Two-User NOMA-based Fast Uplink Grant with Fairness Guarantee in MTC Networks

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Abstract

Based on [1,4], we introduce a fast uplink grant scheme with distributed two-user NOMA [2,3] for resource block(s) (RB) sharing among MTC devices for high spectral efficiency, throughput maximization and fairness, reduced RB wastage due to errors during active devices prediction process. Thus, enhancing the overall system efficiency.

Ⅰ. Introduction

Power-Domain NOMA [3], a scheme based on applying superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at the receiver. A system using NOMA can schedule multiple users in the same RB simultaneously with improved spectral efficiency. In [3] introduced "Fair-NOMA," and derived the exact power allocation coefficient region that allows for applying NOMA to any system in a *fair* fashion such that every involved user can achieve data rate greater or equal than OMA. Making NOMA prime candidate technique to enable and support 5G and beyond networks in term high spectral usage and accommodating greater number of devices for network throughput maximization and fairness.

In MTC networks with thousands of devices sporadically vying for network resources in the uplink direction and based on [4] we propose a *two-user NOMA-based Bandit Learning for FUG with Fairness* in [1] to enhance the overall system performance, detaching performance dependency of the predictor and scheduling algorithms, allowing multiple devices to share the same RB, thus, lowering resource wastage due to prediction errors. To minimize the rise on SIC decoding intricacy and avert the cascading spread of decoding errors, each resource block (RB) is limited to be shared by two-user NOMA pair.

Ⅱ. System Model and Problem Formulation

Consider an uplink of a two-user NOMA MTC enabled cellular wireless network made up of a single access point (AP), with of N devices vying for the shared wireless channel to transmit packets to the common AP using the fast uplink grant (FUG). Assuming frame-based slotted ALOHA scheduling cycle, with a subset A(t)⊂N of available devices at time t and the total available bandwidth is divided each into B RB of m consecutive time slots that can schedule 2m device per cycle.

II.B. *Two-User NOMA*

For two-user NOMA [2] uplink network with users $\mathcal{U}_w, \mathcal{U}_s$ in Raileigh fading propagation channel, with each user's channel gain during transmission (TX) cycle denoted by $|x_w|^2 < |h_s|^2$. Each user TX signal is denoted as x_w, x_s, respectively, with $\mathbb{E}[|x_i|] = 1, i = \{w, s\}$. The superposed signal for m^{th}-RB as seen by the AP is $y_m = \sqrt{\alpha_w P} h_{(w,m)} + x_w + \sqrt{\alpha_s P} h_{(s,m)} x_s + z$.

z denotes the zero mean complex Gaussian r.v. with variance σ^2, i.e., $\mathcal{Z} \backsim \mathcal{CN}(0, \sigma^2)$, and P is the total power. With NOMA, the achievable data rates for each user in the uplink are: (**weak user**) $r_w = B\log_2(1 + \gamma\alpha_w|h_w|^2)$ and (**strong user**) $r_s = B\log_2(1 + \frac{\gamma\alpha_s|h_s|^2}{1+\gamma\alpha_w|h_w|^2})$

$\gamma = \frac{P}{\sigma^2}$, is the TX SNR. For two-user OMA, the achievable data rates are: $r_k{}^{(oma)} = \frac{B}{2}\log_2(1 + \gamma|h_k|^2)$, $k = \{1,2\}$.

The optimal power allocation coefficients for the pair of users $(\mathcal{U}_w, \mathcal{U}_s)$, where the weak user achieves the same data rate as in OMA are as follows:

$\alpha_s = \frac{\sqrt{1+\gamma|h_w|^2}(\sqrt{1+\gamma|h_w|^2}-1)}{\gamma|h_w|^2}$, $\alpha_w = \frac{\sqrt{1+\gamma|h_w|^2}-1}{\gamma|h_w|^2}$

The maximum achievable sum rate for, $\alpha_w + \alpha_s = 1$, may be derived as single-valued function as:

$$r_{(w,s)} = r_w + r_s = B\log_2(1 + \gamma|h_w|^2 + \gamma(|h_s|^2 - |h_w|^2)\alpha_s)$$

II.A. *Optimal Power Allocation for Maximum Reward*

The scheduling procedure for the massive number of MTC devices is aggravated due to the diverse QoS demands. Thus, an optimal NOMA-based MAB scheduler should be able to schedule $2m$ devices at each round with maximum utility under each device's QoS requirement such that,

$$\begin{aligned}
\mathcal{P}(t) = & \underset{S\in\mathcal{S}(A(t)),\alpha_s,I(s,w)}{\operatorname{argmax}} \sum_{s=1}^{|S|}\sum_{w=1}^{|\mathcal{N}^a|}\big(Q_i(t) + \eta w_i \bar{u}_i(t)\big) \\
\textbf{s.t.} \quad & \delta_i(t) \geq t - t_{gp}, \forall(i = \{s,w\}), \\
& r_s^{(s,w)} \geq I(s,w) r_s^{(th)}, \\
& r_w^{(s,w)} \geq I(s,w) r_w^{(th)}, \\
& \theta_s^{(s,w)} \geq \theta_s^{(oma)}, \\
& \theta_w^{(s,w)} \geq \theta_w^{(oma)}, \\
& I_{(s,w)} = I_{(w,s)}, \forall(s,w), \\
& \sum_{s}^{|S|} I_{(s,w)} = \sum_{w=1}^{|\mathcal{N}^a|} I_{(w,s)} = 1, \forall(s,w), \\
& I_{(s,w)} \in \{0,1\}, \forall(s,w), \\
& 0 \leq \alpha_s \leq 1.
\end{aligned} \tag{1}$$

$S, A, \mathcal{N}^a, \mathcal{P}$ are the sets of FUG scheduled (cluster-head), available, not-scheduled active (non-cluster-head), and NOMA paired devices at time *t*; where ($|S| = |\mathcal{N}^a| = m$). $Q_i(t), w_i, \bar{u}_i(t)$ are the queue-length, weight, the UCB1 estimate (utility/reward) of the scheduled device i at t. η, positive parameter balancing the tradeoff between maximum utility and queue-length, $I_{(s,w)}$, is the pairing variable for devices (s,w). Performance-wise the goal of the scheduler is to minimize the cumulative regret $\mathcal{R}$. Let $\theta_i(t)$ be the achieved reward of playing arm *i* at time *t*, and $\theta^*(t)$ be the maximum reward achieved in hindsight at time *t*; the regret up to time *T* is

$$\mathcal{R}_\pi(T) = \mathbb{E}\left[\frac{1}{T}\sum_{t=0}^{T-1}\left(\sum_{i\in S^*(t)}\theta^*(t) - \sum_{i\in S(t)}\theta_i(t)\right)\right] \quad (2)$$

To maximize, $\mathcal{R}_\pi(t)$, the upper confidence bound (UCB1) concept finds the balance for exploitation-exploration. The AP uses UCB1 algorithm [1] to schedule the optimal device $i^*(t)$ as below

$$i^* \in \underset{i\in A(t)\setminus S(t)}{\operatorname{argmax}} \left(\Lambda_i(t)\right)\left(Q_i(t) + \eta w_i \bar{u}_i(t)\right) \quad \text{s.t.} \quad r_i(t) \geq r_i^{th} \wedge \delta_i(t) \geq t - t_{gp} \quad (3)$$

In this scheme, the AP schedules the newly activated devices first before stating (3). The AP is the player, and the devices ate the actions. From (3), the reward of a device *i* may be derived as:

$$\theta_i(t) = \mathbb{I}\left[\delta_i(t) > t - t_{gp}\right] \cdot \mathbb{I}\left[r_i(t) > r_i^{th}\right] \cdot \bar{u}_i(t) \quad (4)$$

$\Lambda_i(t), r_i(t), r_i^{th}$, are the posterior probability, achieved and threshold rates of *i* at time *t*, maximum access delay and time-steps it takes device *i* to get the FUG grant at time *t*; and $1_Y: \chi \to \{0,1\}$ is the indicator function defining the reward.

II.B. *NOMA Pairing for Resource Sharing*

Assuming perfectly known *channel state information* (CSI), NOMA pairing is done distributively among devices seeking pairing after receiving an FUG grant. At each round: (*i*) every device (cluster-head) receiving an FUG grant seeks pairing with seemly active device (non-cluster-head) by sending pairing request via the received signal strength (RSS); (*ii*) the non-cluster-head associates itself with a cluster-head by measuring the latter's RSS signal and choosing a seemly cluster-head; (*iii*) every device pair satisfy a minimum SNR, γ^{th}, for easy SIC decoding at the AP; (*iv*) the AP advertises a tolerance power, Δ, as minimum power difference for efficient SIC decoding; (*v*) assuming that each device acquires the CSI of its link to the AP from the pilot signal sent by the AP.

The cumulative rewards for each cluster-head (s) and non-cluster-head (w) using Eq. (3) are:

$$\bar{u}_s(t) = \bar{u}(t-1) + \theta_s(t) + \varrho\theta_w(t), \quad \bar{u}_w(t) = \bar{u}(t-1) + (1-\varrho)\theta_w(t) \quad (5)$$

Where ϱ is the weight factor due to the pairing. The system reward maximization is obtained via the optimization weights defined as, $\Theta_{(w,s)} = \theta_w + \theta_s$, for any two-user NOMA pair.

II.C. *User Pairing with $2m$-Users*

For an uplink NOMA network scheduling $2m$-users per cycle, for maximum reward, user-*i*, $(1 \leq i \leq m)$, should optimally (based on devices' SNR for channel disparity) be paired with user-$(2m-i+1)$, $(m+1 \leq i \leq 2m)$, *i.e.*, the set of optimal pairs should be: $\{(\mathcal{U}_1,\mathcal{U}_{2m}),(\mathcal{U}_2,\mathcal{U}_{2m-1}),(\mathcal{U}_3,\mathcal{U}_{2m-2}),\cdots,(\mathcal{U}_m,\mathcal{U}_{m+1})\}$

II.D. *NOMA-based Fast Uplink Grant Scheduling*

For two-user NOMA-based FUG resource allocation, we apply the MAB scheduler [1] and the Ordered Pairing (OP) [2] from Sec. (II.C).

Algorithm 1 Two-User NOMA-based UFG Grant Scheduling with Fairness Guarantee

for $i \in \mathcal{N}^a$ **do**
  Initialize $h_i(-1) = 0$ and $Q_i(0)$;
end for
In each round t:
for $i \in \mathcal{N}$ **do**
  if $h_i(t-1) > 0$ **then**
    Update $\bar{u}_i(t)$;
  else
    Set $\bar{u}_i(t) = 1$;
  end if
  Update $Q_i(t)$
end for
Observe the set of available arms $A(t)$;
Calculate the posterior probability $\Lambda_i(t)$, $\forall_i \in A(t)$
Arrange all the arms in $A(t)$ in descending order;
Select super arms $S(t)$ according to (3);
$S(t)$ seeks distributed NOMA pairing according to (II-C) for RB sharing;
Play arms in $\mathcal{P}(t)$ in (1) after pairing and set vector $\boldsymbol{d}(t)$ accordingly;
for $i \in \mathcal{P}(t)$ **do**
  Observe the reward $X_i(t)$;
end for
for $i \in \mathcal{N}$ **do**
  Update $h_i(t)$ and $\hat{u}_t(t)$ according to $d_i(t)$ and $X_i(t)$;
end for

Ⅲ. Conclusion

In this paper, we presented an efficient NOMA-based FUG scheduling scheme for uplink transmission.

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REFERENCES

[1] A.A. Jose, I., H. Park, "Sleeping Combinatorial Bandits with Fairness Guarantees for FUG in mMTC," 2022, 13th Int. Conf. on ICT Convergence.

[2] M.S. Ali, H. Tabassum, E. Hossain, "Dynamic User Clustering and Power Allocation for UL and DL NOMA Systems," 2016, IEEE Access, vol. 4, pp. 6325-6343.

[3] J.A. Oviedo, H.R. Sadjadpour, "A New NOMA Approach for Fair Power Allocation," 2016, IEEE INFOCOM, Workshop on 5G & Beyond - Enabling Technologies & Applications.

[4] M. El-Tanab, W. Hamouda, "Fast Grant Learning-Based Approach for MTC with NOMA," 2021, Proc. IEEE Trans. Int. Conf. Comm. (ICC), pp. 1-6.