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Performance Comparison Between OFDMA and NOMA

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ABSTRACT—

This paper presents a comprehensive performance comparison between Orthogonal Frequency Division Multiple Access (OFDMA) and Non-Orthogonal Multiple Access (NOMA) under various wireless system configurations. We analyze essential performance metrics including sum rate, spectral efficiency (SE), energy efficiency (EE), channel capacity, interference cancellation, and power division. A simulation scenario is considered with one base station and four users positioned at different distances in a circular cell. NOMA leverages power domain multiplexing and successive interference cancellation (SIC), whereas OFDMA relies on orthogonal subcarrier allocation. MATLAB simulations show that NOMA, particularly with near-far user allocation, can outperform OFDMA in terms of throughput and energy efficiency while maintaining acceptable fairness.

Keywords— NOMA, OFDMA, Interference Cancellation, Power Division, Spectral Efficiency, Energy Efficiency, Channel Capacity, MATLAB Simulation.

Introduction

OFDMA has been a workhorse of several access methods in 4G and LTE systems by providing interference-free communication through orthogonal frequency bands being assigned to users. Its spectral efficiency is restricted by the constraint of orthogonality. NOMA provides the capability to allow multiple users to use a common frequency-time resource by distributing different power levels according to channel conditions. It leads to more efficient spectrum use and greater capacity.

The main objective of this research is to compare these two access methods under the same simulation conditions considering various user distributions, power assignments, and signal decoding methods like SIC.

System Model

We model a single-cell downlink scenario where a base station (BS) is located at the center of a circular area serving four users located at different distances. The channel gain for user i is given by:

$h_i = 1 / d_i^\alpha$

where α is the path-loss exponent, and d_i is the distance of user i from the BS.

NOMA Transmission:

The BS transmits a superimposed signal:

$x = \Sigma \sqrt{P_i} * x_i$

Each user receives:

$y_i = h_i * x + n_i = h_i * \Sigma \sqrt{P_j} * x_j + n_i$

Users apply SIC to decode and remove interference from lower-power users.

OFDMA Transmission:

Each user is assigned a unique, non-overlapping frequency band:

$y_i = h_i * \sqrt{P_i} * x_i + n_i$

No interference occurs between users in OFDMA.

User Pairing in NOMA:

User pairing is utilized in NOMA to take advantage of channel gain diversity across users by pairing them up in the same time-frequency resource block. Proper pairing is necessary for maximizing power-domain NOMA performance, especially sum rate improvement and successful successive interference cancellation (SIC).

Pairing Strategies:

- Near-Far Pairing (N-F): A near (strong) user is matched with a far (weak) user. The weak user receives more power and is decoded initially. The strong user uses SIC to eliminate the weak user's signal before decoding its own.
  This match provides the optimum performance because there is a sharp power gap.
- Near-Near / Far-Far Pairing (N-N/F-F): Similar channel users are paired.
  These methods tend to have worse performance because the power separation is not enough, causing poor SIC.
- Dynamic Pairing: Users are partitioned on the basis of instantaneous channel state information (CSI), target rate constraints, and system optimization objectives (e.g., sum rate maximization or fairness).

Sum Rate Calculations:

- In a 4-user system, let g_i be the channel gain for user i, and P the total power. In N-F pairing (e.g., user 1 with user 4), fixed power allocation is used as:
  $P1 = \alpha P, \quad P4 = (1 - \alpha)P \quad (\text{e.g., } \alpha = 0.7)$

  The achievable rates are given by:
  $R1 = E[\log2(1 + (\alpha P\, g1) / ((1 - \alpha)P\, g1 + N0))]$
  $R4 = E[\log2(1 + ((1 - \alpha)P\, g4) / N0)]$

  The total sum rate for NOMA under this pairing:
  $R\_NOMA\_N\text{-}F = R1 + R4 + R2 + R3$
- For Near-Near / Far-Far (N-N/F-F) pairing, users with close channel gains are grouped:
  $R1' = \log2(1 + (\alpha P\, g1) / ((1 - \alpha)P\, g1 + N0))$
  $R2' = \log2(1 + ((1 - \alpha)P\, g2) / N0)$
  $R3' = \log2(1 + (\alpha P\, g3) / ((1 - \alpha)P\, g3 + N0))$
  $R4' = \log2(1 + ((1 - \alpha)P\, g4) / N0)$

  Total sum rate:
  $R\_NOMA\_N\text{-}N/F\text{-}F = R1' + R2' + R3' + R4'$
- For OFDMA, where resources are orthogonally split:
  $R\_OFDMA = \sum \log2(1 + (P_i\, g_i / N0))$,

  with $P_i = P / 4$

Channel Capacity and Power Capacity

Channel capacity is the highest data rate that can be obtained over a channel. In OFDMA, each user is allocated orthogonal subcarriers with no interference and capacity is determined only by power and channel gain. In NOMA, users occupy common resources, and capacity is determined by power allocation and interference, and Successive Interference Cancellation (SIC) is needed. Weaker users are allocated more power, and more powerful users utilize SIC to demodulate their messages. A good division strategy of power in NOMA maximizes overall system throughput as well as fairness.

NOMA:

Power is divided among users using coefficients α_i such that $\Sigma\alpha_i = 1$. Users with weaker channels receive more power.

Channel capacity for each user in NOMA:

$$R_i = \log2(1 + (\alpha_i * P * h_i) / (I_i + N_0))$$

where I_i is the interference from other users..

OFDMA:

Each user experiences no intra-cell interference:

$R_i = \log2(1 + (P_i * h_i) / N_0)$

Interference Cancellation

In NOMA, interference is alleviated through Successive Interference Cancellation (SIC), whereby users with more favorable channel conditions successively decode and cancel weaker users' signals prior to decoding their own. Successful SIC necessitates an evident power gap to separate overlapped signals. Nevertheless, its performance can suffer from practical matters such as channel estimation errors and remaining interference.
Conversely, OFDMA naturally evades intra-cell interference by allocating orthogonal subcarriers to users, and hence there is no need for sophisticated cancellation methods. Accordingly, while NOMA requires cautious power allocation to manage interference, OFDMA provides easier and interference-free communication.

Permormance Metrics

To evaluate and compare the effectiveness of NOMA and OFDMA systems, the following key performance metrics are considered:

Sum Rate:

NOMA attains a greater sum rate than OFDMA by enabling several users to utilize the same time-frequency resources via power domain multiplexing. With proper power allocation and efficient SIC, NOMA can serve multiple users with different channel conditions simultaneously, leading to better aggregate throughput. OFDMA, on the other hand, allocates orthogonal resources to users, which restricts simultaneous transmissions and thus leads to a lower overall sum rate.
$R_{sum} = \Sigma R_i$
It quantifies the overall throughput of the network, where higher values indicate better spectral utilization and system capacity.

Spectral Efficiency(SE):

Its non-orthogonality has resulted in enhancing the spectral efficiency through the power domain exploitation in user separation. It enables additional bits to be delivered per bandwidth unit compared to OFDMA. As much as OFDMA prevents interference during transmission, the high constraint of orthogonality has resulted in low utilization of the spectrum with great underuse whenever user demand is unevenly distributed.
$SE = \Sigma R_i / B$
It is expressed in bits per second per Hertz (bps/Hz) and reflects how effectively the system uses spectrum resources.

Energy Efficiency(EE):

NOMA exhibits greater energy efficiency, especially at low to moderate data rates, by supporting multiple users through a single RF chain and reducing idle time on the spectrum. Its energy benefit is more significant in systems with users at different distances. OFDMA necessitates individual frequency allocations and frequently greater power for far-off users, lowering its energy efficiency compared to that.
$EE = SE / P_{total}$

Simulation Setup and Observations

Simulations were conducted using MATLAB to evaluate the performance of OFDMA and NOMA under the same transmission conditions. The downlink system has a single base station (BS) serving four users at distances of 3 m, 4 m, 9 m, and 10 m, corresponding to a realistic cell configuration with different path losses. The system uses a path-loss exponent of $\eta = 4$ and Rayleigh fading channels. The bandwidth was set at 5 MHz and sum rate performance was tested under 10,000 random realizations of a channel to confirm statistical significance.
In NOMA, fixed and dynamic power allocation schemes were utilized. Fixed pairing was carried out with Near-Far (N-F) and Near-Near/Far-Far (N-N/F-F) schemes. Dynamic allocation dynamically varied power coefficients per user based on channel conditions and target rate limitations. In OFDMA, orthogonal bandwidth allocation and equal power to users guaranteed interference-free communication.
In a separate 2-user scenario, energy efficiency (EE) vs. spectral efficiency (SE) was compared with respect to circuit power and different power budgets. Also, a large connectivity scenario of 100 randomly distributed users was simulated, comparing per-user rate, fairness, EE, and SE. Jain's fairness index was employed to measure fairness in through-put sharing. User pairing in NOMA was performed by arranging users according to their channel gains and pairing large users with small users (near-far).

Key Observations:

- NOMA (fixed and dynamic power allocation) performed better than OFDMA in total sum rate in all SNR values (20 dB to 40 dB).

- In 2-user case, NOMA showcased better energy efficiency particularly at low-to-moderate spectral efficiency.
- For dynamic 100-user scenarios, NOMA offered greater average EE and SE than OFDMA, and a greater fairness index.

Results Obtaines:

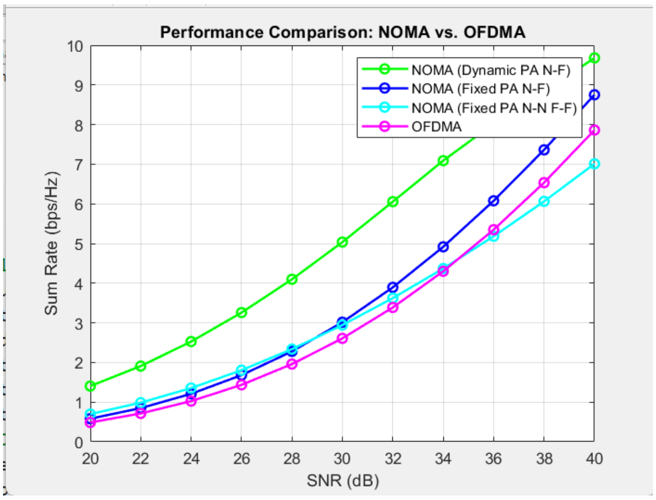


Figure 1. Sum Rate vs. SNR for NOMA (N-F, N-N/F-F) and OFDMA

Figure 1 shows sum rate variation versus SNR for various user pairing methods in NOMA—viz Near-Far (N-F), Near-Near/Far-Far (N-N/F-F)—and for OFDMA. It can be noted that NOMA with near-far pairing provides the largest sum rate over all SNR values because of larger channel gain difference that permits efficient successive interference cancellation (SIC). Conversely, NOMA with near-near or far-far pairing experiences lower performance because of poor channel separation. OFDMA has the lowest sum rate since it does not have power-domain multiplexing and serves users orthogonally, restricting its spectral usage.

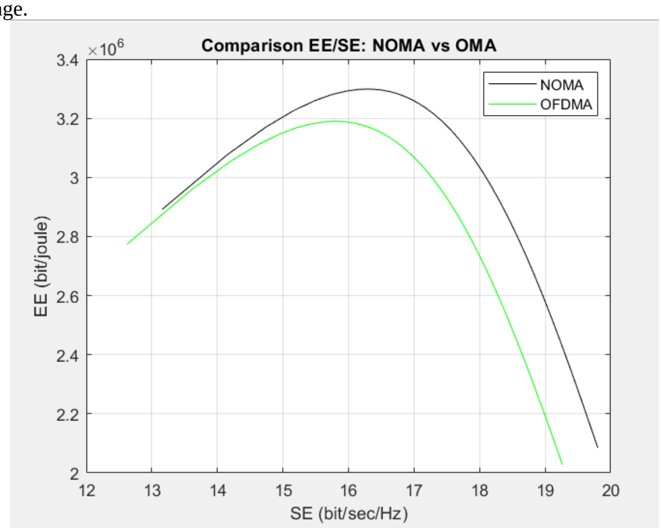


Figure 2. Energy Efficiency vs. Spectral Efficiency (2-user scenario)

Figure 2 illustrates a comparison between NOMA and OFDMA energy efficiency (EE) as a function of spectral efficiency (SE) in a two-user scenario. NOMA shows a greater EE at average SE values, reaching its peak earlier than OFDMA. This is because NOMA can serve both users at the same time on the same frequency, saving transmission time and power wastage. With an increase in SE beyond the optimum, EE decreases for both systems because of the higher power consumption needed to facilitate higher data rates. Yet, OFDMA's orthogonal allocation ensures superior EE at extremely high SE, where interference is negligible.

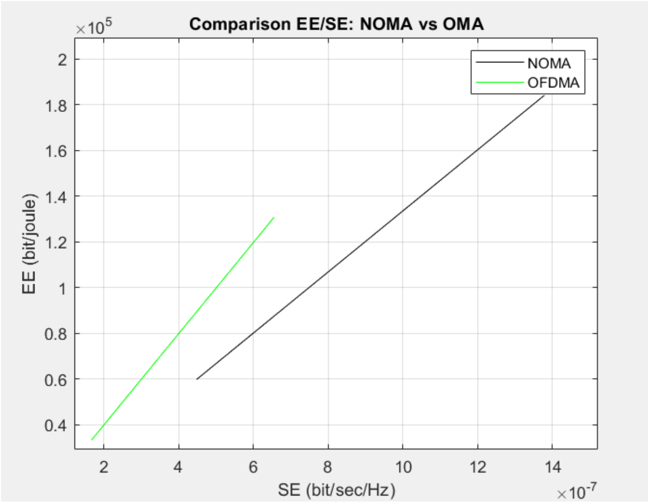
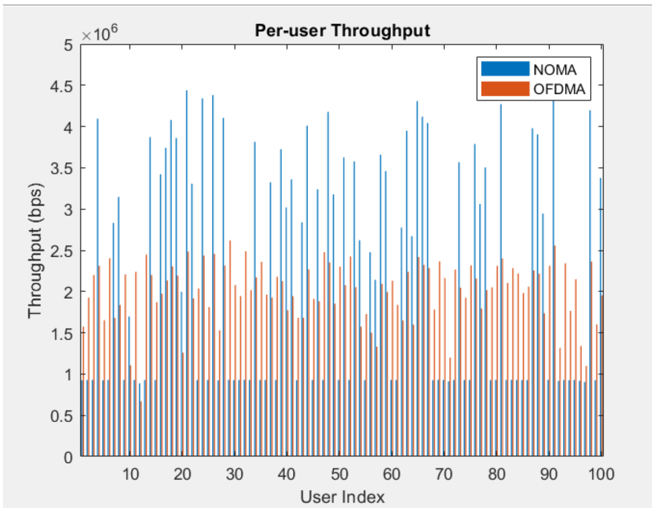


Figure 3. Energy Efficiency vs. Spectral Efficiency (100-user scenario)

Figure 3 is an extension of EE vs. SE analysis to a 100-user dynamic connectivity environment. NOMA still outperforms OFDMA in EE across the whole SE range. The gap is more significant here as a result of NOMA's effective user pairing (weak + strong users) and power sharing mechanism, which enables simultaneous transmission to multiple users without orthogonal resource partitioning. The more flat and longer EE curve of NOMA reflects its energy efficiency and scalability in large connectivity scenarios common to 5G/6G systems.



Per-user Throughput Comparison between NOMA and OFDMA

Figure 4 illustrates the per-user throughput of NOMA versus OFDMA for 100 randomly scattered users. The histogram indicates that NOMA offers greater and more even throughput distribution among users, especially weak users because of power-domain multiplexing. Conversely, OFDMA's orthogonal allocation restricts flexibility, resulting in less throughput for users with bad channel conditions.

Conclusion

The research corroborates that NOMA provides higher spectral and energy efficiency compared to OFDMA for a range of user scenarios. Multiplexing capability of users in the power domain and implementation of SIC impart a strong advantage to NOMA in sum rate and capacity. These gains are, however, contingent upon sophisticated power allocation and adequate channel imbalance. The interference-free architecture of OFDMA brings simplicity and hard fairness, but at a trade-off. Thus, NOMA is a good contender for future networks that require enormous connectivity and effective use of the spectrum.

REFERENCES

[1] Z. Ding, Z. Yang, P. Fan, and H. V. Poor,
"On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users,"
IEEE Signal Processing Letters, vol. 21, no. 12, pp. 1501–1505, Dec. 2014.

[2] Y. Liu, Z. Ding, M. Elkashlan, and H. V. Poor,
"Cooperative non-orthogonal multiple access with simultaneous wireless information and power transfer,"
IEEE Journal on Selected Areas in Communications, vol. 34, no. 4, pp. 938–953, Apr. 2016.

[3] S. Timotheou and I. Krikidis,
"Fairness for non-orthogonal multiple access in 5G systems,"
IEEE Signal Processing Letters, vol. 22, no. 10, pp. 1647–1651, Oct. 2015.

[4] M. Saito, H. Ochiai, and H. Suzuki,
"Performance comparison of NOMA and OFDMA under limited feedback,"
IEICE Transactions on Communications, vol. E100.B, no. 11, pp. 1941–1949, Nov. 2017.

[5] L. Dai, B. Wang, Y. Yuan, S. Han, C.-L. I, and Z. Wang,
"Non-orthogonal multiple access for 5G: Solutions, challenges, opportunities, and future research trends,"
IEEE Communications Magazine, vol. 53, no. 9, pp. 74–81, Sept. 2015.

[6] T. M. Cover and J. A. Thomas,
Elements of Information Theory, 2nd ed., Wiley-Interscience, 2006. [For channel capacity theory]

[7] H. Zhang, Y. Liu, and L. Song,
"Energy-efficient resource allocation in NOMA systems,"
IEEE Transactions on Communications, vol. 66, no. 12, pp. 6628–6639, Dec. 2018.

[8] N. Zhang, J. Wang, G. Kang, and Y. Liu,
"Uplink NOMA in 5G systems: Potentials and challenges,"
IEEE Wireless Communications, vol. 25, no. 2, pp. 56–63, Apr. 2018.

[9] MATLAB Simulations — Custom implementation by the author.
Performance results for sum rate, energy efficiency, user fairness and dynamic user pairing were obtained via MATLAB using a Rayleigh fading model and path loss models with urban parameters.

[10] ECE Wireless Blog,
"User Pairing in NOMA,"
Available: https://ecewireless.blogspot.com/2021/07/user-pairing-in-noma.html