Joint MU-mMIMO-OFDM with Hybrid Beamforming System Spectral Efficiency Improvement based NOMA Technique

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Abstract—**Due to the increasing number of users and high data rate requirements for multimedia applications in fifth-generation (5G) and beyond wireless systems, it's necessary to incorporate spectral efficient techniques to overcome the limited available resources. The proposal of this paper is to employ a technique that improves the performance of a multi-user-massive multiple input multiple output orthogonal frequency division multiplexing (MU-mMIMO-OFDM) system with hybrid beamforming (HBF). The spectral efficiency (SE) is enhanced by incorporating the non-orthogonal multiple access (NOMA) technique within each group of users. Multiple streams of users in a group are served with typical beams that could serve a single stream in existing MU-mMIMO-OFDM systems. Two different scenarios are considered for performance analysis. The SE reaches about 60 bits/s/HZ at 5dB signal-to-noise ratio (SNR) when the base station (BS) is equipped with 64 antennas. The simulation results proved that the proposed MU-mMIMO-NOMA-OFDM system outperforms the existing models, where the user's SE is enhanced by 117% when 128 antennas are deployed at the BS.**

Index terms—**NOMA, Spectral Efficiency (SE), Hybrid Beamforming, Massive MIMO, mmWave.**

I. Introduction

An exponential increase in data traffic and connected devices is realized for the current and next-generation communication systems. The diversity of mobile applications and the developing multimedia traffic require higher throughput and data rates in these generations [1, 2]. These requirements have motivated researchers and industrial collaborators to enhance the system spectral efficiency (SE) by employing some challenging techniques that become the key enabling technologies to achieve the goals of fifth-generation (5G) and beyond networks [3, 4].

With massive multiple input multiple output (mMIMO) technology, the possibility of implementing a massive number of antennas at the base station (BS) enhances the system's spectral and energy efficiencies due to increasing the spatial links between the transmitter and receiver [5, 6].

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Conversely, the large size and complexity problems of the antenna arrays with mMIMO can be solved by moving the available radio spectrum toward the millimeter-wave (mmWave) frequency band [7, 8]. Moreover, the severe path loss and the propagation effect of the mmWave environment can be compensated through the achieved diversity and spatial multiplexing gains from the mMIMO incorporated with beamforming techniques [9, 10]. The system data rate and SE can be improved with this combination by allowing more users to send data simultaneously [11]. The role of incorporating beamforming is to send the signals in concentrated beams toward the users. The signal-to-interference-plus-noise ratio (SINR) for each user can be enhanced by reducing the inference with other users and receiving a more robust signal [12, 13].

There are three main architectures of beamforming: analog, digital, and hybrid. There is a performance limitation in analog beamforming, especially in multi-user scenarios, due to its restriction of a single data stream as long as it uses a single-phase adjustment in the radio frequency (RF) domain. In digital beamforming technology, the highest flexibility and spatial multiplexing can be provided by adjusting the amplitude and phase for each antenna element. A dedicated RF chain is required for each element, which results in higher cost and energy consumption than the analog beamforming technique [14, 15]. Therefore, with the high number of antennas in massive MIMO scenarios, the hybrid digital and analog is the alternate beamforming approach in current and beyond wireless systems. It compromises the cost and performance by reducing the complexity of digital beamforming and provides a higher multiplexing gain than analog beamforming [16, 17].

Depending on the mapping strategy between the RF chains and the antenna elements in the analog domain, hybrid beamforming (HBF) can be either a fully connected structure (FCS) or a sub-connected structure (SCS) [18, 19].

Based on the above discussion, for 5G and beyond wireless communication systems, it is necessary to use a robust system architecture that incorporates different essential enabling techniques together to satisfy performance improvement in terms of SE, data rate, and number of users. Combining mmWave, mMIMO, HBF, and orthogonal frequency division multiplexing (OFDM) can significantly enhance the system performance.

However, when the number of RF chains is limited at the BS, simultaneous access becomes a critical challenge due to the exponential growth of devices. In the existing OFDM-based mMIMO systems, each RF chain serves a single user or stream.

Conversely, non-orthogonal multiple access (NOMA) is a highly recommended technique that provides higher SE for the next-generation system [20, 21]. It enables more users to share the available resources efficiently. Power and code domains are the two main types of NOMA [22, 23]. The power domain NOMA technique is used in this paper due to its compatibility with the current wireless generation. To the best of the author's knowledge, none of the researchers proposed a system combining the MU-mMIMO-OFDM with the NOMA technique and HBF over the mmWave environment.

Joint Spatial Division Multiplexing (JSDM) HBF architecture is employed in this work to optimize the SINR for each user. The NOMA technique is employed within each group to increase the number of users that can be served simultaneously using the limited available RF chains. For performance comparison, the conventional multi-user-massive multiple input multiple output orthogonal frequency division multiplexing (MU-mMIMO-OFDM) system is also simulated in this paper. Two different methods for JSDM beamforming design are considered for MU-mMIMO-OFDM and the proposed system to analyze the effect of channel overhead for the beamforming design on the system performance.

The remainder of this work is organized as follows: section II gives the related work. Section III describes the system and channel models. Section IV discusses the obtained results. Finally, section V concludes the main points.

II. Related Work

This section discusses existing work on employing the beamforming technique with mMIMO, MU-OFDM, and NOMA. Some existing works [5, 7, 9, 19, 24] concentrated on combining mMIMO with MU-OFDM; in such systems, a single RF chain could serve only a single user. In [5], a combination of MU-mMIMO, OFDM, mmWave, and HBF was used. The hybrid precoders were obtained using block diagonalization (BD), while the wideband combiner was designed using a modified orthogonal matching pursuit (OMP) algorithm. Compared with a fully digital beamformer, the obtained SE had a small degradation. Compared with other systems that use similar techniques without combiners, it enhanced the SE.

To analyze the effect of mmWave carrier frequencies, the author in [24] worked on the MU-mMIMO-OFDM system with the HBF technique over 28GHz, 39GHz, and 66GHz different frequencies. The author concluded that increasing the carrier frequency degraded the system performance in terms of error vector magnitude (EVM). Such degradation should be compensated through increasing the number of BS antennas.

The mentioned works of literature considered the MU-mMIMO with OFDM, which employed a single beam to serve one user equipment or a single stream. Increasing the number of users in such systems was limited by the number of RF chains, even though all users share the used resource blocks and OFDM symbols. The concept of serving multiple streams or users per typical beams was not considered here. Further, the NOMA technique needed to be taken into account.

There are some other researchers [25-30] who worked on employing the NOMA technique in MIMO and beamforming environments. The authors in [29] considered combining mMIMO, NOMA, mmWave channel, and SCS-based hybrid beamforming techniques in a line-of-sight environment. They derived the mathematical formulations for the analog precoders and combiners that maximized the system sum rate. On the other hand, the digital precoder was designed using the conventional zero-forcing (ZF) method. The system performance is evaluated in terms of sum rate, energy efficiency, and memory space complexity. The energy efficiency results demonstrated that SCS-HBF-NOMA outperformed FCS-HBF-NOMA due to less complexity and fewer mapped RF chains.

The work in [30] included a study of the performance of a hybrid precoding-based mMIMO-NOMA system over mmWave environment. The authors suggested a symmetric successive over-relaxation with a complex regularized zero-forcing precoder to reduce the complexity in the existing conventional liner precoders. The designed precoder performance was investigated and compared with other existing precoders in terms of computational complexity, energy efficiency, and SE; the complexity of the precoder was reduced. In general, the authors worked on a single carrier-based NOMA system. They also did not consider the process of actual transmission, which includes channel-sounding and receiver signal detection.

Even though those works of literature considered the most trend techniques with beamforming, they worked on single carrier transmission. In contrast, the multicarrier transmission is employed in a realistic 5G environment due to channel conditions. Further, the digital beamforming design and the channel models are different in a multicarrier environment due to their differences according to different subcarriers.

Opportunistic beamforming-based NOMA-OFDM system over the fading channel was established in [31]. The comparison with other beamforming techniques showed SE and computational complexity improvement. The SE gain was 2bps/Hz compared with code domain NOMA. The authors compared the single-carrier and multicarrier schemes with opportunistic beamforming. The results displayed a SE enhancement when a multicarrier-based system was used. Even though the authors in this literature combined beamforming with OFDM and NOMA techniques, they worked on a small number of antennas in the base station (BS) and did not consider the mMIMO scheme. Also, they did not take into account the hybrid beamforming schemes and mmWave realistic channel model, whereas those models are employed in the 5G wireless network. Therefore, motivated by the above observations and to overcome the mentioned limitations, this research focuses on integrating the NOMA technique in mmWave HBF-based mMIMO-OFDM system to meet the extra high data rate requirements and unexpectedly increasing number of users for the upcoming generations of wireless systems. The proposal suggests incorporating the NOMA technique in the MU-OFDM system within each group to increase the number of supportable users served within the distinctive beams. Such a proposal can improve the system's sum capacity by increasing the total number of users.

III. System Modeling

In this paper, a multi-stream-based MU-mMIMO-NOMA-OFDM wireless communication system is proposed. It's assumed that the BS is equipped with N_t antennas and N_{RF}^t RF chains where $N_{RF}^t \ll N_t$. Through employing the OFDM technique, *N* subcarriers are used for data transmission. On the receiving side *K* multi-antenna mobile users, each with N_s data streams, are simultaneously served using the entire band. Each user is equipped with N_r antennas and N_{RF}^r RF chains where $N_r \geq N_{RF}^r \geq N_s$.

The data transmitting model of the proposed system is shown in Fig 1. The processing includes user grouping, power allocation, symbol modulation, NOMA superposition coding (SC), digital precoding, OFDM multicarrier modulation, and analog beamforming. User grouping is performed according to the spatial locations of users; they are distributed into *G* number of groups where each group includes *D* users. In the suggested scenario, two users per group are employed for simplicity. The BS communicates with GN_s data streams, where $GN_s \leq N_{RF}^t \ll N_t$.

The symbol and layer mapping process in Fig.1 includes the quadrature phase shift keying (QPSK) modulation and the construction of the transmit symbols on the available resources. These resources include the number of subcarriers, OFDM symbols, and RF chains. At the BS, NOMA SC signal for each subcarrier *n* is constructed for the user's pairs at each group as follows:

$$s_g[n] = \sqrt{a_1} z_1[n] + \sqrt{a_2} z_2[n] \tag{1}$$

where a_1, a_2, z_1, z_2, are the power allocation factors, and the transmitted symbols assigned to far and near users, respectively, within each group. In the baseband domain, the transmitted symbols are pre-coded through the per subcarrier-based digital precoder: $F_{BB}[n] = [f_{BB,1}[n] \dots \dots f_{BB,G}[n]] \in \mathbb{C}^{N_{RF} \times GN_s}$, where $f_{BB,g}[n]$ is the digital precoder assigned to g$^{\text{th}}$ group.

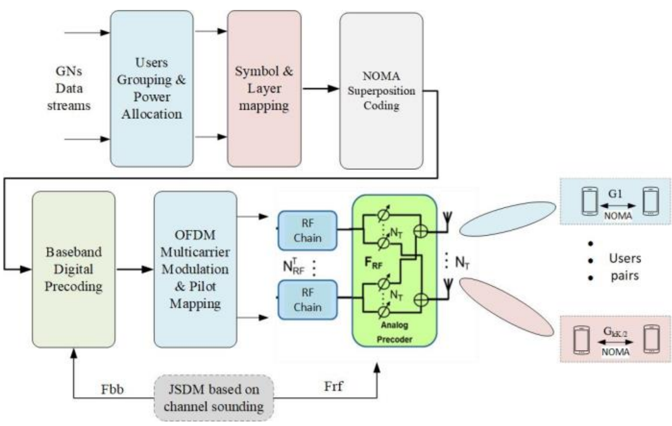

Fig. 1. The block diagram of the MU- mMIMO-NOMA-OFDM system

The resulting pre-coded streams are passed through the OFDM modulation. Pilots' signals are mapped with the OFDM data symbols to estimate the channel through data transmission. This estimated channel information is used at the receiver side to recover the transmitted data. The multicarrier modulated symbols are then pre-coded at the RF domain through the analog precoder $F_{RF} = [f_{RF,1}, \dots \dots, f_{RF,g}] \in N_t \times N_{RF}^t$, which is fixed over all subcarriers. The analog beamforming is implemented using $N_t N_{RF}^t$ phase shifters, which can only modify the angles of signals. Based on selecting FCS, each antenna element uses *GNs* analog gains. The transmit signal for subcarrier n to group g is as follows:

$$x_g[n] = f_{RF,g} f_{BB,g}[n] s_g[n] \tag{2}$$

where $f_{RF,g}, and\ f_{BB,g}[n]$ are the analog and digital precoders associated with group g. $s_g[n]$ is the NOMA superimposed signal for the user's pairs at group g, as described in Eq. (1).

In OFDM-based mMIMO hybrid beamforming systems suggested by previous works, *G* users can be spatially served, where *G* is the number of groups, and a single beam serves each group. In this system, a single beam can serve multiple superimposed users through the NOMA technique. The model in Fig.1 shows that NOMA is incorporated within each group to increase the number of users that can be spatially served by a single beam. Each one of the beams can serve a group of two users or more. As compared with the literature, *K* users can be spatially served where $K = DG$. Furthermore, when multi-streams are considered in the HBF-based system models suggested by the literature, each single beam could serve a single stream due to connecting one antenna element to each stream. While in this system, the NOMA concept architecture allows serving GKN_s total number of streams simultaneously instead of $KN_s = N_{RF}^t$ streams in existing systems.

At the receiver's side, the UEs perform an amplification to compensate for the path loss effect. At each receiver, OFDM demodulation, de-mapping, and MIMO channel equalization with ZF are used for data recovery. NOMA successive interference cancellation is performed by near users within each group. Hybrid combiners are not applied in this research. The received signal *y* at user *k* within group *g* per subcarrier *n* is as follows:

$$\begin{aligned} y_{g,k}[n] &= H_{g,k}[n] f_{rf,g} f_{BB,g}[n] \sqrt{P_g} s_g[n] + H_{g,k}[n] \sum_{\substack{l=1 \\ l \neq g}}^{G} f_{rf,l} f_{BB,l}[n] \sqrt{P_g} s_l[n] + \sigma \\ &= \underbrace{H_{g,i}[n] f_{rf,g} f_{BB,g}[n] \sqrt{P_g a_i} s_i[n]}_{Desired} \\ &\quad + \underbrace{H_{g,j}[n] f_{rf,g} f_{BB,g}[n] \sqrt{P_g a_j} s_j[n]}_{k\ Inter-user\ Interference} \\ &\quad + \underbrace{\sqrt{P_g} H_{g,k}[n] \sum_{\substack{l=1 \\ l \neq g}}^{G} f_{rf,l} f_{BB,l}[n] s_l[n]}_{Inter-beam\ Interference} \\ &\quad + \underbrace{\sigma}_{noise\ signal} \end{aligned} \tag{3}$$

where $f_{BB,g}[n] \in \mathbb{C}^{N_{RF,g} \times N_{s,g}}$, is the digital precoder assigned to group g at subcarrier n. $f_{RF,g} \in \mathbb{C}^{N_t \times N_{RF,g}}$, is the analog precoder assigned to group g. $H_{g,k}[n]$ is the channel matrix between user *k* and BS at subcarrier *n*. σ is the noise signal, P_g is the power allocated to group g. $s_g[n]$ is the SC signal described in Eq. (1). As described in Eq. (3), the power allocation strategy based on NOMA concept is exploited to distinguish multiple beams directed to different streams for different users at the receiving side.

A. Channel Model

The simulated channel model adopted in this work is a scattering-based multipath propagation spatial channel. Due to multi-carrier-based transmission within the system, the modeling is based on a block fading channel. A single-bounce ray tracing approximation with a parametrized number of scatterers is used, and the number of scatterers is set to 100. They are placed randomly within a sphere around the receiver.

The path-loss modeling with non-line of sight propagation condition is assumed. An isotropic antenna element with either a uniform rectangular array or a uniform linear array is used. Similar parameters are used for both data transmission and channel sounding.

Since multiple users are considered in this system, independent channels are modeled for each user. This wideband selective fading channel is considered as a multiple narrowband flat fading subchannels where each subchannel is a sum of rays ($N_{ray,k}$). These rays are divided into clusters ($N_{cl,k}$), each with $N_{i,k}$ rays. The mathematical representation for the used channel for a user k is described as a narrowband channel at each subcarrier n [32, 33]:

$$H_k(n) = \gamma_k \sum_{i=1}^{N_{cl,k}} \sum_{j=1}^{N_{i,k}} \alpha_{i,j}[n]\, a_{r,k}(\emptyset_{i,j,k}^{r} \theta_{i,j,k}^{r})\, a_t^H(\emptyset_{i,j,k}^{t} \theta_{i,j,k}^{t}) \quad (4)$$

where $\gamma_k = \sqrt{\frac{N_t N_r}{N_{ray,k}}}$, $\alpha_{i,j}[n]$ is the complex gain of the ith ray in the jth cluster for subcarrier n, $a_{r,k}(\emptyset_{i,j,k}^{r} \theta_{i,j,k}^{r})$ is the response vector of the antenna array of user k, $a_t(\emptyset_{i,j,k}^{t} \theta_{i,j,k}^{t})$ is the response vector of the antenna array of the BS, $\emptyset_{i,j,k}^{t} \theta_{i,j,k}^{t}, \emptyset_{i,j,k}^{r} \theta_{i,j,k}^{r}$ are the azimuth and elevation angles of arrivals for transmitter and receiver.

B. Channel Sounding

The system maximizes the signal energy in the desired direction by applying the baseband precoding at the transmitter side. The channel sounding is required first for the availability of channel information at the transmitter. The BS sends preamble signals across all antennas to sound the channel. Fig. 2 displays the main steps for channel sounding. During processing the preamble signals by the receivers, they perform amplifications, OFDM demodulation, and channel estimation at the frequency domain. Then, the users fed the channel information back to the BS for the precoding design used for data transmission.

In general, the channel sounding processing is adapted according to instantaneous channel state information (CSI) (called First-order CSI) or average CSI (called second-order CSI). The two methods compromise between performance (higher SNR) and complexity. The employed CSI adaptation method is the second order to reduce the overhead for CSI acquisition.

C. The Hybrid Beamforming Design

To reduce the power consumption and complexity, HBF is used, which significantly reduces the number of used RF chains. All chains' outputs are joined to a network of RF chains and phase shifters, mapped to the large antenna array. Since the computed RF weights (F_{RF}) are mainly determined based on the spatial locations of users, they change slowly over time. On the other hand, due to smaller-scale multipath effects, the digital precoding weight is unique for each subcarrier to comprise the frequency selective fading effect.

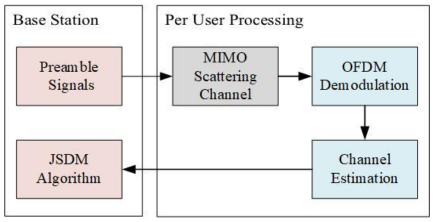

Fig. 2. Channel Sounding Process

An efficient HBF method employed for precoder/beamformer design is the JSDM, which follows the hybrid analog/digital structure. It shows only a slight performance degradation as compared with fully digital precoders while reducing the feedback overhead information. Using JSDM, the spatial clustering of users within the cell can be exploited to formulate groups to these clusters and create virtual sectors that share the RF beams with those groups [34, 35].

The estimation of the analog beamforming is based on second-order CSI, which significantly reduces the dimension of the effective channels that need to be trained and fed back within each fading block. The calculation of the effective channel depends on the evaluated RF weights and the feedback CSI. Those effective channels are used to evaluate the digital precoding weights. JSDM algorithm gathers users with similar channel covariance in a common group.

To mitigate the interference between different beams, as described in Eq. (3), the analog precoder is performed using the BD scheme. The channel overhead is reduced since the downlink training is directed to multiple virtual sectors in parallel, and each UE is only feedback on the group-based channel estimation. Perfect feedback without quantization error is assumed in the model. Since the analog beamforming is applied in the antennas at the RF domain, the analog weights are fixed over all subcarriers. Meanwhile, the digital precoding is variable over different subcarriers in the multicarrier-based proposed model.

The JSDM-based digital precoding is applied to the system in two approaches: Joint Group Processing (JGP) and Per Group Processing (PGP). With JGP, the CSI feedback of all users within all groups is considered in the design of digital precoding. On the other hand, PGP-based precoding is performed depending on the CSI of the streams directed to the specified group. Lower overhead can be achieved with PGP, while a slight performance degradation is expected compared to JGP due to per-group processing rather than per-user processing.

IV. Results and Discussion

To evaluate the SE performance of the proposed system, two models are tested: MU-mMIMO-OFDM and MU-mMIMO-NOMA-OFDM. Both scenarios are operating at 28 GHz mmWave frequency. The distribution of users is 700 meters from the BS. The number of subcarriers in the OFDM technique is 256. In the first scenario, each stream is served by a single beam, while multiple streams are dedicated to each user by various beams. The SE of the MU-mMIMO-OFDM scenario is evaluated as follows [36]:

$$SE_{mMIMO-OFDM} = \frac{1}{N}\sum_{i=1}^{K}\sum_{j=1}^{N} log_2(\left|I_{Nr} + \frac{SNR}{N_{s.i}}(H_i^j f_{RF,i} f_{BB,i}^j f_{BB,i}^{j\,H} F_{RF,i}{}^H H_i^{j\,H}\right|) \quad (5)$$

where N is the number of subcarriers, $N_{s.i}$ is the number of streams dedicated to user i , H_i^j is the channel matrix for ith user in jth subcarrier. $f_{RF,i}$ is the analog precoder assigned to user i, $f_{BB,i}^j$: is the digital precoder assigned to user i at subcarrier j.

In the second scenario, the system model shown in Fig. 1 is simulated; a single beam serves multiple streams of different users within the same group that they superimposed through the NOMA technique. Multi streams are dedicated to pairs of users by multiple beams. The SE of the MU-mMIMO-NOMA-OFDM is evaluated as follows:

$$SE_{Proposed} = \frac{1}{N}\sum_{g=1}^{G}\sum_{j=1}^{N}\sum_{d=1}^{D} log_2(\left|I_{Nr} + \frac{a_d SNR}{N_{s.g}}(H_d^j F_{RF,g} f_{BB,g}^j f_{BB,g}^{j\,H} F_{RF,g}{}^H H_d^{j\,H}\right|) \quad (6)$$

where D is the number of users in each group, a_d: is the power allocation factor assigned to user d in a group g. From the simulation analysis, it's found that the effect of inter-user interference described in Eq. (3) is reduced due to employing specified beams to the user's stream. For this reason, this effect is ignored in the evaluation in Eq. (6). Conversely, the inter-beam interference described in Eq. (3) is mitigated through incorporating the BD-based analog precoding.

The SE result of the proposed system is evaluated as compared with the MU-mMIMO-OFDM system using both PGP and JGP-based JSDM digital precoding. Fig. 3 displays the SE results of the two considered scenarios when the BS is equipped with 32 antennas while each user has two.

In this case, the assigned resources in terms of the number of resource blocks, OFDM symbols, and BS RF chains serve four users, each with two streams in the MU-mMIMO-NOMA-OFDM system, while two users, each with two streams, are served in the MU-mMIMO-OFDM system. The results in Fig. 3 show that the SE of the MU-mMIMO-NOMA-OFDM system, for both PGP and JGP techniques, outperforms that of the MU-mMIMO-OFDM due to increasing the number of users that can be served within the same resource and typical beams.

In Fig. 4, the average SE per user is evaluated. In this analysis, a BS with 64 antennas serves four users in both scenarios. In this case, two JSDM-based grouping strategies are analyzed with the MU-mMIMO-OFDM system: one user and two users per group.

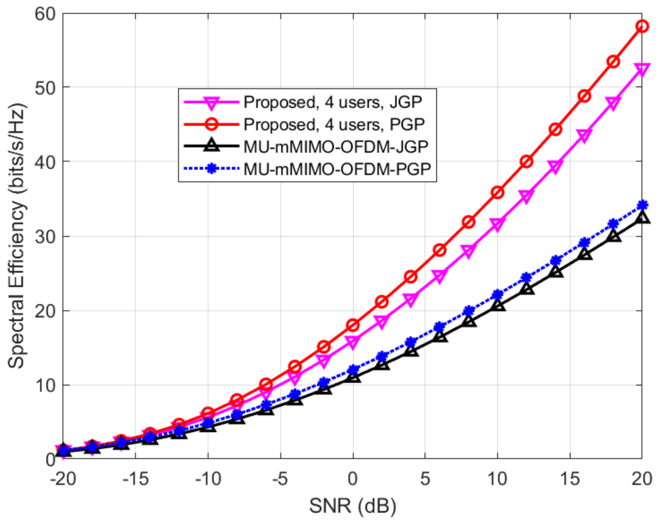

Fig. 3. The SE of the system for four users each with two data streams when the BS is equipped with 32 antennas

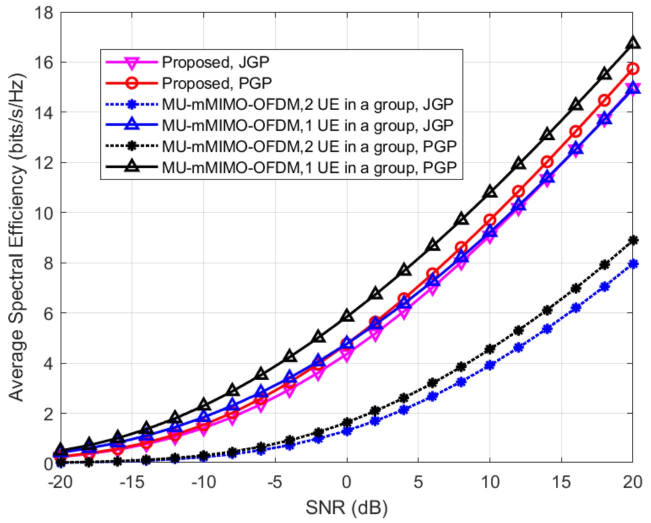

Fig. 4. The average SE per user with two data streams per user when the BS is equipped with 64 antennas

As displayed in Fig. 4, when two-users-grouping is considered, the MU-mMIMO-OFDM system provides a considerable degradation compared to the proposed system. Such a comparison clarifies that the suggested NOMA-based model enhances the average SE when users within a group share typical beams. Conversely, when a single user is allocated in a separate group in the MU-mMIMO-OFDM system, the result provides a little SE performance degradation in the MU-mMIMO-NOMA-OFDM system compared to MU-mMIMO-OFDM. This slight SE difference is due to allocating a smaller power coefficient for near users according to the NOMA concept in the proposed model. On the other hand, identical power distribution is followed in the MU-mMIMO-OFDM.

In Figs. 5 and 6, the number of streams for each user is increased to four; 64 and 128 antennas are assumed at the BS. Fig. 5 displays the SE of the MU-mMIMO-NOMA-OFDM system compared to the MU-mMIMO-OFDM system. The results obtained with the proposed system outperform that of the MU-mMIMO-OFDM due to serving twice the number of users within the same available resources. In Fig. 6, the power allocation difference between users in the proposed system gives an average SE with a slight degradation compared with MU-mMIMO-OFDM.

The number of users is increased in the analysis shown in Fig. 7. Eight users, each with two streams, are served by a BS with 64 antennas in the MU-mMIMO-NOMA-OFDM system, while the same resources can only serve four users in the MU-mMIMO -OFDM system. In this analysis, the SE results display a performance enhancement in the proposed system. It can be noticed from all the obtained results that the PGP-based JSDM-digital precoding provides a slight SE enhancement compared to the JGP-based one. This enhancement occurred due to achieving a lower overhead in the PGP method, as mentioned in section III.

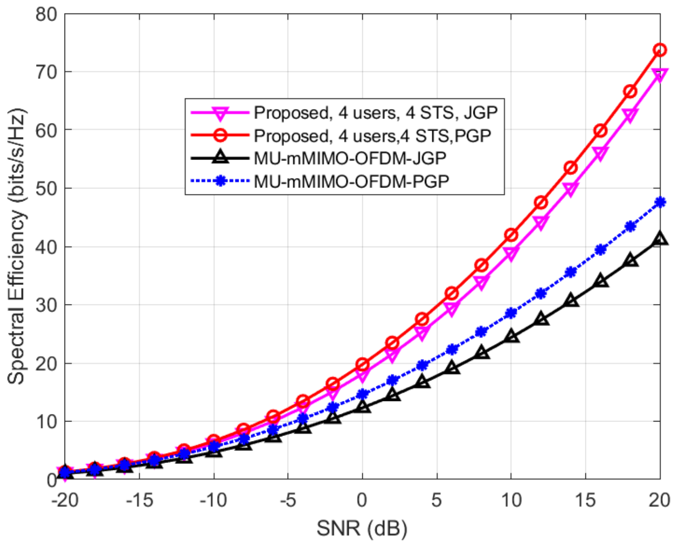

Fig. 5. The SE of the proposed system for four users each with four data streams when the BS is equipped with 64 antennas

In Table I, a comparison is made with the related works mentioned in section II. The proposed work employs all the techniques deployed in the current wireless system. Further, NOMA technique is incorporated into the system, representing a highly recommended technique for the next-generation wireless system. As described in Table I, the previous works that deployed NOMA in their systems only employed some of these techniques that must be considered in 5G and beyond systems. These techniques include multi-carrier, mult-stream, HBF, mmwave, and massive MIMO. This combination provides its effectiveness in the proposed system as obtained in the results. Compared to [24], twice the number of users is achieved in the proposed work of this paper when the same resources are used. The comparison with [19] provides an 85% improvement in system SE at 10dB SNR when 128 antennas are deployed at the BS. The proposed system also provides about 60% improvement in the average SE per user over [31], even though the work in [31] used both NOMA and OFDM.

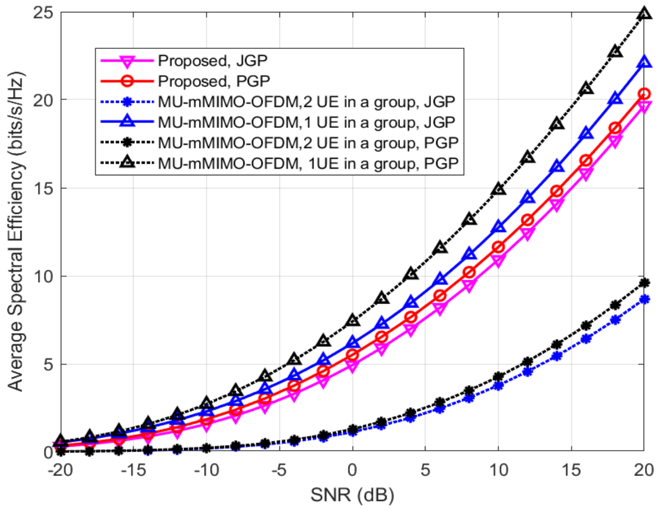

Fig. 6. The average SE per user with four data streams per user when the BS is equipped with 128 antennas

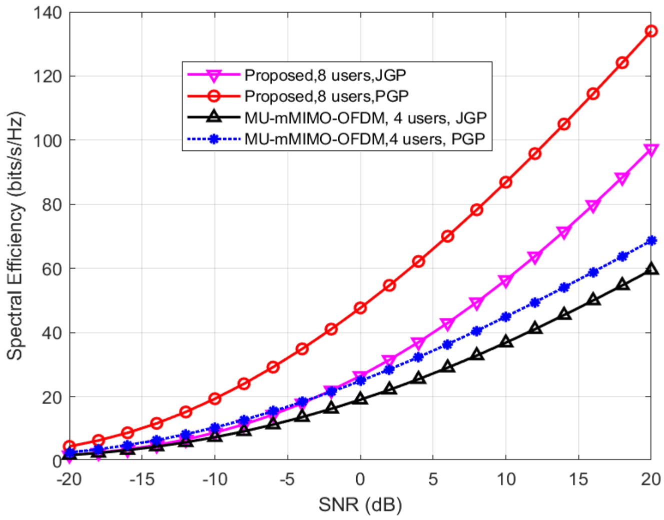

Fig. 7. The SE of the system for eight users each with two data streams when the BS is equipped with 128 antennas

TABLE I
COMPARISON WITH RELATED WORKS

	[5,7,9, 19,24]	[25]	[26]	[27]	[28, 29]	[30]	[31]	Proposed
Multi-carrier (OFDM)	√						√	√
Multi-stream	√				√			√
Hybrid beam-forming	√			√	√	√		√
mmWave	√		√	√	√	√		√
Massive MIMO	√		√	√	√	√		√
NOMA		√	√	√	√	√	√	√

V. CONCLUSION

In this research, a hybrid beamforming-based MU-mMIMO-NOMA-OFDM system is proposed to meet the next-generation demand in number of users and high data rate requirements for multimedia applications. The proposed system, which operates over 28GHz mmWave frequency, incorporates the mMIMO-OFDM multi-user multi-streams-based system with NOMA multiple access within each group. Such a proposal increases the system SE due to sharing group-specified system resources by multiple users.

The JSDM-based HBF is employed in the proposed system using either PGP or JGP methods. A performance comparison for the proposed system is made with MU-mMIMO-OFDM using different numbers of BS antennas and different grouping strategies. The simulation results verify that the MU-mMIMO-NOMA-OFDM system outperforms the MU-mMIMO-OFDM system, where the achievable SE at 0dB SNR is increased by 103% when the PGP method is used and by 46% when the JGP method is used within 64 antennas at the BS. At the same time, the SE achieves 117% enhancement within 128 antennas at the BS.

With the increasing number of users and streams, the performance enhancement is increased due to exploiting the beams to serve multiple users simultaneously within each group. Furthermore, as it's clear from the analysis of the system, a fixed power allocation strategy is used. If dynamic power allocation is employed, further improvement in overall system performance can be satisfactory. This work proposes to support the current multiple access by the NOMA technique to provide massive connectivity in forthcoming wireless technologies.

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