Adaptive Differential Amplitude Pulse-Position Modulation Technique (DAPPM) using Fuzzy Logic for Optical Wireless Communication Channels

Bong Siaw Wee¹, M.F.L Abdullah²,*

¹Department of Electrical Engineering, Polytechnic Kuching Sarawak.
²Department of Communication Engineering, Faculty Electrical & Electronic Engineering, Universiti Tun Hussein Onn Malaysia.

Abstract: Optical wireless communication has the potential for extremely high data rates of up to tens of Gb/s. An optical wireless channel is usually a non-directed link which can be categorized as either line-of-sight (LOS) or diffuses. Modulation techniques have attracted increasing attention in optical wireless communication. In this paper, a hybrid modulation technique named adaptive differential amplitude pulse-position modulation (DAPPM) is proposed to improve the channel immunity by utilizing optimized modulation to channel. The bandwidth requirement and power requirement of the DAPPM equations were determined and compared with other modulation schemes as OOK, PAM, PPM, and DPPM. Simulation result shows that DAPPM gives better bandwidth and power efficiency depending on the number of amplitude level (A) and the maximum length (L) of a symbol. The simulation results also indicate that DAPPM will provide increase immunity against channel noise fluctuation at a relatively low complexity. In addition this paper demonstrates that by utilizing fuzzy systems in a dynamic control environment over a modulation channel reduces potential stability problems.

Keywords: DAPPM, fuzzy logic, optical wireless communication, modulation technique

1. Introduction

Optical wireless communication has emerged as a viable technology for next generation indoor and outdoor broadband wireless application [1]. Indoor optical wireless communication is also called wireless infrared communication, while outdoor optical wireless communication is commonly known as free space optical (FSO) communication [2]. In optical communication applications, there are always tradeoffs between system performance and costs. Thus, there is a pressing need to design a modulation technique for the real time situation.

As mentioned earlier, the optical wireless channel was limited by channel constraints such as the maximum allowable optical power and available bandwidth. Modulation schemes well suited to conventional channel were not necessarily perform well for the optical wireless channel [3]. The optical wireless channel can be easily affected by channel uncertainty. For example, distance between transmitter and receiver, distance from ambient light source or optical propagation path changes can result in bit error rate (BER) variation.

Optical wireless communications (OWC) has the potential for extremely high data rates of up to tens of Gb/s [4]. However, this capacity cannot yet be achieved because of the physical limitations of optical devices and the channel which exhibits path loss, noise from ambient light and the receiver, and multipath dispersion from multiple reflections off walls and objects in the room [5].

Besides this, the BER not only will be affected by noise and transmitted signal power but also by the system modulation level and modulation state. Therefore, in this paper, adaptive DAPPM using fuzzy logic for optical wireless communication channels is proposed to solve this problem. Fuzzy logic was invented by Dr. Lotfi Zadeh at the University of California at Berkeley in 1965. The areas of application of fuzzy logic have spread from consumer electronics to industrial control, information processing, financial analysis and much more in just the past few years [6].

2. Differential Amplitude Pulse-Position Modulation (DAPPM)

Modulation schemes which fit well in electromagnetic channels were not necessarily perform well in the optical domain. Modulation techniques remained active topics amongst both academic researchers and industrial communication system engineers [3]. There is several modulation or encoding schemes that are suitable for optical wireless systems. The classification of pulse modulation techniques is shown in Fig 1.
Selecting a modulation technique is one of the key technical decisions in the design of any communication system. The vital metrics against which a particular modulation technique is assessed are highlighted in terms of power efficiency, bandwidth efficiency and other considerations in the order of importance from optical wireless communication standpoint.

![Fig. 1 Pulse modulation tree](image)

The modulation technique named adaptive differential amplitude pulse-position modulation (DAPPM) is proposed in this paper, which combined the differential pulse position modulation (DPPM) and pulse amplitude modulation (PAM). DAPPM has advantages over other modulation schemes including PPM, DPPM and dual header pulse position modulation in terms of bandwidth requirements, capacity, and peak-to-average power ratio (PAPR) [8]. The symbol length varies from \{1, 2…A\} and the pulse amplitude is selected from \{1, 2…A\}, where A and L are integers. The bit resolution \(M = \log_2(A \times L)\).

A set of DAPPM waveforms is shown in Fig. 2. The average number of empty slots preceding the pulse can be lowered by increasing the number of amplitude levels \(A\) thereby increasing the achievable throughput in the process. When compared with similar modulation techniques, a well designed DAPPM will require the least bandwidth. DAPPM suffers from a high average power and a large DC component, thus restricting its use to applications where power is not a premium. It is also susceptible to the baseline wand.

![Fig. 2 The symbol structure for M=2 bits/symbol](image)

Table 1 shows the bandwidth requirement, power requirement, and bit error rate (BER) of OOK, L-PAM, L-PPM, DPPM and DAPPM.

<table>
<thead>
<tr>
<th>Modulation Schemes</th>
<th>Bandwidth Requirement</th>
<th>Power Requirement (dB)</th>
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<tbody>
<tr>
<td>(i) OOK</td>
<td>(R_0 = 1)</td>
<td>(\sqrt{N</td>
</tr>
<tr>
<td>(ii) PAM</td>
<td>(1 \log_2 L)</td>
<td>(5 \log_2 \left(\frac{(L-1)^{2}}{L}\right))</td>
</tr>
<tr>
<td>(iii) PPM</td>
<td>(\frac{L}{\log_2 L})</td>
<td>(5 \log_2 \left(\frac{2}{L \log_2 L}\right))</td>
</tr>
<tr>
<td>(iv) DPPM</td>
<td>(\frac{L+1}{2 \log_2 L})</td>
<td>(2^{M+1} \left(\frac{2}{L \log_2 L}\right))</td>
</tr>
<tr>
<td>(v) DAPPM</td>
<td>(\frac{L+1}{2 \log_2 (L \times A)})</td>
<td>(A(L+1) \left(\frac{1}{(A+1)^{2}} \right)) (\frac{2}{L \log_2 L})</td>
</tr>
</tbody>
</table>

The normalized optical power versus bandwidth required for OOK, PAM, PPM, DPPM, and DAPPM is shown in Fig. 3. Each point for PAM, PPM, DAPPM(A=2), and DAPPM(A=4) represents the level \(L = \{2,4,8,16,32\}\).
3. Results and Discussion

The Fuzzy logic control module was developed to assist the adaptation process. There are two systems built using the differences rules. System A is BER degradation and rate variation to modulation level and System B is the BER level and variation rate to modulation state.

Fig. 4 Block diagram for BER degradation and variation rate to modulation level (System A).

The block diagram for System A is outlined in Fig. 4. The fuzzy system rules can be expressed as the following, with this system name “Adaptive DAPPM System A”

1. If BER degradation is LOW, then LEVELS change is ZERO.
2. If BER degradation is MEDIUM or RATE of variation is SLOW, then LEVELS change is MINOR.
3. If BER degradation is MEDIUM and RATE of variation is FAST, then LEVELS change is LARGE.
4. If BER degradation is HIGH or RATE of variation is FAST, then LEVELS change is MINOR.
5. If BER degradation is HIGH and RATE of variation is FAST, then LEVELS change is MINOR.

This system has two inputs (BER and Rate), and one output (Levels). After finish setting the fuzzy sets, membership function and rules, the rule viewer for System A is shown in Fig. 5. The five steps for fuzzy inference process are setting the Fuzzify inputs, applying the fuzzy operation, applying implication method, applying the aggregation method, and perform the centroid defuzzification. Finally, the output value will be calculated by Fuzzy Inference System (FIS) after completing the whole process. In this Figure, BER = 2 and Rate = 0.5 is chosen as sample inputs. The required level change is 2.69.

Fig. 5 Rule viewer for system A.

Fig. 6 shows the mapping from “BER” and “RATE” to “MODULATION LEVELS” accordingly. The surface viewer is equipped with drop-down menus X (input), Y (input), and Z (output).

The BER is not only be affected by noise, transmitted signal power, and modulation level but is also affected by modulation state. An fuzzy inference system was set up to solve this problem and named System B. BER level and rate are set as the input fuzzy set, while the Amplitude level (A) and the differential pulse position change will set value (L) as the outputs fuzzy sets as shown in Fig. 7.

Fig. 7 Block diagram for system B.

The rules for System B can be expressed as follows:

1. If BER level is OK, then modulation state is NO_CHANGE.
2. If BER level is LOW, then Amplitude level (A) is change FAST.
3. If BER level is HIGH, then differential pulse position (L) is change FAST.
4. If BER level is OK and rate is NEGATIVE, then Amplitude level (A) is change SLOW.
5. If BER level is OK and rate is POSITIVE, then Amplitude level (A) is change SLOW.

Fig. 8 shows that the rules of fuzzy controller are used to change the system status and stabilize the BER. The surface of amplitude level (A) versus the BER level and change rate is shown in Fig. 9 while the differential pulse position (L) versus the BER level and change rate is shown in Fig. 10.
Fig. 8 Rule viewer for fuzzy controller to change the system status and stabilize the BER.

Fig. 9 The surface of amplitude level (A) versus the BER level and change rate.

Fig. 10 The differential pulse position (L) versus the BER level and change rate.

The fuzzy control method was incorporated with the developed adaptive DAPPM as a viable control process for optical wireless communication channel. From the simulation result, fuzzy logics is able to provide powerful control functionality for BER, variation rate and modulation level. Incorporating with DAPPM, communication systems can provide flexible and efficient adaptations for improving communication system.

4. Summary

This paper introduced an adaptive difference amplitude pulse-position modulation (DAPPM) using Fuzzy logic for high speed optical wireless communication channels. DAPPM provides several advantages. When the simulation results are compared, DAPPM with OOK, PPM, PAM and DPPM on the basis of required bandwidth and required power. According to the results, DAPPM requires less bandwidth when the number of amplitude level is high.

This paper has also applied a two fuzzy logic control module for DAPPM, that is System A and System B. System A was BER degradation and variation rate to modulation level, while System B was BER level and variation rate to modulation state. This system shows that the fuzzy logic control module was very promising in control adaptive modulation scheme process for optical wireless communication channels.

References