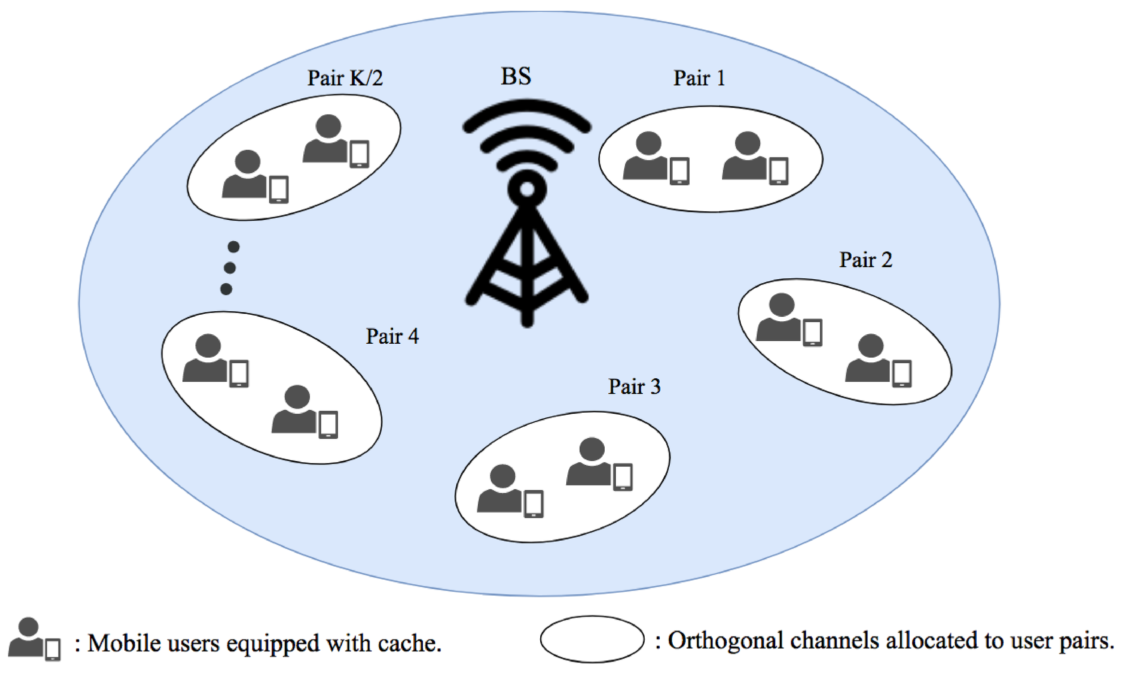
Optimal Power Allocation in Cache-Aided Non-Orthogonal Multiple Access Systems

Khai Nguyen Doan, Wonjae Shin, Mojtaba Vaezi, H. Vincent Poor and Tony Q.S. Quek

Abstract

This work combines non-orthogonal multiple access (NOMA) and caching, two prominent techniques for future communication networks. Specifically, a cache-aided cellular network with Rayleigh fading channels is analyzed. By exploiting the channel distribution, users requests, and cache contents in given time, an optimal power allocation policy for the superposed signal is derived. The goal is to maximize the system success probability, i.e., the probability that all users can successfully decode their desired signals. The analysis highlights the benefits of introducing caching to NOMA-based systems. Simulation results confirm the analysis and demonstrate the efficiency of the proposed power allocation.

System Model

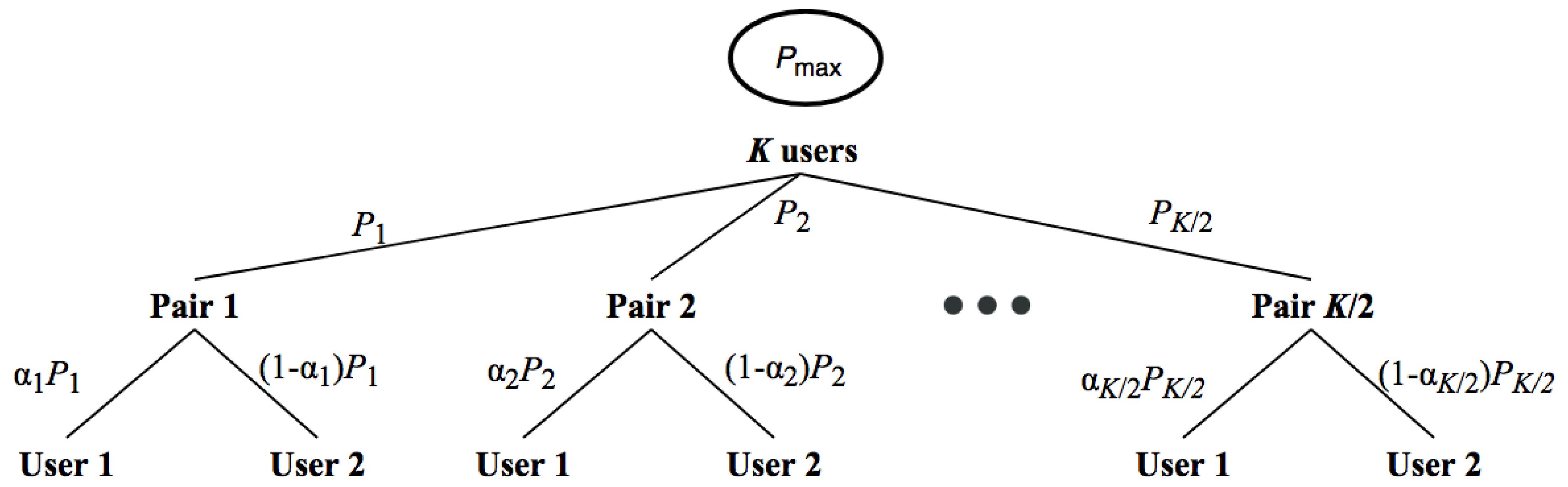


- K users served by a base station (BS). Each user has cached some files in their devices.
- Rayleigh fading channels between users and BS.
- Users are paired. User pairs are allocated with orthogonal frequencies. Frequency reuse can be applied.
- Each user requests for a file in the file library. BS sends superposed signal to each user pair. Each superposed signal is a combination of file information requested by each user in a pair.
- Users decode desired signal using successive interference cancellation (SIC).
- **Objective: Deriving an optimal power allocation policy for signal corresponding to each user to maximize the success probability, i.e., the probability that all users can decode their desired signals.**

Conclusions

- Maximizing the success probability in the system ensures the fairness among users.
- The combination of caching and NOMA yields a better performance compared to OMA, as confirmed by simulation results.
- A new cache hit type is introduced by the combination of caching and NOMA which enhances the overall performance.

Optimal Power Allocation Policy



Considering a specific user pair with total allocated power P (pair index is dropped for simplicity), a user i allocated with portion α_i can successfully decode a signal when

$$\frac{|h_i|^2 \alpha_i}{I+\beta_i} \geq \epsilon_j, \quad \epsilon_j, j=1,2: \text{SINR threshold} \tag{1}$$

where $\beta_i = \frac{d_i^\gamma \sigma^2}{P}$, h_i is the channel coefficient between that user and BS, the nonnegative quantity I is the interference resulted from the signal of the other user and σ^2 is the Gaussian noise power. Since $|h_i|^2$ follows exponential distribution (with parameter λ_i), the success probability is given by

$$P_{success} = \exp\left(-\sum_{i=1}^{2}\sum_{j=1}^{2} \frac{\lambda_i\left(1-C_{ij}\right)\left(1-\theta_{ij}\right)\epsilon_j\beta_i}{\alpha_j - \left[\epsilon_j\left(1-C_{ik}\right)\theta_{jk}\alpha_k\right]_{k\neq j}}\right) \tag{2}$$

where $C_{ij}=1$ if user i has cached file j, 0 otherwise. $\theta_{ij}=1$ if $\alpha_i > \alpha_j$, 0 other wise. $\alpha_i=\alpha$ and $\alpha_j = 1-\alpha$. Here, α is obtained by maiximizing the above considering all possible values of C_{ij} and θ_{ij}. The success probability of both users in a pair has form

$$g(P) = \exp\left(-\frac{\Psi}{P}\right) \tag{3}$$

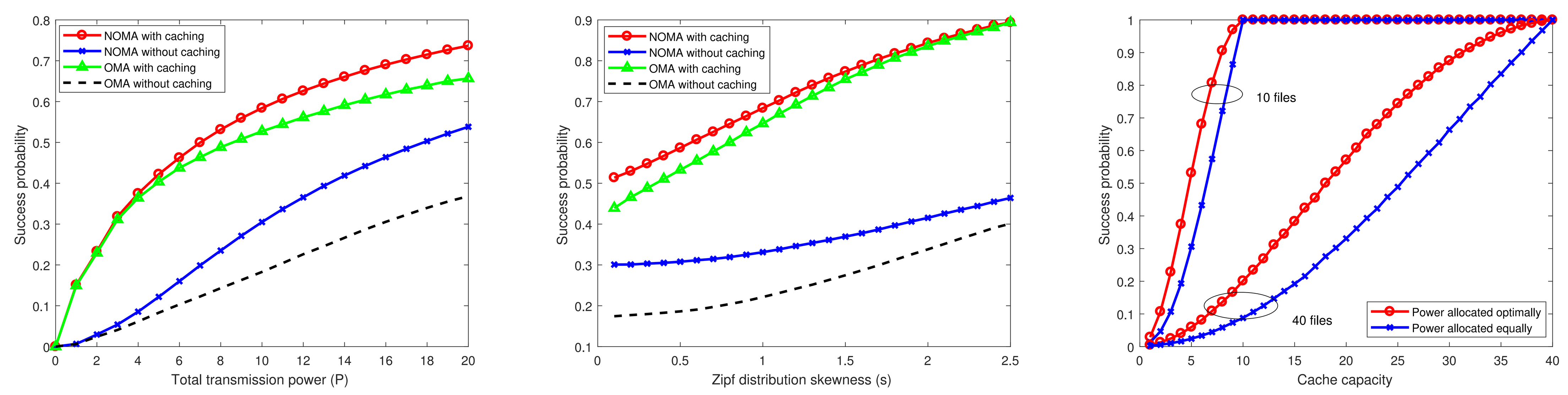
where Ψ is a function of SINR threshold, pathloss, and the exponential distribution parameter of the channel coefficient between the user and BS.
Maximizing the success probability associated with K users in the system is solving:

$$\max_{\mathbf{P}} \exp\left(-\sum_{i=1}^{K/2}\frac{\Psi_i}{P_i}\right), \quad \text{s.t.} \sum_{i=1}^{K/2} P_i = P_{\max},\ P_i \geq 0, \forall i=1,\ldots,K/2 \tag{4}$$

whose solution is obtained from KKT conditions as

$$P_i = \frac{\sqrt{\Psi_i}}{\sum_{j=1}^{K/2}\Psi_j} P_{\max},\ i=1,\ldots,K/2 \tag{5}$$

Numerical Results



Remarks:

1. NOMA improves the success probability by exploiting better the available bandwidth compared to OMA.
2. Caching yields a positive impact due to two types of cache hit, when a user caches his own desired file (conventional type) and when he caches the desired file of the other (new type appearing in the combination with NOMA).
   - The first cache hit type helps reduce the transmission.
   - The second cache hit type helps users cancel the interference in the superposed signal when decoding with SIC.