Effective multiple access technique to support minimum data rate

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***Abstract*—In this paper, we find an effective method to maximize the minimum data rate. The non-orthogonal multiple access (NOMA), especially, is compared with the time division multiple access (TDMA) with user equipment (UE) scheduling. For communication systems with large number of UEs, we assess the minimum data rate of each multiple access techniques and also examine the actual time to support the minimum required data for the entire UEs.**

I. Introduction

The increase of user equipments (UEs) and data traffic is traditional and consistent direction of communication systems development with additional conditions, e.g., lower latency [1]. Within limited time, frequency, and space resources, various methods are exploited to distribute those resources over UEs orthogonally. For examples, frequency division multiple access (FDMA), code division multiple access (CDMA), time division multiple access (TDMA), and orthogonal frequency and time division multiple access (OFDMA) techniques are adopted in previous mobile communication generations [3].

The orthogonal multiple access (OMA) schemes can provide interference-free communication environment for UEs but have their limit that comes form the orthogonality at the same time. With limited number of orthogonal resources, the OMA schems can support only the same or less number of UEs simultaneously [2]. Although TDMA or UE scheduling allows additional UEs to be supported, the scheduling delay follows inevitably.

The non-orthogonal multiple access (NOMA) is a proper technique to support a large number of UEs with low delay. It has been well known that the NOMA provide meaningful performance gain for systems where the number of UEs are larger than that of orthogonal resources or where each UE requires its minimum data rate [4], [5]. In this paper, we compare the NOMA with OMA, especially, TDMA with several scheduling to figure out which scheme is more effective to maximize the minimum data rate under the same frequency resources. In addition to the average minimum data rate itself, the time that consumed to provide a required minimum data is assessed as a metric of the UE scheduling delay.

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II. System model

The downlink communication system consists of one base station (BS) and K UEs where each BS or UE has single antenna. Then, the received signal at the k-th UE is

$$y_k = h_k x_k + \underbrace{\sum_{\substack{\ell=1 \\ \ell\neq k}}^{K} h_k x_\ell}_{\text{interference}} + n_k, \qquad k \in \{1, \cdots, K\}, \tag{1}$$

where h_k is the channel from the BS to k-th UE that following Rayleigh distribution $\mathcal{CN}(0, \eta_k^2)$, and the additive white Gaussian noise n_k has the noise power σ_k^2. Without loss of generality we can suppose that the k-th UE has larger channel gain than that of $(k+1)$-th UE as $|h_k|^2 \geq |h_{k+1}|^2$. For the NOMA scheme, then, the interference in (1) is reduced to $\sum_{\ell=1}^{k-1} h_k x_\ell$ with the typical superposition coding and successive interference cancellation (SIC) [5], [6]. The k-th UE has the signal-to-interference-and-noise-power-ratio (SINR) as

$$\gamma_k = \frac{|h_k|^2 P_k}{\sum_{\ell=1}^{k-1} |h_k|^2 P_\ell + \sigma_k^2}, \tag{2}$$

where P_k is the transmit power that is allocated to k-th UE, and $\sum_{k=1}^{K} P_k \leq P$ for the total transmit power P. The transmit power for UEs is optimized to maximize the minimum data rate [5], [6]. The corresponding data rate can be expressed as

$$R_k = \log_2 \left(\frac{|h_k|^2 P_k}{\sum_{\ell=1}^{k-1} |h_k|^2 P_\ell + \sigma_k^2} \right). \tag{3}$$

Under the TDMA scheme, meanwhile, the interference in (1) completely disappears when k-th UE is scheduled, and the SINR of the k-th UE is computed as

$$\gamma_k = \begin{cases} \frac{|h_k|^2 P}{\sigma_k^2}, & k\text{-th UE scheduled,} \\ 0, & \text{otherwise.} \end{cases} \tag{4}$$

The data rate of the k-th UE, then, depends on the portion of the scheduled time. If the time τ_k is assigned to the k-th UE during a scheduling period T, the average data rate of k-th UE is

$$R_k = \frac{\tau_k}{T} \log_2 \left(\frac{|h_k|^2 P}{\sigma_k^2} \right). \tag{5}$$

For UE scheduling, the round robin and minimum support strategies are considered since the maximization of minimum data rate is targeted. To be specific, the round robin method selects the supporting UE index at the m-th transmission as

$$\text{idx}_m = \mod (m-1, K) + 1, \tag{6}$$

where $\mod (a, b)$ is the remainder of division a by b. The minimum support strategy supports the UE with the lowest accumulated data as

$$\text{idx}_m = \min_{k \in \{1, \cdots, K\}} m_k \log_2 \left(\frac{|h_k|^2 P}{\sigma_k^2} \right), \tag{7}$$

where m_k is the number of transmission supporting the k-th UE until the m-th transmission.

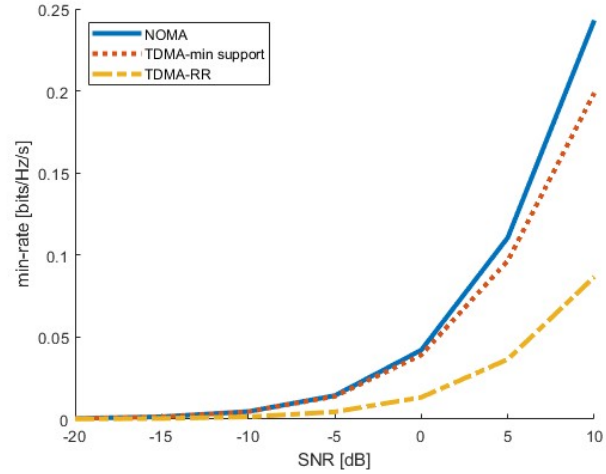
III. Simulation Results

The channel variance of UE is set as $\eta_k^2 = 1$, and the noise power is set as $\sigma_k^2 = \sigma^2$. For a given signal-to-noise-ratio (SNR) ρ, transmit power is set to be $P = \sigma^2 \rho$. The minimum data rate and the lead time to achieve the required amount of data are assessed for K UEs. For a given SNR ρ, the minimum data requirement is set to be similar level with the system average data rate as

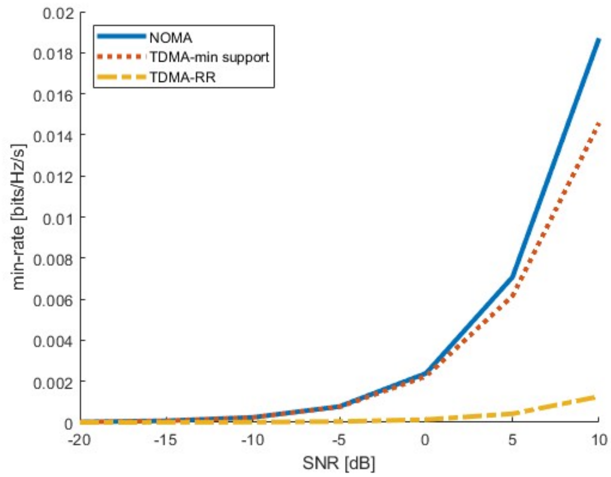
$$D_{\text{required}} = d \log_2 (1 + \rho), \tag{8}$$

where d is a scaling factor, and we set $d = 0.1$ in this section.

In Fig. 1, the average minimum data rate is measured. The NOMA scheme shows the highest minimum data rate for both scenarios of $K = 10$ and $K = 100$ UEs. The TDMA with minimum support provides similar minimum data rate with that of NOMA, but the difference increases with SNR. The TDMA with round robin does not complement UEs suffering weak channels actively, and its minimum data rate falls as the number of UEs increases.



(a) $K = 10$



(b) $K = 100$

Fig. 1: Average minimum data rate over SNR.

It seems that the NOMA and TDMA with minimum support provide similar level of minimum data rate in Fig. 1. To observe the difference between the two schemes more clearly, the actual time length to achieve a required amount of minimum data is assessed as the number of channel use. In Fig. 2, the NOMA scheme provides required data for all UEs with lowest number of channel use. The TDMA with minimum support let the UEs to achieve the minimum data about 8 more use of channel than that of NOMA, which is a comparable to the number of UEs $K = 10$. As the TDMA allocate its entire resources for single UE at each channel use, there is always spare that exceeds the minimum data requirement. Except the UE with the lowest channel gain, therefore, all UEs make the BS to use channel with spare at least once. With large number of UEs $K = 100$, the increase of the gap between NOMA and TDMA is noticeable in Fig. 3.

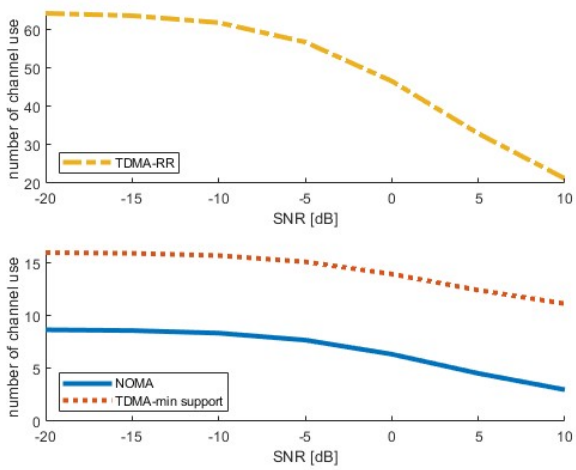


Fig. 2: Number of channel use with $K = 10$ UEs.

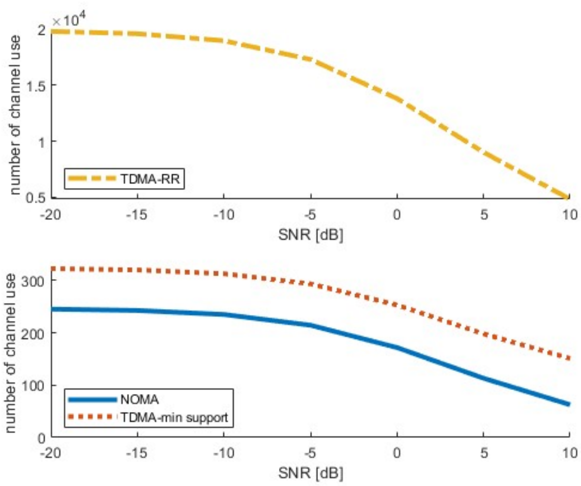


Fig. 3: Number of channel use with $K = 100$ UEs.

IV. Conclusion

The NOMA scheme not just provide a high minimum data rate but achieves the data requirements of all UEs with shortest scheduling delay. As the number of UEs increases, the benefit of NOMA is more remarkable by large performance gain of both the average minimum data rate and the number of channel use, i.e., scheduling delay. The NOMA, of course, has its shortcomings like error propagation in SIC or computation complexity, but it is obvious that the NOMA can improve the potential of system performance than OMA in terms of minimum data rate and delay.

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