A Novel Multipath Dispersion Reduction Technique Based on Controlled-Polarization Optical Wireless Link Set-Up

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Abstract - The detection characteristics of an indoor-optical communication system, which utilizes infrared radiation as carrier has been explored and enhanced for telemedicine, and wireless local area network applications. The novelty of the presented technique consists in the fact that multipath dispersion can be reduced under controlled polarization link set-up. The design of such a network is based on the specifications set by the IEEE 802.11 standard. Significant noise reduction has been achieved by utilizing wavelet transform processing algorithms.

I. INTRODUCTION

The increasing demand for an optical wireless local access network (LAN) has resulted from its attributes of being more secure, fast and immune to electromagnetic interference (EMI). This technology is utilized in large scale in developing portable personal computers, mobile communication, telemedicine, laptops, PDAs etc. [1]-[4], [6]-[9], [11]-[12]. These portable devices integrate computational power and mobility on a single platform and introduce the need for accessing communication networks without the restrictions imposed by cables [4]. The increasing interest in the wireless local access network gave way to the international standardization of this technology. In June 1997, a standard for WLAN for different technologies including radio and infrared set by the IEEE 802.11 committee was approved [4]. An essential characteristic of the IEEE 802.11 standard is that there is one single medium access control sub-layer for all the physical layers [4]. The medium access is based on a carrier sense multiple access with collision avoidance protocol (CSMA/CA)[2]-[4]. The physical layer deals with the actual transmission of the signal. This can be done either by radio or infrared technology. The infrared technology is very well suited for such a low-range application because it is cost effective, has high bandwidth for data transmission and hence offers faster, EM interference free and more secure transmission with low power requirements.

According to the specification, the infrared physical layer can support two data rates: 1 Mb/s and 2Mb/s. The specification is aimed at allowing a smooth migration to higher data rates [4]. There is a different modulation scheme for each data rate: 16-PPM for 1Mb/s and 4-PPM for 2Mb/s. Other modulation schemes such as ASK (Amplitude Shift Keying) and RZI (return to zero, inverted) can also be implemented. Lasers or light emitting diodes (LED) can be used as a transmitter. However, for an indoor environment LEDs are preferred as optical transmitters over lasers because they can produce substantial launch power and yet be Class 1 eye safe [1], [6]-[7]. Infrared radiation has properties similar to light and hence indoor surfaces are good reflectors of infrared [4]. In line-of-sight geometry, an obstacle between the transmitter and receiver can introduce attenuation of the collected optical power which is typically called shadowing effect. In diffused geometry, there is a reduction in the collected optical power due to the multipath propagation of the signal. Propagation through multiple paths can give rise to dispersion of the received pulses, which is called multipath dispersion. These signals can be distinguished based on their state of polarization. Several mechanisms can contribute to dispersion. For instance, multipath dispersion can occur due to the reflection of the infrared beam from different surfaces. Also, local scattering multipath results due to difference in the phase of the received signal. There is random distribution of the phase due to difference in path lengths of

approximately 1m. As a result, multipath spread delay occurs due to reflections from walls and other reflectors. This gives rise to a signal distortion known as Intersymbol Interference. Multipath propagation causes fading and time-spreading of the received signal. Interestingly enough, dispersion can compromise the bandwidth of both analog and digital signals. Various techniques are used to combat multipath dispersion, such as adaptive equalization, digital adaptive equalization, spread spectrum techniques, antenna diversity and directivity. The bandwidth of the infrared link is determined by multipath dispersion [4]. Along with these interferences the system is also vulnerable to fluorescent and incandescent light that flickers on-off at 120Hz [9]. Modulating the infrared signal onto a carrier avoids the interference by florescent lamps. This can also be eliminated by using a suitable optical bandpass filter. Low frequency noises can be removed by an electrical filter [9]. However, this noise can also be eliminated by using signal processing algorithms.

II. WLAN ARCHITECTURE.

A basic IEEE 802.11 architecture for WLAN is shown in Figure 1. A group of stations that can have direct communication are called the basic service set (BSS) and the area occupied is called the basic service area (BSA). The basic service area can overlap or be totally disjoint. Different BSAs are connected by system called distributed system. A group of BSAs interconnected by a distributed system is called as an extended service system. The simplest IEEE 802.11 network is an independent BSS. The communication between the individual stations is based on the infrared technology. The IEEE 802.11 medium access layer is based on the carrier detect multiple access collision avoidance. When a station is ready to send data, it checks whether the channel if free. If the channel is free it starts the transmission immediately. If the channel is busy it keeps on checking the channel till it becomes free. The actual transmission is carried by using a transceiver. A transceiver is capable of communicating in both directions.

Application of polarization technique on optical wireless networks was proposed by Giakos [4] as a solution for multipath dispersion in diffuse optical infrared communication. As a result the effect of multipath can be reduced though not completely removed. In this geometry, LOS (Line of Sight) communication in presence of a reflecting surface was carried out which increased the signal strength. A level six Haar Wavelet transform with thresholding was applied to increase the signal-to-noise ratio.

In this study, experimental results from polarization-controlled experiments, aimed to observe the multipath dispersion occurring in a line of sight parallel to surface geometry, are presented.

III. WAVELET THEORY

The signal received after transmission from a remote station is often contaminated by noise. The noise is further eliminated by using an appropriate signal-processing algorithm. In this case, wavelet transform has been used for high frequency noise removal. A Haar transform has been used to eliminate noise with appropriate threshold up to level 6. The challenge in the construction of wavelets is to keep the best frequency localization allowed by Heisenberg's uncertainty principle, since contrary to sines and cosines, they have a finite duration, which can be arbitrary small. Fourier systems and transforms are not well adapted to the local analysis of a function in time or space domain, since a local perturbation in $f(t)$ may significantly affect all Fourier

coefficients $\hat{f}(n)$.

Discrete Haar transform is related to the original mathematical operator Haar. The formulae for Haar transform are shown below:

$$a(i) = (f(2m\text{-}1) + f(2m))/ \sqrt{2} \quad \text{·····················} \quad (1)$$

$$d(i) = (f(2m\text{-}1) - f(2m))/ \sqrt{2} \quad \text{·····················} \quad (2)$$

where, a is the trend, f is the original signal, d is the fluctuation. Number of data points in a and d are half that of f , but the total energy of the signal is maintained. The inverse wavelet transform is calculated as

$$f(2m) = (a(m) + d(m))/ \sqrt{2} \quad \text{·····················} \quad (3)$$

$$f(2m+1) = (a(m) - d(m))/ \sqrt{2} \quad \text{··························} \quad (4)$$

where, m= 0 …N/2 and N is the length of original signal.

The second level of Haar transform is obtained by applying formulae in equation(1) and equation(2) to the latest trend signal available. Multiple levels can be obtained in such a way. The maximum level of Haar can be calculated as

$$L = \log_2(N) \quad \text{·····································} \quad (5)$$

Each level of transform gives us a trend, which is the signal and a fluctuation, which is the noise. All values of the fluctuations that are below the noise level are set to zero and an inverse transform is applied [5]. This technique gives a good approximation of the signal. Numerous thresholding techniques are available which can be used. Instead of a software filter, a hardware chip can be used that is programmed to give the output directly after applying the wavelet transform.

IV. MULTIPATH DISPERSION AND POLARIZATION

Multipath dispersion occurs when a signal reflects from any surface. Also in LOS point-to-point geometry, multipath

dispersion can occur due the movement of people around the communication link. The total pulse duration of a detected optical signal can be expressed as the root sum of the squares of the initial pulse duration and the pulse duration spread, according to:

$$\Delta t_{output} = \sqrt{\Delta t_{input}^2 + \Delta t_{dispersion}^2} \qquad (6)$$

The maximum bit rate, would be approximately four times the dispersion or, equivalently,

$$\text{Maximum bit rate} = \frac{1}{4\Delta t_{dispersion.}} \qquad (7)$$

For instance, if pulses experience about 1 ns of dispersion, the maximum bit rate is about 250 Mbit/s. Obviously, signal dispersion limits the optical bandwidth.

V. EXPERIMENTAL RESULTS

Figure 1 compares the line of sight (LOS) point-to-point link with LOS point-to-point parallel to surface link to illustrate multipath spreading. In this plot, a dispersion of 1.5 msec can be observed. An impulse with a rise and fall time of 1 msec and 2.5ms FWHM was transmitted with LOS point-to-point and LOS point-to-point parallel to surface link respectively. It can be seen that there was a difference in the rise and fall times and FWHM of the received signal in both geometry. The rise-time, fall-time and FWHM of LOS point-to-point detection geometry was 1.2msec, 1.1 msec and 2.8 msec while that of LOS point-to-point parallel to surface were 1.3 msec, 1.2 msec and 2.95 msec. By applying polarization theory to this phenomenon, it can be said that when an optical ray of light undergoes reflection, scattering, or diffusion, it undergoes change in polarization. Also the reflected light contributions cover larger distances as compared to the direct component and hence these reflected light interference patterns cause dispersion. Experiments were conducted to reduce the dispersive effects of these reflected contributions. Two linear polarizers were used, one in front of the transmitter and one in front of the receiver. The transmitter polarizer has a fixed polarization angle of 0 degrees (parallel polarization) implying that the transmitter emits infrared that is horizontally polarized. The receiver polarizer was rotated through the course of the experiment and rise-time and fall-time measurements were taken at every 5 degree rotation. The rise-time and fall-time results for LOS point-to-point link and LOS point-to-point parallel to surface link are shown in Figures 2 and 3. It can be seen that the when the transmitter polarizer and receiver polarizer are linearly aligned horizontally, the rise-time and fall-times of the detected signals for both the geometries are almost identical. This is

because the receiver polarizer allows only the direct component from the transmitter to pass through it and rejects the reflected light contributions. Until up to 20 degrees of rotation there is a slight increase in the rise-time and fall-time of LOS point-to-point parallel to surface link. This is attributed to the addition of reflected light contributions whose effect is reduced. After 20 degrees of rotation, it can be seen that there is a great difference in the rise-time and fall-time of the two geometries and the rise- time and fall-time for both the geometries increase. However a paired t-test was applied to check the difference in the two readings of fall-time and rise-time. The test had a Pr(t) greater than 0.0001 which proved that there was no significant difference in the two plots. The difference in the graph appears because there is reduction in amplitude in both geometries as direct component form the transmitter is gradually rejected as the angle increases. Due to this, the rise-time and fall-time start increasing. The increase is more in case of LOS parallel to surface because of the higher reflected component.
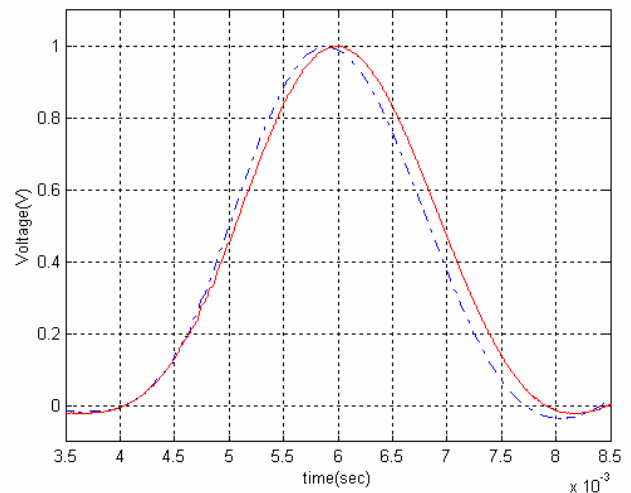

Fig. 1. Multipath dispersion occurring in line-of-sight point-to-point parallel to surface link.

Overall, the rise-time and fall-time of LOS point-to-point link can be optimized by polarization-control transceivers. Further experiments were conducted to check the validity of this technique. A square wave was transmitted in LOS point-to-point parallel to surface geometry, however the reflecting surface was gradually moved away from the transmitter-receiver setup. Readings for rise-time and fall-time were taken at every centimeter the reflecting surface was moved away from the transmitter-receiver setup. The rise-time and fall-time plots at different gains have been presented in Figures 4, and 5, respectively. An independent t-test was performed to evaluate
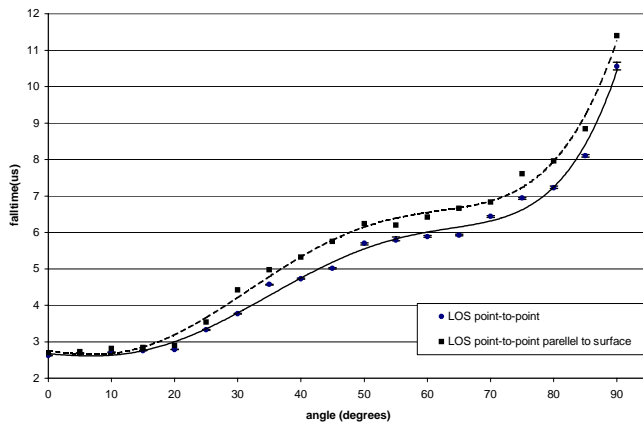
Fig. 2. Rise-time plot of LOS point-to-point link and LOS point-to-point parallel to surface link.

Fig. 4. Comparison of rise-time of LOS parallel to surface link with polarizer and without polarizer with a gain of 10.

the results and the results gave a Pr(t) value less than 0.0001. Hence null hypothesis was rejected and alternative hypothesis was accepted. Hence there was a significant difference in the rise-time and fall-time when measured with polarizer and without polarizers. It can be seen that when polarizers are not used, as the surface is moved away, there is reduction in the rise-time and fall-time. This is because when the surface is close to the setup, there is a significant contribution from the reflected component. As the surface is moved away, most of the reflected component is lost and hence there is less multipath dispersion. When polarizers are used it can be seen form the plots that there is no significant increase or decrease in the rise-time and fall-time and their value was almost constant.
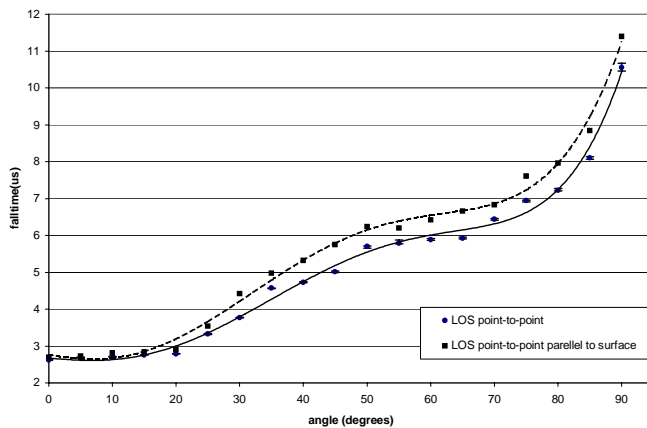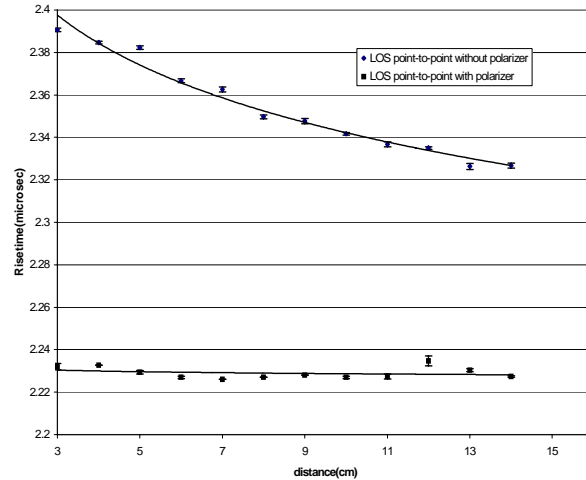
The rise-time and fall-time plots almost appear to be straight. Also it was observed that when the gain is high or the strength of the signal is higher, the rise-time and fall-time are low. Again an independent t-test was performed to test the results and t-test gave a Pr(t) value less than 0.0001. The null hypothesis was rejected and alternative hypothesis was accepted.
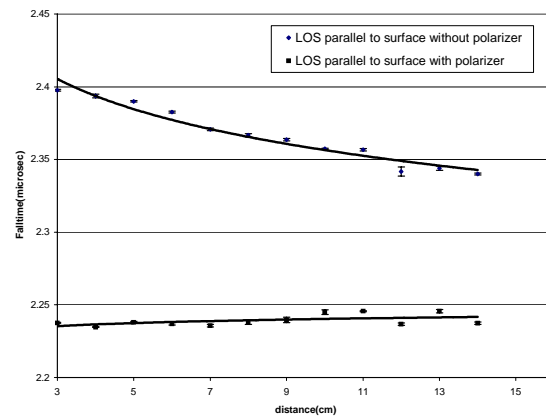

Fig. 5. Comparison of fall-time of LOS parallelto surface link with polarizer and without polarizerwith a gain of 10.

The Figures 6 and 7 show the noisy digital signals and the wavelet-transformed (filtered) signals respectively.

Fig. 3. Fall-time plot of LOS point-to-point link and LOS point-to-point parallel to surface link.
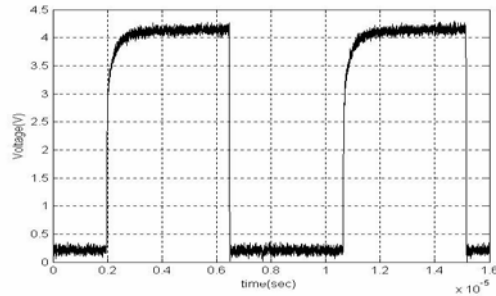
Figure 6. Unfiltered digital detected digital signal using line-of-sight (LOS) optical link geometry.
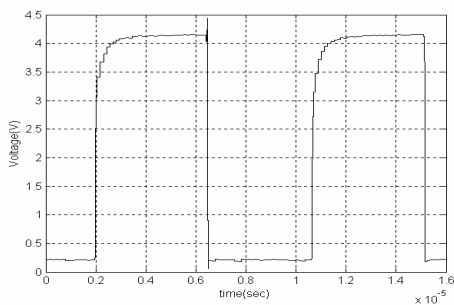

Fig.7 Filtered digital signal (wavelet transform) using line-of-sight (LOS) optical link geometry.

VI. CONCLUSION

An optical technique, aimed at reducing signal multipath dispersion, based on controlled polarization link set-up, was presented. The goal of this study is to improve the signal to noise ratio and bandwidth of the detected optical wireless signals. In addition, signal-to-noise experiments indicate that Haar wavelet transform can be used as an effective tool to filter the high frequency shot noise.

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