Due to the restrictions of laying out fiber cable, the university had to implement an alternative solution for connecting the three buildings. 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.

Measuring the distance gap between the buildings with high precision is crucial in order to avoid an unstable link. 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. FSO system data transmission can be used for a distance up to 1000 meters distance transmitting data through the air

4.4 FSO Installation

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.

5. Performance Analysis of the FSO system

In analysing the performance of the FSO system, two categories of parameters are 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.

5.1 Experimental setup and data collection

Data was gathered through the FSO system logs of the device. Along with the logs, server and client machine and installed *Jperf* software [14] are configured to measure the bandwidth performance of the entire network. With the results of bandwidth performance, link availability needs to be looked with the use of *AireManager* from the *Lighpointe* FSO system.

Besides daily network traffic, the bandwidth performance, daily weather data for a year were collected through the *Accuweather* satellite website. 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.

5.2 Statistical Analysis

91.69 Mbps total bandwidth average was achieved compared to 8.31 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 1.

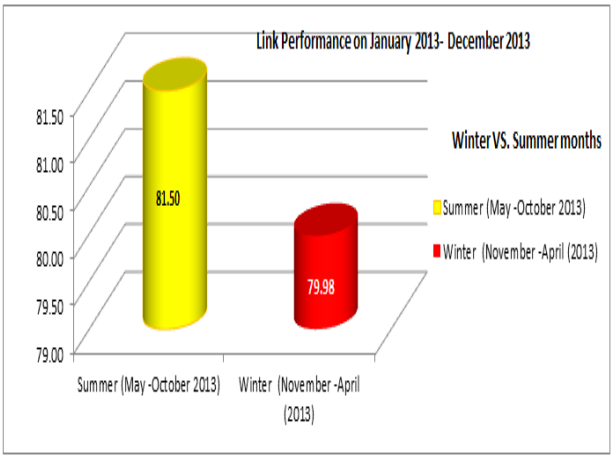

Figure 1 Link Performance Summer vs. Winter

Figure 1 shows the link performance over the period of 12 months within the campus. 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. 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.

The total link performance reached 81.5%, and only 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.

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. 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.

5.2 Descriptive Statistics of the Data Collected

Table 1 presents Descriptive statistic of the data collected throughput the year (365 days) mainly the four climatic factors, link availability and bandwidth. The results reveal that the link availability is 80.46% with a coefficient of variations of 6.92%. The network bandwidth reached on average 91693.31 (kbps) with only 3.46% variation. Whereas, temperature, wind and humidity and have larger variations' coefficients of 18.69%, 29.42% and 23.43% respectively over the 365 days. 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. Only 8 days out of 365 days, rain precipitation was observed with a total of 36 ml.

5.3 Frequency distribution of FSO Performance

The variation in link visibility performance and FSO Bandwidth throughout the 365 days are presented as distribution histograms and shown in figure 2.

TABLE 1. Descriptive Statistics of the data collected

	Temperature (Celsius)	Wind (km/h)	Humidity (%)	Precipitation (ml)	Availability 100%	Bandwidth Achieved
Average	33.57	11.42	52.19	0.10	80.44	91693.31
Median	34.00	11.00	53.00	0.00	81.00	92000.00
Min	21.00	5.00	19.00	0.00	63.00	70705.00
Max	49.00	27.00	79.00	13.00	92.00	99193.00
Std	6.27	3.37	12.23	0.94	5.57	3172.81
Coef- of Variation %	18.69	29.52	23.43	948.33	6.93	3.46

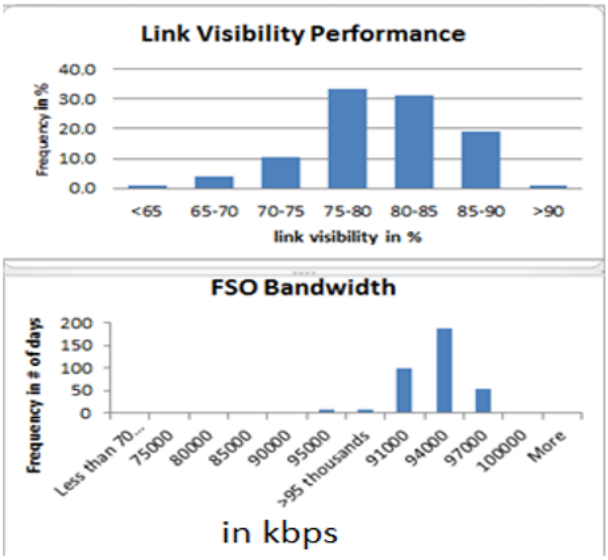

Figure 2. Frequency distributions of the FSO Performance measures (N=365 days)

5.4 FSO Performance as a function of weather conditions

Further, the weather was categorized as being either Thunderstorm, Hazy fog, cloudy, rainy or sunny day and for each category the average FSO performance was calculated. The results are presented as a bar graph for comparison in figure 3. 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.

5.5 Influence of the climatic Factors on FSO Performance

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.

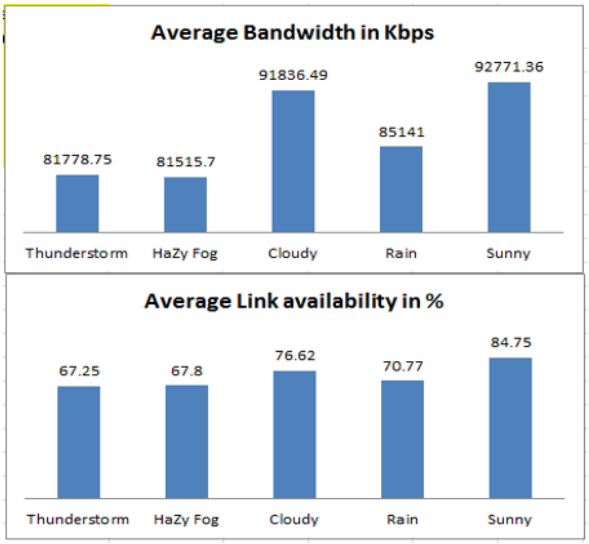

Fig. 3 FSO performance vs. climatic weather conditions

5.5.1 Regression Climatic Factors on FSO Link availability

The first regression is conducted for the *link availability* as a dependent variable; the results presented in table 2 reveal all climatic factors are significant.

Predictor	*Coefficients*	*t Stat*	*P-value*
Intercept	79.767		
Temperature (C)	0.206	4.114	0.000
Wind (km/h)	-0.219	-2.683	0.008
Humidity (%)	-0.070	-2.745	0.006

Table 2. Relationship Link availability versus Climatic Factors R-square 13.1% F(4,364)=13.5 p=0.000

The temperature has positive effect on link availability (coef=+0.206) while both wind and humidity have negative effects Coef.(wind)=-.219 and Coef.(humidity)=-0.70.

5.5.2 Regression Climatic Factors on FSO Bandwidth

The second regression is conducted for the *bandwidth* as a dependent variable; the results presented in table 3 reveal that both the temperature and the wind had no significant effect on Bandwidth. However, Humidity has a significant negative effect on Bandwidth. Further the regression model explains only 8.9% of the variation in the dependent variable.

	Coefficients	*t Stat*	*P-value*
Intercept	92874.5431		
Temperature (C)	42.378	1.455	0.146
Wind (km/h)	21.178	0.444	0.657
Humidity (%)	-53.609	-3.602	0.000

Table 3. Relationship Bandwidth versus Climatic Factors R-square 8.9% F(4,364)=8.8 p=0.000

6. 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 analysed 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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