A Testbed for Remote Wireless Sensing Utilizing Free Space Optical Link

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***Abstract*—Wireless Sensing (WS) using Free-Space Optics (FSO) is an evolving technology that has several applications in diverse Cyber-Physical Systems. FSO communication has several advantages over conventional wireless communication such as avoiding typical radio interference faced by conventional wireless communication links, no or low-cost spectrum license fees, depending on the countries' regulations, and being easy and fast to deploy, especially in critical conditions such those encountered in defence applications and scenarios. In addition, since FSO requires a line-of-sight communication link between the transmitter and the receiver, it can be used to achieve long-distance communication links while being secured. In this paper, an experimental testbed utilizing off-the-shelf hardware component and open-source software tools is described and used to evaluate FSO network communication technology. Further, the theoretical analysis for an FSO system is provided. Such a testbed can be used to advance research in FSO and enable researchers to assess FSO performance under different network conditions and scenarios.**

***Index Terms*—Free Space Optics (FSO); Performance Analysis; Remote Wireless Sensing Technologies; Wireless Communication.**

I. Introduction

With the widespread adoption of several new emerging remote sensing and communication technologies, such as the Internet of Things (IoT), Wireless Sensors Network (WSN) and Free Space Optics (FSO). The need for having an efficient wireless connection between the sensing device and the processing unit becomes a necessity. Recently, Free Space Optical communication, which provides an efficient alternative of typical radio wireless communication in many scenarios has received attention of experts and researchers in optical and wireless communications Field [1]. Free Space Optics is one of the important Radio Frequency (RF)-based wireless alternative techniques, which transmits data through space by utilizing a laser light transmitter and receiver, provided that a line-of-sight setup exists between them [2]. FSO technology is one of the greatest technologies that has seen rapidly growing in wireless communications market, especially with the advantages of being not affected with the typical and widely used RF communication systems, thus attaining an interference- free communication system, in addition to the other advantages of long-range, low or free license cost, (compared with the expensive RF license) in which the complete free spectrum is utilized, ease of deployment, especially with remote and urban areas. However, one should consider the fact that FSO needs a line-of-sight communication channel, which may limit its usage in some scenarios and applications. Although FSO offers a high data rate, reach to Giga Bits per Seconds (Gbps) per wavelength, there are some challenges facing FSO especially in long distance caused by atmospheric turbulence and attenuation, which the impacts the FSO system performance. For instance, when light is transmitted through the air, it may be affected by fog attenuation, physical obstructions, scintillation on bright sunny days; also environmental effect like fog, rain, haze, snow and sandstorms which limits the FSO range [22], which will be negatively reflected in the FSO performance evaluation. FSO experimental trials have been launched since the late 1960's [19] but it's first applications were reported in 1876 [5]. The military interest in FSO lead to the development of FSO link from 1960-1970 [17]. Although, the results weren't as expected due to the large divergence of laser beams and the inability to cope with atmospheric effects. To the end of 1990s most researchers on FSO communication were in military and space applications, such as the European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) [18]. The increase demand for higher data rates and the efficient wireless technologies for long range of transmission distance has advanced FSO technology, which made it available to other civilian applications and scenarios [5]. Recently a huge number of companies provides FSO technologies with high data rate reaching to several Gbps with a communication range up-to several kilometres [4] thus making it viable and attractive solution for many remote sensing cases and scenarios.

Earlier studies find that RF/FSO wireless system improve the cycle Life of sensor to two times compared with pure RF system [15]. The ability of FSO system meets WSN requirement, especially with some applications that may include images or videos, such as: long-range, none interface low power communication, and high-speed communication link makes FSO a perfect choice for these applications. [11]. Another promising application for FSO is in the field of underwater communication. [6], where FSO can provide high bandwidth, speed, and immunity to Inter-Symbol-Interference (ISI) as compared to other technologies. FSO-based networks under water can provide a high performance at high frequency in clear water, ocean, or typical costal water, reaching up to 25, 6, 3.3 meters, respectively, while it is impossible to communicate using Rf under seawater at high frequency. The aim of this paper is to provide the researchers with a testbed that can be used to establish an FSO link and conduct several performance evaluation experiments that can help in fine-tune the FSO link and realize and study it's performance under different network conditions and scenarios. The rest of this article is organized as follows. In section II The testbed setup is presented. Results and Simulation are presented in Section III. Finally, Section IV concludes this paper.

II. FSO Testbed Setup

FSO may be defined as an optical transceiver with a transmitter and a receiver to provide full-duplex (bi-directional) capability. Each side consist of a laser source to send the modulated data, and a sensitive photo detector with a lens used to concentrate the received beam and direct it to the photo detector. Fig. 1 shows the testbed setup and the related components. The testbed can be divided into three parts: a data source (a transmitter), the Koruza-FSO, and a receiver. In the following, we describe each part in detail.

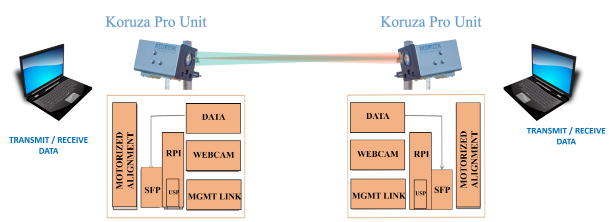

Fig. 1. Block diagram of system.

A. *transmitter a stream of data*

User Datagram Protocol (UDP) was used to send stream data from PC to other PC since UDP protocol provide us a high-speed transmitter data . Unlike TCP protocol it is uncorrected packet loss, for this reason, we use UDP protocol to testbed our Koruza-fso system.

B. *Koruza-FSO*

Koruza is two optical transceivers unit allow to connect Point-to-point with a high capacity could align between them using a security camera. In the Koruza Pro unit, each unit is FSO transmitter and receiver at the same time, there is lens where we send and receive invisible light signal, we have also camera and LED for alignment use after mounting the unit using the mounting point. On the bottom under the lid we attach our cables for the power, management and to feed the unit with the data that we want to send, as we can see on the unit diagram we send and receive data using SFP modules and we have many other things most of them to use when align the units, see 2. Data is securely transmitted point-to-point over a collimated beam of light with 1 Gbps (koruza we have), 2.5

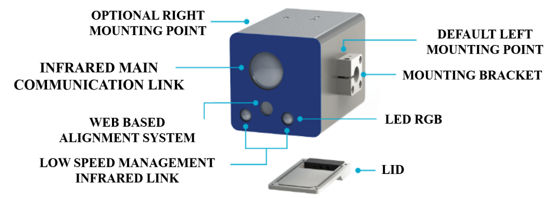

Fig. 2. Kouroza unit.

Gbps (upcoming) or 10 Gbps throughput at distances up to 150 m.

Most FSO technologies need a low to moderate instillation, while in this project we will use Koruza as FSO technology in a point to point bridging which it has ease of installation . The steps to establish Koruza Network is shown in fig 3, each unit is FSO transmitter and receiver at the same time, here is the lens where we send and receive invisible light signal, we have also camera and LED for alignment use after mounting the unit using the mounting point. On the bottom under the lid there is a cable for the power, management and to feed the unit with the data that we want to send.

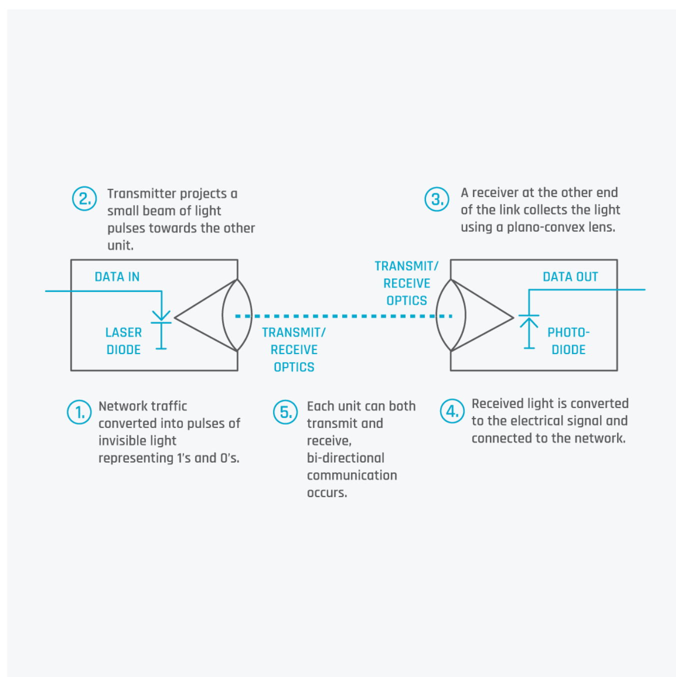

Fig. 3. steps to establish koruza Network.

Fog absorbs and scatters laser beam coming about in Mie Scattering. FSO system has strongly affect by Fog atmosphere in large distances. while the impact of Scattering can be neglected in clear weather, but it is more evident when there is haze or fog.

Water molecules in the air absorb the light energy (photons energy), which reduces the light intensity resulting in a lower data rate. Rainfall in general results in non-selective scattering that is wavelength independent unlike fog. Haze can likewise cause degrade on performance the system depends on the visibility level. Though the research found that 1550 nm wavelength experiences the least attenuation in haze conditions, but it is wave independent in foggy conditions.

The received power defined as:

$$P_r = \beta_L h_i P_t \tag{1}$$

Where P_t is transmitted power from Koruza unit, and β is the normalized path loss coefficient, while h_i is fading channel coefficient. channel irradiance modeled as a log-normal fading channel $hi = e^{2X}$, $X = \sigma^2 + \mu$ Where the Rytov variance for a plane wave given by [23]

$$\sigma_h^2 (d) = 0.124 k^{7/6} C_n^2 d^{11/6}, \tag{2}$$

where $C_n^2 \ \left(m^{-2/3}\right)$ denotes the index of the refraction structure parameter and k is the optical wave number.

The path loss can be calculated by combining weather attenuation with geometric losses as [12]

$$L_{loss} = \frac{D_r^2}{\left(D_t + \theta_t d\right)^2} \times 10^{-\alpha d/10}, \tag{3}$$

where D_r and D_t being respectively the receiver and the transmitter aperture diameters and θ_t is the optical beam divergence angle. while α is the weather-dependent attenuation coefficient (in dB/km),can calculated as:

$$\alpha = \frac{3.91}{v}\left(\frac{\lambda}{550\,(nm)}\right)^k, \tag{4}$$

Where v is the visibility parameter and k is the size distribution coefficient of scattering, the value of k for Kim model given as:

$$k = \begin{cases} 1.6 & v > 50 \\ 1.3 & 6 < v < 50 \\ 0.16v + 0.34 & 1 < v < 6 \\ v - 0.5 & 0.5 < v < 1 \\ 0 & v < 0.5 \end{cases} . \tag{5}$$

III. Simulation and Result

This section presents our implementation of the Remote Wireless Sensing using FSO Link. The medium and the interference in the medium limits the performance of the FSO system. Atmospheric conditions imitate the signal strength over larger distances because the transmission is medium dependent. Most common atmospheric conditions are humidity, water vapor and fog. Weather conditions are the main reason of attenuation.

KORUZA has been engineered with sufficient link margin to provide stable connectivity in reasonable weather conditions. a Several experiments have been tested in such scenarios and a number of scientific studies have been created using KORUZA units which the result show a good performance in fog ,snow or rain. the impact of the different system parameters are evaluated through JPERf, and Wireshark softwares.

IPerf3 is a tool for active measurements of the maximum achievable bandwidth on IP networks. iPerf is a widely used tool for network performance measurement and tuning. It supports tuning of various parameters related to timing, buffers and protocols (TCP, UDP, SCTP with IPv4 and IPv6). though ,There was a graphical user interface (GUI) front end available called jperf. JPerf stands for Java Perf; it's a GUI for running IPerf without need to learn the Command Line Interface (CLI) options.

The aim of this report is to study the impact of distances and packet size on koruza transceiver units. First of all we make sure to align the units of that koruza and try to establish a link between both units by check the webcam configuration as in Table I then use web cam to align them.

After the red Led convert to blue Led which mean that they are alignment, we start our test. We can also check the received Power Rx and transmit power by connect to the computer or mobile to the Koruza Wi-Fi named Koruza and connect to the IP Address 172.22.0.1 and enter the user name and password in order to access the management interface from which we can click on the image where the opposite link is. table II shows the transmitted and received power in Watt at different distance in meters.

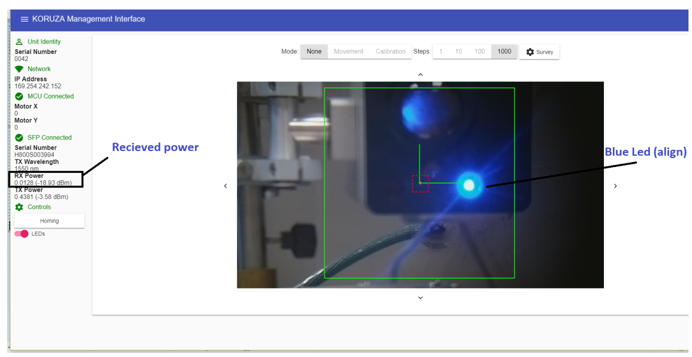

Fig. 4. webcam of korauza unit

The packet Loss using JPerf software and UDP Bandwidth 1Gbyte and Transmit data =10000 total packet at different distances is displayed in Fig. 5. While Fig. 6 represent the jitter time for 6m , 9m, 12m link range.

IV. Conclusion

Koruza is considered as one of the ease insulation FSO technology , which can any one establish the network (not hard).Koruza provide a point to point (fulduplex)Network,with high Bandwith from 1Gps to 10Gps. koruza has limitations same as any FSO technologies which contains the weather conditions and line of sight(LOS).

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A. technical Challenges

Transmits data through space by FSO technology face has similar challenges as Rdio frequency which include the

TABLE I
KORUZA WEBCAM CONFIGURATION.

Configuration	Unit 1	Unit 2
Wavelength	1550 nm	1310 nm
Webcam Zoom X	0.31	0.32
Webcam Zoom Y	0.22	0.25
Webcam offset X	439	498
Webcam offset Y	225	242

TABLE II
THE TRANSMITTED AND RECEIVED POWER AT DIFFERENT LINK RANGE.

Distances	**Koruza unit XX79**		**Koruza unit xx94**	
	TX (watt)	***RX (watt)***	***TX (watt)***	***RX (watt)***
$3m$	0.592	0.0038	0.4364	0.0217
$6m$	0.595	0.021	0.4364	0.0936
$9m$	0.59	0.0024	0.4364	0.0079
$12m$	0.59	0.002	0.4364	0.007

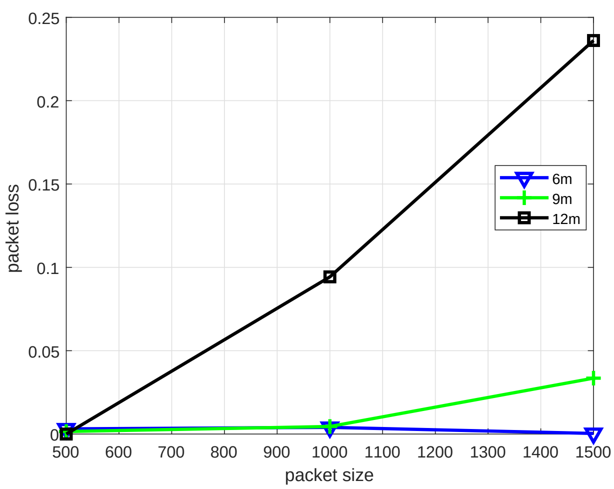

Fig. 5. packet Loss at different distances and Packet size using JPerf.

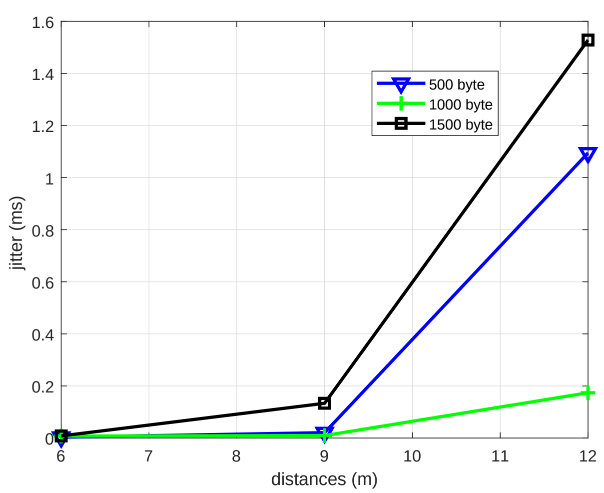

Fig. 6. Jitter time vs different distances at Packet size.

weather conditions atmosphere. When light is transmitted through the air, as with Free Space Optics (FSO) optical wireless systems, it effect by atmosphere attenuation, Physical obstructions, and hot on sunny days.

In kouraza the challenges that faced during experiment is a problem with the network, Ethernet connection between the SFP and computer wasn't stable and it kept on disconnecting. Plus in system outdoors, it is needed to install a mount to hold it because according to the manual, the mounting location should be stable with no vibrations or movement. To solve this we repeat every test more than 10 times and make an average to ensure we able to get accurate result. we also need to change the configuration parameters for Webcam on every distances to can we make the alignment.

B. future Work

In this paper, we introduced aKoruza-FSO network and evaluate the system at different distances outdoor. Our future work will aim to used Remote Wireless Sensing Technologies includes connection of Arduino Ethernet shield with koruza-FSO technology as shown in figure 7. Also, we will compare the performance of the system with using RF communication system and we can focus on improved and enhanced system to meet ... according to its application.

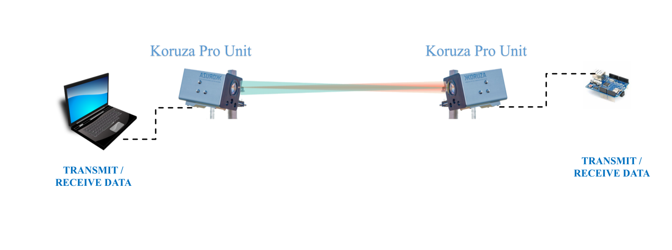

Fig. 7. Block diagram of wireless ardunio system using Koruza-FSO technology.

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