Semantic Utility Aware User Grouping for 6G NOMA Networks

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***Abstract*—This paper looks into optimal algorithms for user pairing and triplet grouping in Non-Orthogonal Multiple Access (NOMA) wireless systems, aiming to maximize total utility by unifying channel characteristics with semantic relevance. As 6G wireless systems move toward task-oriented communication, it becomes increasingly important to consider the meaning and importance of user data in resource allocation. We evaluate several existing algorithms including brute force, Hungarian, and greedy approaches under a utility model that incorporates semantic value. Our study show that many traditional algorithms, designed without semantics in mind, perform suboptimally in this setting. Therefore, we propose a greedy algorithm called Semantic Greedy NOMA (SG-NOMA) that considers both channel diversity and semantic value, and demonstrate through simulations that it closely approximates brute force performance with significantly lower complexity. These findings highlight the importance of integrating semantic considerations into user grouping strategies for 6G wireless NOMA deployments.**

***Index Terms*—Non Orthogonal Multiple Access (NOMA), Semantic Aware Communication, NOMA Algorithms, SG-NOMA.**

I. Introduction

The demand for higher data rates, low latency, and massive connectivity has made Non-Orthogonal Multiple Access (NOMA) a cornerstone of next-generation wireless systems. By allowing users to share time and frequency resources with different power levels, NOMA improves spectral efficiency and fairness compared to Orthogonal Multiple Access (OMA). Optimal user pairing, typically between strong and weak users, remains central to achieving NOMA's gains, but as user density rises, optimal pairing becomes computationally exhaustive search.

Recent advances in semantic communication shift the design focus from bit-level accuracy to task-oriented meaning. Instead of transmitting all bits equally, systems prioritize content that carries higher semantic value or contextual importance [1], [2]. This paradigm calls for revisiting traditional NOMA grouping methods, which largely depend on physical-layer metrics such as channel gain or distance.

This paper investigates how existing user grouping algorithms perform when semantic importance is integrated into the utility function. We propose a Semantic Greedy NOMA (SG-NOMA) algorithm that jointly considers channel diversity and semantic value. Simulations show that SG-NOMA achieves near-optimal performance compared to brute force with far lower complexity, underscoring the value of incorporating semantics into 6G user grouping strategies.

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II. System Model and Problem Formulation

Consider a single-cell downlink NOMA system with a base station and multiple users randomly distributed in space. Users are grouped into pairs or triplets that share the same time–frequency resources with different power levels. The channel gain of user i is modeled as $h_i = \frac{\sigma_i}{d_i^{\eta/2}}$ where d_i is the distance to the base station, σ_i as the Rayleigh fading coefficient sampled from Rayleigh distribution, and η the path loss exponent.

Pairs have a total utility $U_{\text{pair}} = R_1 + R_2$ and power allocation factors $\alpha_1 > \alpha_2$. Triplets have a pair utility $U_{\text{triplet}} = R_1 + R_2 + R_3$ and power allocation factors $\alpha_1 > \alpha_2 > \alpha_3$.

$$R_i = \log_2\left(1 + \frac{\alpha_i P h_i^2}{\sum_{j=i+1}^{N} \alpha_j P h_i^2 + N_0}\right) \tag{1}$$

To capture task importance, each user i is assigned a semantic weight $w_i \in (0, 1)$. This is a simplified version of the *semantic information concentration model* $I/(K \times W)$ from [3], where I represents the semantic information per sentence, K the average number of mapped semantic symbols per word, and W the average number of words per sentence. In this work, we approximate this value by assigning random weights w_i sampled uniformly between 0 and 1. The overall semantic-aware utility becomes

$$U_{\text{sem}} = \sum_{i=1}^{N} w_i R_i, \quad N \in \{2, 3\}. \tag{2}$$

This formulation prioritizes users transmitting more meaningful data while maintaining NOMA's power-domain multiplexing. The objective is to find user groups that maximize U_{sem} under given power and channel constraints.

III. Algorithm and Results

We propose a *Semantic Greedy NOMA (SG-NOMA)* algorithm that jointly maximizes semantic-aware utility and channel diversity. Each user is assigned a semantic value w_i and channel gain h_i derived from Rayleigh fading. All valid user pairs or triplets are generated and sorted in descending order of channel gain to determine SIC decoding order. For each group, achievable rates R_i are computed using (2), and the overall semantic utility U_{sem} is evaluated using (3). The group yielding the highest utility is selected, and its users are removed from the candidate pool. This process repeats until all users are assigned or no further groupings are possible. Unlike distance-based greedy approaches, SG-NOMA prioritizes semantically important users while preserving NOMA's power-domain multiplexing, achieving near-optimal results with polynomial complexity.

Algorithm 1 Proposed SG-NOMA Grouping Algorithm

Require: User set in 3D positions, Rayleigh fading z_i, path loss exponent η, semantic weights w_i

Compute and sort distance d_i of each user to base station

Compute channel gain $h_i = \frac{\sigma_i}{d^{\eta/2}}$ for each user

Set group size $g \in \{2, 3\}$

Let $m \leftarrow n/g$, users are sorted weak to strong by distance

for $i = 1$ to m **do**

  Form group $S_i = \left(u_i, u_{i+m}, \ldots, u_{i+(g-1)m}\right)$

  Power splits $\alpha_1 > \alpha_2 > \cdots > \alpha_g$, $\sum_{k=1}^{g} \alpha_k = 1$

  for $k = 1$ to g **do**

$$R_k \leftarrow \log_2\left(1 + \frac{\alpha_k P\, h_k^2}{\sum_{j=k+1}^{g} \alpha_j P\, h_k^2 + N_0}\right)$$

  end for

  $U_{\text{sem}}(S_i) \leftarrow \sum_{k=1}^{g} w_k R_k$

end for

Return groupings with maximum U_{sem}

Simulations were conducted in MATLAB with users randomly positioned in a single cell. Channel gains follow the Rayleigh model, with default parameters $\eta = 3$, $\alpha = \{0.6, 0.4\}$, $P = 1$, $N_0 = 10^{-4}$, and $\sigma = 1$. We benchmarked SG-NOMA against brute force, D-NOMA [4], LCG [5], and Hungarian methods [6]. Figure 1, illustrates utility variations under different channel and noise conditions. As expected, total utility decreases with higher path-loss exponent η or noise N_0, while higher transmission power and fading variance σ improve utility.

Figure 2 visualizes the user groupings produced by SG-NOMA. The algorithm adaptively pairs users carrying high-value data with those of complementary channel strengths, maximizing both throughput and semantic relevance. Triplet grouping further amplifies semantic effects, as each additional user increases diversity and sensitivity to channel variations. SG-NOMA maintains competitive performance under both pair and triplet modes, showing strong scalability for real-time 6G deployments. These findings highlight the importance of combining semantic awareness with physical-layer adaptability in next-generation NOMA systems.

IV. Conclusions and Future Work

This paper introduced SG-NOMA, a semantic-aware user grouping algorithm for 6G NOMA networks. By incorporating semantic utility, SG-NOMA achieves near–brute-force performance with far lower complexity. Future work will extend this framework with more practical semantic simulations and reinforcement learning for adaptive grouping under dynamic conditions.

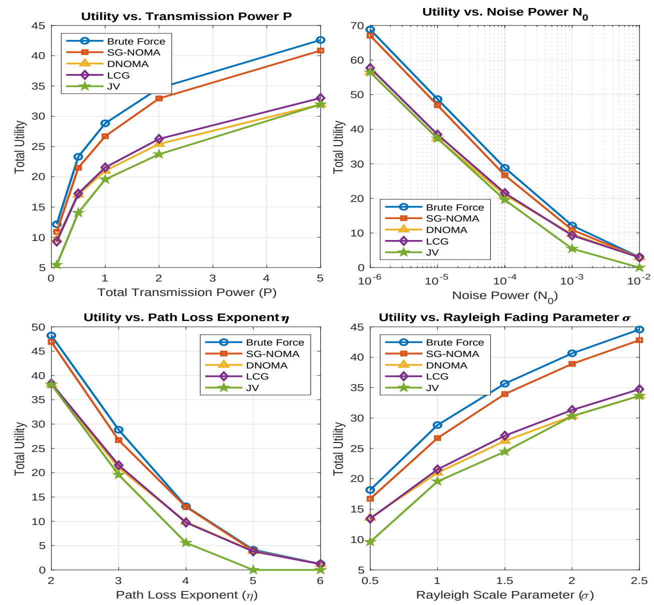

Fig. 1. Utilities as a function of power, noise, path loss, and rayleigh

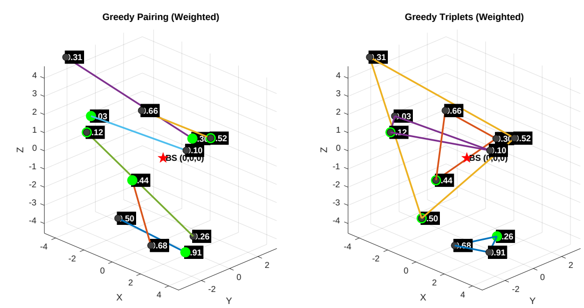

Fig. 2. SG-NOMA algorithm based user grouping

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