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Adaptive Equalization System for Wireless Communication Using White LED

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Abstract— White LEDs were invented the 1990's. The white LED has lower power consumption, lower voltage requirements, longer lifetime, smaller size, faster response, and cooler operation. We have proposed an indoor visible light wireless communication system that utilizes multiple white LED lighting equipment. In this system, the equipment is used not only for illuminating rooms but also for an optical wireless communication system. It functions as the main lighting equipment. One problem is we tend to install many lighting sources on a ceiling in order to illuminate the room as evenly as possible. While the number of sources permits site diversity transmission over LOS links, the optical path difference between the multiple sources triggers inter symbol interference (ISI), which significantly degrades system performance. This paper overcomes the ISI problem by proposing an adaptive equalization system. The adaptive equalization system with the effectual interval alleviates the influence of shadowing.

Keywords - Optical communication, light-emitting diodes, lighting, communication systems, adaptive equalizers, wireless LAN.

I. INTRODUCTION

In the 21st century, high data rate transmission will play a pervasive role in our life. To achieve high data rate transmission, radio frequencies are the dominant choice in offices and homes. However, the radio frequency spectrum is so congested that it will be impossible to provide a truly ubiquitous high data rate service. We need a new wireless medium. One exciting new wireless medium has emerged with the development of the InGaN light emitting diode (LED). With the recent release of blue and green LEDs, we can create highly efficient white light sources by combining the three primary colors (red, green, and blue). The white LED is a strong candidate for the future lighting technology. Compared with conventional lighting methods, the white LED has lower power consumption, lower voltage requirements, longer lifetime, smaller size, and cooler operation. The Ministry of Economy, Trade and Industry of Japan estimates that if half of all incandescent and fluorescent lamps currently in use were replaced by LEDs, Japan could save the equivalent output of six mid-size power plants, and reduce the production of greenhouse gases. A national program underway in Japan has already suggested that white LED deserves to be considered as a general lighting technology of the 21st century to offset the growth in electric power energy consumption. A group including the author has proposed an optical wireless communication system that employs white LEDs for indoor wireless networks. In this system, LEDs are used not only as lighting devices, but also as communication devices. The system employs visible light, free-space optical wireless communication links. This dual function, lighting and communication, creates many new and interesting applications. The communication function is released by modulating the sources at rates that preclude visible flicker. The system has much higher power levels than an infrared system and a large radiation pattern at the sources (transmitters) since they also function as lighting devices. This means that the system has a specific impulse response that is different from that of infrared communication. The specific delay profile and the basic communication performance were evaluated. The BER performance of the indoor visible light wireless system is degraded significantly by the effects of intersymbol interference (ISI). Here, we define the ISI as interference by path delay of same signal. The zero forcing decision feedback equalizer (ZF-DFE) is generally applied to mitigate the effects of ISI in infrared wireless systems. However the performance of visible light wireless systems that use equalizers has not been clarified. Prior works on infrared wireless systems with equalizers assume that the impulse response is known to the receiver. They also assume that the impulse response is static during each communication session. These assumptions are appropriate in infrared wireless communications because tracking is required by the low transmission power needed for eye-safety. And the receiver has to be the small FOV for achieving the high signal-to-noise ratio (SNR). Therefore, since the optical path is blocked easily by a pedestrian, connection is closed often. However, visible light wireless communication system can achieve sufficient SNR based on the large transmission power by the lighting function, even if the field-of-view (FOV) of receiver is large and the system has no tracking structure. And the receiver can be mobile and have seamless communication. Therefore, the system can have dynamic impulse response by the move of terminal or pedestrian. In this paper, we propose an adaptive equalization system and evaluate its performance in a visible light wireless system. Moreover, we discuss the influence of shadowing. We transmit training sequences and estimate the channel by the least mean square (LMS) algorithm. Incidentally, the modulation bandwidths of recent white LEDs in typical low cost lighting sources range from 10 MHz to 100 MHz. Recently, Resonant Cavity LEDs (RCLED) have been developed. The modulation bandwidth of RCLEDs is achieved to approximately 500 MHz. Moreover, by using a pre-emphasis circuit at transmitter, the extension of the modulation bandwidth1 is reported. As mentioned above, recently, a considerable number of studies have been conducted on extension of wide modulation bandwidth. Therefore, it is important to study the visible light wireless communication system with adaptive equalizer at high speed data transmission. In addition, the adaptive equalization system is a promising approach to the compensation of the frequency response of white LED devices. In other words, the adaptive equalization system enables the development of a high speed communication system. Computer simulations show the most effective training sequence interval for channel estimation. The simulation results show that a visible light wireless system with adaptive equalization is robust against shadowing and can accommodate more connections.

II. LIGHTING DESIGN AND BASIC PERFORMANCE

We will discuss the communication performance of a typical visible light wireless environment: a small office with general lighting requirements. The room is 5 × 5 × 3 m3. A 2 ×2 lighting grid with communication function is installed on the ceiling. The center positions each node are A: 1.0, 1.0, 3.0 , B: 4.0, 1.0, 3.0, C: 1.0, 4.0, 3.0, and D: 4.0, 4.0, 3.0 , respectively. Each lighting source has 10 × 10 LEDs. LED spacing is 4 cm. Each LED has a semi angle of half power of 80.0 deg., center luminous intensity of 23.81 cd, and optical output power of 0.452 W. These represent the measured and calculated values of the commercial product LXHL-LW6C. The ceiling, wall, and floor have reflective index values of 0.8, 0.5, and 0.2, respectively. We assume that the receiver lies on a desk. The height of the desk is 0.85 m.

A. *Illuminance Distribution Based on Lighting Engineering*
B. *B. Average Received Optical Power*
C. *C. Propagation Delay by Multiple Lighting Equipment's*
D. *D. Electrical SNR*

III. ADAPTIVE EQUALIZATION

A. Decision Feedback Equalization

The basic idea behind DFE is that once an information symbol has been detected and decided upon, the ISI that it induces on future symbols can be estimated and eliminated before detecting the subsequent symbols. The DFE can be realized in direct transversal form. It consists of a feedforward (FF) filter and a feedback (FB) filter. The FB filter is driven by decisions on the output of the detector, and its coefficients can be adjusted to cancel the ISI on the current symbol from past detected symbols. The equalizer has *NFF* + 1 taps in the FF filter and *NFB* taps in the FB filter.

$$\hat{d}_k = \sum_{n=0}^{N_{FF}} c_n^* y_{k-n} + \sum_{i=1}^{N_{FB}} F_i^* d_{k-i},$$

B. Least Mean Square Algorithm

Since adaptive equalization can compensate an unknown and time-varying channel, it requires a specific algorithm to update the equalizer coefficients and track the channel variations. A wide range of algorithms exist that can adapt the filter coefficients, but we assume an LMS algorithm. The LMS equalizer is a common design that minimizes the mean square error (MSE) between the desired equalizer output and the actual equalizer output. The LMS equalizer maximizes the signal to distortion ratio at its output within the constraints of the equalizer tap length. The convergence rate of the LMS algorithm is slow due to fact that only one parameter, the step parameter μ, controls the adaptation rate.

C. Mean Square Error

In this section, we discuss the validity of the value of step parameter and the length of the training sequence for the BER performance at each position. Figure 5 shows the relation between MSE by the LMS algorithm and the length of training sequence at the receiver positions of (0.1, 2.1, 0.85) where the FF filter has 4 taps and the FB filter has 2 taps. At the position, the received optical power is -5.55 dB m/cm2. The received optical power is determined by function of lighting equipment. The data drawn represents the average of 1000 trials. From the figure, we can see that the value of the step parameter has hardly influence on the MSE values at each data rate when the number of iterations is enough, but does determine the tracking ability of the LMS equalizer. The larger the step parameter is, the better the tracking ability of the equalizer becomes. However, large step parameters cause excess noise. We can also see that MSE yields high data rates since the received SNR depends on the data rate. From the result, for the following simulations, we set the number of iterations and the step parameter at 10000 and 0.01, respectively.

D. BER Performance

Figure 6 shows the distribution of BER performance versus receiver position on a 0.20 m grid. We can see that the low BER area is increased by DFE, which indicates high data rates. DFE effectively mitigates the influence of ISI. We can also see that the performance directly under the sources is degraded. Because, at these positions, the powers of first and second paths become approximately equal. Therefore, the consecutive paths, which have sub-equal power, cause error propagation. The relation between data rate and outage area rate. We define the outage area rate as the ratio of the area where BER is larger than 10−6 to the total service area. We can see that increasing the data rate increases the outage area rate. A system with some taps FF filter and a 0 tap FB filters is an FIR equalizer (linear equalizer).We can see that the system with DFE effectively mitigates the ISI effects. When data rate is over 200 Mbit/s, the FIR equalizer and DFE are effective. The DFE is especially effective at data rates over 700 Mbit/s, compared with the FIR filter. And adaptive equalizer with few taps is improved the outage area rate performance, effectively.

IV. INFLUENCE OF SHADOWING

In this section, we discuss the effect of shadowing on the adaptive equalization system assuming multiple sources with a specific impulse response. Generally, lighting equipments are distributed within a room and the irradiance of light has a wide angle to function as lighting equipment, which helps minimize a shadowing effect. However, the signal from multiple lighting

equipments causes the ISI. Therefore, there is a correlation between the influence of shadowing and the ISI. We consider downlink transmission based on time-division multiple access (TDMA) and perform theoretical analyses and computer simulations to evaluate the effects of shadowing caused by pedestrians. We show that the visible light communication system with adaptive equalization is robust against shadowing.

A. Traffic Consideration

B. Outage Call Duration Rate

C. Blocking Rate

IV. CONCLUSION

The visible-light free-space communication system described herein has much larger transmission power than infrared wireless communication systems since it also provides ambient lighting. It is seen as a very cost effective solution since lighting engineers will install many light sources on the ceiling to provide adequate a lighting throughout the room. From the viewpoint of communication engineers, transmission via LOS links without shadowing can be achieved because of the many lighting sources distributed across the ceiling. However the optical path difference between multiple sources causes ISI. This paper proposed the use of an adaptive equalizer to overcome the ISI problem. The performance of an adaptive equalizer with LMS algorithm was evaluated. The results showed that for data rates of over 200 Mbit/s, FIR equalizer and DFE were very effective. When the data rate exceeded 700 Mbit/s, the DFE effectively mitigated the influence caused by ISI. We showed that the simple equalizer with few taps is very effective even if the data rate is 1 Gbit/s. And we elucidated the most effective training sequence interval for channel estimation. Moreover, the influence of shadowing with the multiple sources was discussed. An optimal number of the lighting equipment for communication on the model room was shown. And the optimal number of source depended on the data rate, mean density of pedestrians, room model, and so on. We showed that the system with adaptive equalization was robust against shadowing and could accommodate more calls. The analyses and simulations presented here confirm that the proposed system is very promising for future high speed wireless access networks and it could be one of the choices for an indoor optical wireless data transmission system

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