Evaluation of Power Efficiency of Hybrid Modulation Techniques

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Abstract— **We investigate the power efficiency of different hybrid modulation techniques constrained to a specific spectral efficiency. Furthermore, the BER performance is compared with that of traditional schemes. It is found that, *L*DPSK-based hybrid techniques achieve power efficiencies near that of *L*QAM-based hybrid ones.**

Keywords— **Hybrid modulation, power efficiency, spectral efficiency.**

1. Introduction

Hybrid modulation techniques achieve the design goals for modern optical communication systems, namely, high power and spectral efficiencies [1]. In hybrid modulation techniques, multipulse position modulation (MPPM) schemes provide the high power efficiency. In addition, the spectral efficiency is achieved from different phased modulation schemes, such as *L*-ary phase-shift keying (*L*PSK) [2, 3], *L*-ary quadrature-amplitude modulation (*L*QAM) [4], and direct-detection *L*-ary differential phase-shift Keying (DD-*L*DPSK) [5]. The power efficiency of *L*QAM-MPPM techniques is compared with that of traditional *L*QAM techniques in [6]. The investigation of power efficiency of other hybrid modulation schemes (DD-*L*DPSK- and *L*PSK-MPPM) has not been discussed yet.

In this paper, we provide an inspected discussion for the power efficiency of hybrid modulation techniques: *L*PSK-MPPM, *L*QAM-MPPM, and DD-*L*DPSK-MPPM. In addition, the BER performance of the hybrid schemes is compared with that of traditional ones. An improved power efficiency is achieved by the hybrid modulation schemes over traditional phase modulation techniques. Moreover, a comparable power efficiencies for *L*DPSK-MPPM with *L*QAM-MPPM modulation schemes are noticed.

2. Preliminaries

The performance of hybrid-modulation based systems can be measured by the bit-error rate (BER) [2–5], the spectral efficiency (η), and the power efficiency (γ) [1, 6].

2.1. Spectral Efficiency

Th utilization of the system bandwidth is measured by the spectral efficiency η that is expressed in [bit/s/Hz] as: $\eta = R_b/B_\omega$, where R_b is the transmission data-rate and B_ω is the system bandwidth [1]. The spectral efficiency for different hybrid-modulation techniques (*L*PSK-MPPM, *L*QAM-MPPM, and DD-*L*DPSK-MPPM) can expressed as:

$$\eta = \frac{n \log_2 L + \log_2 \binom{M}{n}}{M}, \qquad \text{bit/s/Hz} \qquad (1)$$

where L is the number of constellation symbols, M and n are the number of total time slots and occupied time-slots of the MPPM frame, respectively.

2.2. Power Efficiency

The power efficiency of a modulation scheme is a measure for the efficient use of the bit energy to achieve a given BER. The asymptotic power efficiency (γ) is expressed as: $\gamma = d_{min}^2/4E_b$, where d_{min} is the minimum Euclidean distance between two symbols in the constellation space and E_b is the average energy per bit [1]. The asymptotic power efficiency for different hybrid-modulation schemes can be obtained as:

$$\gamma = \frac{n \log_2 L + \log_2 \binom{M}{n}}{n} \times \begin{cases} \min\left\{\frac{1}{2}, \sin^2\left(\frac{\pi}{L}\right)\right\}; & *, \\ \frac{3}{2(\kappa_l - 1)}; & **, \end{cases} \qquad (2)$$

where * "denotes for both *L*PSK-MPPM and DD-*L*DPSK-MPPM modulation schemes", ** "denotes for *L*QAM-MPPM", and κ_l is a factor that depends on the constellation level L for *L*QAM-MPPM scheme [6].

By following the same procedures as in [6], we obtain the maximum achieved power efficiency (Γ) for both *L*PSK-MPPM and DD-*L*DPSK-MPPM modulation schemes. It is expressed under a constraint on a specific spectral efficiency (S_e) as:

$$\Gamma = \max_{\eta \geq S_e} \left\{ \left[\log_2 L + \frac{M}{n} h\left(\frac{n}{M}\right) \right] \min\left\{0.5,\ \sin^2\left(\frac{\pi}{L}\right)\right\} \right\}, \qquad (3)$$

where $h(x) = -x\log_2(x) - (1-x)\log_2(1-x)$. The maximum achieved power efficiency of the *L*QAM-MPPM is expressed in [6].

3. Discussions

Here we numerically study the performance of different hybrid modulation techniques to measure their power and spectral efficiencies in comparison with that of traditional phase-modulation techniques.

First, Fig. 1 shows the BERs versus the energy per bit divided by twice the noise power spectral density (E_b/N_0) for different hybrid and traditional phase-modulation techniques under the same transmission data rate. It can be seen that there is an improvement in the BER performance of the hybrid techniques over traditional ones due to the introduction of MPPM technique. The reason behind this improvement is the increase in the peak power per slot (i.e., power efficiency enhancement) of traditional phase-modulation techniques by combining them with MPPM technique. Furthermore, it should be noticed that, by combining the traditional phase-modulation techniques with MPPM technique (i.e., hybrid techniques), an E_b penalty of ≈ 1.1 dB at BER $= 10^{-3}$ for the traditional differential binary phase shift keying (DBPSK) over traditional binary phase shift keying (BPSK) disappeared. Also an E_b penalty of ≈ 2.4 dB at BER $= 10^{-3}$ for the traditional differential quadrature phase shift keying (DQPSK) over traditional quadrature phase shift keying (QPSK) disappeared. This is because the dominant effect on the BER performance of the hybrid modulation techniques is the MPPM BER as depicted in [3–5].

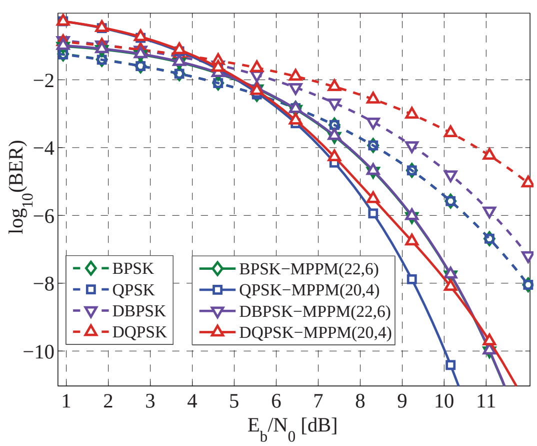

Fig. 1: Bit-error rate versus E_b/N_0 for different hybrid (solid) and traditional (dashed) modulation techniques under the same transmission data rate.

Fig. 2 shows a comparison for the constrained power efficiencies of different hybrid and traditional techniques versus spectral efficiency constraint. It is clear from the figure that the most power efficient technique is LQAM-MPPM as depicted in [6]. Furthermore, by using LDPSK-MPPM or LPSK-MPPM, we can get nearly the same power efficiency of LQAM-MPPM for $Se \leq 3.2$ bit/s/Hz. LDPSK-MPPM is better to be used for $S_e \leq 3.2$ bit/s/Hz, as it is based on direct-detection schemes. However, for $S_e > 3.2$ bit/s/Hz, it is better to use LQAM-MPPM as its power efficiency is greatly better than that of LDPSK-MPPM in this region.

From Figs. 1 and 2, although LDPSK-MPPM is based on direct-detection receivers, it could achieve results almost similar to that of LQAM-MPPM.

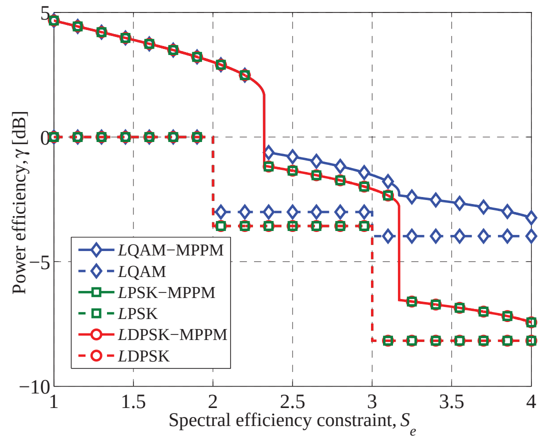

Fig. 2: Maximum power efficiencies of different hybrid (solid curves) and traditional (dashed curves) modulation techniques versus spectral efficiency constraints.

4. Conclusion

Our results reveal that the BER performance of hybrid techniques has a great improvement over traditional ones. Moreover, we can greatly decrease the energy per bit penalty of direct-detection based techniques over coherent based techniques by combining MPPM with traditional techniques. Finally, for spectral efficiency ≤ 3.2 bit/s/Hz, the LDPSK-MPPM is preferred over LQAM-MPPM.

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