Variable weight MPPM technique for rate-adaptive optical wireless communications

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A novel rate-adaptive transmission scheme using block coding of variable Hamming weight is presented 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.

Introduction: Wireless optical communications systems based on non-directed configurations [1], more suitable for indoor networking, can be affected by large dynamic variations of signal to noise ratio (SNR), leading to possible link failures. In this sense, rate-adaptive transmission schemes are preferred in order to make the communication suitable to the adverse channel conditions, depending on the available SNR, until a sufficiently low error probability can be attained [2]. The use of conventional pulse-position modulation (PPM) was proposed and specified in the Advanced Infrared standard (AIR) by the Infrared Data Association (IrDA), although on-off keying formats with variable silence periods insertion (OOK-GS) provide a better bit error rate (BER) performance [3, 4]. Recently, the multiple PPM (MPPM) technique has been used in wireless optical systems to reduce the average optical power transmitted [5, 6].

In this Letter, a novel rate-adaptive transmission scheme using block coding of variable Hamming weight is presented. This coding scheme is based on the MPPM technique [5], where codewords with different Hamming weight are allowed, including the all-zero one [7]. Additionally, the use of very simple decoding schemes based on maximum likelihood (ML) detection has been proposed as an alternative to the Viterbi algorithm adopted in previous work [3].

System model: Significant elements of the system model used in the analysis, shown in [3], are: first, the exponential decay channel model [1], corresponding to a favourable office environment, with a 50 MHz equivalent 3 dB bandwidth; secondly, a three-pole Bessel highpass filter with a 1 dB cutoff frequency of 500 kHz for fluorescent light interference suppression; and, last, a five-pole Bessel lowpass filter employed as a rough matched filter. The encoder and detection elements are the component parts depending on the modulation technique employed.

In previous papers, BER results have shown an excellent agreement with the peak to average optical power ratio (PAOPR), this being a key parameter in comparing the novel block coding method proposed here and other techniques such as OOK formats with memory (OOK-GS, OOK-GScc) or the standard HHH(1, 13) [4, 8]. In this sense, the increase in PAOPR regarding the NRZ signalling is defined as a more suitable parameter [3, 4]:

$$\Delta_{PAOPR}(\text{dB}) = 10 \log_{10}\left(\frac{1}{\text{prob}_{a_k = 1}}\right) - 3$$  \hspace{1cm} (1)

where $a_k$ is the transmitted symbol.

Multiple PPM of variable Hamming weight: The coding process consists of a translation procedure between the input data alphabet $C_{x}$, with k-bit codewords, and the coded alphabet $\tilde{C}_x$, a subset of $C_{x}$ comprising $2^k$ possible n-bit codewords. The proper choice of $\tilde{C}_x$ is not only based on the MPPM strategy but also on the use of codewords with different Hamming weight, leading to a block coding with a variable amount of pulses. In this sense, if $C_{x,w}$ is the block code consisting of all possible codewords of length $n$ with a Hamming weight of $w$, the code $\tilde{C}_x$ is defined using the following codes $C_{x,w}$:

$$\tilde{C}_x = \left( \bigcup_{w=0}^{n-1} C_{x,w} \right) \cup \tilde{C}_{x,n}$$  \hspace{1cm} (2)

where $\tilde{C}_{x,n}$ denotes the codewords subset of $C_{x,n}$ used in $\tilde{C}_x$. Thus, the coding table associated with $\tilde{C}_x$ consists of all the possible codewords with Hamming weight $i$, $0 \leq i \leq (x-1)$, together with a number of $x$-weighted codewords given by (3), where $(\cdot)^{\overline{n}}$ is the number of codewords of $C_{x,i}$:

$$\binom{n}{i} = 2^n - \sum_{i=0}^{n-1} \binom{n}{i}$$  \hspace{1cm} (3)

The main goal of the block coding scheme proposed here is to maximise the PAOPR parameter, minimising the presence of pulses at the optical signal. In this sense, this coding method is optimised, reducing the probability of pulse presence in the transmitted codewords. Either classical MPPM techniques or recently proposed MPPM formats as the $n'$-PPM scheme define $C_{x,n'}$ by keeping the Hamming weight $w$ at a constant value for every codeword used [5, 6]. Thus, the probability of presence of pulse can be easily obtained from $p(a_k = 1) = w/n$ leading to an increment in PAOPR of $\Delta_{PAOPR}(\text{dB}) = 10 \log_{10}(w/n)$. In contrast, the coding method proposed here provides a probability of the presence of a pulse of

$$p(a_k = 1) = \frac{2^k - 1}{2^n} \frac{1}{n} - \frac{1}{2^n} \sum_{i=1}^{n-1} \binom{n}{i} \frac{x - i}{n}$$  \hspace{1cm} (4)

assuming a code rate of $k/n$ and codewords with a maximum weight of $x$.

Fig. 1 shows the increase in PAOPR against data block length $k$ for values of code rate between 1/8 and 4/5. The increments in PAOPR obtained in [3, 4] are references for the analysis of this new coding technique. In this sense, OOK-GS, OOK-GScc and HHH(1, 13) provide increments of 4.7, 9 and 2.8 dB for code rates of 1/2, 1/4 and 2/3, respectively. As shown in Fig. 1, these increments are clearly improved by this block coding method. Moreover, taking into account the prevalent use of MPPM modulation with Hamming weight of 2, i.e. $C_{x,2}$, the lower increase in PAOPR provided by this code is also shown in Fig. 1. At the same time, memory has also been considered in the encoding process, modifying the block coding scheme by using some codewords to indicate data block repetition. The increment in PAOPR for block codes with memory is also shown in Fig. 1, shown as $\times'$, concluding that the improvement in performance achieved by using memory is negligible as $k$ is increased.

Numerical results: The PAOPR results are shown in Fig. 2, where BERs for different code rates and modulation techniques are presented at 50 Mbit/s, using the system model shown in [3] and Monte Carlo simulation. The BERs obtained in [3, 4] for OOK-GS, OOK-GScc and the HHH(1, 13) modulation schemes are redrawn in this Figure. Note that the hybrid HHH(1, 13) technique is the modified version of the HHH(1, 13) coding scheme, proposed in the VFlr standard, with additional silences to perform code rates of 1/2, 1/4 and 1/8. The block codes simulated here have no memory and, hence, the decoding method is based on the ML detection procedure. The selected codes have been considered representative in relation to the PAOPR results of Fig. 1. BER results achieved by the block coding schemes are considerably better than those obtained by OOK formats with memory. This performance is even better if compared to the HHH(1, 13) code, either the VFlr standard coding method or the hybrid HHH(1, 13) with silence periods presented in [3, 4]. For instance, we can achieve a cut in average optical power requirements above 1.5 and 1 optical dB if compared with the OOK-GScc format at a bit rate of $10^{-6}$ and $RR = 8$ and $RR = 4$ by using block codes with

![Fig. 1 Increment in PAOPR against data block length k for different code rates](image-url)
rates of 5/40 and 4/16, respectively; and a cut in average optical power requirements above 1 optical dB is achieved using a code with rate of 6/12, if compared with the hybrid HHH(1, 13) when $RR = 2$.

Fig. 2 BER comparison for block coding scheme with different code rates together with OOK formats using variable silence periods at bit rate of 50 Mbit/s

**Conclusions:** A novel rate-adaptive transmission scheme using block coding of variable Hamming weight is presented for use in indoor optical wireless communications systems. This coding scheme is based on the MPPM technique, where codewords with different Hamming weight are allowed. The superiority of this block coding method has been corroborated by BER computation using Monte Carlo simulation, obtaining a higher improvement in performance as the length of the data block is increased. Additionally, the use of very simple decoding schemes based on ML detection has been proposed as an alternative to the procedure based on the Viterbi algorithm adopted in previous work.

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**References**