Enhanced Dynamic Range Free Space Optical Receiver

J.J. Shemmans, D.Z. Janse van Vuuren, B.J. van Wyk
F’SATIE, Staatsartillerie Road, TUT Main Campus
Building 6, Room 347, Pretoria West, South Africa
Tel. +27 12 318 4191, Fax. +27 12 318 5294
jeff@periseo.com, dawie@periseo.com, vanwykb@tut.ac.za

Abstract — This paper presents the idea on how to improve the performance of a free space optical communication (FSOC) system by enhancing the dynamic range of the receiver. Free Space Optical Communication uses the atmosphere as the transmitting medium and is becoming the preferred solution for the ‘last mile problem’. New requirements on optical receivers are being driven by the rapid expansion of optical communications beyond traditional wire and fiber-optic links. To design such an optical receiver, three specific requirements need to be addressed. The requirements here are a wide dynamic range, ambient light rejection, and high bit-rate operation.

Index Term — FSOC, Last Mile, Wide Dynamic Receivers.

INTRODUCTION

THE global telecommunications network has seen massive expansion over the last few years. Optical communication through clear atmosphere provides a means for high data rate communication over relatively short distances (e.g. 2km). However, the loss in the atmosphere leads to fades of varying depths, some of which may lead to heavy bit rate errors.

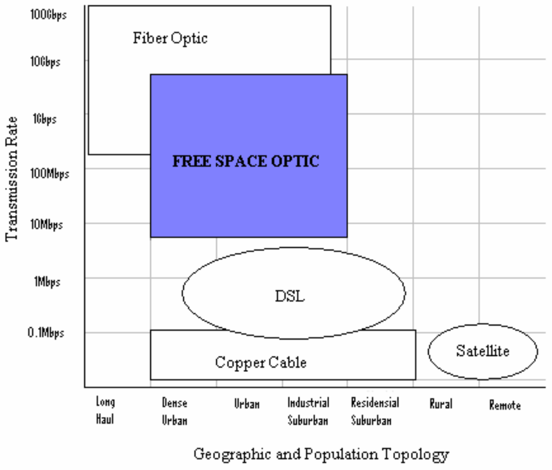
Wi-Fi or IEEE802.11 has become the dominant term for home networks. IEEE has defined three physical layer specifications for 802.11, two of them are radio standards at 5 GHz and 2.4 GHz frequencies while the third one specifies infrared as the physical medium. Infrared is the least researched option although it has plenty of potential. Infrared spectrum lying in the THz range does not fall under the Federal Communications Commission (FCC) regulations and there is no electro-magnetic interference (EMI) with radio systems. As a result, infrared offers an unregulated huge bandwidth for high data rate multimedia applications. Infrared has a similar behavior to that of visible light. It is absorbed by dark objects and diffuse due to reflections on surfaces. It penetrates through glass but not through walls. This makes the infrared secure. This also means that the same optical wavelength can be reused in adjacent areas without interference. IrDA is a good example for line of sight links.

Ambient light also has significant energy in the infrared band. This is a major concern with infrared systems. The Sun as well as fluorescent and incandescent lamps emit infrared noise. Although out of the band optical power can be filtered using a fixed narrowband optical filter, in-band noise remains an issue. The spectrum of the fluorescent light switching noise extends up to 1 MHz with electronic ballasts. This poses a more serious impairment and can not be filtered out using electrical high pass filters

The SNR can not be arbitrarily increased in this noise limited scenario by increasing signal power. High power IR radiation may cause damage to the human eye and skin. Therefore the safety limits enforced by IEC825 limit the infrared power density. Detectors with relatively large photosensitive area are required at low power levels. However, detector junction capacitance which, inherently increases with the photosensitive area limits the data rate with large area detectors. From the foregoing, it is clear that advanced signal processing techniques are needed to provide high-speed wireless services in the infrared band.

THE TELECOMMUNICATIONS LAST MILE

In most cases, fiber installation is the preferred method for broadband telecommunications access. Optical fiber signals transmitted via a fiber network deliver the most reliable means for transmission because it is a protected medium and has the ability to transmit at the highest data rate available. In some cases, the time required to obtain licenses and trenching cable could be unacceptable, while there are other instances where it is unrealistic to consider cable due to geography or building density. Exactly how service providers cost effectively extend service from the nearest network node to end users, is known as the 'last mile problem' and it is one that free space optics can play an important role in solving.



The above chart shows the optimal last mile technology solutions versus end-user demand and geographic/population topology. The relative positions of the last kilometer technologies are based on technology capabilities such as reach, bandwidth, reliability and economics of the technology in that particular application.

ENHANCING THE DYNAMIC RANGE

The dynamic range is the heart of the free space communication link system. In a nutshell, improving the dynamic range of the receiver will improve the distance workability between the two units. FSOC systems will probable work very well in a long distance installation, for example 2km, if the receiver has a sensitivity of approximately -60dBm. But if that same receiver has a high gain front-end, to achieve that sensitivity, it can cause saturation with a shorter installation, for example 500m, and force the receiver not to function as intended. It is critical to design a receiver with a wide dynamic range, to ensure that the system will work at short and long distance installations.

Atmospheric losses like fog, rain and scintillation also plays an important role in the dynamic range performance of a free space setup. On a clear day the atmospheric loss can be as good as 6 dB/km, but on a foggy day the loss can be as bad as 350 dB/km [6].

6.5dB/km Vs 150dB/km

REJECTING THE AMBIENT LIGHT NOISE

One of the biggest problems, when a system has to work outside in Mother Nature, will be the sunlight. With a free space optical system the sun not only causes a temperature problem but with the infrared component in sunlight it causes noise to fall on the detector. It is a big concern because the signal to sunlight noise ratio will be very low and the system will probably not work as expected.

OPERATING AT 1GBPS BIT RATES

High bit rate operation enforces new problems. Electrical signals behave differently at the traditional low bit rate, like asynchronous computer serial communication, than high bit rates of 100Mbps and higher.

Also to increase the bit rate, we need to focus on the detector size. The physical size of the detector area determines the detector capacitance and also the sensitivity. If the detector size is reduced the detector capacitance will decrease.

$$Fc = \frac{1}{2\pi RC} \qquad \mathbf{(1)}$$

Fc determines the cutoff frequency where C is the value of the detector capacitance.

FUTURE WORK

Shannon defined the channel capacity C as the maximum rate for which information can be transmitted over a noisy channel. He stated that if it is possible to distinguish reliably M different signal functions of duration T on a channel, we can say that the channel can transmit log2 M bits in the time T. The rate of transmission is then (log2 M)/T. He approached the maximum rate of the transmission of binary digits by,

$$C = W\log_2\left(1+\frac{P}{N}\right) \qquad \mathbf{(2)}$$

Where W is the channel bandwidth starting at zero frequency, and P/N is the signal-to-noise ratio (SNR) [1].

$$\lim_{W\to\infty} C = 1.44\frac{P}{N_o} \qquad \mathbf{(3)}$$

Equation 3 means that channel capacity cannot be increased to any desired value by increasing W thus imposing a fundamental limitation on the maximum achievable channel capacity [1].

Clearly with this noisy channel the probability for bit errors are quite high. This makes it a necessity to use a forward bit error correction coding scheme, like the convolutional encoding. With bit encoding, a decoding scheme like the veterbi decoding algorithm can detect and correct bit errors.

Error-correction coding (ECC) is where controlled redundancy is added to the transmitted symbols to improve the reliability of communication over noisy channels. With ECC the transmission rate one can achieve is close to the channel capacity. The channel bandwidth of an optical communication system (~100THz) is larger than the channel bandwidth of a microwave system (~10GHz). The channel capacity given by 1.1 is the theoretical upper limit for a given optical fiber and depends upon the type of fiber. The same relation can be achieved for free space communication and the theoretical upper limit. Absorption scattering and dispersion will also limit the performance and need to be dealt with in a free space optical system.

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J.J. Shemmans is currently pursuing a MAGISTER TECHNOLOGIAE at the French South African Technical Institute in Electronics and Periseo as the industrial partner. He completed his BACHELOR TECHNOLOGIAE in 2004.