Pulse Position Based Modulation Techniques for Optical Communication

Puneet Chandra Srivastava¹ & R. K. Singh²

¹ Associate Professor, ECE Dept., Raj Kumar Goel Institute of Technology, Ghaziabad,
² Professor, ECE Dept., Kumaon Engg. College, Dwarahat (Almora), Uttarakhand, India
(E-mail : cs.puneet@gmail.com)

Abstract: Intensity modulation with direct modulation (IM/DD) favors low duty cycle modulation schemes such as pulse position modulation (PPM) and multiple PPM(MPPM). In this paper, the channel model over IM/DD is introduced. Then, a brief summary is given about some of the modulation techniques used in this area. Finally, some of the pulse position based coded modulation techniques are reviewed.

Keywords: Multiple pulse position modulation, Trellis coded modulation, Spectral efficiency.

1. INTRODUCTION
The most practical modulation technique in a wireless optical system is intensity modulation and direct detection (IM/DD). In this modulation technique, the information is modulated using the instantaneous power of the carrier and special detection devices such as photocurrent diode are used to convert the instantaneous power of the signal to an electrical current. The receiver has a photo diode that responds to the received signal by generating an electrical current that is proportional to the instantaneous power of the received signal.

2. CHANNEL MODEL
The channel model for optical communication systems depends on the intensity of the background noise. For the case of low background noise the received signal is modeled as a Poisson process with rate \( \lambda_r(t) = \lambda_s(t) + \lambda_n \) where \( \lambda_s(t) \) is proportional to the instantaneous optical power of the received signal, and \( \lambda_n \) is proportional to the instantaneous optical power of the background noise and \( \lambda_n \) is zero. If \( \lambda_n \) is very large and the receiver exploits a wideband photodetector or if the background light is very intense even after using narrowband optical fibers then the optical channel with intensity modulation (IM/DD) can be accurately modeled by a baseband additive white Gaussian noise (AWGN) model [1].

\[
Y(t) = x(t) + n(t)
\]  

Here \( y(t) \) is the instantaneous current of the receiving photocurrent, \( x(t) \) represents the instantaneous optical power of the transmitter and \( n(t) \) is the additive white gaussian noise with \( N_0/2 \) power spectral density.

The instantaneous transmitted power \( x(t) \) for this model, given by

\[
P_t = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} x(t)dt,
\]  

Where \( P_t \) is the average optical power at the transmitter. In this Equation the amplitude of \( x(t) \) is constrained while the energy of \( x(t) \) determines the performance of the system.

2.1. Modulation Schemes
PPM is one of the modulation scheme [2] that is common with IM/DD modulation systems. PPM is known for its good power efficiency. In the PPM format, there are \( L \) symbols each of duration \( T \). Each symbol is divided into \( L \) chips (with duration \( T_c = T/L \)). The PPM duty cycle is \( a_{PPM} = 1/L \). The Transmitter sends an optical pulse in only one of these chips at a time. The intensity of each pulse is \( L \). The spectral efficiency of PPM modulation is

\[
\eta_{PPM} = \log_2(L)/L \text{ bits}/\text{S}/\text{Hz}
\]  

Overlapping PPM (OPPM), suggested in [3] and used in [4], is another form of pulse modulation scheme. For this modulation, each \( b \) bits are mapped into one of
$L=2^b$ symbols and transmitted to the channel. The symbol interval of duration $T$ is partitioned into $n$ chips. Each chip has a duration $T/n$. The transmitter sends a rectangular optical pulse that spans $w$ chips beginning from any of the first $L=n-w+1$ chips to convey one of the $L$ symbols. The reason for using $w$ consecutive chips for every symbol is to increase the spectral efficiency. Here, information is conveyed by the positions of the chips and the symbols are allowed to overlap; this is why this modulation format is called overlapping PPM. The most important parameters of modulation scheme are $L$, $n$ and $w$ and only two of them completely define the modulation scheme. The three parameters are related by

$$L = n - w + 1$$  \hspace{1cm} (6)$$

The duty cycle of this modulation scheme is $\alpha = w/n$. For an information rate of $R_b$ bits/second, the bandwidth requirement of the uncoded modulation is $n/(wT)$, where $T = \log_2 (L/R_b)$. So, the bandwidth requirement of the noncoded OPPM compared with the bandwidth of the on-off keying (OOK) modulation scheme could approximated by [5].

$$BW_{OPPM} / R_b = \frac{n/w}{\log_2(n-w+1)}$$  \hspace{1cm} (7)$$

Which result in a spectral efficiency of

$$\eta_{OPPM} = \frac{\log_2(n-w+1)}{n/w} \text{ bit/s/Hz}.$$  \hspace{1cm} (8)$$

2.2. Coded Modulation Schemes

To improve the power and spectral efficiencies of infrared links, trellis coded modulation scheme [6] were used. Lee and Khan [7] introduced the use of trellis coded modulation (TCM) [6] with PPM. By using 8-TCM-PPM, a range of 7.0-8.2 dB power efficiency was achieved with a spectral efficiency of 0.25 bit/Hz. Here the power efficiency is computed with respect to the power required by OOK modulation schemes to achieve the same bit error rate (BER) $10^{-6}$. In addition, 8.2-9.4 dB power efficiency was achieved by 16-TCM-PPM. The normalized spectral efficiency of 16-TCM-PPM is 0.19 bit/Hz. For better spectral efficiency TCM codes, Park [8] proposed the use of MPPM instead of PPM modulations. By using, 128-TCM-MPPM, high power efficiencies of 7-8.5 dB were achieved with spectral efficiency of 0.35 bit/Hz.

3. RESULT

In this paper, several types of pulse position-based modulation techniques: PPM, MPPM and OPPM have been compared. The Y-axis represents the power efficiency compared to the OOK power requirement for BER=$10^{-6}$. The x-axis represents the spectral efficiency in terms of bits/Hz. The figure shows that PPM modulation scheme is the most power efficient modulation scheme and that MPPM modulation outperforms PPM in the spectral efficiency. In addition to the uncoded modulation scheme, the figure shows the performance of 8-TCM-PPM, 16-TCM-PPM [6] and 128-TCM-MPPM [8].

References