

PAPR-Constrained Throughput of OTFDM with DFT-s-OFDM as a Baseline

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Abstract—OTFDM’s post-DFT processing widens the occupied bandwidth and shapes the spectrum to lower PAPR. Motivated by upper-mid-band operation for 6G, we compare OTFDM with DFT-s-OFDM using a spectral-efficiency-centric evaluation. We derive empirical PAPR distributions per waveform and MCS, map PAPR to PA back-off to obtain effective SNR, and apply adaptive MCS constrained by a target BLER using per-MCS BLER curves. Spectral efficiency is computed as TBS divided by TTI times the occupied bandwidth, so any shaping-induced expansion is fully counted. Although OTFDM lowers PAPR, its worse BLER largely cancels the back-off gain. As a result, both waveforms often choose the same MCS, and after accounting for bandwidth growth OTFDM offers no clear spectral-efficiency gain. Competitiveness would require less bandwidth expansion from shaping and better BLER without sacrificing the PAPR advantage.

Keywords—OTFDM, PAPR

I. INTRODUCTION

Next-generation cellular systems must meet simultaneous demands for power efficiency, coverage, and spectral efficiency (SE). A major transmitter constraint is the peak-to-average power ratio (PAPR) of multicarrier waveforms, since high PAPR forces power amplifier (PA) back-off and lowers the receiver’s effective SNR, which pushes link adaptation to lower-rate MCS. For a nominal SNR and a PAPR realization p in dB, the effective SNR under a PAPR limit is

$$\text{SNR}_{\text{eff}} = \text{SNR}_{\text{nom}} + (\text{PAPR}_{\text{limit}} - p). \quad (1)$$

Reducing PAPR raises SNR_{eff} and can make higher-rate modulation and coding scheme (MCS) feasible at the same nominal SNR, especially in low-to-moderate SNR conditions. Reducing PAPR becomes increasingly important in upper-mid bands envisioned for 6G, where larger path loss, poorer penetration, and tighter user equipment (UE) power budgets make PA back-off a significant coverage penalty. Low-PAPR uplink waveforms such as Discrete Fourier Transform-spread-Orthogonal Frequency Division Multiplexing (DFT-s-OFDM) are therefore attractive, and downlink adjacent channel leakage (ACLR) and spectral-regrowth limits also link back-off to PAPR and out-of-band (OOB) emissions.

Orthogonal Time-Frequency Division Multiplexing (OTFDM) has been proposed as a way to lower PAPR through spectrum shaping [1][2][3]. OTFDM widens the occupied band and shapes the spectrum to reduce PAPR. The added subcarriers increase bandwidth and can reduce SE unless larger transport blocks or consistently higher MCS offset the cost. Shaping may also perturbs strict symbol orthogonality

which degrades BLER and introduce additional implementation complexity, so OTFDM must deliver clear PAPR relief with minimal bandwidth and error-rate costs.

In this paper, we first obtain empirical PAPR distributions of OTFDM and DFT-s-OFDM and incorporate those statistics into the throughput evaluation. Specifically we translate PAPR into required PA back-off, convert nominal SNR to effective SNR, model adaptive MCS with a target BLER, and compare the throughput of the two waveforms.

II. OTFDM: POTENTIAL BENEFITS AND TRADE-OFFS

A. OTFDM

One of the most distinctive features of an OTFDM system is that the reference signal for channel estimation and the data symbols reside within a single OTFDM symbol. The reference block is briefly wrapped by a cyclic prefix and cyclic suffix to protect it from delay spread, and an additional reference signal (ARS) may be placed near the symbol end to refine the estimate under fast channel variation.

Another defining feature is spectrum shaping, employed to decrease PAPR and ease PA back-off requirements. After symbol formation, DFT converts the signal to the frequency domain. Bandwidth is then expanded by copying low-frequency components to higher frequencies and vice versa, followed by spectrum shaping. This shaping smooths the time-domain waveform, reduces the PAPR, and helps confine the impulse response to mitigate inter-symbol interference (ISI). The shaped spectrum undergoes subcarrier mapping, inverse FFT, and CP insertion, identical to conventional cyclic prefix orthogonal frequency division multiplexing (CP-OFDM). Because the time-domain data are first transformed by a DFT and then mapped to subcarriers, the overall flow resembles DFT-s-OFDM, with the added bandwidth-expansion and shaping stages that deliver the PAPR advantage.

B. Spectral-Efficiency-Centric Evaluation

We evaluate waveforms by normalizing throughput to the occupied bandwidth, converting measured PAPR into PA back-off to obtain effective SNR, and applying adaptive MCS that requires the target BLER to be met, so the analysis stays focused on SE as the primary objective. We adopt a SE-centric evaluation methodology as

$$\text{SE}_{m,\gamma} = \frac{\text{TBSize}_m}{\text{TTI} \times \text{BW}_\gamma}, \quad (2)$$

where TBSize_m is the TB size for an MCS m and BW_γ is the bandwidth with any extra subcarriers used in shaping governed by γ . This reflects practical scheduling behavior and keeps the analysis focused on performance within both power and bandwidth budgets. Within this framework,

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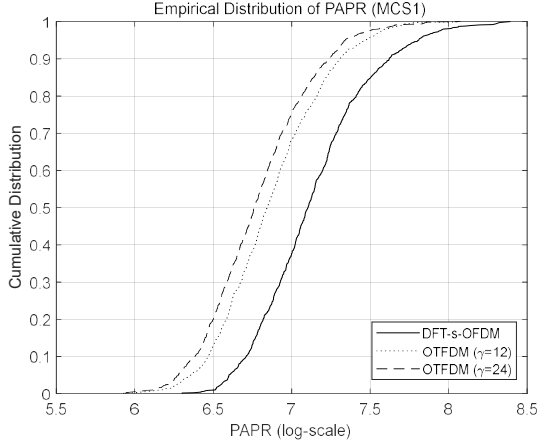


Fig. 2. Empirical CDFs of PAPRs

waveform comparisons such as DFT-s-OFDM versus OTFDM can be made fairly across SNR ranges and deployment conditions.

III. SIMULATIONS

To compare each waveform's SE under PAPR constraints, we first simulated empirical PAPR and BLER, then applied adaptive MCS to compute SE. Fig. 1 shows the empirical CDFs of the waveforms, plotted for MCS1 only. For OTFDM, two settings are included, $\gamma = 12$ and $\gamma = 24$. Here, γ denotes the number of additional subcarriers used in square-root-raised-cosine (SQRC) filter to shape one side of the spectrum. The modulation order and code rate used by the adaptive MCS scheme is defined in Table 1. As shown in the figure, OTFDM's PAPR is about 0.3~0.4 dB lower than that of DFT-s-OFDM, and it decreases further as γ increases.

TABLE I. MCS TABLE

MCS	Modulation Order	Code Rate
1	2	0.19
4	4	0.48
7	6	0.78

Fig. 2 illustrates the BLER performance of the waveforms. In the simulation, TDL-E channel model with 22 dB of K-factor is employed and the delay spread is set to 10 ns. The

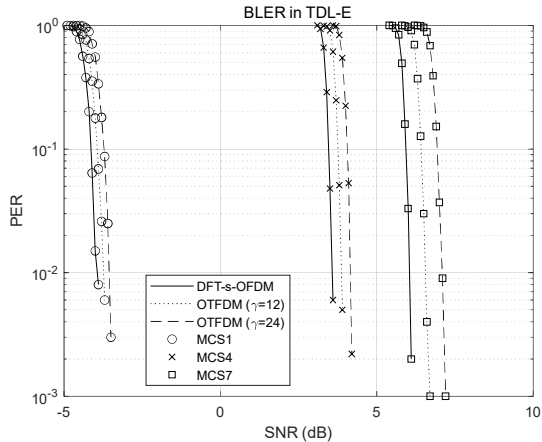


Fig. 1. BLER Performance of Waveforms

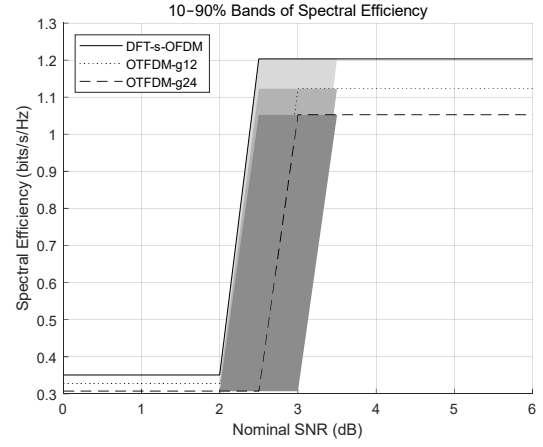


Fig. 3. Spectral Efficiencies of Waveforms

signal bandwidth of DFT-s-OFDM is 20.16 MHz which is the same with that of OTFDM with γ set to zero. The BLER results show DFT-s-OFDM performing better than OTFDM, and they also show that increasing γ in OTFDM leads to poorer BLER, likely due to the spectrum-shaping filter, which may perturb symbol orthogonality.

Fig. 3 shows SE derived from per-MCS PAPR distributions and BLER curves. Lines denote the median and the shaded band spans the 10~90% of the SE distribution. A wider band implies higher sensitivity to PAPR fluctuations. OTFDM gains about 0.2 dB in effective SNR from lower PAPR, but its BLER curves are worse than DFT-s-OFDM by roughly 0.2 dB at low MCS and about 0.3~0.4 dB at high MCS, leaving only 0.1~0.2 dB margin, which is typically insufficient to shift MCS levels. Because increasing γ introduces extra subcarriers and expands the occupied bandwidth, OTFDM would need consistently higher MCSs to exceed DFT-s-OFDM in bps/Hz, which the small effective SNR margin does not provide. Consequently, under the SE metric, DFT-s-OFDM remains more favorable despite OTFDM's PAPR advantage.

IV. CONCLUSION

In this paper, we compared OTFDM against DFT-s-OFDM in terms of SE while explicitly accounting for PAPR and BLER. Although OTFDM exhibits better PAPR characteristics than DFT-s-OFDM—suggesting potential gains in goodput under power-limited operation—our simulations show that this advantage is offset by two effects as the OTFDM spectrum-shaping parameter γ increases: (i) BLER degrades relative to DFT-s-OFDM, and (ii) OTFDM requires additional subcarriers, which reduces SE when normalized by occupied bandwidth. Consequently, OTFDM's SE curve does not improve noticeably over DFT-s-OFDM once PAPR and bandwidth expansion are both taken into account.

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