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Performance Analysis of Spectrum and Energy Efficiency in Millimeter-Wave Massive MIMO-NOMA and MIMO-OMA

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ABSTRACT

Non-orthogonal multiple access (NOMA) is multiple access technology that is employed in the fifth-generation (5G) wireless communication systems since, it serve multiple users at same time and frequency. Based on the power level users are differentiated. It offers high energy and spectral efficient communication for growing different quality of service (QoS) requirements. Non-orthogonal multiple access (NOMA) has been recently considered in millimeter-wave (mmWave) due to its massive connectivity. Massive MIMO systems use large number of antenna to improve both the spectrum and energy efficiency. In this paper , we consider mmWave massive MIMO-NOMA system. As mmWave massive MIMO uses hybrid precoding (HP) for downlink to significantly reduce the number of radio-frequency (RF) chains without any performance loss, where hybrid precoding (HP) is a combination of analog and digital precoding. The cluster-head selection algorithm is used to select one user for each beam at first, to reduce error and then the analog precoding is designed according to the selected cluster heads for all beams to improve the array gain . Then, the digital precoding is designed by selecting users with the high channel gain in each beam is to reduce interference. Finally, the maximum sum rate is obtained by optimizing power allocation for mmWave massive MIMO-NOMA . Simulation results show that for the proposed algorithm the HP- based MIMO-NOMA can achieve higher spectrum efficiency by increasing the number of users in each beam and higher energy efficiency compared with other precoding technique in MIMO-OMA.

Keywords : mmwave, massive MIMO, NOMA, hybrid precoding, power allocation

I. INTRODUCTION

The explosive traffic growth in the demand of wireless communication services has received significant interest in academia and industry which fuels the development of the next-generation wireless networks, which can significantly improve the coverage and user experience. The 5G cellular networks are expected to provide high spectral efficiency via advanced multiple access technologies, which plays a significant role in

determining the performance of wireless communication systems. With the popularity of intelligent terminals and the development of mobile network business, the capacity of the wireless network systems has to fulfill the stringent QoS requirements. Hence, the future of mobile communication systems is facing enormous challenges, mainly in the following two aspects. First, massive number of mobile terminals will be connected to mobile networks via limited spectrum resources. The increasing rate of the number of smartphones and intelligent terminals requiring mobile data services double every year. It is predicted that in 2020, the data load will be 500- 1000 times more than it is now, and there will have about 50 billion terminal access to wireless networks in the world [1]. Second, the demand for green communications has become an emerging need in the design of communication system. As the current report, information and communication technology (ICT) industry requires a massive energy consumption, accounting for 10% of global energy consumption. In particular, 2% of global greenhouse gases are emitted as a by-product of the ICT sector, which equivalent to the overall emissions of the aviation industry [2]. Due the rapid development of wireless networks and the emergence of massive network nodes and terminals, communication industry will consume an enormous amount of energy in the future. Thus, we need to develop the next generation wireless networks to solve these problems, which should support higher data rate, lower latency, larger capacity, and lower energy consumption [3]. The 5G communication systems aim to improve the quality of communication in different aspects. For instance, the 5G networks are expected to offer extreme capacity (10 Tbps per square kilometer) and data rate (multi-Gigabits per second), which is known as enhanced mobile broadband. 5G should also enable an ultra-high density (1 million nodes per square kilometer), ultra-low complexity (10s of bits per second) and energy consumption, which mainly supports the development of the Internet-of-Things (IoT) [4]. Specifically, IoT gives an opportunity to realize smart cities, smart homes, long-range object tracking, etc. Besides, 5G should provide ultra-low latency (as low as a millisecond), ultra-high reliability (less than 1 out of 100 million packets lost) and strong security [5], which helps to achieve mission-critical control such as autonomous vehicles, robotics, industrial automation, etc . There are various disruptive technologies for realizing the 5G communication system, such as massive multiple-input-multiple-output (MIMO) [6], millimeter wave [7], visible light communication [8], and NOMA, etc. In this paper, we will focus on NOMA systems. In a mobile communication system, all users share limited resources such as power, time, and bandwidth. Thus, we need technology to achieve that different users can communicate with each other at various locations and minimize the inter-user interference. This approach is called multiple access technology. Multiple access technology not only determines the basic capacity of the network and the system complexity but also have a high impact on deployment costs. Traditional mobile communication systems, e.g. 1n-4G, we use OMA technology, which including frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and orthogonal frequency division multiple access (OFDMA) [7], [11] to avoid inter user interference. In 4G and other existing communication systems, the reason of the general use of OMA is to reduce the computational complexity of the transmission and the multiple access interference (MAI) due to different users are allocated to orthogonal power region with in time, frequency or code domain in OMA technologies. From the viewpoint of multi- user information theory, OMA systems can reach the inner boundary of multi-user capacity region [11]. However, the OMA systems are not competent to support large- scale connections with different QoS requirements. Actually, because of the limited degrees of freedom (DoF), some users with better channel quality have higher priority and other users with poor channel quality must wait for access, which leads to more severe unfairness and longer delay. NOMA overcomes the near-far problems of the 3G systems and improve the fairness in resource allocation in the 4G systems. NOMA is a multi-user multiplexing scheme that exploits the frequency domain, time domain, and power domain similarly. Compared with the traditional orthogonal transmission, NOMA uses non-orthogonal transmission at the sending terminals, introducing interferenced information deliberately, and realizes the demodulation by the successive interference cancellation (SIC) technology at the receiving terminals [15]. NOMA technologies can still use the OFDM symbol as the smallest unit in the time domain, and insert the cycle prefix (CP) between the symbols to prevent inter-symbol interference (ISI). While, in the frequency domain, the smallest units can still be the sub-channels, and OFDM technologies are used in each sub channels to keep the sub-channels are orthogonal and non- interference with each other mm wave technology is used to have high data transfer i.e as bandwidth is high even the transmission speed is increased that improves the spectrum efficiency [1], [2]. It is well known that in conventional MIMO systems, each antenna usually requires one dedicated radio- frequency (RF) chain to realize the fully digital signal processing [3], [4]. In this way, the use of a very large number of antennas in mmWave massive MIMO systems leads to an equally large number of RF chains, which will result in unaffordable hardware cost and energy consumption [5]. To address this issue, hybrid precoding (HP) has been proposed to reduce the number of required RF chains in mmWave massive MIMO systems where we use large number of transmitting antenna to improve the performance of the system [8]. The main function of HP is to decompose the fully digital precoder into a high-dimensional analog precoder (realized by the analog circuit) to increase the antenna array gain and a low-dimensional digital precoder to cancel inter user interference by selecting user in each beam with strong channel gain [6]–[9]. To further increase the spectrum efficiency, non-orthogonal multiple access (NOMA) has been recently considered in mmWave massive MIMO systems [10]–[12]. It has been shown that NOMA can significantly improve the spectrum and energy efficiency compared to the conventional orthogonal multiple access (OMA) [4]–[7]. By using NOMA, more than one user can be supported in each beam we use intra-beam superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver side [4], [5], which is essentially different from conventional mmWave massive MIMO using one beam to serve only one user at the same time-frequency resources. Particularly, NOMA power allocation plays the major role to achieve higher sum rate that helps to improve the performance of the system. Comparison of spectrum and energy efficiency of massive MIMO-NOMA and MIMO-OMA is a challenging task in this project. Simulation results are obtained in section VI. Finally, conclusion and future work in section VII.

II. IDENTIFICATION OF OMA AND NOMA

The mathematical definition of NOMA is expressed as shown. The general definition of NOMA is a technique, which allows multiple users to simultaneously occupy the same time-and-frequency resource. Based on this definition, we When we have |h| 2 < |h | 2 , the sum throughput of mnmay have power-domain NOMA, code-domain NOMA and spatial-domain NOMA, as mentioned in Section I. In this paper, we focus on power- domain NOMA. The narrow sense definition of power-domain NOMA is to superimpose the signals in the same time-and-frequency resource at different power levels, and then to adopt SIC techniques at receivers for interference cancelation. For illustrating the relationship between NOMA and OMA mathematically, below we provide a simple analytical characterization by examining the achievable performance with the aid of signal-noise ratio (SNR) expressions. Let us consider two-user downlink NOMA transmission. The channel coefficients of user m and user n are hm and hn. Let us denote the transmit SNR at the BS by ρ and assume that we have |hm| 2 < |hn| 2 without loss of generality.

OMA: According to Shannon's capacity theorem, when power control is used, the throughput of OMA can be expressed for user m and user n as [2]

NOMA is higher than that of OMA, and this gain is imposed when the channel conditions of the two users become more different. Chen et al. [8] provided a rigorous mathematical proof to demonstrate that NOMA always outperforms the conventional OMA together. In this paper, the fully-connected hp architecture is considered. In HP-based mmWave massive MIMO systems, the number of beams cannot exceed the number of RF chains, and more than one user is supported in each beam G[7]. Therefore, to achieve high multiplexing gain, we assume that the number of beams G is equal to the number of RF chain. We can connect more user in NOMA because it supports massive connectivity.

In order to gain more insights into the spectral efficiency advantage of NOMA over OMA, we investigate the following special case as an example. At high SNRs, assuming that the time/frequency resources are equally allocated to each user, based on (3), (4), (5) and (6), the sum

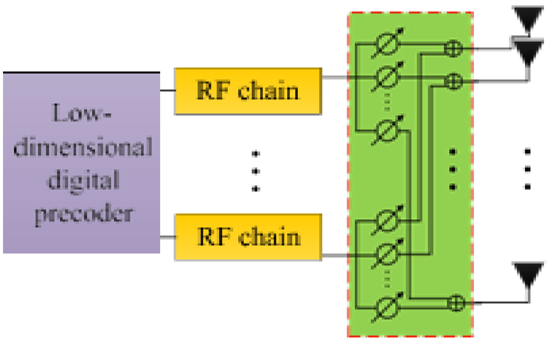

Fig.1 Fully connected HP architecture The channel model is given as, throughput of OMA and NOMA can be expressed

Where N is the transmitting antenna, denotes the number of paths for the m beam user in the gth beam . is the complex gain in lth path and are the azimuth angle of departure and the azimuth angle elevation of lth path of the Nx1 array that is obtained

Hybrid precoding is the combination of analog and digital precoding technique. The number of users K is larger than the number of RF chain NRF . Therefore to enable hybrid precoding CHS algorithm is been used to select the cluster head for each beam to avoid inter user interference at successive interference cancellation at receiver side. Analog precoding is done first to improve the array gain according to that of the selected cluster head. Then user is been grouped together in the corresponding beam based on the correlation between the remaining users in the particular beam. Finally digital precoding is done to improve the performance by reducing the inter user interference in the particular beem between the users.

A. CHS Algorithm to select the cluster head

CHS algorithm is to improve the system performance, we select the cluster head for each beam with high channel gain and less correlation as the cluster head is to minimize the channel

In order to avoid error this algorithm is been processed so that system does not suffer from inter-beam interference.

Algorithm 1 CHS Algorithm

Input: The number of users K, and the number of beams G;

Channel vectors: hk for k = 1, 2, ,K; The initial threshold: δ.

Output:The cluster head set Γ.

Step1: Λ =[a1,a2,⋯,aK], where ak =‖ ‖ ; Step 2: ˜ = hk/ak for k =1 ,2,⋯,K;

Step 3: [~,O]= sort(Λ,descend); Step 4: Γ = O(1) ;

Step 5: Γc =O /Γ; Step 6: Ω=Γ c; Step 7: g =2 .

Step 8: while g ≤ G do Step 9: if Ω == Φthen Step 10: while Ω == Φdo Step 11: δ = δ +(1−δ)/10;

Step 12: Ω={˜ ˜ }

correlation. In this way the user can have low channel correlation and has the benefits of inter-beam interference cancellation

In the CHS algorithm , an adaptive threshold δ is set to measure the channel correlation between the cluster head. The user with the highest channel gain is selected as the cluster head for the particular beam. The user who has the channel correlation less than that of the cluster head of first selected user is been choosen and compared with the threshold δ and considered as the cluster head for all other beams. The user with high channel gain is selected as the cluster head for second beam. The cluster head is updated based on the channel

Step 13: end while Step 14: end if
Step 15: Ω={˜˜ - - - }
Step 16: $\Gamma=\Gamma\cup\Omega(1)$;
Step 17: $\Gamma c = O / \Gamma$; Step 18: g = g +1 . Step 19: end while Step 20: return Γ.

correlation with the second selected user whose channel correlation is less than the threshold δ.

The threshold will be adaptively updated until the cluster heads are selected for all beams(G). The details of the proposed CHS algorithm are described in Algorithm 1, and the set of the

B. Analog Precoding

In this paper key idea of hp precoding is divided into two steps as analogand digital precoding as

follows. Analog precoding is a simple design with low complexity and less hard ware cost as the number of RF chain is less and it used phase

high channel gain in the particular beam. Assuming that the mth user has the hign channel gain in the gth beam is given as, shifters to connect it to the antenna . Due to phase shifters the array gain is been improved. This has advantages

Then, the digital precoding matrix of size NRF×NRF can be generated.

III. SYSTEM MODEL

Lets consider a downlink mmWave massive MIMO-NOMA system, Where base station has N antennas at the base station(BS) and Nrf chain to serve K users. Fig.1 shows fully connected HP architecture where each RF chain is connected to N antennas by using phase shifters where it requires NNRF phase shifters thus high array gain can be obtained hence, hardware cost is reduced as the number of RF chain is been reduced. It is energy efficient and easy to implement. In this technique, the number of RF chains in HP architectures is less than the number of antennas. HP architecture has both analog and digital precoding combined After normalizing, the digital precoding vector for the gth beam can be written as

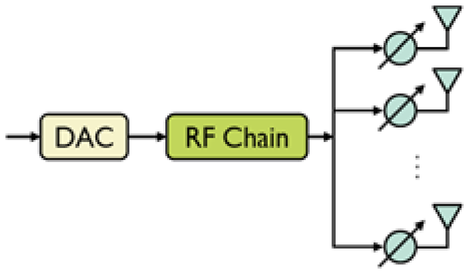

Fig.2 Analog precoding

The key idea of HP based precoding is to divide the HP design into two step, i.e., analog

Upto this, user grouping and hybrid precoding have been designed carefully to obtain high array gain and to avoid complexity and there is a performance increase. In the next section optimization of power allocation is discussed to achieve high sum rate to improve the spectral and the energy efficiency of the system.
The rate of the user u can be written as precoding and digital precoding. Particularly, for analog precoding, only quantized phase changes can be applied due to the practical constraints of phase shifters [10]. As shown in figure 2.

Considering B bits quantized phase shifters, The rate of the user can be written as non-zero elements of the fully-connected analog precoding matrix A(full) belong to Now, the term in the denominator of

B. User Grouping

After obtaining the analog precoding, User grouping is performed to select the user for the particular beam based on the channel gain. The channel vector equation for K user is obtained as

.

Then considering only the case when gives the achievable rate

IV. POWER ALLOCATION

Power allocation has been considered in the existing technology of MIMO-NOMA systems. where k =1 ,2,···,K. Then according to the correlation of equivalent channels, user grouping can be realized. Specifically, user m (m Γ) can be classed as the gth beam.

The joint power optimization is not considered and is the major challenge that taken place in the mmwave massive MIMO technology. Since, in this technique each user is allocated with different power based on the distance the user is present.

When the user is at near distance he is allocated with less power and when the user is at far away distance he is allocated with more power in order to The user in the particular beam can enjoy high correlation of the channel. To avoid correlation in different beams based on users and the correlation between them we use CHS algorithm to lower the correlation and to avoid inter-beam interference this could improve the multiplexing gains.

C. Digital Precoding

After analog precoding and user grouping the optimize the power that improves the energy efficiency of the system. In this process we come with two types of interference as inter group interference and intra group interference exist and is difficult to find an optimization solution hence we use an optimization algorithm to over come this optimization problem, The joint power allocation and power splitting optimization can be formulated as channel vector is obtained for th mth user and the gth beam and is denoted as ¯as explained in section

Then, the design of digital precoding is been used in conventional MIMO-NOMA is to eliminate the inter-beam interference among the user having By iteratively solving the optimal values where Rg,m is the achievable rate of the mthe user in the gth beam, The constraint C1 indicates that the power allocated to each user must be positive, C2 is the transmitted power constraint with Pt being the maximum total transmitted power by the BS, C3 is the data rate constraint for each user with being the minimum data rate for the mth user in the gth beam, and C4 is the QoS constraint for each user with being the minimum harvested energy for the mthe user in the gth beam. This helps in solving the non convex problem that occurred hence we can improve both the spectral and energy efficiency of the system

The optimization problem in (23) can be reformulated as optimal solution for the iterative optimization algorithm for joint power allocation is carried out to improve the spectral and energy efficiency.

V. SIMULATION RESULTS

The performance is evaluated in terms of spectrum efficiency and energy efficiency of the mmWave massive MIMO-NOMA for the fully- connected HP architecture. In this paper the system bandwidth is assumed to be Bw= 1 Hz, which coincides with the achievable sum rate. The BS has N = 64 antennas, B = 4 bits quantized phase shifters are adopted and number of radio frequency chain = 4 RF chains to simultaneously serve K users. All the K uses are grouped into G 4 beams, and there are more than one user in each beam. For the mth user in the gth beam, the channel vector is generated based on channel vector, where we assume: 1) Lg,m = 3, including one line-of-sight (LoS) component and two non-line-of-sight.

(NLoS) components; 2) α(1) g,m ∼ CN (0,1), andα(l) g,m ∼ CN (0,10−1) for 2≤ l ≤ Lg,m; 3)ϕ(l) g,m and θ(l) g,m follow the uniform distribution U(−π,π) for 1 ≤ l ≤ Lg,m. and the signal-to-noise ratio (SNR) is defined as/. The maximum transmitted power is Pt = 30 mW, the minimal achievable rate for each user is Rfm/10, where Rfm is the minimal achievable rate among all users and the minimal harvested energy for each user is 0.1 mW. In this paper, the spectrum efficiency is defined as the ratio between the achievable sum rate, bandwidth and the energy efficiency is defined as the ratio between the achievable sum rate and the total power consumption , i.e.

Furthermore, we rewrite the function in as,

Ptr is the total transmitted power, Prf is the power consumed by each RF chain, Pps is the power consumption of each phase shifter, and Pbb is the which is a standard convex optimization problem, and can be solved by numerical convex program solvers . baseband power consumption. Particularly, we adopt the typical values Prf = 300 mW, Pps = 40

mW (4-bit phase shifter), and Pbb = 200 mW [8]. NPS Number of phase shifter is equal to NRF Number of RF chain.

In the simulation, we consider (1) Single user with out any interference (2) Proposed HP architecture (3) Digital precoding (4) Analog precoding.

In this we compare the spectral efficiency of various users. This is to observe that how far the efficiency is varied as the user is increased based on the power that is been allocated. Because the spectral efficiency varies for the constant power allocation as the user and te transmission of data is been increased.

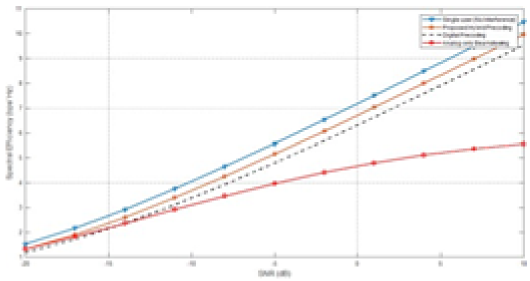

Fig 3 Spectral efficiency against SNR for 4 user

Spectral efficiency for various user is been obtained for different cases. Fig.3 show the spectral efficiency against SNR for k= 4 user . We can find that the proposed Hybrid precoding technique for mmWave massive MIMO-NOMA can achieve high spectral efficiency compared to other precoding technique which is used in Orthogonal Multiple Access Technique.

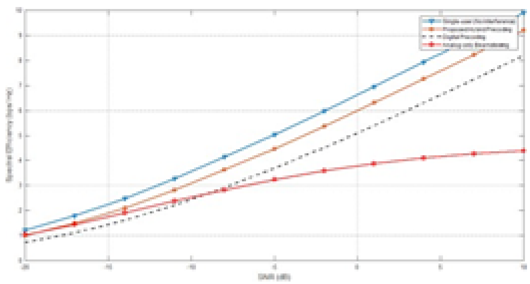

Fig 3.a Spectral efficiency against SNR for 6 user

Spectral efficiency for various user is been obtained for different cases. Fig 3.a show the spectral efficiency against SNR for k= 6 user . We can find that the proposed Hybrid precoding technique for mmWave massive MIMO-NOMA can achieve high spectral efficiency but in Fig 3 the user was less compare to that of fig 3.a but spectral efficiency was high compared to that of Fig 3.a. From Fig 3 and Fig 3.a its been observed that as user increases the efficiency is been reduced dur to the information bits over the particular bandwidth.

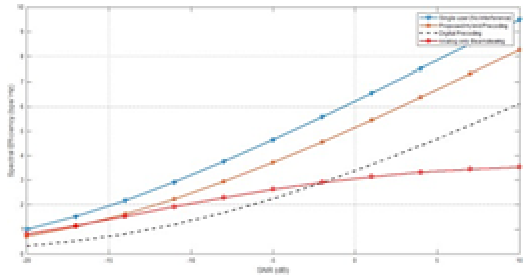

Fig 3.b Spectral efficiency against SNR for 8 user

Spectral efficiency against SNR is been calculated by varying the number of users as k=4, k=6, k=8 respectively and been found that as user increases the spectral efficiency is been reduced. From the Fig 3, Fig 3.a and Fig 3.b that compared to other precoding technique hybrid precoding technique is more efficient than other precoding technique. It is been observed that as user increases the spectral efficiency is been reduced but other precoding technique shows huge difference compared to that of hybrid precoding technique.

A.COMPARISON TABLE FOR DIFFERENT SNR

TABLE 6.1 for SNR=-5dB vs SE

PRECODING	USER 4 (S.E)	USER 6 (S.E)	USER 8 (S.E)
Hybrid	5.3	4.2	3.6
Digital	4.8	3.5	1.8
Analog	4	2.8	2.2

TABLE 6.2 for SNR=0dB vs SE

PRECODING	USER 4 (S.E)	USER 6 (S.E)	USER 8 (S.E)
Hybrid	6.5	6	5.2
Digital	6.2	4.5	3.3
Analog	4.5	3.8	2.8

TABLE 6.3 for SNR=5dB vs SE

PRECODIN G	USER 4 (S.E)	USER 6 (S.E)	USER 8 (S.E)
Hybrid	7.7	7	6.5
Digital	7	6	3.8
Analog	4.5	3.2	3

From this TABLE 6.1,TABLE 6.2,TABLE 6.3 we could observe the spectral efficiency for different signal to noise ratio (SNR). Here hybrid precoding technique show minimum variation compared to that of other precoding technique. Where Analog and Digital shows a vast variation in spectral efficiency whereas hybrid precoding show minimum variation with respect to increase in the number of users. From the above table its clear that the variation of spectral efficiency for hybrid precoding shows less variation for increase in the number of users

Energy efficiency for various user is been obtained for different cases. Fig 4 show the energy efficiency against SNR. We can find that the proposed Hybrid precoding technique for mmWave massive MIMO-NOMA can achieve high energy efficiency compared to other precoding technique which is used in Orthogonal Multiple Access technique. Even when the number of user is increased the efficiency remains same because of the power allocation in MIMO-NOMA.

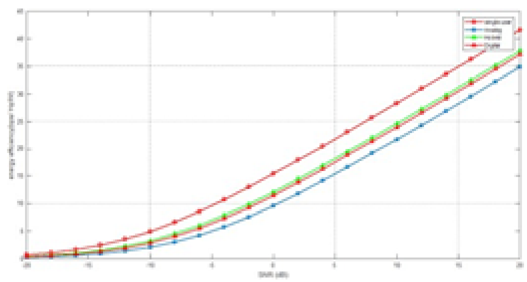

Fig. 4 Energy efficiency against SNR

VI. CONCLUSION

In this project, we propose to apply HP-based mmWave massive MIMO-NOMA systems to achieve high spectrum efficiency and energy efficiency. To enable the spectrum- and energy-efficient systems, user grouping, hybrid precoding, and power allocation are carefully designed. Specifically, the CHS algorithm is first proposed to select one user for each beam as the cluster head to avoid interference at (successive interference cancellation) receiver side , and then the analog precoding is designed according to the selected cluster heads for all beams to improve the array gain. After that, user grouping is performed to select the user for each beam. Then, the digital precoding is designed by selecting users with the strongest channel gain in each beam to avoid inter user interference. Simulation results show that the proposed Hybrid precoding based mmWave massive MIMO-NOMA systems can achieve higher spectrum and energy efficiency compared with other precoding technique that is employed in OMA. In the future, optimized algorithm for hybrid precoding design can be integrated with mmWave massive MIMO-NOMA systems with Simultaneous Wireless Information and Power Transfer (SWIPT) to further improve the performance.

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