that achieves the optimum could have an exponential time complexity. Thus, to reduce the complexity, we propose a suboptimal algorithm that separates the resource allocation into two steps: subcarrier allocation and power allocation. This suboptimal approach has a linear complexity in the number of users and subcarriers, and achieves optimality gaps of less than 5%. With the suboptimal approach, the achieved throughput in the rate-distortion limit is more than twice of the throughput achieved under the threshold-based quantization approach, when the feedback rate is low.

**Notations:** Bold letters denote vectors and matrices, and denotes the transpose of \( \mathbf{B} \). Also, \( E[\cdot] \) denotes the statistical expectation, and in particular \( E_X[\cdot] \) denotes that with respect to \( X \).

### A. Overview

We continue the introduction with a brief review of related work in Subsection I-B. Section II outlines the downlink channel model, and derives the RDF for the downlink CSI. Section III presents the expression of outage throughput, formulates the outage throughput maximization problem with quantized CSI, and proposes the resource allocation algorithm that achieves a suboptimal solution. Numerical results are given in Section IV to illustrate the performance of the outage throughput using the proposed algorithm. Conclusions are drawn in Section V.

### B. Related Work

In practice, it is difficult for the transmitter to obtain perfect CSI due to feedback delay (for both FDD and time division duplexing (TDD)), channel estimation error (for both FDD and TDD), and quantization error (for FDD) [13]. The impact of imperfect CSI for OFDM systems has been an active research area in recent years. The effect of feedback delay was addressed in [14]. The author considered a minimum square error channel prediction scheme to overcome the detrimental effect of feedback delay, and proposed resource allocation algorithms to maximize the downlink throughput. The works in [15]-[17] focused on the imperfect CSI resulting from channel estimation error, and proposed power loading algorithms for the single user OFDM system. Resource allocation with quantized CSI was investigated in [3]-[5]. The authors in [3] assumed uniform power distribution over subcarriers and derived closed-form expressions for the downlink throughput. In [4] and [5], the design parameters related to imperfect CSI, such as quantization levels and the feedback period, were optimized to reduce the feedback overhead with a guaranteed system performance for OFDMA systems. However, most previous research works, such as [3]-[5], were based on suboptimal quantization method. Recently, the authors in [18] proposed OFDMA throughput maximization algorithm under the assumption that quantization for CSI feedback is optimized in terms of the rate-distortion theory point of view. In [18], the feedback of CSI is assumed to be the Gaussian channel gain \( H \). However, in resource allocation for OFDMA systems, we only need the real value of value of \( H \). Thus, it could be more efficient to feed back...