ADAPTIVE DIFFERENTIAL AMPLITUDE PULSE-POSITION MODULATION TECHNIQUE (DAPPM) USING FUZZY LOGIC FOR OPTICAL WIRELESS COMMUNICATION CHANNELS

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ABSTRACT

In the past few years, people have become increasingly demanding for high transmission rate, using high-speed data transfer rate, the number of user increased every year, therefore the high-speed optical wireless communication link have become more popular. Optical wireless communication has the potential for extremely high data rates of up to tens of Gigabits per second (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, therefore in this project; a hybrid modulation technique named Differential Amplitude Pulse-Position Modulation (DAPPM) is proposed to improve the channel immunity by utilizing optimized modulation to channel. The average symbol length, unit transmission rate, channel capacity, peak-to-average power ratio (PAPR), transmission capacity, bandwidth requirement and power requirement of the DAPPM were determined and compared with other modulation schemes such as On-Off Key (OOK), Pulse-Amplitude Modulation (PAM), Pulse-Position Modulation (PPM), Differential Pulse-Position Modulation (DPPM), and Multilevel Digital Pulse Interval Modulation (MDPIM). 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. In addition, the fuzzy logic module is developed to assist the adaptation process of differential amplitude pulse-position modulation. Mamdani fuzzy logic method is used in which the decisions made by the system will be approaching to what would be decided by the user in the real world.

ABSTRAK

Sejak kebelakangan ini, bilangan pengguna yang menggunakan kadar penghantaran dan pemindahan data yang berkelajuan tinggi semakin meningkat. Dengan itu, pautan komunikasi optik tanpa wayar yang berkelajuan tinggi menjadi semakin popular. Komunikasi tanpa wayar optik mempunyai potensi untuk menghantar data dengan kadar yang sangat tinggi sehingga berpuluh-puluh Gigabit per saat (Gb/s). Satu saluran wayarles optik yang pautan bukan-arahan boleh dikategorikan sebagai menggunakan *line-of-sight (LOS)* atau *diffuses*. Teknik modulasi telah semakin mendapat perhatian dalam komunikasi tanpa wayar optik. Dalam projek ini, satu teknik modulasi hibrid yang bernama *differential amplitude pulse-position modulation* (*DAPPM*) dicadangkan untuk meningkatkan imuniti saluran dengan menggunakan modulasi dioptimumkan kepada saluran. Purata panjang simbol, kadar penghantaran unit, saluran kapasiti, nisbah kuasa puncak-ke-purata (*PAPR*), kapasiti penghantaran, lebar jalur dan kuasa yang diperlukan untuk *DAPPM* akan ditentukan dan dibandingkan dengan pemodulatan yang lain seperti *on-off key (OOK), pulse-amplitude modulation (PAM), pulse-position modulation (PPM), differential pulse-position modulation (DPPM), and multilevel digital pulse interval modulation (MDPIM).* Hasil dapatan simulasi telah menunjukkan bahawa *DAPPM* akan memberikan lebar jalur dan kecekapan kuasa yang lebih baik bergantung kepada bilangan tahap amplitud (A) dan panjang maksimum (L) simbol. Di samping itu, *fuzzy logic module* akan dihasilkan untuk membantu proses penyesuaian bagi *differential amplitude pulse-position modulation (DAPPM)*. Kaedah *Mamdani fuzzy logic* digunakan supaya hasil dapatan daripada sistem ini adalah menghampiri dengan situasi sebenar.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Pulse amplitude
B	-	Bandwidth
C	-	Channel capacity
L	-	Average symbol length
M	-	Bit Resolution
N_0	-	The power spectral density of the White Gaussian Noise
N(t)	-	Signal-Independent Noise
P_t	-	The average transmitted optical power
$Q(x)$	-	The customary Q-function of digital telecommunication
R	-	Transmission rate
R_b	-	Information rate
T	-	Slot width
$x(t)$	-	Instantaneous optical power
$y(t)$	-	Output signal
τ	-	Pulse duration
r_p	-	Duty ratio
γ	-	Unit information transmission rate
AMI	-	Alternate-Mark Inversion
ATM	-	Asynchronous Transfer Mode
BER	-	Bit Error Rate
CPPM	-	Chaotic-Pulse-Position Modulation
DAPPM	-	Differential Amplitude Pulse-Position Modulation
DPIM	-	Digital Pulse-Interval Modulation
DPIWM	-	Digital Pulse Interval and Width Modulation.
DPPM	-	Differential Pulse-Position Modulation
FIS	-	Fuzzy Inference System

FL	Fuzzy Logic
FOV	Field-of-View
FSO	Free Space Optical
Gb/s	Gigabits per second
GUI	Graphic user interface
IM	Intensity Modulation
IM/DD	Intensity Modulation/Direct Detection
IR	Infrared
ISM	Industrial, Scientific and Medical
Km	Kilometer
LDs	Laser Diodes
LEDs	Light Emitting Diodes
LMDS	Local Multipoint Distribution Service
LOS	line-of-Sight
Mbps	Megabits per second
MDPIM	Multilevel Digital Pulse Interval Modulation Scheme
M. Eng	Master of Engineering
MPPM	Multi-Pulse pulse position modulation
NRZ	Non-Return-to Zero
NRZI	Non-Return-to-Zero-Inverted
NRZL	Non-Return-to-Zero-Level
PAM	Pulse-Amplitude Modulation
PAPR	Peak-to-average Power Ratio
PCM	Pulse-code modulation
PD	Proportional Derivative
PFM	Pulse Frequency Modulation
PI	Proportional–Integral
PID	Proportional–Integral–Derivative
PIM	Pulse Interval Modulation
PIWM	Pulse Interval and Width Modulation
PPM	Pulse Position Modulation
PSD	Power Spectral Density
PWM	Pulse-Width Modulation

RF	-	Radio Frequency
RZ	-	Return-to-Zero
SNR	-	Signal-to-Noise Ratio
SWFM	-	Square Wave Frequency Modulation
UTHM	-	Universiti Tun Hussein Onn Malaysia
OOK	-	On-Off Keying
OPPM	-	Overlapped Pulse Position Modulation
OW	-	Optical wireless
OWC	-	Optical wireless communication
VLSI	-	Very-Large-Scale Integration

LIST OF APPENDICES

LIST OF PAPERS PUBLISHED FROM THIS PROJECT

NCEEE Conference Publication & Presentation:-

1. Bong, S.W. and Abdullah, M.F.L. Adaptive Differential Amplitude Pulse-Position Modulation Technique (DAPPM) using Fuzzy Logic for Optical Wireless Communication Channels. *National Conference on Electrical and Electronics Engineering* 2012. May 8 – 9, 2012, pp. 87-90.

Papers submitted to Journals:-

2. Abdullah, M.F.L. and Bong, S.W. Adaptive DAPPM Technique for Optical Wireless Communication Channels based on Fuzzy Logic. *IEEE Transactions on Communications*.
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CHAPTER 1

INTRODUCTION

1.1 Background of research

In recent years, the need to access wireless local area networks from desktop to portable and mobile formats has grown rapidly. High performance links are necessary to allow data exchange from these portable devices to established computing infrastructure such as backbone networks, data storage devices and user interface peripherals [1]. Many of these networks have been designed to support multimedia with high data rates, thus the systems require large bandwidth. Since radio communication systems have limited available bandwidth, a proposal to use indoor optical wireless communications has received wide interest [2].

Optical wireless communication has emerged as a viable technology for the next generation of indoor and outdoor broadband wireless applications. Applications range from short-range wireless communication links providing network access to portable computers, to last- mile links bridging gaps between end users and existing fiber optic communications backbones, and even laser communications in outer-space links [3]. Indoor optical wireless communication is also called wireless infrared communication, while outdoor optical wireless communication is commonly known as free space optical (FSO) communication [4]. An Optical wireless system diagram is shown in Figure 1.1.

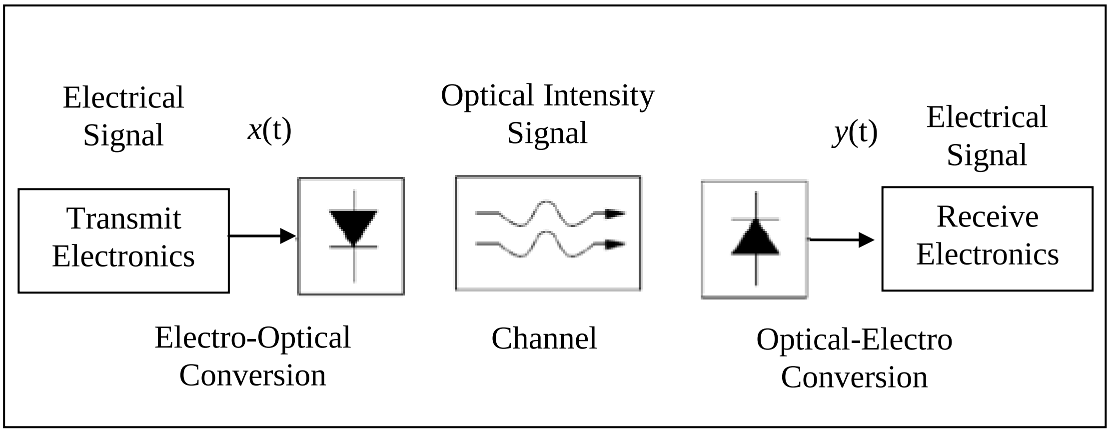


Figure 1.1: Block diagram of an optical intensity, direct detection communications channel [5].

Traditionally, wireless technology is always associated with radio transmission, although transmission by carriers other than radio frequency (RF) waves, such as optical waves, might be more advantageous for certain applications. The principal advantage of FSO technology is very high bandwidth availability, which could provide broadband wireless extensions to Internet backbones providing service to end-users. This could enable the prospect of delay-free web browsing and data library access, electronic commerce, streaming audio and video, video-on-demand, video teleconferencing, real-time medical imaging transfer, enterprise networking and work-sharing capabilities, which would require as much as a 100 Mbps data rate on a sustained basis. Summary of difference between FSO and RF technologies is shown in Table 1.1.

Table 1.1: Properties of terrestrial FSO and RF communications [4].

Properties	FSO Links	RF Links
Typical Data Rate	100Mbps to ~ Gbps	Less than 100 Mbps
Channel Security	High	Low
Component Dimension	Small	Large
Networking Architecture	Scalable	Non-scalable
Source of Signal Degradation	Atmospheric turbulence and obscuration	Multipath fading, rain, and user interferences

The free space optical wireless link is mainly applied in short range (less than 2 kilometers) and inter-building data connections complementary to existing RF networks [5]. Although challenged by several competitive RF bands, including the industrial, scientific and medical (ISM) radio bands, and the local multipoint distribution service (LMDS) bands [6], optical wireless showed promising features of higher data throughput and immunity to the interference which is usually suffered by RF systems. Table 1.2 presented a comparison of ISM, LMDS and optical wireless systems.

Table 1.2: Comparison of ISM, LMDS and FSO systems [7].

System	ISM Band	LMDS	Optical Wireless
Frequency	2.4 GHz	24-40GHz	30-60THz
Licensed	No	Yes	No
Multipoint Topology	Omni or Sectored	Omni or Sectored	Virtual Multipoint
Cell Radius	8-15Km	2-3Km	1-2Km
Downstream Bandwidth	3-8 Mbps per sector (per frequency)	155Mbps per sector	1.5Gbps per user
Upstream Bandwidth	3 Mbps peak per user	3-10Mbps per user	1.5 Gbps per user
Symmetric	No	No	Yes
Protocol Independence	No	No	Yes
Fade Mechanism	Heavy Rain	Rain	Thick Fog, Snow
Initial Investment for few subscribers	High	High	Low
Investment for 50-100 subscribers per cell	Medium	Medium	Medium

From the above table, optical wireless (OW) channel surpassed the RF system in the following aspects: downstream bandwidth per user/sector/frequency of OW system was nearly 10 times that of the LMDS system and up to 500 times that of the ISM system. The upstream bandwidth is similar to that of the downstream bandwidth. In the cell radius comparison, the OW system provided the shortest distance coverage, where ISM and LMDS systems can achieve a range which is 7.5 and 1.5 times further than the OW system respectively [6]. Noticeably, weather conditions had an impact on the reliability of the channel, which could affect the transmission data rate.

1.2 Problems statement

In optical communication applications, there is always tradeoff between system performance and costs. There is thus 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 [5]. 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) [8] has the potential for extremely high data rates of up to tens of Gb/s. 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 [9].

Besides that, the BER not only it will be affected by noise and transmitted signal power but also by the system modulation level and modulation state. Due to this constraint, adaptive Differential Amplitude Pulse-Position Modulation (DAPPM) technique using fuzzy logic for optical wireless communication channels is proposed to solve this problem.

1.3 Project objectives

At the end of this project the following objectives will be achieved:-

(i) To analyze the performance of Differential Amplitude Pulse-Position Modulation (DAPPM) technique for optical wireless communication channel.

(ii) To develop the fuzzy logic control module for DAPPM.

(iii) To evaluate the achievable Bit Error Rate (BER), variation rate, and modulation level and state for DAPPM.

1.4 Scopes of project

(i) The performance of DAPPM for optical wireless communication channel model is analysis and compare with the other modulation schemes.

(ii) The Fuzzy logic control module for DAPPM is developed by using Graphic User Interface (GUI), MATLAB.

(iii) The BER, variation rate, modulation level and state performance for DAPPM is determined.

1.5 Expected Result

The expected result from the proposed, Differential Amplitude Pulse-Position Modulation (DAPPM) technique will provides several advantages when the simulation results are compare between the DAPPM with On-Off Key (OOK), Pulse-Amplitude Modulation (PAM), Pulse-Position Modulation (PPM), Differential Pulse-Position Modulation (DPPM), and Multilevel Digital Pulse Interval Modulation (MDPIM) in terms of average symbol length, unit transmitssion rate, channel capacity, bandwidth requirement, peak-to-average power ratio (PAPR), normalized power and bandwidth required.

The adaptive DAPPM system will be develop using fuzzy inference system. This simulation result will shows that the fuzzy logic control module is very promising in controlling adaptive modulation scheme process for optical wireless communication channels.

1.6 Thesis structure outline

This thesis is a documentary to deliver the generated idea, the concepts applied, the activities done, and finally, the project product produced. The thesis consists of five chapters.

Chapter 1 discusses the background of the research. In addition, the objectives of project, problems statement, scopes of work, expected result and thesis structure outline are presented.

Chapter 2 contains literature review discussing the applications of optical wireless communication and modulation schemes. On the others hand, this chapter also includes the recent research of modulation schemes from the year 2006 until 2011 and the author's view on these research. Furthermore, a review of fuzzy logic and the reason of using fuzzy logic control will be discusses in this chapter.

Chapter 3 concentrates on the performance of Differential Amplitude Pulse-Position Modulation (DAPPM) modulation for optical wireless communication channels analysis, and comparison between DAPPM with other modulation schemes in terms of average symbol length, unit transmission rate, channel capacity, bandwidth requirement, Peak-to-average power ratio (PAPR), transmission capacity and normalized power and bandwidth requirement analysis.

Chapter 4 presents the design of system architecture for a fuzzy logic controlled adaptive modulation system. Besides that, the design flow and simulation of the project is introduced. It provides a brief description on each procedure in completing the project. This chapter also covered MATLAB Fuzzy Inference System (FIS) result and analysis. The Fuzzy logic control module was developed to assist the adaptation process.

Finally, Chapter 5 presents the conclusions and suggestions for future work. Important results and methodology obtained from previous chapters are summarised, and the possibilities for future directions is discussed.

CHAPTER 2

LITERATURE REVIEW

At the beginning of this project, some of the previous case studies have been reviewed to obtain maximum information and data on how to design and implement the project. This chapter uncompressed all of the related fields and knowledge for completion of this project.

2.1 Optical wireless communication

The use of optical emissions to transmit information has been used since antiquity. Homer, in the Iliad, discusses the use of optical signals to transmit a message regarding the Grecian siege of Troy in approximately 1200 BC. Fire beacons were lit between mountain tops in order to transmit the message over great distances [1]. Optical fiber depended on the phenomenon of total internal reflection, which can confine light in a material surrounded by other materials with lower refractive index, such as glass in air. In the 20th century, inventor realized that bent quartz rods could carry light, and optical fibers went a step further.

The modern era of indoor wireless optical communications was using the diffuse emissions in the infrared band for indoor communications [10]. Since that time, much work has been done in characterizing indoor channels, designing receiver and transmitter optics and electronics, developing novel channel topologies as well as in the area of communications system design.

An optical wireless communication system is an attractive alternative to radio, primarily because of a virtually unlimited, unregulated bandwidth. The optical spectrum is a universally available resource without frequency and wavelength regulations. An optical wireless communication system has the advantage of requiring low-cost and low power consumption components [11]. On the other hand, the channel can be severely interfered by background noise: shot noise induced by the background ambient light and the interference induced by artificial light sources [5]. Meanwhile directed line-of-sight (LOS) IR systems had the potential to achieve a data rate of a few gigabits per second and higher. A comparison between RF and IM/DD infrared systems for indoor wireless communications is shown in Table 2.1.

Table 2.1: Comparison between radio and IM/DD infrared systems for indoor wireless communications [8].

Property of Medium	Radio	IM/DD Infrared	Implication for IR
Bandwidth Regulated?	Yes	No	Approval not required. Worldwide compatibility
Passes Through Walls?	Yes	No	Less coverage. More easily secured. Independent links in different rooms .
Multipath Fading?	Yes	No	Simple link design.
Multipath Distortion?	Yes	Yes	
Path Loss	High	High	
Dominant Noise	Other Users	Background Light	Limited range .
Input X(t) Represents	Amplitude	Power	Difficult to operate outdoors
SNR Proportional to	$\int \lvert X(t) \rvert^2 \, dt$	$\int \lvert X(t) \rvert^2 \, dt$	High transmitter power requirement .
Average Power Proportional to	$\int \lvert X(t) \rvert^2 \, dt$	$\int X(t) dt$	Choose waveform X(t) with high peak-to-average ratio.

Radio and lightwave are complementary transmission media, and difference applications favor the use of either one medium or the other. Radio is favored in applications where user mobility must be maximized or transmission through walls or over long ranges is required and may be favored when transmitter power consumption must be minimized. Lightwave is favored for short-range applications in which per-link bit rate and aggregate system capacity must be maximized, cost must be minimized, international compatibility is required, or receiver signal-processing complexity must be minimized.

2.1.1 System configuration

The different kinds of links for indoor optical wireless communications have been classified, depending on the existence of a line-of-sight (LOS) path between the transmitter and the receiver, and the degree of directionality [12]. According to orientation between the transmitter and receiver, the optical link can also be divided into 3 categories that are Directed, Hybrid and Nondirected [5]. The six basic configurations are shown in Figure 2.1. LOS link systems improve power efficiency and minimise multipath distortion. Non-LOS links, on the other hand, increase link robustness as they allow the Directed Hybrid non-Directed system to operate even when obstacles are placed between the transmitter and receiver, and alignment is not required.

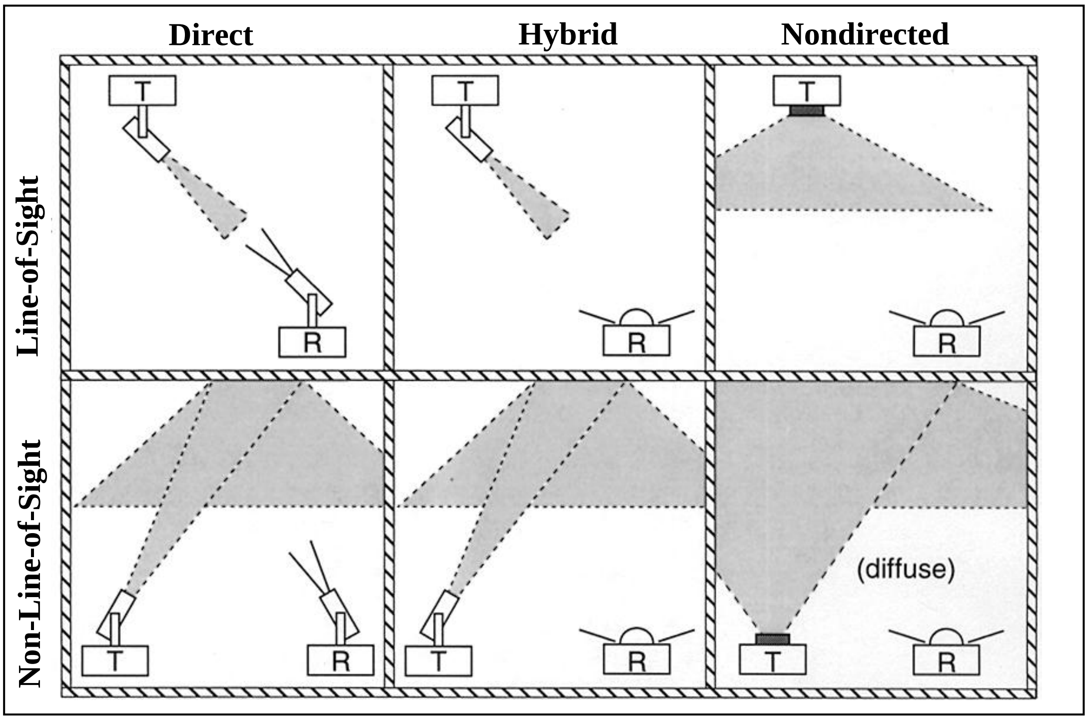


Figure 2.1: Classification of simple infrared links according to the degree of directionality of the transmitter and receiver and whether the link relies upon the existence of a LOS path between them [8].

Directed links also improve power efficiency as the path loss is minimised, but this kinds of systems require alignment of the transmitter, the receiver, or both, making them less convenient to use for certain applications. Directed-LOS link systems improve power efficiency because the transmitted power is concentrated into a narrow optical beam, making possible the use of narrower field-of-view (FOV) receivers, and an improved link budget. Also, this kind of system does not suffer from multipath distortion, and a predetermined maximum transmission distance can always be assured for a given optical power, independently of the reflective properties or the shape of the room, as far as the line of sight is not interrupted. This configuration presents the advantages of maximum power efficiency, and high coverage.

Hybrid-non-LOS systems do not present the blocking problem, but suffer from multipath distortion that increases as the area is increased. One of the most attractive configurations is the nondirected-non-LOS, or diffuses. Systems working under configuration do not require a direct line of sight, or alignment, between the optical transmitter and the receiver because the optical waves are spread as uniformly as possible in the room by making use of the reflective properties of the walls and the ceiling. This kind of link has the advantage that it can operate even when barriers are placed between the transmitter and the receiver. This makes it the most robust and flexible configuration. In spite of the advantages of the diffuse configuration, this kind of system suffers from multipath dispersion and higher optical losses than LOS and hybrid-LOS [12].

Most of the manufacturers of indoor infrared systems nowadays base their designs on the directed-LOS and hybrid-LOS configurations, being these the topologies that allow higher bit rates (sometimes above 100 Mb/s), as they are free from multipath distortion. Besides, this system can be developed at very low costs because the receivers are simple and consume little power. This is a very important consideration, taking into account that this kind of system cannot recover its cost by call tariffs. Different manufacturers have taken advantage of the properties of Directed and LOS links, making the Directed-LOS configuration one of the most popular currently. Table 2.2 shows the chronology of published indoor optical wireless communication research [12].

Table 2.2: Chronology of published indoor optical wireless communication research [12].

Date	Organisation	Configuration	Bit rate	Characteristics
1979, 1981	IBM	Diffuse	64-125 kb/s	100 mW, 950 nm, BPSK
1983	Fujitsu	Los	19.2 kb/s	15 mW, 880 nm, FSK
1985	Hitachi	Hybrid	0.25-1 Mb/s	300 mW, FSK
1985	Fujitsu	Hybrid	48 kb/s	880 nm, BPSK
1985	HP Labs	Directed LOS	1 Mb/s	165 mW, 880 nm
1986	Motorola	Wide LOS	50 kb/s	16 mW, 950 nm, RZ OOK
1987	Bell Labs	Directed LOS	45 Mb/s	1 mW, 800nm, OOK
1988	Matsushita	Hybrid	19.2 kb/s	880 nm, FSK
1992	MRR Teltech Ltd	Non-Directed	230.4 kb/s	DPSK, 800/950 nm
1993	BT Labs	Cellular	50 Mb/s	
1994	Berkeley	Diffuse	50 Mb/s	475 mW, 806 nm, OOK
1994	BT Labs	Cellular	155 Mb/s	40 mW

2.1.2 Transmitter options

The two more commonly used sources for IR transmitters are: light emitting diodes (LEDs) and laser diodes (LDs). LEDs are usually cheaper and harder to damage than laser diodes, which make them the preferred choice for different manufacturers. Also, LEDs achieve higher power capability. Laser diodes, on the other hand, can be used at higher modulation rates than LEDs [12]. Due to eye safety, a LD can easily damage human eyes if used directly. In comparison, the LEDs were relatively safer to operate. More importantly, the cost of an LED was usually less than that of a LD, making it a good choice for mass production and for quick adoption to the consumer market. Table 2.3 listed detailed comparisons between LEDs and LDs.

Table 2.3: Comparison of LEDs and LDs [8].

Characteristic	LED	LD
Optical Spectral Width	25-100nm	$< 10^{-5} - 5\,nm$
Modulation Bandwidth	Tens of kHz to Hundreds of MHz	Tens of kHz to Tens of GHz.
Special Circuitry Required	None	Threshold and Temperature Compensation Circuitry
Eye Safety	Considered Eye safe	Must be Rendered Eye Safe
Reliability	High	Moderate
E/O Conversion Efficiency	10-20%	30-70%
Cost	Low	Moderate to High

2.1.3 Receiver options

The two more common detector types for the different configurations are: PIN and avalanche photodiodes. The PIN detector is preferred in most of the systems, because of its low-bias-voltage requirement and its tolerance to temperature fluctuations. However, PIN detectors are about 10 to 15 dB less sensitive than avalanche photodiodes avalanche photodiodes. On the other hand, PIN provides a more robust communication link due to their increased power margin. This reduces the problem of accurate alignment of lenses and allows for reduction of preamplifier noise, laser power and miscellaneous losses [12].

2.2 Channel Model

The two modulation scheme for free space optic communication system are intensity modulation/direct detection (IM/DD) and coherent modulation/heterodyne detection. Coherent optical detection is not feasible in the indoor wireless infrared communication environment. Practical wireless infrared links use intensity modulation and direct detection (IM/DD). An IM/DD system has an equivalent baseband model that hides its carrier frequency [13].

Direct detection system has small volume, light weight, simple structure, low cost and easy to implement, but low bandwidth efficiency. Heterodyne detection system has the high receiver sensitivity, but it is difficult to implement, and it is difficult to ensure that the coherence property of light signal which is spread in atmosphere, therefore FSO communication system are usually designed using intensity modulation/direct detection [14].

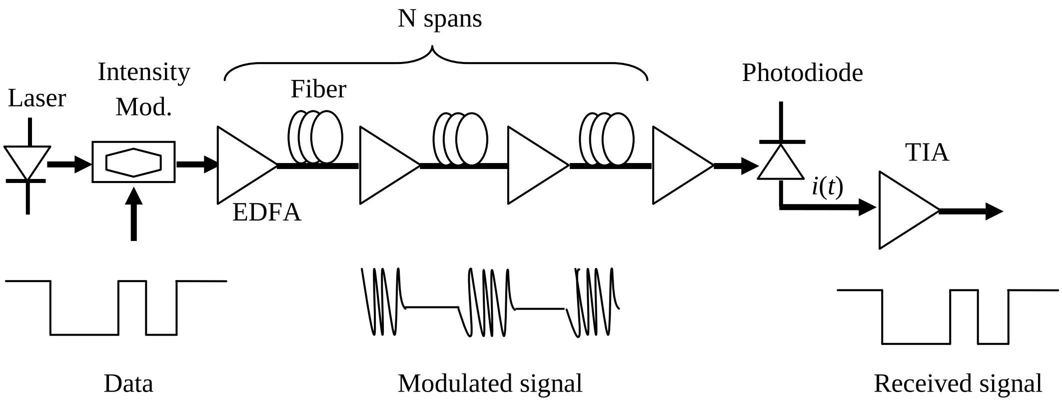


Figure 2.2: Typical configuration of an intensity-modulated/direct-detection (IM/DD) system [15].

The IMDD system illustrated schematically in Figure 2.2 is very simple. The receiver decides whether the transmitted bits are either “0” or ‘1” based on the presence or absence of light. This class of system can use either non-return-to zero (NRZ) or return-to-zero (RZ) pulses for digital transmission.

In many applications, optical wireless links are operated in the presence of intense infrared and visible background light. While received background light can be minimized by optical filtering, it still adds short noise, which is usually the limiting noise source in a well-designed receiver. The equivalent channel model can be illustrated in Figure 2.3. The transmitter is an optical emitter and the detector is a large-area photodetector.

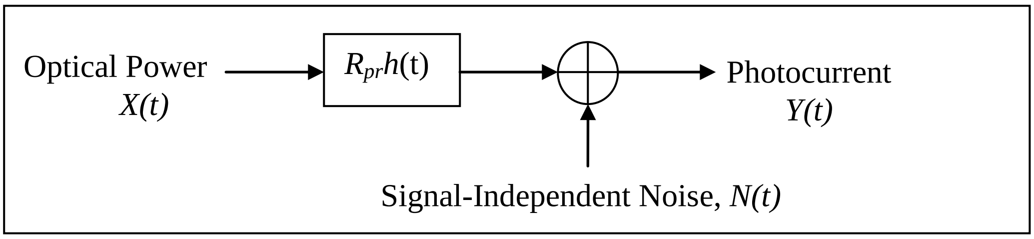


Figure 2.3: Equivalent channel model.

Let $x(t)$ represent the instantaneous optical power, the channel input is non-negative:

$$x(t) \geq 0 \tag{2.1}$$

and the average transmitted optical power P_t is given by:

$$P_t = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} x(t)dt \tag{2.2}$$

Using the Gaussian model, the output signal $y(t)$ given by:

$$y(t) = Rh(t) \otimes x(t) + n(t) \tag{2.3}$$

Where

R = photodetector reponsivity (A/W)

$h(t)$= channel impulse reponse

$x(t)$ = transmitted signal

$n(t)$ = noise or white Gaussian noise

When $x(t)$ represents amplitude, the average received optical power is

$$P = H(0)P_t \tag{2.4}$$

Where H(0) = the channel d.c gain

$$H(0) = \int_{-\infty}^{\infty} h(t)dt \tag{2.5}$$

The performance of a wireless optical link at bit rate R_b is related to the received electrical SNR and assuming that N(t) is dominated by a Gaussian component having double-sided power-spectral density $N_{0.}$

$$SNR = \frac{R^2 P^2}{R_b N_0} = \frac{R^2 H^2(0) R_t^2}{R_b N_0} \tag{2.6}$$

Based on the Eq. (2.6), the SNR depends on the square of the received optical average power, implying that IM/DD optical wireless link must transmit at a relatively high power and can tolerate only a limited path loss. This stands in contrast to the case of radio wave channels, where signal to noise ratio (SNR) is proportional to the first power of the received average power.

The channel capacity is the highest rate in bits per channel use at which information can be sent with arbitrarily low probability of error [6]. The capacity of discrete-time memory-less channel subject to various input constraints had been studied following the Shannon's information theory [16]. The most common input constraints for the optical wireless channel are average power and bandwidth.

2.3 Modulation schemes

Modulation schemes which fit well in electromagnetic channels does not necessarily perform well in the optical domain. Modulation techniques remained active topics amongst both academic researchers and industrial communication system engineers [5]. There is several modulation or encoding schemes that is suitable for optical wireless systems.

Higher average power efficiency can be achieved by employing pulse modulation schemes in which a range of time-dependent features of a pulse carrier may be used to convey information. The classification of pulse modulation techniques is shown in Figure 2.4.

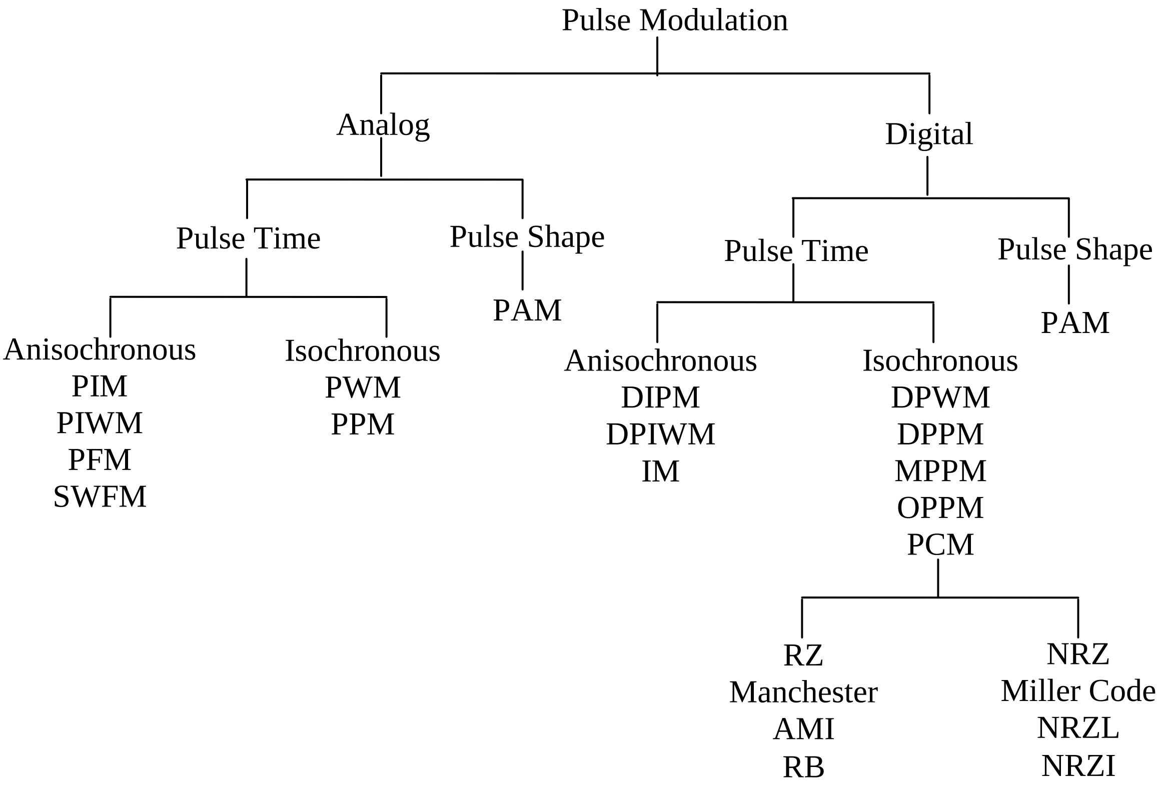


Figure 2.4: Pulse modulation tree [17].

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 below in the order of importance from optical wireless communication stand point:

i) Power Efficiency

The transmitted optical power is limited due to eye and skin safety requirement [10] and for battery powered optical wireless gadgets the power consumption need to be minimised as well. The factor that cause the power efficiency of a particular modulation technique becomes the most important consideration is the different signaling schemes which are usually compared in terms of the required average optical power (or signal to noise ratio) to achieve a desired error performance at a given data rate.

ii) Bandwidth Efficiency

Even though the optical carrier can be said to have ‘unlimited bandwidth’ but the other constituents such as photodetector, multipath channel and others in the system limit the amount of bandwidth that is practically available for a distortion-free communication system. Besides that, the ensuing multipath propagation in diffuse link/non-directed LOS limits the available channel bandwidth.

iii) Other Considerations

Implementation simplicity is another design requirement when considering a modulation scheme. The cost of implementing a very complex modulation scheme might render the scheme unfeasible irrespective of its power/bandwidth efficiency. Resilience to interference from the artificial ambient light sources and the channel induced dispersion as well as power contained at and near DC are other indices against which modulation schemes are compared and evaluated [18].

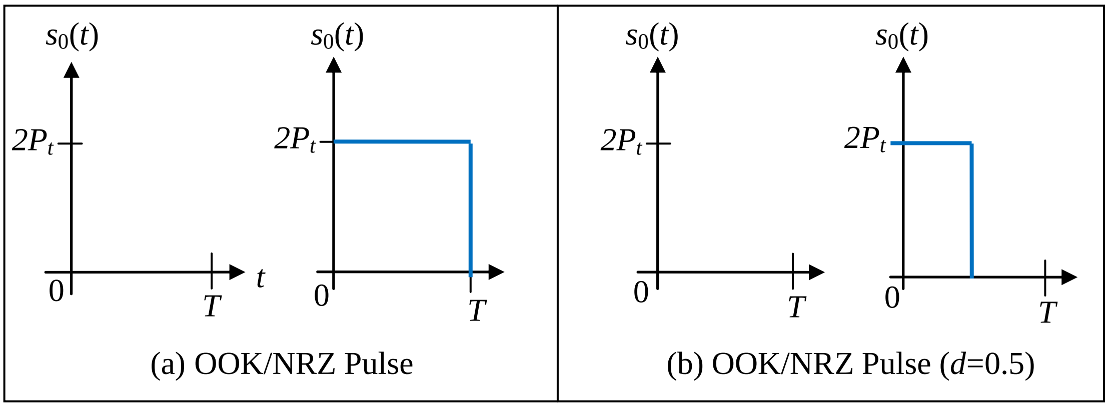
Although the primary attention in this project is indoor optical wireless modulation techniques, the modulation or signaling techniques discussed herein are by no means restricted to this. They are equally applicable in both optical fiber and free-space optics communication links. In all cases, the intensity of the optical carrier signal is modulated by the data and direct photo detection in which the received signal (photocurrent) is proportional to the received optical irradiance is assumed, i.e. intensity modulation with direct detection (IM/DD).

2.3.1 Common modulation schemes suitable for optical wireless systems

There are several different modulation schemes for optical wireless systems. The most common modulation schemes are On-Off Keying (OOK), Pulse-Position Modulation (PPM), Pulse Amplitude Modulation (PAM), Differential Pulse-Position modulation (DPPM), Digital Pulse Interval Modulation (DPIM) and Different Amplitude Pulse-Position Modulation (DAPPM).

(i) On-Off Key (OOK)

The most reported modulation techniques for IM/DD in optical communication is the On-Off Key. OOK is the simplest technique to implement in wireless infrared transmission. Prior to transmission, the information is translated to a specific code such as Manchester, Return to Zero (RZ), or Non Return to Zero (NRZ) codes, to get a stream of pulses. In OOK, a pulse is transmitted if the code bit is ‘one’ during a fixed time slot and a ‘zero’ is represented by the absence of the pulse during the time slot [19]. The pulse can have different duty cycles (d). When using a duty cycle d <1, the required bandwidth is increased by a factor of $1/d$ while the average power requirement is decreased. This is the main reason why OOK with RZ pulses is common in infrared systems. The RZ-OOK signaling requires $5\log_{10}(d)(dB)$ more optical power than NRZ-OOK to achieve the same BER, where presents the duty cycle d [18]. Figure 2.5 shows the waveforms of OOK/NRZ, and OOK/RZ with duty cycle d=0.5.



(a) OOK/NRZ Pulse (b) OOK/NRZ Pulse (d=0.5)

Figure 2.5: The waveforms of OOK/NRZ [10].

(ii) Pulse-Position Modulation (PPM)

PPM is an orthogonal baseband modulation technique well researched in optical communications, especially for power-limited intensity modulation with direct detection (IM/DD) communication systems. Even though, PPM offers higher average power efficiency, due to its poor bandwidth efficiency, it is more susceptible to multipath-induced ISI as compared to NRZ OOK. Figure 2.6 shows the four possible waveforms of 4-PPM that represent the two bits of information.

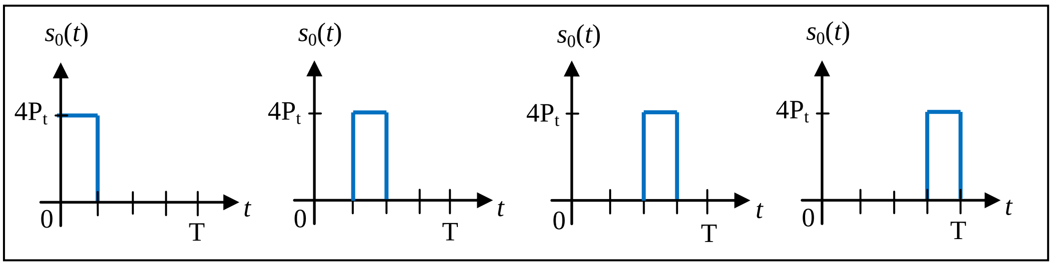


Figure 2.6: The four possible waveforms of 4-PPM that represent the two bits of information [10].

(iii) Pulse Amplitude Modulation (PAM)

The Pulse Amplitude modulation technique belonged to pulse amplitude level modulation scheme. L-level PAM (L-PAM) is one of L possible amplitude levels transmitted from the transmitter to represent a specific value. The time waveform of 4-PAM modulation can be found in Figure 2.7.

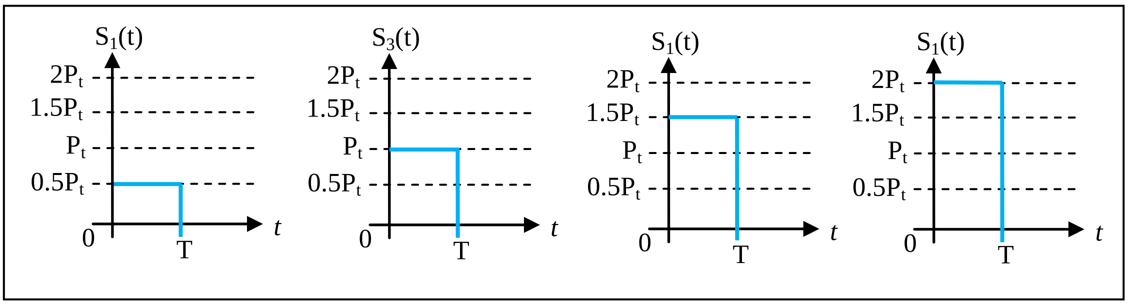


Figure 2.7: Time waveform of 4-PAM [5].

(iv) Differential Pulse-Position Modulation (DPPM)

Differential Pulse-position modulation (DPPM) is a simple modification of PPM that can achieve improved power or bandwidth efficiency in applications where low cost dictates the use of hard-decision detection, and multipath ISI is minimal. The 4-DPPM signal sets are shown in Figure 2.8.

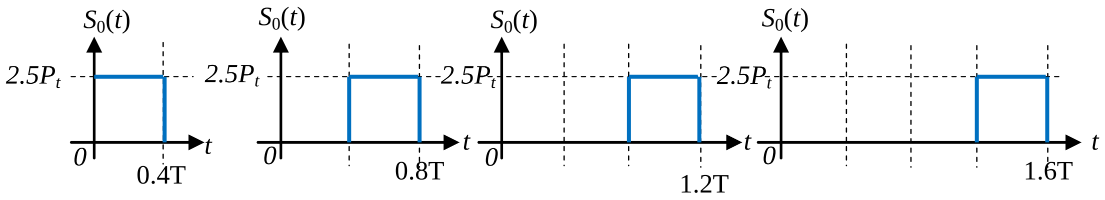


Figure 2.8: The 4-DPPM signal sets [19].

(v) Digital Pulse Interval Modulation (DPIM)

DPIM will displays a higher transmission capacity by eliminating all the unused time slots within each symbol, and requires no symbol synchronization since each symbol is initiated with a pulse. Based on Figure 2.9, data is encoded as a number of discrete time intervals, or slots, between adjacent pulses. The symbol length is variable and is determined by the information content of the symbol. In order to avoid symbols in which the time between adjacent pulses is zero, an additional guard slot may be added to each symbol immediately following the pulse.

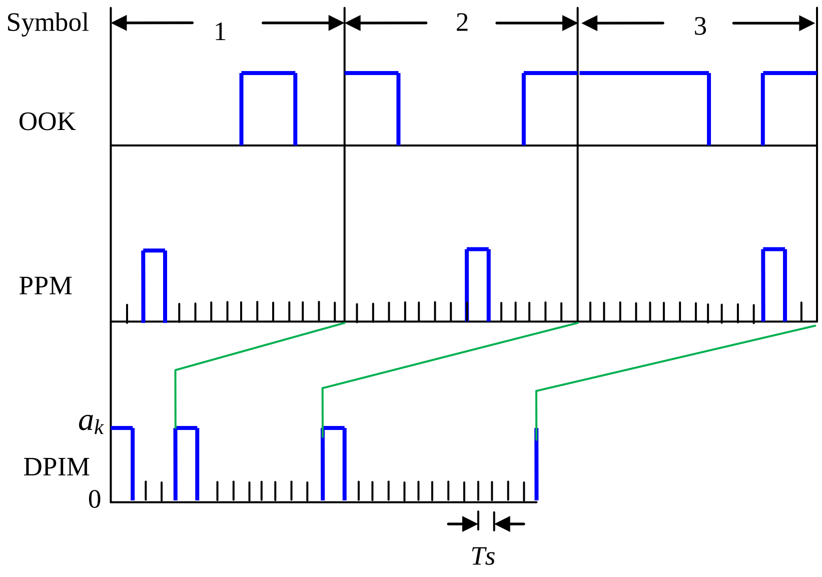
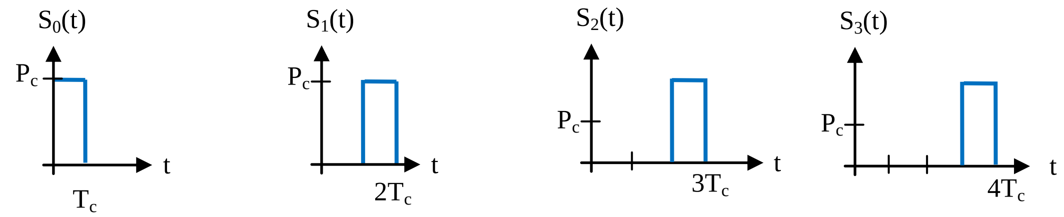


Figure 2.9: Symbol structure of OOK, PPM, and DPIM.

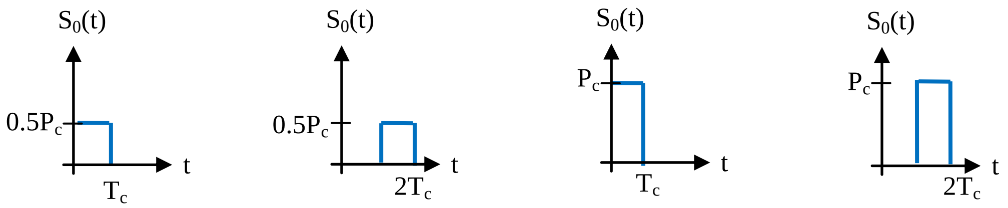
(vi) Differential Amplitude Pulse-Position Modulation

The pulse modulation schemes named Differential Amplitude Pulse-Position Modulation (DAPPM) is a combination of 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) [18].

The symbol length varies from $\{1, 2 \ldots L\}$ and the pulse amplitude is selected from $\{1, 2 \ldots A\}$, where A and L are integers. A set of DAPPM waveforms is shown in Figure 2.10. 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.



(a) DAPPM (L=4)



(b) DAPPM (A=2, L=2)

Figure 2.10: The symbol structure for M=2 bits/symbol.

2.3.2 Summaries of modulation schemes for wireless communication

Symbol mapping for OOK, PPM, DPPM, DAPPM (A=2, L=4), and DAPPM (A=4, L=2) for bit resolution of M=3 is shown in Table 2.4. While a comparison of 13 papers on modulation schemes for wireless communication is shown at Table 2.5, for the following modulation schemes such as on off keying (OOK), pulse position modulation (PPM), pulse amplitude modulation (PAM), difference pulse-position modulation (DPPM), Multiple pulse and position modulation (MPPM), pulse position amplitude modulation (PPAM), pulse amplitude and position modulation (PAPM), and differential amplitude pulse-position modulation (DAPPM).

Table 2.4: Symbol mapping of OOK, PPM, DPPM, DAPPM (A=2, L=4), and DAPPM (A=4, L=2) for bit resolution of M=3.

OOK	PPM (L=8)	DPPM (L=8)	DAPPM (A=2, L=4)	DAPPM (A=4, L=2)
000	10000000	1	1	1
001	01000000	01	01	01
010	00100000	001	001	2
011	00010000	0001	0001	02
100	00001000	00001	2	3
101	00000100	000001	02	03
110	00000010	0000001	002	4
111	00000001	00000001	0002	04

Table 2.5: Summaries of modulation schemes for wireless communication.

No.	Author & Year	Title	Types of modulation schemes								
			OOK	PPM	PAM	DPIM	DPPM	MPPM	PPAM	PAPM	DAPPM
1.	Garrido-Balsells et al., 2006	Variable weight MPPM technique for rate-adaptive optical wireless communications [20]						*			
2.	Ghassemlooy and Aldibbiat, 2006	Multilevel Digital Pulse Interval Modulation Scheme for Optical Wireless Communications [21]				*					
3.	Gulliver, 2006	Modulation and Coding Techniques for Infrared Wireless Local Area Networks [22]			*		*				*
4.	Ubolthip and Gulliver, 2006	Channel Capacity of Differential Amplitude Pulse-Position Modulation (DAPPM) over Indoor Optical Wireless Communications [12]		*			*				*
5.	Ghassemlooy et al., 2007	A synopsis of modulation techniques for wireless infrared communication [18]	*	*		*	*				*
6.	Yu et al., 2006	Adaptive pulse amplitude and position modulation for optical wireless channels [23]	*	*	*						
7.	Rajbhandari et al., 2007	The Performance of PPM using Neural Network and Symbol Decoding for Diffused Indoor Optical Wireless Links [24]		*							
8.	Yu et al., 2007	Tunable Pulse Amplitude and Position Modulation Technique for Reliable Optical Wireless Communication Channels [25]	*	*	*					*	
9.	Yu et al., 2008	Multiple pulse amplitude and position modulation for the optical wireless channel [26]		*	*			*		*	
10.	Meihong et al., 2009	The Evaluation of Modulation Techniques for Underwater Wireless Optical Communications [27]	*	*			*				
11.	Song et al., 2009	Performance of wireless optical communication systems Using DPSK modulation [28]	*								

Table 2.5: (continued).

No.	Author & Year	Title	Types of modulation schemes								
			OOK	PPM	PAM	DPIM	DPPM	MPPM	PPAM	PAPM	DAPPM
12.	Yu, 2010	Adaptive Modulation Schemes for Optical Wireless Communication Systems [5]	*	*	*					*	
13.	Jinni et al., 2011	The Performance Analysis of Dual-Amplitude Pulse Position Modulation for Optical Wireless Communication [14]	*	*		*					

Garrido-Balsells et al [20] had developed the rate-adaptive transmission scheme using block coding of variable Hamming weight for use in indoor optical wireless communications systems. This coding scheme is based on multiple pulse-position modulation, where codewords with different Hamming weight are allowed. The improvement in performance is corroborated by bit error rate computation using Monte Carlo simulation.

Ghassemlooy and Aldibbiat [21] had introduced a multilevel DPIM and results show that M-DPIM offer symbol length, improved transmission rate, capacity and bandwidth requirement compared with PPM and DPIM.

Gulliver [22] had introduced a combination of pulse-amplitude modulation (PAM) and differential pulse-position modulation (DPPM), named differential amplitude pulse-position modulation (DAPPM), in order to gain a better compromise between power and bandwidth efficiency. Since these modulation schemes over an ISI channel can be represented by a trellis diagram, their channel capacity is determined using a method for calculating the capacity of a Markov process channel.

According to Yu et al [5, 23, 25&26], an adaptive modulation technique was proposed. System adaptation under different channel impairments were analysed together with modulation schemes without adaptation. The results showed substantial improvements for channel impaired by ISI and ambient background noise. The fuzzy logic control method was applied to the adaptive modulation scheme. The control model used in the test case showed the capability of the fuzzy logic control process.

The ANFIS model developed was validated using different data set from the system, and provided excellent approximation to model the unknown control pattern though training.

Artificial Neural network (ANN) can be an attractive alternative for adaptive equalization especially while channel is nonlinear or non-stationary. Pulse position modulation (PPM) requires the least average optical power compared to other modulation schemes in line-of-sight links but suffer severely in diffused links. The performance of PPM in a diffused channel can be improved by using different equalization techniques. In this work equalization using ANN is proposed and studied. The ANN equalized PPM shows promising results and its performance is comparable to the traditional equalization techniques. The performance can further be enhanced by using 'soft' decision decoding and the simulation results show a 2 dB gain in signal-to-noise was reported by Rajbhandari et al [24].

Meihong et al [27] had evaluated the performance of different modulation schemes for underwater optical wireless communication with marine bio-optical model. It is demonstrated that the Pulse Position Modulation (PPM) is better suited for low powered undersea systems and the phase shift keying (PSK) yields the best performance in term of bandwidth and error performance with poor power efficiency.

Song et al., 2009 [28] had developed a coherent differential phase-shift keying (DPSK) transmission system to improve the receiver sensitivity for wireless optical communications. The simulation result shows that DPSK system has a higher sensitivity than OOK, and to a certain extent DPSK format can reduce the impairment from turbulence-induced scintillation for its threshold being signal intensity insensitive, and hence, DPSK format is very suitable for atmosphere channels and has a broad prospect in wireless optical communications.

Finally, Jinni et al [14] had introduced the work principle of dual-amplitude pulse position modulation, analyzed the transmission efficiency, channel capacity, power spectral density, and compared with the other modulation schemes as OOK, PPM, DPIM, DAPIM analyzed the bandwidth, information rate of unit and transmission capacity. Simulation show that dual-amplitude pulse position modulation has better bandwidth efficiency than DPIM and PPM, dual-amplitude pulse position modulation is more suitable transmission in the communication environment and the channel of encoded.

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