Engineering Letters, 13:3, EL_13_3_8 (Advance online publication: 4 November 2006)

Real Time Adaptive Nonlinear Noise cancellation using Fuzzy Logic for Optical Wireless Communication System with Multi-scattering Channel

L.R.D.Suresh, Dr.S.Sundaravadivelu, *Member,IAENG*

Abstract-**Optical wireless communication from tower to tower on the earth's surface consists of heavy rain, snow, hail, haze etc. are part of optical channel. Propagation of optical signals through these atmospheric turbulence channels cause attenuation and scattering of the transmitted beam. These effects reduce the received signal quality and decrease the information bandwidth of the system. The atmospheric turbulence effects are analyzed and proposed an intelligent optical receiver under multiscattering condition. The train of optical pulses are transmitted and coherent detection is used in the receiver. Based on the value of received power and Signal to Noise Ratio (SNR) levels, the receiver is adapted by changing its sensitivity using Fuzzy Logic concept. By means of this concept, the non-linear noises incorporated in the optical signal at the receiver were cancelled upto -40dB SNR level and upto -50dBm of received power. The channel is considered as Additive White Gaussian Noise (AWGN) and estimated the desired signal. The entire Optical Wireless Communication system model was derived and obtained the results for various climatic conditions. This Optical Wireless links are very much useful to meet the high availability requirements of the telecommunication industries. For, Laser power through the atmosphere, the exponential Beers-Lambert law is applied and for simulation MATLAB 7.0 software with Pentium-IV personal computer is used.**

Keywords - **adaptive system, fuzzy logic, intelligent receiver, optical wireless.**

I.INTRODUCTION

The Optical Wireless Communication is the only elucidation to the next generation wireless communication owing to a quantity of advantages over the existing RF wireless systems are, large information bandwidth (THz-range), low transmitted power (mW-range), high directionality (beamwidth-mrad.), high speed data transmission (Gb/s), high signal security, free from electromagnetic interference, very less Bit Error Rate (10^{-12}), size and weight of the optical components are very small etc..Figs.(1) and (2) represent the

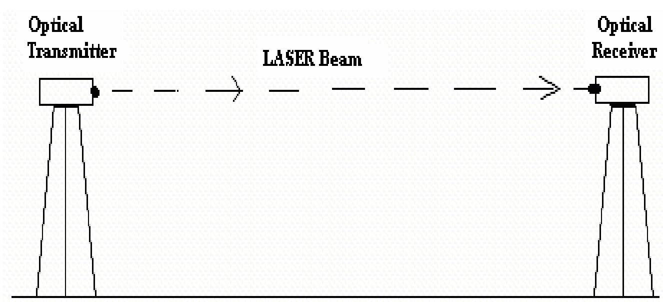
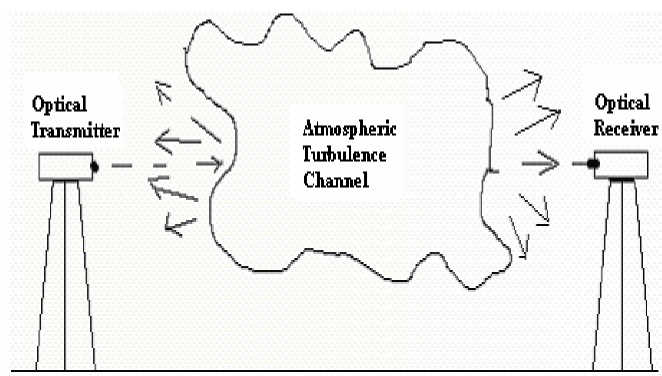


Fig (1). Optical wireless communication system under clear sky condition.



Fig(2). Optical wireless communication system under worst climatic condition

general block diagram of optical wireless communication system for point to point link for both clear sky and turbulence conditions respectively.

In the optical wireless communication systems, the Laser Beam from the source is used as the carrier wave and is transmitted through the free-space (atmosphere) directly. Because of highly directional beam, the transmitted signal is traveling in the straight line with long distance. The transmitter and receiver should be in face-to-face,i.e.,line of sight(LOS) condition to be applied for this system. Even though optical wireless communication system has great potential, there are some limitations to overcome the existing optical wireless communication becomes highly efficient one. The major problem in the available optical wireless

Manuscript received July,21,2006.
L.R.D.Suresh is presently faculty member in the Electronics and Communication Engineering Department at Thiagarajar College of Engineering, Madurai, Tamil Nadu. India. E-mail : lrdsuresh@hotmail.com
Dr S. Sundaravadivelu is presently Professor and Head in the Electronics and Communication Engineering Department at Thiagarajar College of Engineering, Madurai, India.
E-mail : sundaravadivelu@hotmail.com

communication system is multiscattering effect, i.e., in the presence of fog, hail, heavy rain, etc. in the atmosphere causes serious signal degradation in the propagation path [1],[2]. Under clear sky condition, the optical wireless communication system has very less attenuation and scattering effects, but in the fog or snow form condition, the attenuation and scattering effects are very high. This effect limits the maximum system bandwidth and increases bit error rate (BER) [3]. The use of optical wireless communication can be improved only when the environmental effects are controlled or overcome by system performance. In the existing research papers, the impulse response function of atmospheric clouds for optical pulses is derived and modeled the optical wireless communication system and used only for earth to low earth orbit(LEO) satellites, geo synchronous orbit(GEO) satellites and downwards[4]. But, this paper proposes an optical wireless communication system for worst climatic condition, is considered as atmospheric turbulence channel, on the Earth's surface between tower to tower or high building to building. By analyzing these effects by extension search of the literature survey and propose a novel approach of using an intelligent method called Fuzzy Logic concept to overcome these problems[5].

II.INTELLIGENT OPTICAL RECEIVER WITH CHANNEL DESCRIPTION

The changes in the parameters of the optical channels, like atmospheric attenuation coefficient, radius of the scattering particle, visibility, the size distribution of the scattering particles etc.can be measured [6] and the optical receiver can be adapted to these changes. In this paper an engineering model of an intelligent receiver for optical wireless communication through atmospheric turbulence channel is described with system approach and analysis of climatic effects on atmosphere that deals with the variation of the reflected power from the snow or rain like effects of the transmitted power and the variation of the attenuation in the environmental conditions [7],[8]. This paper elucidates the principles of the proposed intelligent optical wireless communication system and presents the mathematical analysis of the system employ the operating wavelength of 1550nm which is suitable for optical wireless communication [9] and the optical components are available in that wavelength also. The optical receiver is designed for intelligent in nature under various climatic conditions. The front end of intelligent optical receiver consists, the fuzzy logic unit performs adaptive non-linear noise cancellation upto -40dB SNR level and able to extract the signal upto -50dBm.

A. Fuzzy logic control Scheme

Although tunable or matched optical filter based on fiber Bragg gratings are a flexible and promising solution for dispersion compensation, but still have the problem of variable optical communication path characteristics, environmental fluctuations, and the indifference of applications that are themselves in a constant state of change and requires re-design and re-fabrication of an appropriate fiber Bragg grating for each case. Therefore an alternative novel technique of signal detection based on adaptive, intelligent optical scheme would overcome these problems. In such a scheme the pulse profile is continuously monitored for any distortion caused by atmospheric turbulence effects, and the adaptive tuning parameters together with the control strategy are updated continuously in order to compensate for dispersion - regardless of the data rate or range. Figure (3) is showing the model of the proposed real time intelligent optical scheme, which comprises Fuzzy logic control.

Fuzzy Logic has emerged as a profitable tool for the controlling of complex processes, it is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large systems. It provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy Logic incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The reasons for selecting fuzzy logic control in this paper are: (i) relatively easy implementation, (ii) can manage with different initial conditions, (iii) the Fuzzy Logic control model is empirically-based, relying on a knowledge base system, where all operating parameters and optical filter tuning optimization constraints can be stored, with a self learning algorithm it has the ability to adapt itself and update its knowledge base, (iv) the ability to respond to random changes in the atmosphere, so that the light signal detection process can be further extended, that may arise from other environmental effects. The outputs of the Fuzzy Logic controller are used to control the fluctuations in the optical signal, (v) the Fuzzy Logic control is the main intelligence that provides the adaptability of the entire schemes. The purpose of the error signal in this case is to drive the firing of the fuzzy logic control rules, which is different to that of the error signal in a feedback control system where the aim is to reduce the error signal to zero if possible.

Fuzzy logic algebra is used to improve the detection of signals in an optical wireless communication system where signals are modulated by intensity modulation scheme. New fuzzy signal detection techniques are proposed based on the application of fuzzy operations such as multiplication, addition, and integration mixed with ordinary algebraic operations. Because the task of fuzzy detector has to decide which signal is present in a waveform out of *M* possible reference signals, the concept of the classical cross-correlator detector is being extended. The fuzzy Hamacher product, the fuzzy algebraic sum, and the new combined fuzzy product are deployed to detect the presence of signals in a noisy received waveform. The feasibility of employing the fuzzy detector in an Intensity Modulated (IM)-Coherent Detection optical communication system is investigated.

In order to maintain the sensitivity of the receiver above 0.1 μw, the coherent optical receiver with 20 Gbps was implemented. So that the adaptive filter is designed by the function as,

$$F(f) = [(Y_1-Y_0) / (Z^2+2Z+1)G_1] * [\{k_1/(k_2-j2\pi f)^2 \}+ \{k_3/(k_4-j2\pi f)^2 \} + \{k_5/(k_6-j2\pi f)^2 \} + \ldots \ldots+\{k_{n-1}/(k_n-j2\pi f)^2 \}] \exp(-j2\pi f t_d) \qquad (1)$$

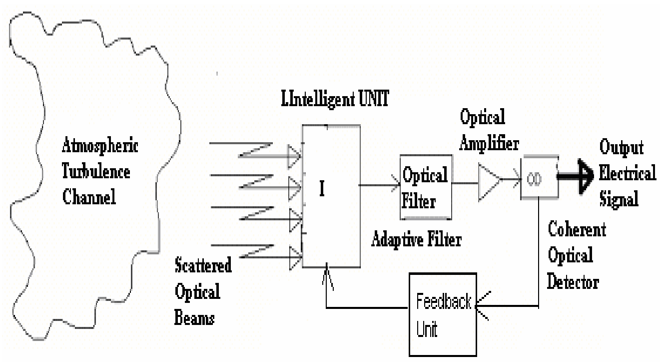


Fig (3). Intelligent Optical Receiver performs adaptive non-linear noise cancellation using fuzzy logic algorithm.

where, F(f) is the adaptive filter transfer function, Y_1 & Y_0 are functions of receiver parameters and transmitter power for receiving 1 and 0 respectively, k_1,k_2 …… k_n are n-gamma function constants depends upon the visibilities, f is the operating frequency, and t_d is the time at which signal is at the filter output, and $Z^2 = (G_0/G_1)$, where G_0&G_1 are the noise spectral densities of the receiver for receiving 0 and 1 respectively.

After received the light signals, are processed by the intelligent unit which performs non-linear noise cancellation using fuzzy logic algorithm and passed through optical filter, it is amplified by optical amplifier and then down converted into electrical signal by coherent optical detector, the error is reduced and the estimated signal is obtained by feedback network [10], finally the original message signal is obtained.

III.NUMERICAL ANALYSIS

The link equation for optical wireless communication system using Beers-Lambert law is given by,

$$P_r = P_t[A_r / (D.R)^2]\exp(-\sigma R) \qquad (2)$$

where, P_r is the received power at the optical receiver in Watts, P_t is the transmitted power at the optical transmitter in Watts, A_r is the receiver aperture area in cm^2 with the radius of r = 20cm, the transmit beam divergence D = 2mrad, the distance between the optical transmitter and receiver(range) R=2km and σ is the atmospheric attenuation coefficient in km^{-1} is given by,

$$\sigma = [3.91/V]\,(\lambda / 550\text{ nm})^{-q} \qquad (3)$$

where, V is visibility in the atmosphere in km and q is the size distribution of the scattering particles depends on visibilities, and given by,

$$q = \begin{cases} 1.6 & \text{,for } V>50\text{km} \\ 1.3 & \text{,for } 6\text{km}<V<50\text{km} \\ 0.16V+0.34 & \text{,for } 1\text{km}<V<6\text{km} \\ V-0.5 & \text{,for } 0.5\text{km}<V<1\text{km} \\ 0 & \text{,for } V<0.5\text{km} \end{cases} \qquad (4)$$

The data rate is taken as 20Gbps and range is restricted to 2km under this worst climatic condition, but for clear sky conditions the data rate and range can be augmented further[11]. From this equation (2) the amount of received power is directly proportional to the amount of transmitted power and area of the collection aperture. It is inversely proportional to the square of the beam divergence and link range. It is also inversely proportional to the exponential of the product of the atmospheric attenuation coefficient times the link range. In the above equation the variables P_t , A_r , D and R are controllable and σ is uncontrollable and depends upon climatic conditions, also independent of operating wavelength(λ) in heavy attenuation (worst climatic conditions) [12]. But, P_r is exponentially decreases with the product of σ and R. Hence, σ and R play major role in the amount of P_r, but σ is not controllable and R should be maintained at moderate level, otherwise the entire optical wireless communication system becomes highly expensive. From the statistics, the receiver sensitivity should be greater than 0.1µw and up to this minimum level the optical receiver is able to detect the received signal. It is understood that the atmospheric turbulence effects occurred for entire transmission path and the range R is taken as 2km. So the received power at the receiver from atmospheric turbulence channel is calculated using the equ(2) for various climatic conditions.

IV. ADAPTIVE NOISE CANCELLATION USING FUZZY LOGIC

The noise present in the optical wireless communication system is modeled to high accuracy as additive white Gaussian noise that is statistically independent of the desired signal. The transmitted optical signals are scattered more by the atmospheric turbulence channel and part of these scattered signals are received by the receiver. Since, multiple signals reflected from turbulence channel of various directions are received, there is in need of special algorithm to detect these signals. So, that Fuzzy Logic concept is used to detect the reflected signal from the turbulence channel.[13]

This paper proposes adaptive nonlinear noise cancellation using the Fuzzy Logic functions ANFIS and GENFIS1 by MATLAB Ver7.0. ANFIS is the Adaptive Neuro-Fuzzy training of Sugeno-type Fuzzy Inference Systems. ANFIS uses a hybrid learning algorithm to identify the membership function parameters of single-output, Sugeno type fuzzy inference systems (FIS). A combination of least-squares and back propagation gradient descent methods are used for training FIS membership function parameters to model a given set of input/output data.

Defined below is an optical pulse information signal (x) sampled at 1550nm (≈194THz) over $6*10^{-13}$ seconds. Regrettably, the information signal (x) cannot be measured without an interference signal (n2), which is generated from another noise source (n1) through unknown nonlinear process. The interference signal (n2) that appears in the measured signal (m) is generated by means of an unknown nonlinear equation,

$$n2(k) = 4*\sin(n1(k))*n1(k-1)/(1+n1(k-1)^2) \qquad (5)$$

Note that n2 is related to n1 using highly nonlinear process and it is difficult to see if these two signals are correlated in any way. The measured signal (m) is, sum of the original information signal (x) and the interference (n2), but n2 is not known. The only signals available in the receiver are the noise signal (n1) and the measured signal (m), and the task is to recover the original information signal (x). The function ANFIS is used to identify the nonlinear relationship between n1 and n2. Though n2 is not directly available, take m as an "infected" version of n2 for training. Thus x is treated as "noise" in this kind of nonlinear fitting. Here, take the order of the nonlinear channel in this case is 2, so use 2-input ANFIS for training. Two membership functions are assigned to each input, so the total number of fuzzy rules for learning is 4. Also, set the step size equal to 0.2. STEPSIZE is an array of step sizes and increased or decreased by multiplying it by the step size increase or decrease rate as specified in the training options. The training process stops whenever the designated epoch number is reached or the training error goal is achieved. Over fitting can be detected when the checking error starts increasing while the training error is still decreasing.

After training, the estimated n2 is calculated using the command EVALFIS. EVALFIS-Perform fuzzy inference calculations that simulates the Fuzzy Inference System for the input data and returns the output data and specifies number of sample points on which to evaluate the membership functions over the input or output range. The aggregate values sampled at N points along the output range for each output. The results are obtained by evaluating the input and output values through the membership functions. The original n2 and estimated n2 (output of ANFIS) are generated. The estimated information signal (x) is equal to the difference between the measured signal (m) and the estimated interference (i.e., ANFIS output). The original information signal (x) and the estimated information signal (x) by ANFIS are plotted.

V.RESULTS AND DISCUSSION

In fig(4) the graph is drawn between visibility(V) and received power (Pr) with various transmitted powers of P_t=10mW, 100mW, 500mW and 1W with the distance of R=2km. It is observed that for clear sky conditions (i.e,V>50km) the received power is nearly 80% of transmitted power, but in the worst case (i.e,V<0.5km), the received powers are less than $1*10^{-8}$W, which are not detectable by any optical receiver. The optical receiver sensitivity should be greater than 1µW, hence lofty transmitter power is required to meet the above condition. So, we are in need of towering transmitted power (i.e., Pt >1W) to meet 1µW in the receiver, but practically this much amount of soaring power is not efficient for 2km distance.

Table :1

Parameters: R=2km, λ=1550nm.

Transmitted Power (Watts)	Received Power (Watts) For V=0.48km	Received Power (Watts) For V=50km
10mW	$0.01*10^{-7}$W	7.6mW
100mW	$0.08*10^{-7}$W	77mW
500mW	$0.36*10^{-7}$W	390mW
1W	$0.70*10^{-7}$W	0.79W

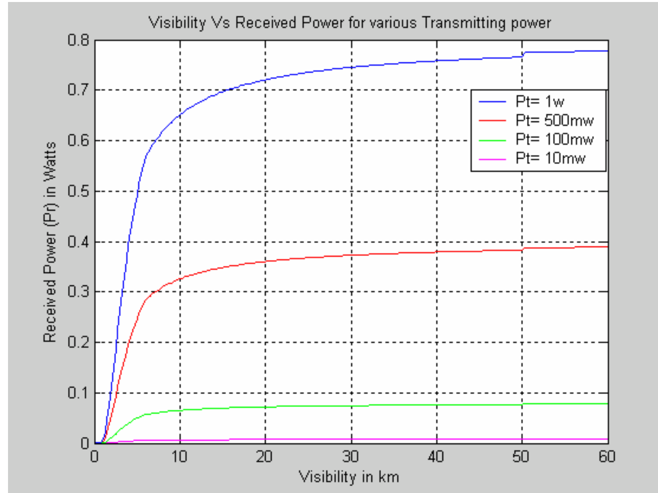
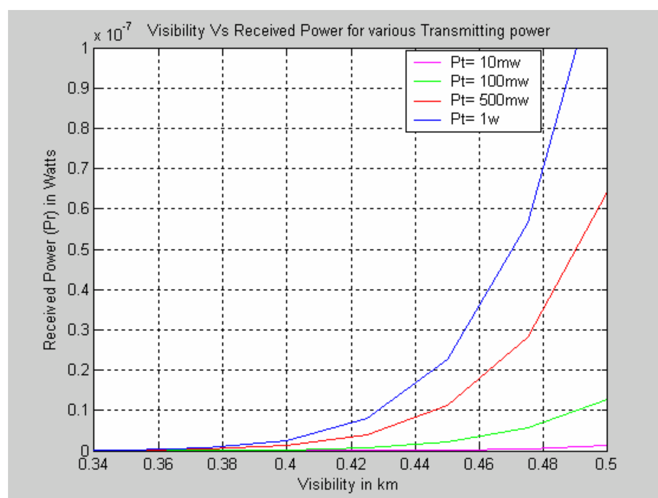


Fig (4): Performance of atmospheric turbulence channel effects for various visibility conditions which affects the received power in the optical receiver

In fig(5), the results are plotted by calculating the received power in the receiver for worst climatic conditions with the distance of 2km.

So that, the coherent optical receiver is positioned, this is able to detect upto 0.1µw of optical power. But, this sensitivity is also not enough to meet the present scenario. Hence, there is a need of some intelligent system, one among them is fuzzy logic method, which is able to detect signal upto -50dBm (i.e., 0.01 µw) of received optical power with SNR level of -40dB.



Fig(5): Relation between transmitted and received Powers under worst climatic conditions (V≤0.5km)

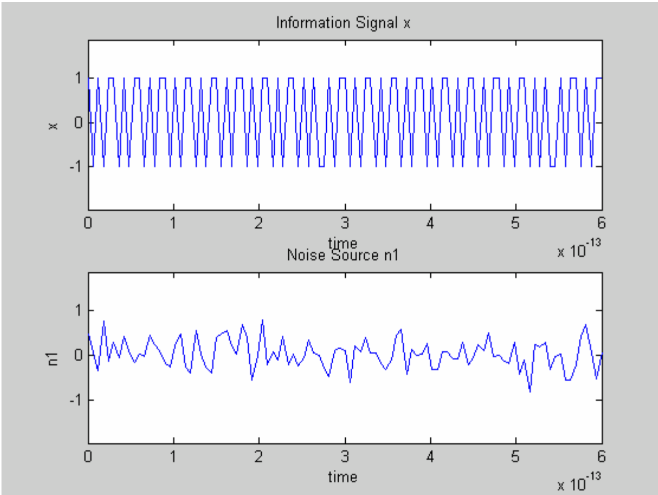


Fig.6.a) Information signal for time Vs amplitude.
b) Noise signal for the same time Vs amplitude.

The information signal is taken as train of optical pulses has the amplitudes -1 and +1 for $6*10^{-13}$ seconds time period as shown in fig(6.a). The random noise is generated for the same time period with the amplitudes varied from -1 to +1 as shown in fig (6.b). The AWGN channel of -40dB SNR level & -50dBm received power level is modeled based on the same information signal and random noise as shown in fig(7).

Because of this n1, this AWGN channel generates interference (n2) for the same time period with the amplitudes varies between -2 and +2 as shown in fig(8.a). Hence, the output signal is measured, which is the combination of information signal, random noise and interference as shown in fig(8.b).

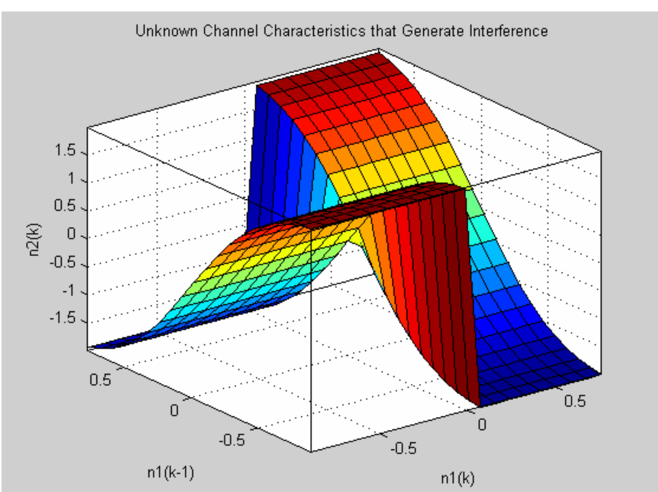


Fig.7. The AWGN channel is modeled based on the information signal and random noise.

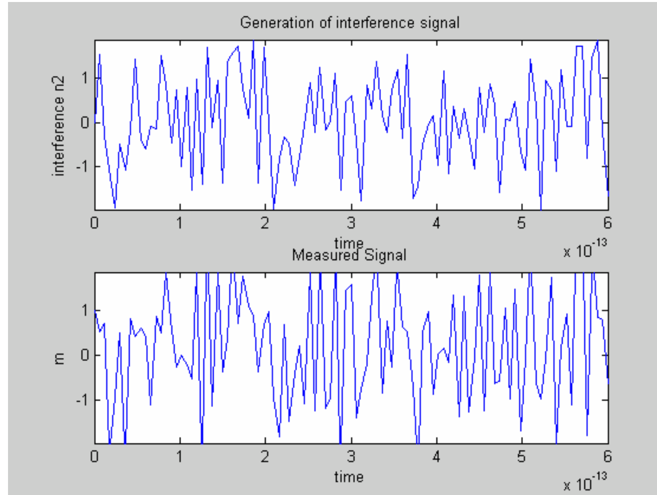


Fig.8.a). Interference signal generated by AWGN channel.
b).The measured output signal is the combination of information signal, random noise and interference.

Now, the information signal (x) is to be extracted from this measured signal (m). So, the fuzzy logic algorithm is applied here to extract the information signal (x) from the measured signal (m).

After applying fuzzy logic algorithm, the interference (n2) is estimated based on channel model and noise (n1) as shown in fig(9). Following the estimation of interference (n2) and already known noise (n1), then the information signal (x) is extracted from the measured signal (m) as shown in fig(10.b).

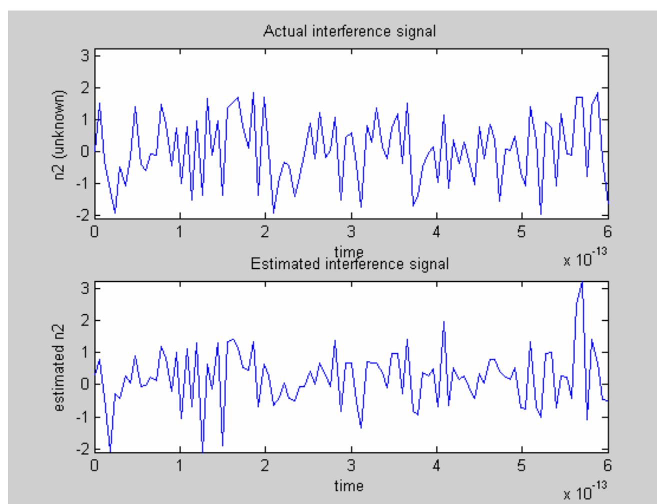


Fig.9.Estimated interference after applying fuzzy logic algorithm

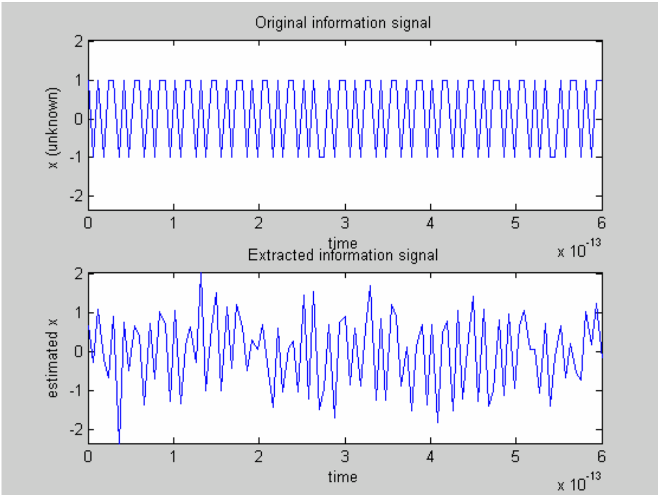


Fig.10.a). The original Transmitted Information signal.
b). The extracted Information signal at the receiver.

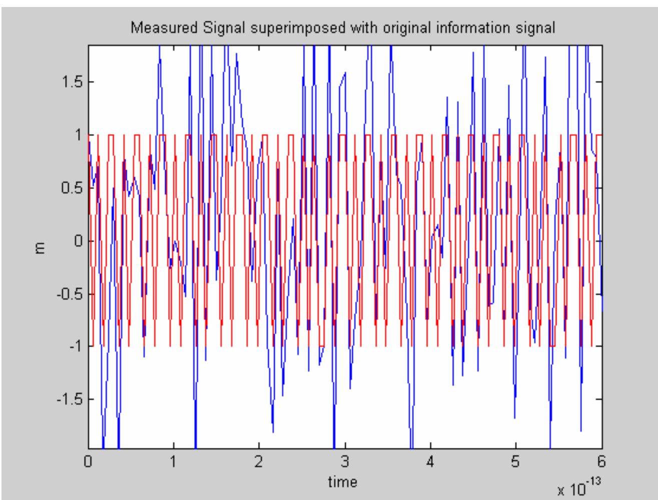


Fig.11 Measured Signal superimposed with original information signal for BER calculation

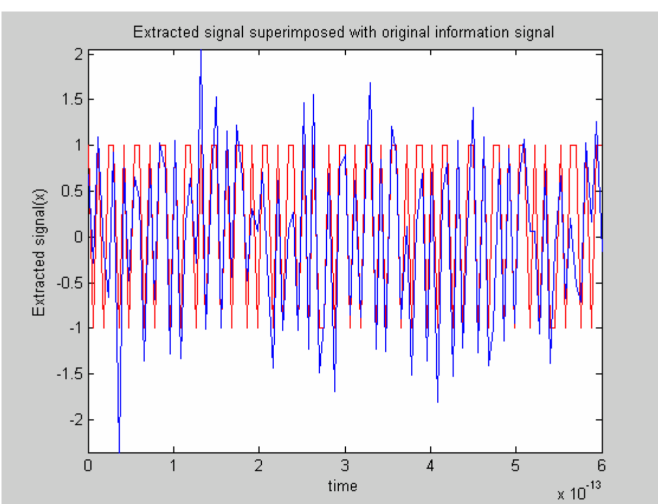


Fig.12. Extracted signal superimposed with original information signal for BER calculation

Fig(11) shows the measured signal (m) superimposed with original information signal (x), before applying fuzzy logic algorithm, for comparison and BER calculation. The BER is calculated for this time period as 26/80 = 32.5%. Fig(12) shows the extracted signal (x)superimposed with original information signal (x), after applying fuzzy logic algorithm. The BER is calculated for this time period as 15/80 = 18.75%. This result shows that the extracted information signal is similar to the original transmitted signal. This BER is pragmatic in the order of 10^{-1} for the above situation.

VI.CONCLUSION

The presence of snow, heavy fog, hail etc., in the atmospheric turbulence channel causes intense attenuation and scattering of optical signals. This limits the performance of the optical wireless communication system. It is observed that for V<0.5km, the required transmitted optical power is increased upto 10W to get atleast 1µW power in the receiver to meet the minimum sensitivity of the optical receiver, but practically it is highly inefficient for this 2 km range. So, the coherent optical detector was used to detect this received power upto 0.1µW, but it is also not enough to meet the minimum sensitivity of the receiver. Hence, the Fuzzy Logic concept is applied here to detect the signal upto -50dBm of received power level with -40dB SNR level. Simulation of optical pulse propagation through atmospheric turbulence channels makes it possible to derive mathematical model for optical wireless communication system. By using the derived model, the intelligent optical system was developed which performs better on heavy turbulence conditions compared with clear sky conditions. The results show that the extracted information signal matches with the original transmitted signal. In this heavy turbulence condition, the BER achieved is in the order of 10^{-1} at -40dB SNR level which is really near to the ground. After applying Fuzzy logic algorithm, the BER is abridged significantly. So, these intelligent optical wireless communication links are must for the emerging next generation wireless communication to meet the increased availability requirements.

ACKNOWLEDGMENT

The author would like to express his appreciation to Mrs.S.Ponmalar for her sensible help and honorable support.

REFERENCES

[1] Xiaoming Zhu and Joseph M.Kahn, "Free-Space Optical Communication Through Atmospheric Turbulence Channels," IEEE Transaction on communications, Vol.50,No.8, August 2002.

[2] Xiaoming Zhu and Joseph M. Kahn, "Performance Bounds for Coded Free-Space Optical Communications Through Atmospheric Turbulence Channels", IEEE Transactions on Communications, Vol. 51, No. 8, August 2003.

[3] B.R.Strickland, M.J.Lavan et.al, "Effects of fog on the bit error rate of a free-space laser communication system," Applied Optics,38, 1999.

[4] S.Arnon and N.S.Kopeika, "Adaptive optical transmitter and receiver for space communication through thin clouds," Applied optics, Vol.36.No.9, 20 March 1997.

[5] Alexander V.Pavlov "Optical Neuro-Fuzzy Systems to Networking Problems", ESIT 2000, 14-15 September 2000, Aachen, Germany.

[6] Szu-Cheng Ou, Yoshihide Takano, Kuo-Nan Liou, Randy J. Lefevre, and Michael W. Johnson, "Laser transmission–backscattering through inhomogeneous cirrus clouds", Applied Optics ,Vol. 41, No. 27, 20 September 2002

[7] Xiaoming Zhu, Joseph M. Kahn, and Jin Wang ,"Mitigation of Turbulence-Induced Scintillation Noise in Free-Space Optical Links Using Temporal - Domain Detection Techniques" IEEE Photonics Technology Letters, Vol. 15, No. 4, April 2003.

[8] Debbie Kedar and Shlomi Arnon,"Urban Optical Wireless Communication Networks: The Main Challenges and Possible Solutions" IEEE Communications Magazine, February 2003.

[9] Haim Manor and Shlomi Arnon, "Performance of an Optical Wireless Communication System as a function of Wavelength" Applied Optics, Vol. 42, No. 21, 20 July 2003.

[10] M.Aharonovich and S.Arnon, "Performance improvement of optical wireless communication through fog with a decision feedback equalizer",J.Opt.Soc.America ,Vol. 22, No. 8,August 2005.

[11] G.Nykolak P.F.Szajowski, et.al, "A 40 Gb/s DWDM free space optical transmission link over 4.4 km," Free-Space Laser Communication Technologies XII, Proc.SPIE,3932, 2000.

[12] Debbie Kedar and Shlomi Arnon, "Optical wireless communication through fog in the presence of pointing errors", Applied Optics,Vol. 42, No. 24, 20 August 2003.

[13] Hancock, P. A., Masalonis, "On the Theory of Fuzzy Signal Detection: Theoretical and Practical Considerations", Theoretical issues in Ergonomic Science, 1, 207 – 230, 2000.

L.R.D.Suresh is presently faculty member in the Electronics and Communication Engineering Department at Thiagarajar College of Engineering, Madurai. He received B.E. degree in Electronics and Communication Engineering from Madras University and M.E. degree in Communication Systems from Madurai Kamaraj University. He is currently pursuing research in the optical wireless communication at Anna University, Chennai. He has published several papers in this field. He is a member of ISTE, India, IAENG, Hong Kong and IMRS, Singapore.

Dr S. Sundaravadivelu is presently Professor and Head in the Electronics and Communication Engineering Department at Thiagarajar College of Engineering, Madurai. He received B.E. degree in Electronics and Communication Engineering from Thiagarajar College of Engineering, Madurai Kamaraj University, M.E. degree in Communication Systems from Regional Engineering College,Bharathidasan University, Trichy and Ph.D in CAD of Optical integrated Circuits from Thiagarajar College of Engineering, Madurai Kamaraj University.

He has published several papers in National and International journals. He is a research guide and guiding in the fields of Optical wireless Communication, Optical MEMS, Optical signal processing, Optical Image processing, Optical Networks, Optical Instruments, Optical Neural Network, Optical Computing and Optical Sensors. He is a member of ISTE, OSI, India, IAENG, Hong Kong and IMRS, Singapore.