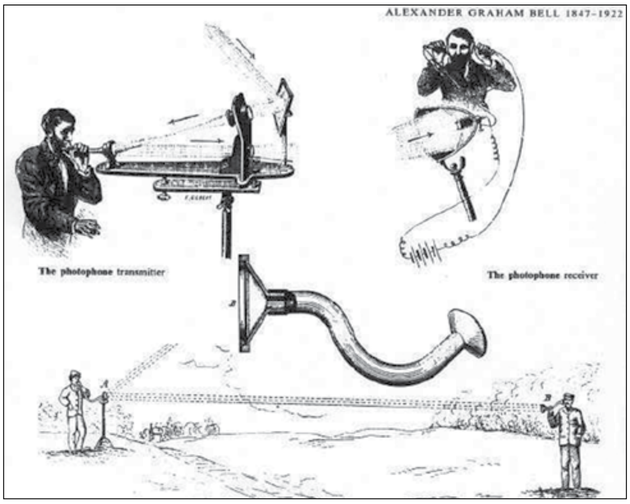


Figure 1. Bell's demonstration of the "photophone" in 1880 (Sound Choice, 2013)

In the late 60s, Dr. Erhard Kube, a German scientist known as the father of the FSO technology, published a paper which explained the possibility of data transmission through the atmosphere using light beams. FSO was first used in military research providing secure data and voice transmissions in their military defense. The limited ranges of only few kilobits per second transmission provided by FSO technology was a major disadvantage. Furthermore, it witnessed a vulnerability to weather interferences (Willerbrand & Ghuman, 2001 p.42). Today, because of a significant increase in FSO power, the feasible range distance of transmission reaches up to 4 km.

After the 70s, the introduction and the deployment of the fiber optic cable in the telecommunication industry became widely popular due to its advantages of performance, such as its high bandwidth, reliability and high securities. In the 80s, by addressing the principal challenges and issues, scientists and researchers began to produce an improved FSO system until it became commercially available in the market. Today, the FSO is one of the options for most of the telecommunication industries because of its similar performance of the fiber optic cable.

3.1. Key drivers of Free Space Optics in Enterprise level

Bandwidth Market Demands

The Middle East is one of the fastest growing regions in the world creating an ever growing demand for bandwidth. Regional telecoms are urged to provide more bandwidth to meet this demand and sustain the growth (Al-Soulah 2013).

According to Adjovi (2013), United Arab Emirates is becoming a world leader in terms to Fiber to the home (FTTH) with a penetration at 65% of households at the end of 2012. UAE is ahead of South Korea, the previous FTTH worldwide leader (57% of households as of December 2012). Further, Shah (2013) states that the UAE is sitting in the middle of the world and hence acting as a hub. But it is far behind other hubs like London or New York. It is therefore very important to be connected to the fastest form of traffic growth and it is important to have as much bandwidth as possible.

In 2013, Optics.org forecasted that the demand trend will continue to rise in the future and the market for FSO device system will increase (figure 2). The global market for this technology grew by 13% from the previous year. In the EMEA (Europe, Middle East and Africa) region it will grow at merely 4.6%.

United Arab Emirates has a huge demand for high bandwidth to support their current infrastructures because of its technological advancement.

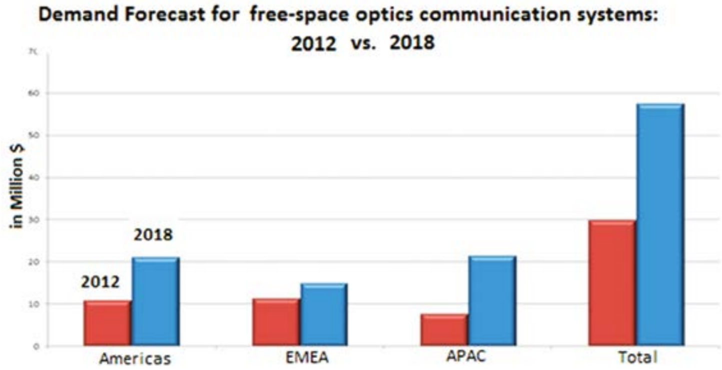


Figure 2. Demand forecast for FSO technology

Cost and Convenience

Southwell (2013) stated that “When deployed in urban areas, free space optics can act as a low-cost yet high-speed link for last mile connectivity”. In addition, Akilie (2013) explains that the multitude of benefits offered by FSO is also helping establish its enterprise credentials. It has a relatively low acquisition cost compared to leased line connectivity. Lightpointe Middle-East, an FSO provider, uses a return on investment (ROI) model that is based on either a European Format (E1) or the digital subscriber line (DSL) that amortizes its costs within six months to one year. Southwell (2013) mentions that currently “FSO technology is also license free, which means that end users wishing to implement the technology do not have to wait for official permission, nor invest in the license itself. Organizations do not need to pay for frequency license to Country regulatory authorities”. The author adds that legal advantages of FSO could be overturned if local operators see it as a threat to their leased line business and start lobbying governments, which is the case in the UAE.

Security

Terabema, an FSO vendor, proposes a uni-directional optical stream with a small diameter in order to ensure high security, and only Terabeam’s site equipment can receive data sent from the Terabeam network (http://www.terabeam.com/our/our_gen.com). The same solution is proposed by Furtera, which is another FSO provider. (http://www.furtera.com/fsofaq.html).

In addition, the OPTera Metro 2400 is laser-based and is much more secure than other wireless solutions. Its narrow laser beam is not accessible unless viewed directly on the transmission path. Therefore, it is virtually impossible to intercept its signal without being detected.

3.2. Basic Overview of Free Space Optics

FSO components

As shown in Figure 3, FSO is composed of a transmitter, an FSO channel, and a receiver. FSO uses either LED or diode semiconductor lasers transmitting at wavelengths of 750785-- nm or 15001550- nm. The laser can be either directly modulated or it uses an external modulator. Receivers can have light detectors based on either PIN diode or avalanche photodiode (APD).

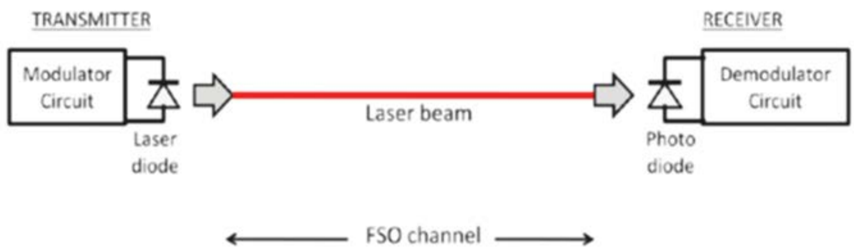


Figure 3. Basic Component link of Free Space Optics

Free Space Optic propagation Aspect FSO signal propagates through space as formulated by the Friis free space propagation antenna equation

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$$

This equation describes in terms of the received power P_r, the relationship when a transmitter at point A makes a transmission to a receiver at point B with a distance R between them. The equation indicates that a lower frequency and higher antenna gain will improve transmission rate. It also indicates that the received power P_r depends on the transmit power P_t, the wavelength (λ) and the gains of transmitting and receiving antennas G_t, G_r, respectively in an ideal free space environment. Received power will decrease over distance, although in real world situations the decay rate is also affected by reflection, diffraction, scattering due to obstacles and atmospheric conditions.

3.3 Comparison Free Space Optics (FSO) vs. Radio Frequency (RF) Microwave Link

RF and FSO are two common wireless technologies that are used for last mile solution. According to Ahmad et al. (2012), there is no direct competition between the two technologies. Table 1 below lists a summary of the differences between FSO and RF.

Table 1. Summary of differences between FSO and Microwave Link (RF-based) technology.

Classification Criteria	FSO	Microwave radio (RF based)
Speed/Bandwidth	Gbps	Mbps
Installation	Moderate	Difficult
Uses	P2P/P2MP short and long distance	P2P short distance
Advantages	Price vs performances, security	Speed vs installation
Disadvantages	Dependent of weather conditions	Dependent of weather conditions, can be intercepted
Security	Good	Poor
Maintenance	Low	Low
Skills	Moderate	High

Singh and Singh (2011) stated that FSO is just starting to be applied for solving Internet last-mile interconnectivity problem. Some believe that it may be the unlimited bandwidth solution for the metro-urban core of downtown building-to-building communication, as well as the optimal technology for home-to-home and office-to-office connectivity. FSO systems have been shown to be reliable (99.9% to 99.999%) communication channels with fast bandwidth. They are easy to set up and provide cost-effective solutions. However, the industry still does not know how to properly deploy them in telecom networks. To address these concerns, the FSO community recently launched the Free Space Optics Alliance to educate the communication industry as a whole. It is believed that such industry-wide education will enable standards to emerge and growth of FSO technology to occur. Finally, it should be noted that to better quantify the technical and scientific aspects of FSO, there is still a need for research in new laser sources, atmospheric spectroscopy, multi-beam and active alignment techniques and multi-detector averaging.

In addition, Singh and Singh (2011) further conclude that the main problems in today's last mile solutions that are based on microwave communication technology are bandwidth limitations and security. FSO, however, offers solutions to these two problems. Free Space Optics (FSO) is an optical technology that offers high-speed last-mile solution and has capabilities to be used for Quantum Key Distribution. FSO requires no licensing or frequency synchronization. It allows transmission of data with theoretically "unlimited" bandwidth and thus represents a viable solution for the last-mile problem.

3.4 Major Challenges of FSO

Technical Challenges

Maintaining the Line of Sight (LOS) between the end-points, i.e. the sender and receiver during the transmission is one of the major challenges facing FSO. This problem is called "Pointing Acquisition Tracking" process. Several researchers have developed adequate solutions to this problem using different techniques. Dereneck et al. (2005) proposed the use of a hierarchical point, or the acquisition and tracking PAT system as a vision-based system to maintain LOS. The system assumes prior knowledge regarding the initial position of each FSO node and its partner and receiver. The alignment process is carried out using feedback from a high zoom camera system. In contrast, Akallaet. et al. (2005) proposed an omnidirectional spherical FSO transceivers to maintain the line of sight (LOS) of the FSO system. The LOS transceiver is a promising approach to the alignment problem in mobile environments. However, the current hardware implementations are not fast enough to switch the beam to another FSO channel without significant breaks of the connectivity.

Nichols (2005) proposed a framework using a dynamic RF/FSO staged acquisition technique. This approach also seems a promising solution to the point, acquisition and tracking system (PAT) problem but there has been no implementation or field test to this proposal until now.

Routing and Path protection in FSO

Another challenge facing FSO is the disparate and time varying nature of the FSO channel making routing difficult within FSO network. Kashyap and Shayman (2005) introduced a routing framework for traffic demand compared with FSO link. Based on their article, they introduced a concept called "critically index" which determines the fraction of each traffic profile entry. This means that the path is implemented as an extension of the Open Shorted Path First (OSPF) routing protocols.

Environmental Challenges

A further serious challenge to FSO technology is due to environmental and climatic factors. Kim et al. (1999) point out that one of the main limitations of FSO technology is due to fog and severe weather conditions which can have a detrimental impact on the performance of the Free Space Optic systems. Fog, rain and snow contribute negatively to the maximum distances that can be achieved. Table 2 presents the FSO operational distance performance as a function of weather conditions.

Table 2. FSO operational distance performance as a function of weather conditions

Weather condition		Precipitation	mm/hr	Visibility	dB loss/km	TerraLink 0-155 Range
Dense fog				0 m		
				50 m	– 315,0	140 m
Thick fog				200 m	– 75,3	460 m
Moderate fog	Snow			500 m	– 28,9	980 m
Light fog		Cloudburst	100	770 m	– 18,3	1,38 km
				1 km	– 13,8	1,68 km
Thin fog		Heavy rain	25	1,9 km	– 6,9	2,39 km
				2 km	– 6,6	2,79 km
Haze		Medium rain	12,5	2,8 km	– 4,6	3,50 km
				4 km	– 3,1	4,38 km
Light Haze		Light rain	2,5	5,9 km	– 2,0	5,44 km
				10 km	– 1,1	6,89 km
Clear		Drizzle	0,25	18,1 km	– 0,6	8,00 km
				20 km	– 0,54	8,22 km
Very clear				23 km	– 0,47	8,33 km
				50 km	– 0,10	9,15 km

Although, Table 2 was established by the vendors for an average yearly fog level for major cities, Kim et al. (1998) suggested that it is recommended that these data should be constantly reviewed for other climatic conditions. Still the vendor's product specification should be used to ensure the product will perform in a satisfactorily manner for connection.

Several research studies have shown that the weather conditions have a large effect on FSO link availability. Mainly, Kim et al. (2001) in their article entitled "Wireless optical transmission of Fast Ethernet, FDDI, ATM, and ESCON protocol data using the TerraLink laser communication system" have studied in deep the effect of climatic factors on the FSO performance.

Adhaikari et al. (1998) stressed that atmospheric conditions such as temperature and wind speed have a significant impact on limiting the distance of the connections: as the beam goes through small pockets of differing variations in air temperature and wind speed the light can be refracted. Since the variations in these factors are very small, most vendors will use multiple lasers in parallel on the Free Space Optic system to compensate, especially on units designed for longer distances. Since RF wireless systems like the ones based on the 802.11b standard are not affected so much by fog, some manufacturers are using them as a redundant system and have incorporated them into their FSO systems.

Scintillation defined by Nawani (2009) as being the sequential and spatial variations in light intensity caused by atmospheric turbulence which is caused by wind and temperature gradients that create pockets of air with rapidly varying densities. In his studies he suggests that the signal attenuation caused by scintillation depends on the time of day and can vary by orders of magnitude during a hot day. Various climate possibilities are shown in figure 4. Rain though it causes attenuation of visible radiation on the other hand, also attenuates visible radiation but the optical link can be engineered such that, for a large fraction of time, an acceptable power can be received even in the presence of heavy rain.

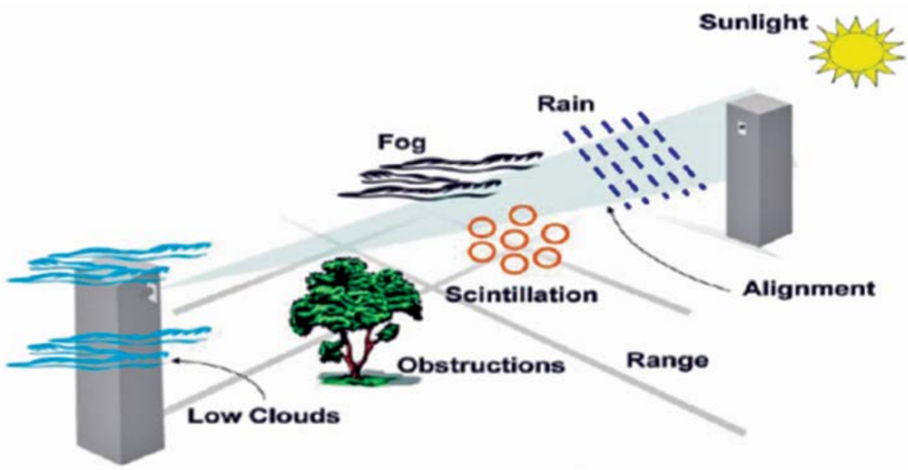


Figure 4. Environmental and climatic factors affecting the signal of FSO system.

FSO deployment System

UOWD Campus Network Architecture

The internet backbone connection between various buildings of the University of Wollongong in Dubai (UOWD) is provided by Du Telecom with a bandwidth speed of 70 Mbps. UOWD campus has three segregated buildings; namely Block 5, Block 14 and Block 15 at Knowledge Village campus in Dubai, UAE. These buildings are connected to a LAN network with the use of optical wireless link system with a speed of 1.25 Gbps. The distance from block 5 to block 15 is measured with a 200 meters gap. UOWD implemented various solutions to link these separated buildings by implementing the leased line from ISP and Microwave Radio frequency based transmission. As the property management guidelines do not allow cable trenching, the University was seeking other solutions. In the past, the University through its IT department implemented a Microwave RF wireless bridge with a 100 Mbps bandwidth speed connections.

Due to the technological advancement and change in the requirements of the University computing needs, Microwave RF became expensive to maintain and most of all, the Microwave RF was no longer coping up with the growing need of a larger bandwidth.

The university has more than 350 faculty and administration staff and 4500 students. The entire campus has nine computer laboratories with a total of 250 workstations, and it has 300 individual workstations. Other services are provided to students such as virtual desktop infrastructure (VDI) consisting of 500 virtual machines. Students' electronic data such as lecture notes, e-books, class schedules that were previously available only on UOWD computer labs, are now accessible from any device at any time, on or off campus. Students and staff have now virtual access to teaching software programs such as Adobe Creative Master Suite, SPSS, NVIVO, Matlab, RobotC, Oracle, visual studio and Arena.

Technical Specification of FSO System deployed

FSO device has 4 laser beams in order to stabilize the transmission, and to assure the connectivity when some beams are blocked. Lightpointe Hybrid-FSO device is designed for 99.999 % link availability in all-weather conditions. These links include a multi frequency adaptive rate modulation technology, which automatically adjusts the system throughout, based on the available system fade margin and operating condition (Lightpointe2013). Table 3 summarizes the technical specification of UOWD Lightpointe FSO unit, Model: HyBridge LXR-5 (Hybrid-FSO) :

Table 3 : Technical Specification of I

Lightpointe FSO Optical	Components Features
Description	Four-Beam Optics System with Auto Tracking and Automatic
Receiver/Transmetter(s)	Four transmitters, four receivers
Operating Voltage	Direct 48 Vdc or 48 Vdc via PoE injector
Alignment System	Heavy duty pan/tilt alignment bracket
Power Consumption	Max 40 W
Bit Rate	1.25 Gbps, full-duplex
Operational Range	Up to 1 mile (1600 meters) @17 dB/km attenuation
Free-Space Wavelength	850 mm
Back up Redundant	RF Unit with 150 Mbps
Temperature	– 25 C to 60 C (– 13 F to 140 F)
Humidity Range	Up to 95% non-condensing

FSO point-to-point Implementation

The university has three segregated buildings located inside the knowledge village campus. Due to the restrictions of laying out fiber cable, the university had to implement an alternative solution for connecting these three buildings, namely block 5, block 14 and block15. Based on the physical layout of the buildings, the type of network applications needed to implement is the point-to-point network architecture; which means that endpoints need to be connected to each other. This type architecture will resolve the issues of linking the gap between the buildings.

Measuring the distance gap between the buildings with high precision is crucial in order to avoid an unstable link. The vendor inspected the physical site and checked the possibility of blockage or physical hindrances between buildings in order to provide the right equipment and to plan correctly the implementation. GPS positioning was used to mark each location at both ends and to work out the exact distance between the laser heads. Heights of the installation requirements are also taken into consideration in order to achieve stable performance and to ensure the use of the correct size unit. The physical visualization of the site is shown in Figure 5.

Figure 5. Physical visualization of the UOWD FSO link area

The distance between block 5 and block 15 building is 200 meters without any physical hindrances or interferences. FSO system data transmission used by UOWD can be used for a distance up to 1000 meters distance transmitting data through the air. Thus it is expected that UOWD FSO system will have a better and stable performance since the distance is much shorter.

FSO Installation

Since this system would be installed in an outdoor area, a heavy duty mounting kit was required for the installation to minimize the effects of strong winds which can cause misalignment of the FSO unit. There are two common ways of installing the device on the rooftop: penetrating (bolted to the roof) or non-penetrating (weighted down by water containers, cinder blocks, or sand). Penetrating mounts are firmly affixed directly to the most stable area of the supporting structure. In the case of UOWD, the FSO system was installed in one of the most stable ways by doing penetration of the bolts going to the cement.

FSO system was installed in the rooftop of a building that is 120 feet high; this is to avoid link interruption for the people walking in front of the FSO system. Other factors that need to be considered are for example: the utilization of a special cable for outdoor areas for longer use and durability.

Figure 6. UOWD FSO installation with mounting bracket

4. PERFORMANCE ANALYSIS OF THE FSO SYSTEM

In analyzing the performance of the FSO system, there are two categories of parameters that must be considered: internal parameters and external parameters. Internal parameters are related to the design of the FSO system ; this includes the optical power, wavelength, transmission bandwidth, optical loss on the transmit side, receiver sensitivity, bit error rate (BER), receiver lens diameter, and the receiver field of view. External parameters or non-system parameters are related to the environment in which the system must operate and includes visibility, atmospheric attenuation, scintillation, deployment distance, window and pointing loss. In this experimental study, two factors have been investigated: The installation and the climatic factors as they may have a significant impact on FSO performance. In general, the weather and the installation characteristics can have a great impact on impairing or reducing the link performance of the FSO system. Internal configuration has already been checked in contrast to the performance of the FSO system.

In the event of low performance of the FSO system, weather conditions such as fog, rain and sandstorm are difficult to handle because these types of events are uncontrollable and unavoidable.

Experimental setup and Data Collection

In analyzing the performance of the FSO system, data was gathered through the FSO system logs of the device. Along with the logs, the researcher configured a server and client machine and installed Jperf software to measure the bandwidth performance of the entire network of the University campus. With the results of bandwidth performance, link availability needs to be looked with the use of AireManager from the Lighpointe FSO system.

The impact of weather conditions on the performance of FSO link has been researched. The researcher gathered daily data for the year 2013. Weather information data were collected through the Accuweather satellite website (see figure below). The weather data includes the temperature, wind speed, humidity, and precipitation. Every single datum was recorded and tabulated carefully until the end of the day.

The whole network of the university campus was connected to the Local Area Network through the use of FSO link system. At both locations, building 5 and building 15, there were dedicated servers for collecting the data that were used for initiating traffic over the FSO link. As shown in Figure 7.

Figure 7. FSO system pointed from block 15 to block 5

Daily network traffic, the bandwidth performance, and the result of the measurements were collected and saved in the database logs from the FSO system. An example of the Jperf window reporting the bandwidth of the FSO system is presented by Figure 11.

Statistical Analysis

Daily data was collected from a real-life condition during the period of January 2013 to December 2013. A 91.91 Mbps total bandwidth average was achieved compared to 10.15 Mbps total average loss of bandwidth. Although there is a loss of bandwidth performance throughout the year, it is obvious that the actual achieved performance is much higher than the loss. The bandwidth performance is higher because the FSO system performed well, despite of having sometimes bad weather conditions. Higher link percentage is translated to availability of the FSO system. Further the higher the link, the higher the bandwidth is achieved from the network. Bandwidth performance is usually related to the performance of the link availability. The loss performance by the FSO link failure is due to weather conditions, such as fog and rain; which attenuate the performance of the FSO link. This happens more in winter time as can be seen in figure 8. Therefore UOWD campus communication is characterized to be reliable and stable realm of data transmission in their campus network.

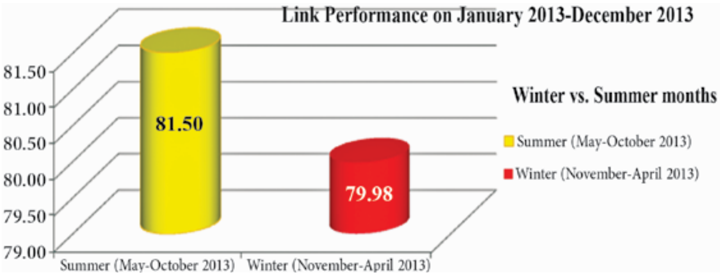


Figure 8. Link Performance Summer vs. Winter

Figure 8 shows the link performance over the period of 12 months within the campus of UOWD. Throughout the summer months (May to August), the implemented FSO system had link performances as high as 81.5%. On the other hand, throughout the winter months (November to April) link performances reached as high as 79.98%. This decrease in performance mainly happened because of external factors such as the weather conditions discussed above. During the winter period, Dubai tends to witness unstable weather conditions. Some days are foggy; others are rainy, while others are sandy. This instability in the weather conditions is mainly what hinders the link performance during the winter months. Still, the hindered performance was not that important as the performance only decreased by 1.52%. Despite of some bad weather conditions, FSO system still performed better than expected. In addition, having a good base of installation of FSO system helps maintain the alignment of the beams despite of any unstable weather conditions. Through the implementation of a good installation base, the improvement the link performance of the FSO system is significantly added up.

Figure 9 shows the average FSO link availability within the year 2013. There is a total link performance of 81.5%, but a 19.5% total performance loss. Some external factors, such as weather conditions, have great effects over the link availability and performance of the FSO system. Diverse atmospheric and weather conditions like rainfall, direct sunlight, snow or fog can cause some disturbances to the connection of the FSO system. Contrary to the FSO links that are used in space for inter-satellite connections and communications, the reliability of FSO systems and links on Earth are influenced by the troposphere, which is the layer of the atmosphere that we live in and it is where all weather patterns take place.

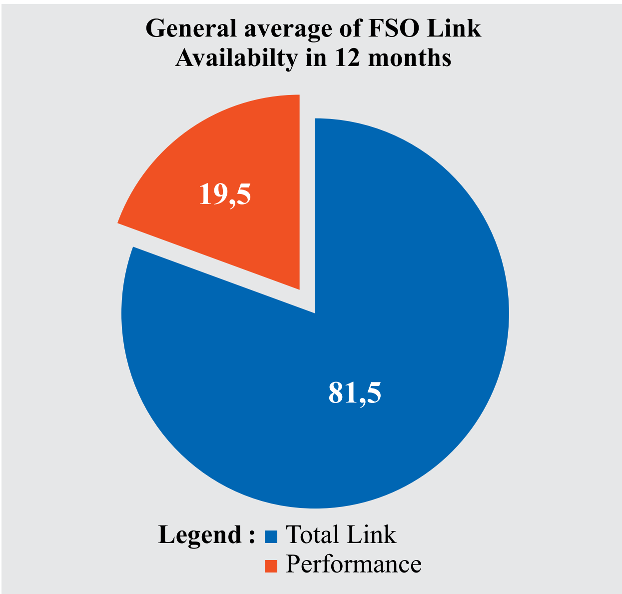


Figure 9. Average FSO link availability

Figure 10 shows a detailed monthly FSO system performance throughout the whole year and climatic factors. The performance measures include the average network bandwidth and link availability. Climatic factors include the average monthly temperature of the city in degree Celsius, and the average monthly wind speed in km/h. The lowest total link availability was in January, while the highest was in May. The lowest network bandwidth was in April, whereas the highest was in June.

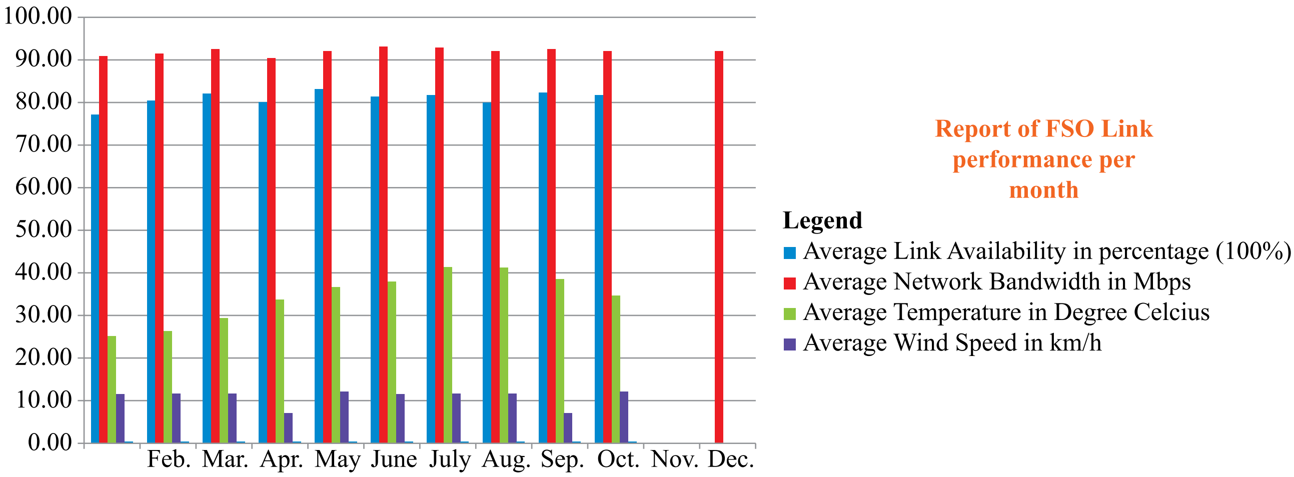


Figure 10. *Monthly FSO performance and link availability.*

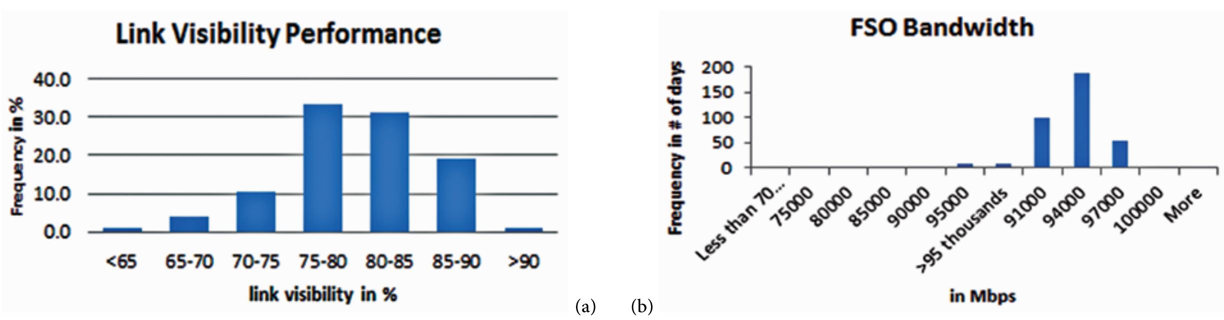
The highest performance in both the link availability and the network bandwidth were during summer mainly in May and in June. The lowest performances were during winter mainly in January to April. This illustrates and proves that the downturn of the FSO system is linked to some extent to climatic weather conditions.

Descriptive Statistics of the Data Collected year 2013

Descriptive statistic of the data collected presented in table 4 which shows that the coefficient of variations of the network bandwidth and the link availability are only 3.46% and 6.92% respectively. Whereas, wind, humidity and temperature, have larger variations' coefficients of 29.52%, 23.42% and 18.69% respectively. Initially, these results may reveal that there only a minor effect of the weather conditions on FSO performance measures as the later parameters are more stable. Histograms corresponding to Performance measures reveal that time series distribution is close to normal.

Table 4. Descriptive Statistics of the data collected

	Temperature (C°)	Wind (km/h)	Humidity (%)	Link Availability 100%	Network Bandwidth Achieved	Precipitation
Average	33.58	11.41	52.15	80.46	91700.98	0.10
Median	34	11	53	81	92000	0
Min	21	5	19	63	70705	0
Max	49	27	79	92	99193	13
Standard Deviation	6.28	3.37	12.23	5.57	3173.80	0.94
Coefficient Variation %	18.69	29.52	23.45	6.92	3.46	947.02



(a) (b)

Figure 11. FSO Performance measure

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Regression Results

In order to assess the dependency of FSO performance (link availability and network bandwidth) on the climatic variables (temperature, wind speed and Humidity), two Regressions were conducted. The first regression is conducted for the network bandwidth as a dependent variable; the results presented in table 5.a reveal that only the humidity variable had a significant effect on network bandwidth (p=0.00). Temperature has a weak effect while wind did not show any significance at α=0.05. This regression model explains only 6.8% of the variation of the Network Bandwidth. The overall model is significant as its F pvalue is equal to (p=0.00).

Dependant Variable : **Network Bandwidth tn (Kbps)**			
Regression Statistics			
R Square	0.068		
Observations	364		
D_f	*F-value*	*Significance F-p-value*	
3	8.71	**0.00****	
	Coefficients	*t Stat*	*P-value*
Intercept	92376.76	57.43	0.00
Temperature (C°)	47.68	1.62	0.11
Wind (km/h)	32.84	0.68	0.50
Humidity (%)	– 50.84	– 3.38	**0.00****

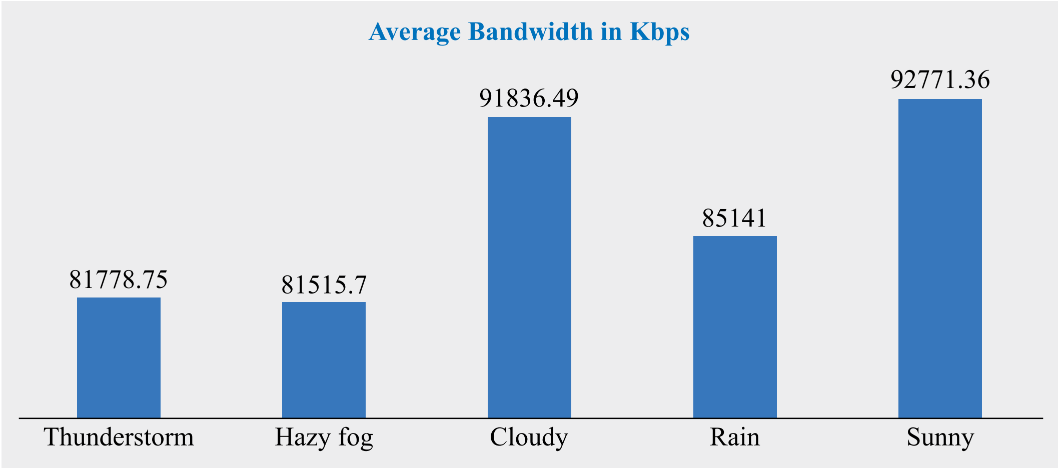
Table 6a. *Regression Results, Dependent variable (Network bandwidth)*

The second regression tests the relationship between the the link visibility as a dependent variable and the three climatic variables. The model as shown by table 5.v explains 12% of the variability in the link visibility. All the three climatic variables have a significant effect on link visibility.

Dependant Variable : **Link Visibility (%)**			
Regression Statistics			
R Square	0.12		
Observations	364		
D_f	*F-value*	*Significance F*	
3	16.04	0.00	
	Coefficients	*t Stat*	*P-value*
Intercept	79.11	28.83	0.00
Temperature (C°)	0.21	4.23	**0.00**
Wind (km/h)	– 0.20	– 2.46	**0.01**
Humidity (%)	– 0.07	– 2.58	**0.01**

Table 6b. *Regression Results, Dependent variable (Link visibility)*

Further we categorized the weather as being either Thunderstorm, Hazy fog, cloudy, rainy or sunny day and for each category we have calculated the average FSO performance. The calculations are presented as a bar graph for comparison in figure 12. Clearly during Sunny days both performance measures are much higher than other days. The difference is estimated to be around 20% for link availability and around 8% for bandwidth.



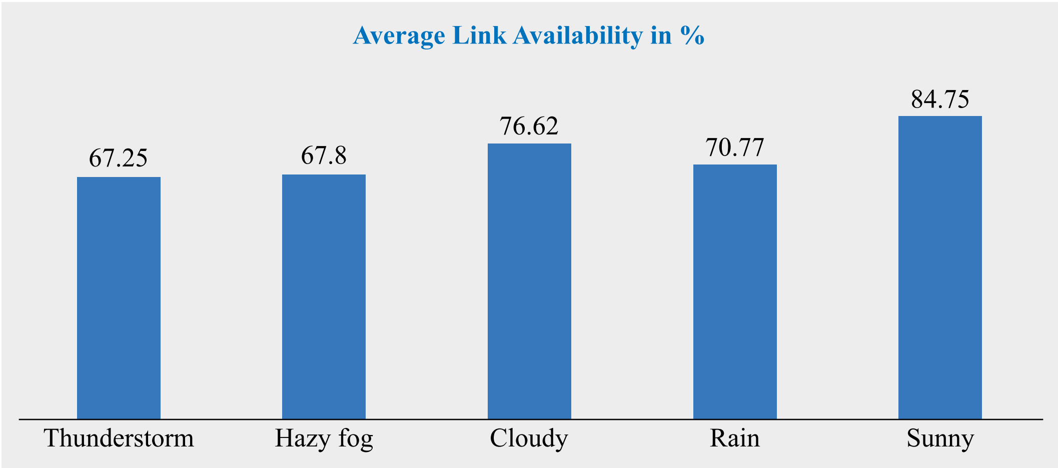


Figure 12. *FSO performance vs. climatic weather conditions*

CONCLUSION

An experimental evaluation of the performance of FSO system has been presented. Two important parameters for evaluating the performance of the FSO system have been analyzed and measured in relation to the weather conditions in the university campus. The results show that the FSO system performed well; despite of having some turbulence in weather conditions, it achieved a 91% percent in total in terms of performance during the year 2013. Furth the network bandwidth is significantly stable during the year with less than 4% variation. Similarly the link availability is also stable with less than 7% variation. This study shows that the FSO system can provide a reliable connection with a total availability of 81.5% over 12 months. Finally, the collected data that was successfully conducted greatly challenged the impact of fogs in the FSO link. The observation of this FSO link performance has shown that the link availability of the FSO system in the summer months obviously performed better than in winter months in Dubai, UAE. All in all, implementing a free-space optics system in order to link connection gaps does face many challenges, but if they are addressed and confronted with careful attention, the FSO performance is effective, efficient, and undoubtable.

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