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Improving Efficiency in NOMA Schemes Having Inter-User Interference Using Mechanism Design

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ABSTRACT

Modern wireless systems utilize non-orthogonal multiple access to increase their rate capacities; however, the efficiency of the individual utility defined in bits per Joule has yet to be considered. Multiple variations of non-orthogonal multiple access have the interference of the signa l-to-interference-plus-noise ratio as a function of the received power from multiple other users due to code implementations that are non-orthogonal or non-ideal cancellation in successive-interferenc e-cancellation methods. Game theoretic concepts are used to improve user bits-per-Joule performance. Previous solutions increment transmit power and are not based on closed form systematic methods. The mechanism design presented here led to a non-cooperative Nash equilibrium solution based on detrimental inter-user effects. The resulting algorithm not only converged but also yielded a Nash bargaining and Pereto optimal solution that Pareto dominated the non-cooperative solution sans mechanism. Operating power may decrease 20 dB–45 dB, while utility gains may increase between 28 dB–46 dB.

KEYWORDS

NOMA, Code Spreading, Power Control, Game Theory, Nash Equilibrium, Pareto Optimal

INTRODUCTION

The ubiquity of wireless communications to allow constant connectivity is the ultimate goal within the field of wireless communications. Beginning with broadcast only systems, evolving to push-to-talk, cellular data systems, internet of things (IoT), and vehicular to everything communication (V2X), these systems have steadily increased information transmission rates and reduced transmission powers. Starting with cellular systems, the need for multiple access techniques to permit multiple user equipment to communicate with a base station has resulted in numerous methodologies that are broken up into two groups: orthogonal-multiple-access schemes and non-orthogonal multiple access (NOMA) techniques. Time-division multiple access and frequency division multiple access/ orthogonal frequency–division multiple access techniques permit multiple user equipment to access a single base station by allocation of specific timeslots or frequency bands, respectively, thereby classifying them as orthogonal-multiple-access techniques. These are the key techniques in 1G, 2G, and 4G/5G/Wi-Fi/satellite systems (De Gaudenzi et al., 2022; Gopal & BenAmmar, 2018; R. Liu et al., 2024). Methods such as code-division multiple access, which was the foundation of 3G/3.5G

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systems, work on the concept that users are assigned long codes that have very small correlation values to differentiate them. This places it under the classification of NOMA when implemented with sparse user codes (Dai et al., 2018). Modern NOMA techniques utilize the spread spectrum methodology and, in conjunction with power control and successive interference cancellation (SIC), are able to increase the sum rate of the system. Much of the research done in NOMA performance focuses on given arbitrary target signal-to-interference-plus-noise ratio (SINR) values to achieve the information theoretic sum of transmission rates (Benjebbour et al., 2015; Saetan & Thipchaksurat, 2020; Saito et al., 2013).

RELATED WORK

Since NOMA is used in both the uplink and the downlink, there are many studies focused on the downlink. These include analysis of power allocation for specific two-user cases (Arora & Jaiswal, 2025) or focus on rate splitting multiple access (Chen et al., 2025). However, one concept examined in the downlink, also valid for the uplink scenario, is the lack of perfect channel-state information, which has a non-negligible effect on system performance (Madya Saputri et al., 2025), and is more realistic than considered perfect channel-state information, as in Z. Wang et al. (2025). Furthermore, the net rates considered are all the information theoretic values (Arora & Jaiswal, 2025; Chen et al., 2025; Luo et al., 2025; Madya Saputri et al., 2025; Ou et al., 2025; Z. Wang et al., 2025; Yin et al., 2025; Yonaga et al., 2025; H. Yue et al., 2025) and not the actual cumulative distribution functions for the channels, which has a non-concave shape and is strictly quasi-concave. Other studies have considered how to optimize power relative to coding efficiency (Ou et al., 2025), while this study considered utility in terms of bits/Joule efficiency.

One of the idealistic considerations of SIC is that the symbols for a particular user are completely removed from the received signal composed of the net sum of the signals from all users. Imperfections (in channel-state information, synchronization, etc.) cause partial energy from the “canceled” terminals to propagate and affect the demodulation of further terminals (Miridakis & Tsiftsis, 2017; X. Yue et al., 2020; Zhang & Haenggi, 2014). This study proposed an algorithm that takes into account this “leakage” and optimizes the individual terminal energy efficiency in terms of bits (transmitted) per (radiated) Joule (BPJ) of energy and is defined as the utility that each terminal would like to optimize independently. In Fang et al. (2016), the analysis was done using a resource scheduling technique on the downlink where power domain NOMA is used and differs from the uplink case being considered here. This optimization is achieved through the use of a taxing mechanism as a tool to improve a mobile station’s performance of its utility. Though mechanism designs have been applied previously, no closed form systematic solution for improving the energy efficiency has been proposed that was not based on an iterative change with an arbitrary incremental value (Kelly, 1997; J. Lee, 2002; J. W. Lee et al., 2002; C. Saraydar et al., 2002; Yaiche et al., 2000). Previous work utilizing taxation for achieving Pareto improvement was based on incremental changes of the tax as well as the use of certain quasi-linear functions based on arbitrary price allocations (C. Saraydar et al., 2002; Saraydar et al., 2001b). The method introduced here yields a final operating value that results in a Pareto improved operating point (i.e., yielding a utility at least as good or better for all players than that achieved non-cooperatively). It will be shown that this point is also the solution to the Nash (1950) bargaining problem that results in a Pareto dominant solution, where no single user may do any better without causing harm to another. This tax value may easily be communicated at the beginning of link setup and throughout the active link time.

Much of the literature that uses taxing to improve the utility of data users works within the logarithmic domain (Aalpcan et al., 2002; Ji, 1997; Qiu & Chawla, 1999). Specifically, those studies penalize the information theoretic transmission rate, which is a function of the logarithm of the SINR and yields a purely concave function.

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