Pilot-Free Polar-Coded Communications for Short-Packet Transmission

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Abstract—This paper proposes a pilot-free polar-coded communication framework to eliminate pilot overhead in short-packet transmission. The proposed method uses a code-splitting architecture that partitions information into two polar-coded segments: a QPSK-modulated portion enables blind channel estimation, while a higher-order QAM portion optimizes the overall code rate. Channel state information is jointly estimated during decoding using successive cancellation and constraints imposed by polar code frozen bits. Simulation results show that the proposed pilot-free scheme achieve up to 1 dB coding gain over pilot-aided transmission in block-fading channels.

Keywords—polar codes, pilot-free communication, short-packet transmission, blind channel estimation, URLLC.

Ultra-reliable and low-latency communication (URLLC) for emerging applications such as autonomous driving and robot control requires highly efficient short-packet transmission [1]. Conventional pilot-assisted transmission (PAT) allocates a fraction of each packet to pilot symbols for channel estimation, resulting in a significant spectral efficiency loss when packet sizes are small [2]. This overhead presents a fundamental bottleneck in latency-critical control systems where every transmitted bit must count, motivating the search for pilot-free communication schemes.

We propose a rate-matching, pilot-free polar-coded transmission framework using a code-splitting architecture. Our key innovation separates transmission into two segments: i) a QPSK-modulated portion that leverages the constant-amplitude property and algebraic structure of polar codes to enable blind channel estimation, and ii) a higher-order QAM portion that delivers high spectral efficiency. We partition information bits into sub-messages $\mathbf{m}_0$ and $\mathbf{m}_1$, processed independently through polar codes $\boldsymbol{C}_0$ and $\boldsymbol{C}_1$, with the constraint $\{N_1\text{-}2, N_1\text{-}1\} \subseteq \boldsymbol{F}_1$ for QPSK segment. The notation N_i is a mother code length of polar code $\boldsymbol{C}_i$ and $\boldsymbol{F}_i$ is frozen index set of $\boldsymbol{C}_i$.

Our decoding process consists of blind decoding for the QPSK segment and coherent decoding for the QAM segment. We exploit the constant-amplitude of QPSK for channel magnitude estimation, while employing the Viterbi and Viterbi phase estimation algorithm for fractional phase offset estimation [3], followed by integer phase ambiguity resolution using polar code structure with frozen index set constraints [4]. The successfully decoded QPSK symbols serve as implicit pilots for enhanced channel estimation, enabling coherent detection of QSM symbols without dedicated pilot overhead.

Our performance evaluation over block-fading channels with AWGN demonstrates that the proposed scheme consistently achieves approximately 1 dB coding gain across QPSK, 16-QAM, and 64-QAM modulations compared to optimized pilot-aided benchmarks. The gain stems from the dual functionality of our QPSK segment, which simultaneously transmits data and enables channel estimation, while the QAM portion benefits from reduced code rates.

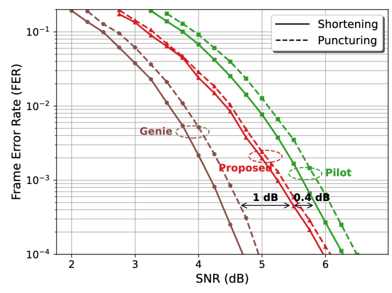

Fig. 1. Simulation for QPSK, 120 channel uses, 120 information bits transmission.

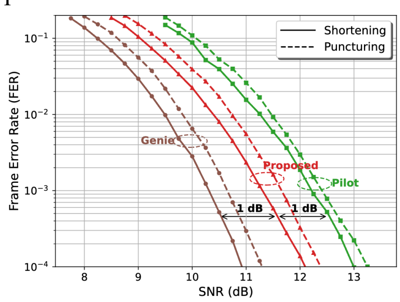

Fig. 2. Simulation for 16-QAM, 60 channel uses, 120 information bits transmission.

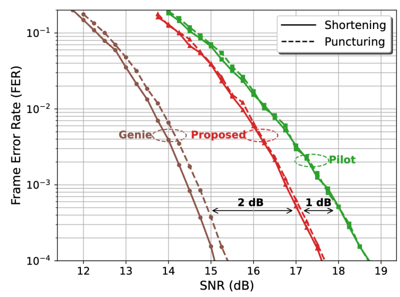

Fig. 3. Simulation for 64-QAM, 40 channel uses, 120 information bits transmission.

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