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Non Orthogonal Multiple Access verses Orthogonal Multiple Access performance comparison in 5G communication system

***Abstract**. The current generation of mobile networks requires speeding up the steps to meet the future demand for high data rates, and low latency. In 5G, the Third Generation Partnership Project (3GPP) is working to support numerous users and high spectral efficiency via different technologies, such as the Non-Orthogonal Multiple Access (NOMA) scheme. This paper provides a study of NOMA and how NOMA addresses the 5G requirements, ongoing standardization efforts for NOMA, and a comparative study of NOMA with other OMA schemes like orthogonal frequency division multiple access (OFDMA). The results show improved user productivity in NOMA compared to OFDMA. We also proposed a new technique called the multi-tier hybrid NOMAOMA to get the robustness of OMA and the flexibility of NOMA to increase the spectrum efficiency and the number of users. The multi-tier facilitates the user such that to reduce the interference. We also study the impact of several tiers on the capacity, the result shows that five tiers provide the best capacity in multi-tier hybrid NOMAOMA.*

***Streszczenie.** Obecna generacja sieci komórkowych wymaga przyspieszenia kroków w celu zaspokojenia przyszłego zapotrzebowania na dużą szybkość transmisji danych i niskie opóźnienia. W ramach 5G, Projekt Partnerstwa Trzeciej Generacji (3GPP) pracuje nad wsparciem wielu użytkowników i wysokiej wydajności widmowej za pomocą różnych technologii, takich jak schemat nieortogonalnego dostępu wielokrotnego (NOMA). Ten artykuł zawiera analizę NOMA i sposobu, w jaki NOMA spełnia wymagania 5G, trwające wysiłki normalizacyjne dla NOMA oraz badanie porównawcze NOMA z innymi schematami OMA, takimi jak wielokrotny dostęp z ortogonalnym podziałem częstotliwości (OFDMA). Wyniki pokazują lepszą produktywność użytkownika w NOMA w porównaniu z OFDMA. Zaproponowaliśmy również nową technikę zwaną wielowarstwową hybrydową NOMAOMA, aby uzyskać solidność OMA i elastyczność NOMA w celu zwiększenia wydajności widma i liczby użytkowników. Wielopoziomowy ułatwia użytkownikowi tak, aby zmniejszyć zakłócenia. Badamy również wpływ kilku warstw na pojemność, wynik pokazuje, że pięć warstw zapewnia najlepszą pojemność w wielowarstwowej hybrydowej NOMAOMA. (**Porównanie wydajności nieortogonalnego wielodostępu w porównaniu z ortogonalnym wielodostępem w systemach komunikacyjnych 5G**)*

Keywords: 5G, NOMA, MIMO, OFDMA.
Słowa kluczowe: 5G, NOMA, MIMO, OFDMA.

1. Introduction

In the past few decades, the telecommunication industry has been a drastic evolution in communication technologies starting from 1G to 4G [1]. The arrival of 5G presents both opportunities and challenges as it is supposed to be 1000 times faster than 4G [2][3]. This could only be accomplished by increasing efficiency across several domains using the network capacity formula, which comprises three elements. The first is higher cell density, which is achieved by using a Heterogeneous Network (HetNet) to install more cells. The second element is having a higher spectral efficiency, which is achieved using technologies such as multiple input multiple output antenna called (MIMO) and massive MIMO [3], and the third is the millimeter wave technology (mmWave) [4][5]. Even though the three significant advancements are planned to be achieved, new technologies are needed to achieve the high data rate of 5G [2].

One technology has been brought to implement 5G, in [6] the authors proposed the concept of non-orthogonal multiple access (NOMA) for the first time. NOMA provides higher spectral efficiency over orthogonal multiple access technologies (OMA) such as orthogonal frequency division multiple access (OFDMA) and code division multiple access (CDMA) and others by super-positioning multiple users in the power domain on top of OFDMA. Successive interference cancellation (SIC) technology has, also, been used to improve capacity and performance over OFDMA in the downlink.

NOMA has been in the literature over the past few years to conclude that NOMA is an essential technology for increasing the spectrum in 5G. In [7], NOMA has been studied and summarised. Different NOMA techniques, such as power and code domain and some related multiple access schemes have been investigated [7]. NOMA has sparked significant research interest as a well-qualified contender for sixth-generation (6G) mobile networks, because of its great high spectral efficiency and massive connectivity [8]. The article in [9] compared the error performance of the JT-CoMP-NOMA system to that of the NOMA system. In [10] the NOMA and sensor node selection techniques are investigated over Rayleigh fading in a relaying wireless sensor network (WSN). The article in [11] shows the performance of the NOMA system is evaluated using organized (uniform), random, and distance-based user matching techniques. The article [12] has used the DDPG algorithm to develop an efficient IRS-NOMA communication system. By adjusting the settings in power, frequency, bandwidth, and the number of user areas, NOMA was shown to be the closest from OFDMA technology to LTE. The energy improvement of NOMA is predicted to be greater than that of OFDMA.

In this paper, Firstly, studied the effect of transmitting power, bandwidth, number of users, cell radius, and number of tiers on the system capacity for each of the techniques NOMA and OMA, and choosing the best values for each of the above variables to conduct the study on. Then, proposed a mix-type between NOMA and OMA called hybrid NOMA or NOMAOMA, that provides better capacity in different scenarios, such as transmitted power, bandwidths, number of users, cell sizes, and number of tiers in the cell. The design and the architecture of cells have been clearly described and explained in the paper. We also study the impact of multiple tiers on the capacity, we will find the best number of tiers that provide the best capacity in NOMA, OMA, and multi-tier hybrid NOMAOMA.

The rest of the paper is structured as follows: the working concept of NOMA is described in Section 2, which discusses the use of NOMA in the uplink and downlink. Section 3 explains the relationship between NOMA and OMA and Section 4 described the hybrid technique of NOMA and OMA and explains the new model architecture. Section 5 describes the simulation and results of the comparison of NOMA with other OFDMA techniques. Section 6 summarizes the work of the authors and concludes the paper.

2. Developing the model

NOMA is a novel type of multiple access system that has never been used in 2G, 3G, or 4G networks. It provides for regulated interference by assigning time, frequency, and code block resources to many users in a non-orthogonal yet sophisticated manner. The non-orthogonality in NOMA is intentionally introduced so that improved spectral efficiency and massive connectivity can be obtained [6], [13], [14], [15], [16], [17]. There are two forms of NOMA: power domain multiplexing and code domain multiplexing. We will discuss the SIC to conduct the study for uplink and downlink.

2.1 Successive Interference Cancellation (SIC)

When using the NOMA concept, there could be numerous users supported by the NOMA group. However, in practice, when the number of users increases, Multiple Access Interference (MAI) limits the capacity of the NOMA system. Network capacity can be improved via the use of better interference management techniques.

Several techniques have been used to reduce the challenges caused by interference. In the case of the NOMA power field, the SIC was found to be very efficient and outperform parallel interference cancellation (PIC) when the power level difference between paired users is large, operating iteratively and thus causing less hardware complexity than the combined decoding approach [18].

It is very important to allocate sufficient power to the first detected signal so that the probability of its detection error will be minimum. To solve the drawbacks of SIC in decoding, better ways of interference-avoiding techniques should be applied, such as coverage rate /outage where the impact of these imperfections/failures in decoding can be captured in a more accurate manner [19].

Power domain NOMA performs better when two or more users share the same resource block. As the number of users increases, the power level difference among users decreases. As a result, co-channel interference will be strong and will cause severe performance degradation of the power domain NOMA. Therefore, in order to have a better performance, different approaches can be employed. For example, in the downlink, users on the cell edge are more vulnerable to inter-cell rather than intra-cell interference. Therefore, exploiting coordinated multi-point transmissions can mitigate interference at the cell-edge users. [19], [20].

2.2 Downlink and Uplink Power Domain in NOMA Equations

From Fig. 1, the transmission power in the downlink scenario is divided between User'1 and User'2. When allocating a transmit power to each user, fine-tuning must be done to enable better detection accuracy of individual signals in the receiver. Therefore, less power is allocated to User 1 (closers to the base station) because it has better channel state information (CSI) while more power is allocated to User 2 which has a worse channel gain. This helps a user with a bad channel gain face less interference than a user with a good channel gain. A SIC is implemented to uniquely extract and decode User1's signal. The reason for applying a SIC only in user 1 signal and not in user 2 as that user 1's signal has less power than user 2. In user 1 the signal cannot be utilized unless user 2's signal is removed from the overlapped using SIC. Whereas if the User 2 signal is detected, SIC is not used because the User 2 signal is stronger than the User 1 signal and is not subject to interference from other signals.

For the case of uplink, the principle of SIC is similar to that of downlink NOMA in which the signal of the strong user is detected first by implementing a SIC on the received signal, then followed by the detection of the weak user signal as shown in Fig. 2.

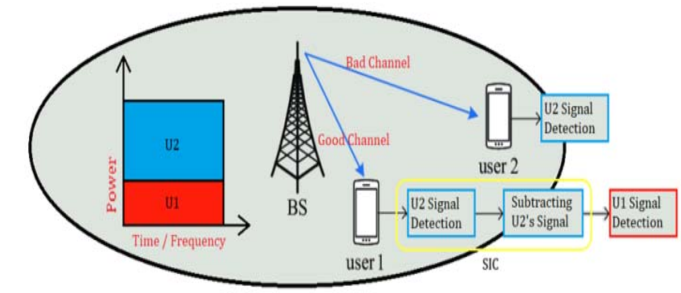

Fig. 1 Downlink power domain in NOMA

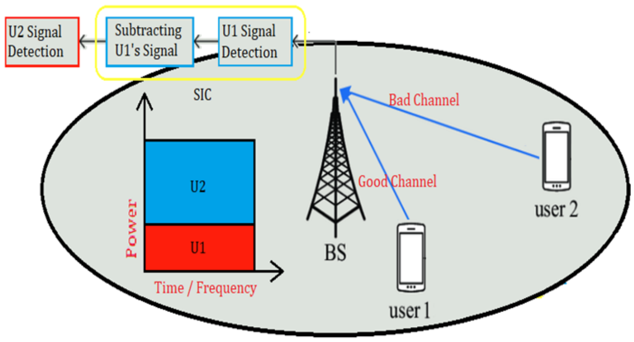

Fig. 2 Uplink power domain in NOMA.

3. The relationship between NOMA and cOMA

The mathematical relationship between NOMA and OMA can be determined by transmitting the NOMA downlink to two users. Consider h_1 and h_2 are the Rayleigh channel parameters for users 1 and 2. The signal-to-noise ratio (SNR) of the transmission at the base station is represented by f and is imposed $|h_1|^2 < |h_2|^2$.

The normalized throughput of typical multiple-access systems may be given to users 1 and 2 using the notion of Shannon's channel capacity theory and power control [4], [21], [22], [23], [24], [25].

(1) $$R_1^{OMA} = \beta\ x\ \log_2(1+\frac{\alpha_1 f}{\beta}|h_1|^2) ,$$

(2) $$R_2^{OMA} = (1-\beta)\ x\ \log_2(1+\frac{\alpha_1 f}{1-\beta}|h_2|^2) ,$$

where α1 and α2 are the power allocation coefficients. These coefficients satisfy the condition α_1+α_2=1. Whereas β is a normalized parameter between 0 and 1 that stands for the resource allocation coefficient. When power control is not considered at the base station, equations (1) and equation (2) can be re-written into the following form:

(3) $$R_1^{OMA} = \beta\ x\ \log_2(1+f|h_1|^2) ,$$

(4) $$R_2^{OMA} = (1-\beta)\ x\ \log_2(1+f|h_2|^2) ,$$

Form k uses the throughput for *i* user is

(5) $$R_i^{OMA} = (\beta/k)\ x\ \log_2(1+f|h_k|^2) .$$

For NOMA, we have the throughput of users 1 and 2 given by [4].

(6) $$R_1^{NOMA} = \log_2(1+\frac{\alpha_1 f|h_1|^2}{1+\alpha_2 f|h_1|^2}) ,$$

(7) $$R_2^{NOMA} = \log_2(1+\alpha_2 f|h_2|^2) .$$

For k users, the throughput for *i* user is

$$R_i^{\mathrm{NOMA}} = \log_2\left(1 + \frac{\alpha_i f|h_1|^2}{1+\sum_{j\neq i}^{k}\alpha_j f|h_1|^2}\right) \quad (8)$$

When equal time or frequency resources are allocated to each user at very high SNRs, the overall throughput of OMA and NOMA systems can be derived from the above equations and written as [4]:

$$R_{sum}^{OMA} \approx \log_2\left(f\sqrt{|h_1|^2|h_2|^2}\right), \quad (9)$$

$$R_{sum}^{NOMA} \approx \log_2\left(f|h_2|^2\right) \ . \quad (10)$$

Finally, the overall throughput gain for NOMA over OMA can be expressed as:

$$R_{sum}^{Gain} = R_{sum}^{NOMA} - R_{sum}^{OMA} = \frac{1}{2}\log_2\left(\frac{|h2|^2}{|h1|^2}\right) . \quad (11)$$

It is clear from equation (9) that NOMA has a higher overall throughput than OMA, and that this advantage is gained as the channel circumstances for the two users become more dissimilar, however, OMA provides a better multiband that is not available in NOMA.

4. multi-tier hybrid technique of NOMA and OMA

4.1. Why Hybrid NOMA

In OFDMA, which is the most advanced multiple access technique among OMA communication systems, the power transmitted to each user is equal but the bandwidth will divide by the number of users in the cell, as shown in Fig. 3-a. Each user is assigned a specific bandwidth, which is not shared inside the tier.

In NOMA, every user is allowed to use all available bandwidth, but the power will be divided by the number of users, as shown in Fig. 3-b. Therefore, the number of levels in power is equal to the number of users in the cell.

In our new multi-tier hybrid technology between NOMA and OMA is proposed, the OFDMA technique will be used to divide the bandwidth to multi-band according to the number of users. And each sub-band will apply NOMA on it, that means, in each sub-band, the power will be divided into multi-level, and the number of these levels equals the number of users in each cell, as shown in Fig. 3-c. Then, for k users throughput can be:

$$R_i^{\mathrm{NOMA}} = (\beta/k)\ x\ \log_2\left(1 + \frac{\alpha_i f|h_1|^2}{1+\frac{1}{k}\sum_{j\neq i}^{k}\alpha_j f|h_1|^2}\right) \quad (12)$$

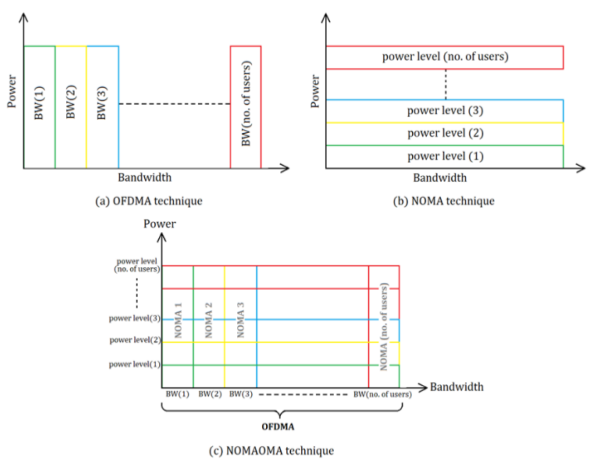

Fig. 3 OFDMA, NOMA, and NOMAOMA techniques.

4.2 Model Architecture

We compare the models of NOMA, OFDMA (OMA), and hybrid NOMAOMA systems, using the MATLAB program to simulate the models and obtain results. Model A considers a cell with different coverage states, as shown in Fig. (4). The user's distribution inside the cell is randomly simulated, such that the number of users in every tier will not exceed 10 users per tier. So, the maximum number of users inside the cell in this model will be 100 users. The frequency used in this simulation is 3.6 GHz.

Five parameters were modified through the simulation: number of cells, bandwidth-per-tier, power, number of total users, and radius of the cell. These parameters were investigated to see their impact on performing all techniques. The typical values of these parameters are shown in table 1:

Table 1. System parameters.

number of tiers	1-10
Bandwidth	5-50 MHz
Power	up to 100 watts
Number of users in the cell	20-50
Radius for cell	up to 1Km

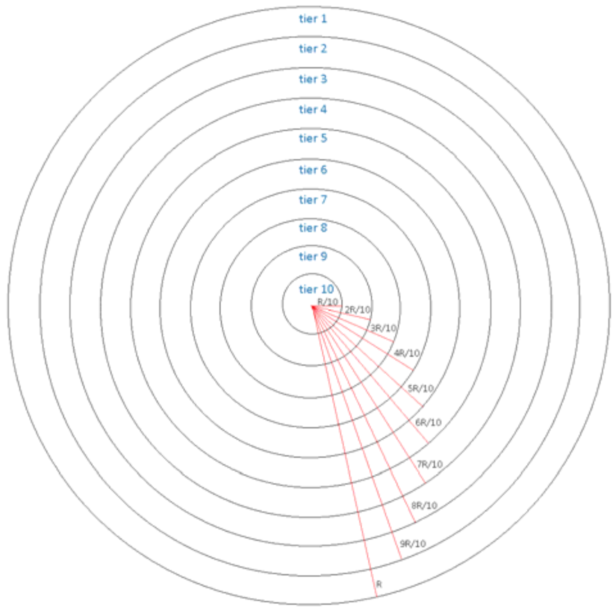

Fig. 4 divides the cell into multi-tiers.

5. Results and Discussion

In this paper, we study the cases of OFDM, NOMA, and the new NOMAOMA. First, in OFDMA, the bandwidth will be divided by the number of users in each tier. In NOMA, the number of multi-level power is equal to the number of users in the tier. In the NOMAOMA, after finding the number of users in every tier, the bandwidth will be divided into multi-band according to the number of users. Further, in each sub-band, the power will be divided into multi-levels equal to the number of users in each tier. The capacity for each technique is the sum of the capacities of all users in the cell. And the capacity for each user is calculated according to Shannon's Law

$$C = W * log_2(1 + SINR) \ . \quad (13)$$

For the received signal of each user, only take into account the losses due to free-space propagation as a large-scale fading channel, which depends on the distance to the base station.

All the results of NOMA, OFDMA, and NOMAOMA capacities are the average of ten iterations with the same parameter values, to get more reliable results. Regarding the available power, the results show that NOMA capacity obtains a higher difference from OFDMA capacity when the available power increase. But the capacity of the

NOMAOMA system is bigger than NOMA and OFDMA systems as shown in Fig. 5. This is due to how the increment in power affects the SINR and how this is reflected in the capacity. In the case of OFDMA, each user is provided with a high SINR since there is no interference from other users. On the other hand, NOMA's users have a much lower SINR because of the interference of the other users in the tier who are using the same band of frequency. But, the hybrid system will have less SINR because the interference will reduce. Since in Shannon's law for the capacity the SINR is located inside a logarithm, improvements in the SINR when it is low will make a higher impact on the capacity than when the SINR is already high.

When increasing the bandwidth, NOMA manages to outperform OFDMA, as shown in Fig. 6. The capacity of the hybrid system is surpassing the capacity of both techniques, NOMA and OFDMA. Therefore, an increment in the bandwidth will cause more improvement in NOMAOMA and then NOMA capacity.

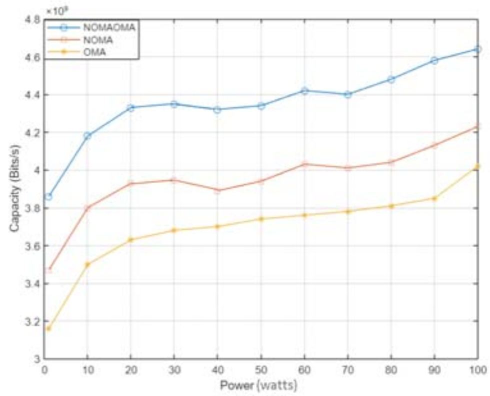

Fig. 5 Capacity of systems NOMA, OFDMA and NOMAOMA as a function of power.

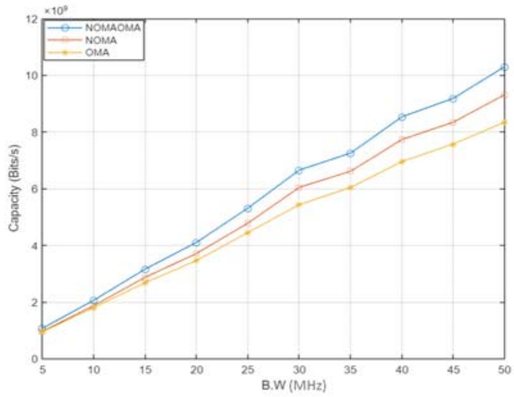

Fig. 6 Capacity of systems NOMA, OFDMA and NOMAOMA as a function of bandwidth.

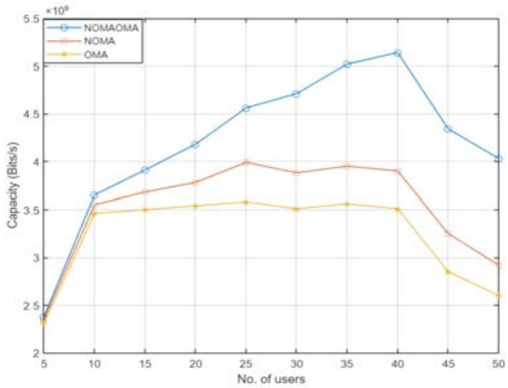

Fig. 7 Capacity of systems NOMA & OFDMA as a function of no. of users.

The multiple access technique chosen for 5G must sustain a great number of users, as we know. Therefore, NOMA should present a better performance than OFDMA when users increase. But, the hybrid technique has the best performance of the two techniques. The simulation proves that, because of the reuse of the frequency band in NOMA, the NOMA capacity keeps increasing as the number of users goes up. But, if the increase in the number of users continues, the signal interference will increase and the capacitance of all technologies will decrease, as shown in Fig. (7).

The performance as a function of the radius of the cell is done, and the comparison is done between the three techniques. In general, when the radius increases, the capacity will decrease. But still, the capacity of NOMAOMA is outperforming the capacity of NOMA and OFDMA, as shown in Fig. (8).

The last comparison between the techniques is a function of the number of tiers, as shown in Fig. (9). From Fig. (9), the capacity of the three techniques is reached to top amount in five tiers, for this rezone it has been used five cells a default value of a number of cells in other results.

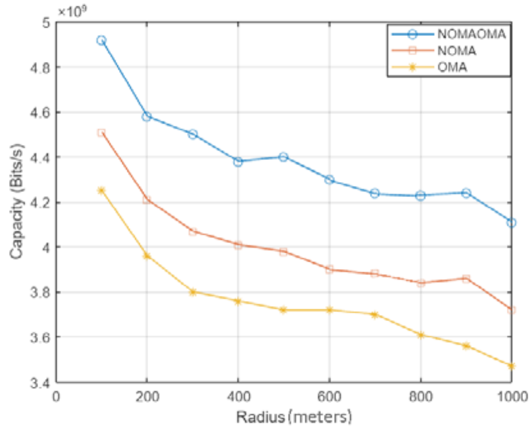

Fig. 8. The capacity of systems NOMA, OFDMA, and NOMAOMA as a function of the radius of the cell.

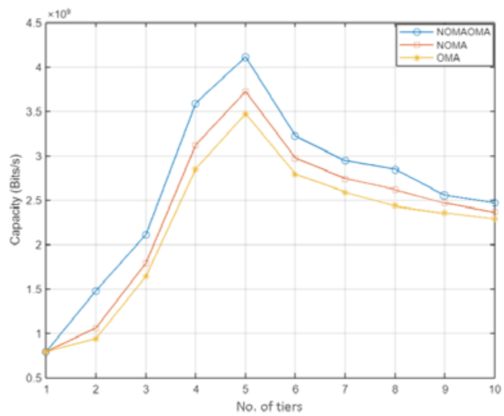

Fig. 9. The capacity of systems NOMA, OFDMA, and NOMAOMA as a function of the number of tiers.

6. Conclusion

In this paper, we study the capacity of NOMA and OMA against five variable dimensions, such as power, bandwidth, number of users, cell radius, and cell count. The results show that NOMA outperforms the results of OMA. We also proposed a multi-tier hybrid NOMAOMA scheme to increase the capacity. The results show that the higher the transmit power and the bandwidth provides, the higher the capacity. As for the number of users, in the Noma and OMA systems, the increase in the number of users does not affect the system capacity for values between (10 to 40) users, but in the hybrid NOMAOMA system, the capacity increases directly with the number of users for the same values, until 40 users, the relationship starts to decrease with the capacitance for the three systems. Furthermore, for the cell diameter, it is inversely proportional to the capacitance for all systems. For cell division, it was noted that the best number of cell divisions is 5 tiers, which provides the best result in capacity for the three systems.

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