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A novel method for improving the capacity in 5G mobile networks combining NOMA and OMA

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Abstract — **Non-Orthogonal Multiple Access (NOMA) has been suggested as one of the technologies to be implemented in the fifth generation - 5G - mobile networks. NOMA helps increasing the capacity by offering a more effective use of the available resources, but it also intentionally introduces interference in the transmitted signal. This means that higher signal-to-interference-plus-noise ratio (SINR) values are required to decode the received signal, in comparison to orthogonal multiple access (OMA). Since it is unrealistic to consider a system working only with NOMA because not all the users (UEs) will meet the requirements to use this multiple access (MA) method, a hybrid MA system combining NOMA with OMA is expected. In this paper we present the performance evaluation of a hybrid MA system combined with a novel pairing algorithm based on modulation and coding scheme (MCS) adjustment and extra transmission power (Tx power) allocation. The purpose of such pairing approach is to help the NOMA UEs reach the needed SINR while improving the overall system capacity. Moreover, we use mmWave for the signal propagation to further increase the system capacity. The results show that such a system with an extra Tx power between 14% and 19% of the total Tx power for OMA, can offer the best tradeoff with a system capacity gain up to 1.78-fold for a total of 6.7 Gbps, an average 3.31-fold increase for the UEs bit rate, and a block error rate (BLER) below 10%.**

Keywords—NOMA, hybrid MA, capacity, power allocation, BLER, SINR, MCS, 5G

I. Introduction

Among the key capabilities expected for the fifth generation of mobile networks – 5G networks –, higher system capacity is one of the most important and challenging. 5G networks must be able to cope with the continuously increasing data demand that will be driven mainly by the Internet of Things (IoT) and video streaming applications. The maximum achievable bit rate per user/device in 5G networks should reach values in the order of Gbits/s under ideal conditions, and ubiquitous connection in the order of Mbits/s or Gbits/s should be guaranteed across the coverage area of the network[1]. Non-orthogonal multiple access (NOMA) is one of the radio access technologies proposed so far as a possible option to satisfy the future capacity demands[2].

NOMA, unlike the orthogonal multiple access (OMA) methods, exploits the power domain by multiplexing the users (UEs) and intentionally introducing interference by sharing the same resources without spatial separation. This can be done by implementing superposition techniques [4]. NOMA have been considered as part of possible implementations for 5G networks, the works in [2]–[4] are some examples. Our work in [5] presents a performance analysis for a 5G NOMA system combined with mmWave frequencies; the results showed that although up to 70% of channel capacity gain can be achieved by implementing NOMA instead of OMA, a penalty of about 12 dB in the minimum required signal-to-interference-plus-noise ratio (SINR) is needed in order to maintain a block error rate (BLER) below 10%. Furthermore, in [5] it is concluded that a successful signal decoding with NOMA is possible only when a QPSK modulation is assigned to one of the power multiplexed UE. This means that not all the UEs within the cell can be paired. Hence, it is sub-optimal to consider NOMA as the only multiple access (MA) method; on the contrary, a hybrid system combining NOMA with OMA is expected, along with possible modulation and coding scheme (MCS) adjustment to make up for the extra SINR, when needed.

The implementation of such hybrid system has also been suggested by other authors. In [4], cooperative NOMA is suggested as a technique to improve the signal decoding, but due to the complexity of a NOMA only system, a hybrid MA approach is suggested. In [6], the performance of a system switching between three types of non-orthogonal transmissions and OMA is evaluated.

Moreover, the work in [7] shows how the combinations of NOMA and OMA offers the largest rate regions in a two-user interference channel, following the Han-Kobayashi scheme [8], which it its basic form implies NOMA. The works in [9] and [10] focus on the improvement in spectral efficiency of multicarrier (MC) NOMA. In [9] an optimal power and subcarrier allocation algorithm for full-duplex MC-NOMA, designed to maximized the weighted sum throughput in such, is proposed. In [10] also an optimal power allocation is proposed for MC-NOMA based on quality of service (QoS) constrains under statistical channel state information (CSI) at the transmitter. Both [9] and [10] compare the performance of the proposed methods with OMA systems, showing that a NOMA implementation outperforms OMA in terms of spectral efficiency.

Up to date, no previous studies have evaluated the performance of a hybrid MA system focusing on techniques that help increasing the total system capacity while maintaining desirable BLER values. The purpose of this paper is to evaluate the UEs bit rate gain, system capacity gain, power consumption, and BLER, of a system that implements hybrid MA scheduling. We combine this system with a pairing method for NOMA based on MCS adjustment and extra transmission power (Tx power) allocation in order to reach the needed SINR values and maintain a BLER below 10%. Moreover, we combine this system with mmWave wireless transmission to further increase the overall system capacity.

II. NOMA FUNDAMENTALS

A. NOMA Overview

MA techniques increase the network capacity by using the resources in a more effective way than in single user transmissions. Unlike orthogonal division multiple access (OFDMA) used in the DL in Long Term Evolution (LTE) networks, NOMA takes advantages of the channel rate quantization, allowing an UE to access a portion of the power resources allocated to another UE, and that do not help improving the data rate of the latter. The principle behind NOMA consists on pairing UEs with large channel gain difference; this difference is then translated into multiplexing gain [11]. In NOMA UEs are multiplexed in the same time/frequency resources; this is possible by implementing superposition transmission schemes and adaptive power allocation in the transmitter. The power ratio assigned to an allocated UE will depend on its channel conditions; the lower the channel gain, the higher the power ratio. Fig. 1 shows a resource allocation comparison between OMA and NOMA for two UEs. In the receiver, interference cancellation (IC) techniques are used.

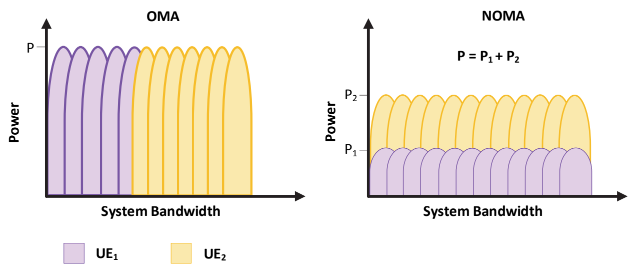

Fig. 1 Resource allocation comparison for OMA and NOMA for two UEs.

B. Superposition transmission

Superposition transmission is a physical layer technique that allows the transmitter to simultaneously send independent signals to different UEs. The number of UEs selected to be allocated in the same time/frequency resources can vary depending on the system configuration. However, the more users are paired together, the more interference there will be in the received signal, resulting in a higher BLER and hence in an increased number of retransmissions. After implementing superposition transmission for two UEs, the transmitted signal would be as follows:

$$x = \sqrt{P_1}x_1 + \sqrt{P_2}x_2 \tag{1}$$

where x_i and P_i are the signal from UE_i and its power ratio, respectively; the maximum transmission power $P_{TX_{max}} = P_1 + P_2$. If no adaptive power is implemented in the transmitter, $P_i = P_{TXmax}$.

C. Receiver Schemes

The joint transmissions in NOMA cause a large amount of interference in the received signal. To mitigate the interference effect, IC methods can be applied. The received signal by UE_i will be of the form:

$$y_i = h_i x + w_i \tag{2}$$

where x is the transmitted superposed signal, h_i represents the complex channel coefficient between the UE_i and the base station (BS), and w_i represents the Gaussian noise plus interference received by UE_i. The optimal order for decoding the received signal in NOMA, is in the order of increasing channel gain normalized by the noise and inter-cell interference power, $|h_i|^2/N_{0,i}$ [2]. Assuming that UE_1 has better channel conditions than UE_2, $|h_1|^2/N_{0,1} > |h_2|^2/N_{0,2}$, then the signal from the UE_2 would be the first in the decoding order. Therefore, UE_2 can decode its message from the superpositioned signal with a linear receiver, treating the signal from UE_1 in y_2 as additional interference. For UE_1, the decoding process consists on first decoding and reconstructing the UE_2 signal, and subtracting it from y_1.

III. SYSTEM MODEL

In the model developed, a single cell was considered with LTE as the wireless technology; only the DL transmission was analyzed. The number of UEs was limited to 50, and they were randomly located following a normal distribution with mean $\mu = 25$, and standard deviation $\sigma = 10$. For simplicity reasons, no mobility was considered; the reason for this is that since the channel can considerably vary when using mmWave, an approach as the one proposed with these frequencies would be limited to stationary or semi-stationary environments. The size of the packet to be transmitted to the scheduled UEs was chosen randomly, from 16 to 97880 bits. If the TBS assigned to a UE was not enough to send the whole packet, a total of bits equal to the TBS were sent and the rest of the bits were buffered. For the PRBs allocation, the UEs were divided into four groups according to the modulation order and the PRBs assigned to each group were proportional to the number of UEs; a minimum of two PRBs was set.

The MCS assignment and resources allocation in the model is done in two steps. In the first step a preliminary assignment is done and only the channel quality indicator (CQI) reported by each UE is used as a reference; the UEs map the wideband SINR calculated through simulations into a CQI value. The minimum SINR for each CQI was estimated in the model under constrains of a 10% BLER and assuming an OMA transmission (without considering co-cahnnel interference). In the second step the system evaluates which UEs, if any, are candidates for NOMA. To determine this, a pairing method based on MCS adjustment and extra Tx power allocation is implemented. Such pairing guarantees that the throughput of each UE using NOMA either remains the same as in OMA or increases.

A. Proposed pairing algortihm with MCS adjustment and extra Tx power allocation

The purpose of implementing a MCS adjustment when pairing the UEs in NOMA, is to compensate for the higher SINR needed, in comparison to OMA, to successfully decode the received superposed signal [5]. In the proposed pairing algorithm all possible pairs are tested, starting with those with the highest channel gain difference, e.g., UE_1 with 256QAM and UE_2 with QPSK. The condition to determine whether two UEs can be paired or not, is that the throughput of each UE must not be degraded. To do this the transport block size (TBS) must remain the same or be bigger than with OMA. If the MCS is adjusted to a more robust value, the only way to guarantee the same TBS is to assign more physical resource blocks (PRBs). When in NOMA, more PRBs can be assigned to a UE by pairing it with another UE. However, as the extra SINR needed is on average 12 dB [5], if the MCS adjustment is not enough to cover such difference while guaranteeing that the throughput will not be degraded, there is the possibility that only a few (i.e., 2 or 4) or none of the UEs can be paired. Moreover, it is important to consider that at least one of the paired UEs has to use QPSK as modulation [5]; otherwise the superposed constellation becomes too complex to decode. This only lowers the possibilities of finding suitable UEs to pair.

To overcome this limitation, extra Tx power allocation can be considered. For example, let us assume that for OMA, the BS is not transmitting at the maximum regulated power, because lower Tx power is enough to guarantee the desired BLER and to cover the desired area. Then, a Tx power headroom can be considered in a hybrid MA system for the subcarriers that are using NOMA, as long as the total Tx power does not exceed the regulated maximum limit. By allocating extra Tx power when needed in NOMA, it is then possible to provide the extra dBs that cannot be provided with the MCS adjustment to reach the desired SINR. Although allocating extra Tx power to some UEs could be considered going against the idea of having 5G networks that are more energy efficient, if such extra power does not exceed the regulations, it could help increasing the probabilities of having UEs paired which impacts directly on the total channel capacity.

For the proposed pairing method to work effectively, extra signaling information needs to be shared between the BS and the UEs. Since the BS does not know the exact value of the SINR that the UE experiences, the latter needs to inform the BS if the MCS adjustment is enough or if extra Tx power needs to be sent to cover the extra dBs needed in the SINR. Table 1 shows the grouping method used to classify the UEs during the pairing process; this method aims at giving priority to the UEs with the larger difference in channel gain. A total of six iterations are run to test all the possible pairs as long as the modulations of the UEs are different. In Fig. 2 the logical process of the pairing algorithm is shown.

B. User bit rate

The rate of each UE depends on the MA method that was used for their scheduling. Assuming that a UE occupies β of the total bandwidth, B, during a subframe, then the bit rate for that UE with OMA can be calculated as:

$$R_{OMA} = B * \beta * \log_2(1 + SINR) \quad (3)$$

With NOMA, the UE rate depends as well on the power allocated, α, and can be calculated as [6]:

$$R_{NOMA} = B * \beta * \log_2(1 + (\alpha * SINR)) \quad (4)$$

Table 1 Modulation of the UEs ∈ Group X, with X=1,2 for each iteration *i* of the proposed pairing method

i	1	2	3	4	5	6
Group 1	256QAM	256QAM	256QAM	64QAM	64QAM	16QAM
Group 2	QPSK	16QAM	64QAM	QPSK	16QAM	QPSK

Proposed pairing algorithm

Input:
Group 1 and group 2 for each iteration (Table 1)
Maximum allowed extra power (mep)
Preliminary PRBs, MCS and TBS for all UEs in each group

for iteration=1 to 6 **do**
  Update group1 and group 2
  M=number UEs in group1, N= number UEs in group2, m=1, n=1
  while m<=M **do**
    if UE_m not paired **then**
      while n<=N **do**
        if UE_n not paired **do**
          TPRBs = Sum preliminary PRBs for UE_m and UE_n
          if MCS adjustment is activated **do**
            Find new MCS < preliminary MCS, new TBS>=preliminary TBS for UE_m and UE_n with TPRBs and throughput constraints
          end if
          if modulation for UE_n equals QPSK **do**
            Calculate extra transmission power needed
            if extra transmission power <= mep **do**
              Pair UE_m with UE_n
              Update MCS, TBS, PRBs, and extra transmission power for UE_m and UE_n
            end if
          end if
        end if
        n=n+1
      end while
    end if
    m=m+1
  end while
end for

Output: UEs paired and their new MCS, new TBS, and extra Tx power for each pair

Fig. 2 Proposed pairing algorithm for NOMA based on MCS adjustment and extra Tx power allocation

IV. Performance Evaluation

Table 2 shows the six study cases considered for the evaluation of the hybrid MA system, where the percentage of maximum extra Tx power is based on the Tx power for OMA. In Table 3, the extra Tx power for case 6 is based only the value reported by the UE to reach the extra 12 dB needed in the SINR. The propagation parameters used for the simulations are shown in Table 3; UE_1 is assumed to be the UE with highest channel gain. The performance evaluation was based on four system aspects: the UE's bit rate, the overall system capacity, the required extra Tx power, and the BLER. For all the results shown in this paper, an OMA only system was used as benchmark. The results are shown in Fig3 – Fig 6 and they were averaged over different runs of the model, with 100 subframes being transmitted in each run.

If we focus on the UEs bit rate, we can see from Fig. 3 that with the case 6 some of the UEs can experience up to a 30-fold increase in their bit rate, with 90% of the UEs experiencing increases up to 9.4-fold. The reason for the high increase in this case is that there is no limit in the extra Tx power that can be allocated to the NOMA UEs, therefore two UEs which require a large amount of extra power can still be paired. Hence, their bit rate will significantly increase since NOMA is more effective as the difference in the channel gains is larger. Case 5 was the one that offered the lowest performance, with no UEs paired. The reason for this is that the maximum 10% extra power for this case was not enough to make up for the extra dBs needed in the SINR. Cases 2 and 3 showed a similar performance, and the same trend was shown for cases 1 and 4. Table 4 summarizes the results shown in Fig. 3 for the 90th, 80th, and 50th percentile.

Table 2 Study cases

Case	1	2	3	4	5	6
MCS adjusment	Yes	Yes	Yes	Yes	Yes	No
Maximum extra TX power	0%	75%	50%	25%	10%	Unlimited

Table 3 Simulation parameters [12]

Carrier Frequency	73 GHz
Channel Bandwidth	800 MHz
Coding /Decoding	Turbo coding
Modulation Scheme	QPSK, 16QAM, 64QAM, 256QAM
Maximum DL Tx Power	30 dBm
DL Tx Power	15 dBm
Power allocation factor per UE	OMA: 1
	NOMA: 0.25 for UE1 and 0.75 for UE2
Waveform	OFDM
Transmission mode	SISO
TX Antenna Gain	37 dBi
Path Loss Model	P_L=69.8dB+A log(d)+x_σ [1]
Channel estimation	MMSE
RX Antenna Gain	0 dBi
Noise figure	6 dB
Receiver type	OMA: LMMSE
	NOMA: SLIC for UE1 and LMMSE-IRC for UE2

[1] x_σ represents the shadowing factor and it is a radom Gaussian variable with mean zero and standard deviation σ =5.2 dB for LOS and σ =57.6 dB for NLOS. For LOS the constant A =20 and for NLOS A=33 [12]

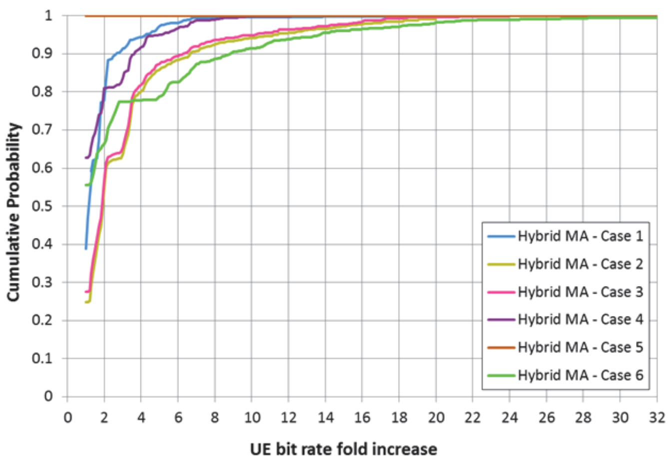

Fig. 3 Cumulative probability for the UEs bit rate fold increase for a hybrid MA system, using an OMA only system as benchmark

Table 4 UEs bit rate fold increase for the 90th, 80th and 50th percentile for a hybrid MA system, using an OMA only system as benchmark

	Case	1	2	3	4	5	6
Percentile	90th	2.7	6.7	6.3	3.8	1	9.4
	80th	2.1	4	3.7	2	1	5.3
	50th	1.1	1.9	1.9	1	1	1

If we now analyze the overall system capacity, we can see from Fig. 4 that case 2 is the one that offers the best performance with a 1.78-fold increase, corresponding to a channel capacity of approximately 6.7 Gbps. If we also look at Fig. 5 which shows the UEs pairing probability, we can see that case 2 is the one with the highest pairing probability, along with case 1, with 0.4. For case 2 this is because when combining the MCS adjustment with a high percentage of extra Tx power (e.g., 75%) is more likely to reach the average extra dBs needed in the SINR values, which also impacts on the UEs bit rate (equations 3 and 4). For case 1, although it also showed the highest pairing probability, as it does not implement extra Tx power allocation, the UEs bit rate is lower than in case 2, as confirmed in Fig. 4, with a 1.12-fold increase. Case 3, with 50% maximum extra Tx Power, offered a pairing probability similar to cases 1 and 2, with 0.46 for a 1.72 fold increase in the system. For case 5 there was no gain in the system capacity, since no UEs met the requirements to be paired.

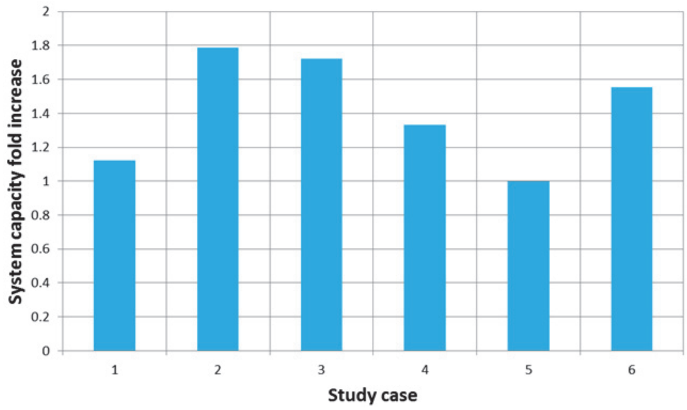

Fig. 4 System capacity fold increase for a hybrid MA system, using an OMA only system as benchmark

The performance for cases 4 and 6 was very similar with 1.33 and 1.55-fold increase in the system capacity, and pairing probabilities of 0.24 and 0.28, respectively. The reason for this behavior is that, although for case 6 the UEs bit rate was superior than for case 4, there is no MCS adjustment in case 6. As stated earlier, at least one of the paired UEs in NOMA has to have QPSK as modulation. When MCS adjustment is implemented, some of the UEs with higher order modulations can be assigned a QPSK modulation, which increases the probability of having candidates to be paired for NOMA.

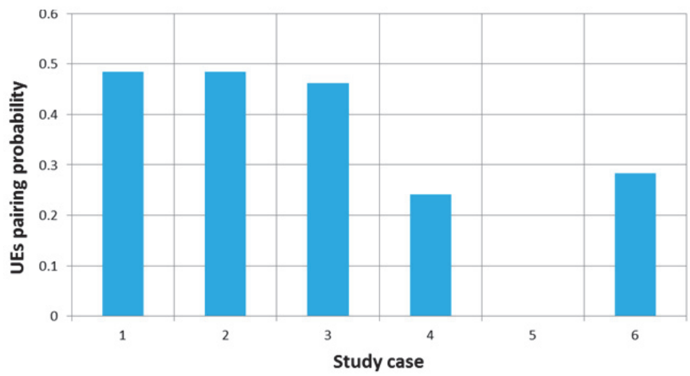

Fig. 5 UEs pairing probability for a hybrid MA system

From a power consumption point of view, the results are shown in Fig. 6. For case 1 there is no extra Tx power allocated, while for case 6 there is no limit in the amount of extra power that can be assigned for the NOMA transmissions. We can see that case 6 requires an average of 73% extra power. For case 5 a higher power allocation should be considered if the main concern relies on the overall system capacity. A higher power allocation along with the CQI adjustment leads to more NOMA UEs and a higher system capacity. Case 4 requires on average 14% of extra Tx power, 11% less that the maximum allowable. This is an indication that this amount of maximum extra power could offer a good tradeoff between power consumption and system capacity. Cases 2 and 3, require on average less power than the maximum allowable, with 19% and 18%, respectively. These results confirm that no more than 14-19% of extra Tx power would be necessary to expect a significant performance improvement. Finally, from a BLER perspective, all the cases except case 1 offered a BLER below 10%, which is usually the maximum allowable. For case 1, the BLER could reach values up to 30%; this is because since there is no extra power allocation for this case, some of the paired UEs require extra dBs to reach the SINR values needed to successfully decode the received superposed signal.

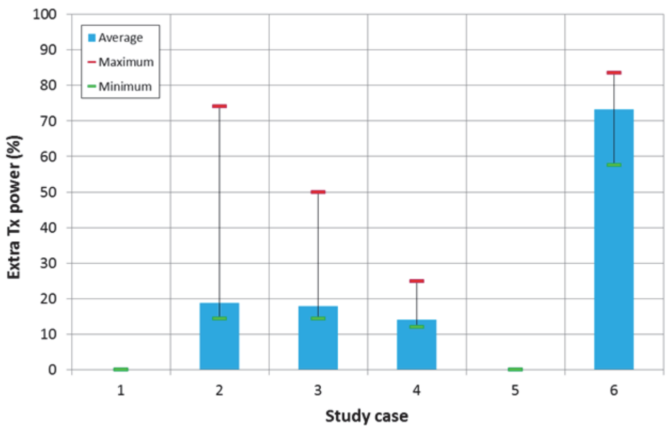

Fig. 6 Extra Tx power for the NOMA UEs in a hybrid MA system

From the results analysis we can conclude that best tradeoffs between the UEs bit rates, overall system capacity, power consumption, and BLER, are achieved when a hybrid MA system is implemented along with MCS adjustment and extra Tx power allocation for the NOMA transmissions. In the case of applying MCS adjustment but not extra Tx power allocation, the BLER values might be higher than the maximum desired, which eventually affects the QoS since the number of HARQ retransmissions will increase. If on the contrary, no MCS adjustment in performed, and all the needed extra Tx power is allocated, there would be an improvement in the system performance but not a significant one if compared with other cases, at the expenses of using on average 73% extra Tx power.

We therefore suggest an implementation of a hybrid MA system with a pairing algorithm based on MCS adjustment and an allowed extra Tx power allocation between 14% and 19% (e.g., cases 2, 3 and 4), since with this configuration the UEs bit rates average fold increase could be between 1.75-3.31, the overall system capacity could also increase between 1.33 and 1.78-fold, corresponding to approximately 5.1-6.7 Gbps, and the BLER will remain below 10%.

With this proposed method a significant gain can be achieved in the overall system capacity when a Tx power headroom is available. Moreover, the only additional signaling needed, in comparison with any NOMA implementation, is to verify whether the MCS adjustment was enough for the UE to achieve the desired SINR with NOMA or if extra Tx power is needed. Hence, the impact of this method in the signaling overhead is expected to be low.

V. Conclusions

In this paper we presented the performance evaluation of a hybrid MA system, combining OMA and NOMA, combined with a proposed pairing algorithm based on MCS adjustment and extra Tx power allocation techniques. The purpose of using these techniques is to aid the UEs reaching the extra dBs needed in the SINR when NOMA is implemented instead of OMA. Moreover, we used mmWave for the signal propagation to further increase the system capacity. We evaluated six cases for the hybrid MA system: one with only MCS adjustment and no extra Tx power allocation; one with unlimited extra Tx power allocation and no MCS adjustment, and four combining both proposed techniques for different percentages of maximum extra Tx power. The results show that implementing the proposed hybrid MA system jointly with the MCS and power adjustment offers the best tradeoff in terms of UEs bit rate, overall system capacity, power consumption and BLER. Moreover, we show that allowing an extra Tx power allocation between 14% and 19% can offer the best performance, with a system capacity gain up to 1.78-fold for an approximate of 6.7 Gbps, an average UE bit rate increase up to 3.31-fold, and a BLER below 10%.

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