Hindawi
Wireless Communications and Mobile Computing
Volume 2018, Article ID 2328954, 10 pages
https://doi.org/10.1155/2018/2328954

*Research Article*

# Opportunistic NOMA-Based Massive MIMO Precoding for 5G New Radio

**Ke Xiao**[1], **Michel Kadoch**[2], **Humphrey Rutagemwa**[3], **and Chen Li**[1]

[1]*North China University of Technology, Beijing, China*
[2]*École de Technologie Supérieure, Montreal, QC, Canada*
[3]*Communications Research Centre, Canada*

Correspondence should be addressed to Ke Xiao; zehan_xiao@163.com

Received 30 November 2017; Revised 21 February 2018; Accepted 23 May 2018; Published 20 June 2018

Academic Editor: Eva Antonino-Daviu



This work investigates multicast services, which play a critical role in 5G new radio (NR). In particular, we propose a hybrid unicast/multicast MIMO precoding based on NOMA. Our scheme first categorizes unicast users into NOMA and non-NOMA types and then utilizes null space and successive interference cancellation to eliminate the signal leakage. To justify the effectiveness and efficiency of our design, we also present simulation results in typical massive MIMO scenarios.

## 1. Introduction

With the development of wireless communication systems, the requirement of even higher data rate becomes an urgent concern worldwide. One of the trends is the change from single antenna to multiple antennas [1, 2]. Large-scale antenna arrays have been regarded as one of the crucial technologies in 5G new radio (NR) since the very beginning. In massive multiple-input-multiple-output (MIMO) system, the base stations (BSs) are equipped with tens or even hundreds of antennas to serve multiple users. By increasing the development of wireless resources in the spatial dimension, large-scale antenna arrays can significantly increase both power efficiency and spectral efficiency [3]. However, the general wireless multicast beamforming in MIMO scenario is always a nondeterministic polynomial-time hard (NP-hard) challenge. In [4], the authors used massive MIMO technology for multicast transmission for the first time; by deploying a large number of antenna arrays at the BSs, massive MIMO can significantly improve the spectrum and energy efficiency [5]. From the aspects of asymptotic analysis, this problem can be solved with closed-form solutions, which is important for the design of 5G NR. Existing studies have focused on the asymptotic analysis of multicast problems under perfect and imperfect channel state information (CSI) scenarios. In this study, we alternatively investigate the massive MIMO and the multicast under the context of 5G NR.

As the newest member of the multiple access family, nonorthogonal multiple access (NOMA) is envisioned to be an essential component of 5G NR networks. In addition, NOMA further promotes the spectrum utilization by allowing MU to transmit from the same source to multiple devices simultaneously. Particularly, NOMA effectively utilizes superposition coding (SC) and successive interference cancellation (SIC) and multiuser diversity to enhance the spectrum utilization. By allocating more transmission power to users with poor channel conditions, NOMA can achieve a balanced tradeoff between system throughput and user fairness [6].

The combination of NOMA and multiantenna MIMO technologies exhibits significant potential in improving the spectral efficiency and providing better wireless services, especially when the users of a multicast group are far away from the BS [7]. In this article, we propose an important scheme for a 3D massive MIMO model, called opportunistic NOMA-based hybrid unicast/multicast precoding scheme, which provides both interference cancellation and the ability of user selection/grouping. The contribution of this study is the investigation of the NOMA-based hybrid unicast/multicast services. To the best of our knowledge,

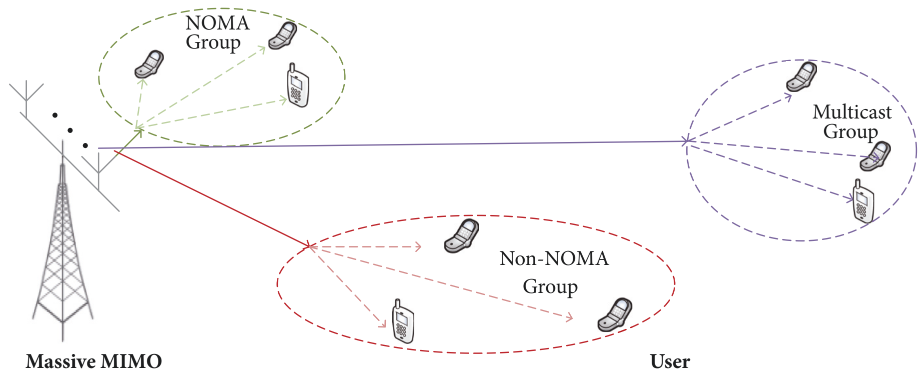


Figure 1: Opportunistic massive MIMO-NOMA system model.

there are no previous studies on hybrid 5G unicast/multicast systems, even though this topic represents a practical challenge to the industry.

This article is arranged as follows: Section 2 explains the 5G NR multicast services and opportunistic NOMA, as well as 3D hybrid unicast/multicast precoding. Section 3 elaborates on the opportunistic MIMO-NOMA scheme under hybrid multicast transmission services. The simulation results and analysis of the proposed scheme are described in Section 4 and Section 5 presents the summary.

Notation: $T$, superscripts $*$, and $H$ represent the transpose, complex conjugate, and Hermitian transpose, respectively. The column vectors and matrices are represented by lowercase letters and bold uppercase letters, respectively. In addition, $\mathbb{N}_+$ stands for a set of positive integers, and $\mathbb{C}$ denotes a set of complex numbers. $\mathbf{I}_N$ is the $N \times N$ identity matrix. $\otimes$ represents the Kronecker product.

## 2. System Model

*2.1. Multicast of 5G NR in Massive MIMO System.* Massive MIMO is an emerging technology that extends MIMO to several orders of magnitude with all the advantages of traditional MIMO. It will provide a driving force for the development of broadband networks in the future and it will be highly energy-efficient, secure, and robust and will use the spectrum more effectively [8]. In addition, an energy-saving and stable wireless communication has become an objective of the new wireless access structure to achieve the purpose of resource conservation. 5G NR is characterized by a large number of devices connected to a packet data network (PDN) and the ability to handle large amounts of data. However, the intense communication traffic is still a serious challenge for 5G massive MIMO systems [9]. Although multicast bloom filters can overcome the massive traffic leakage of users, the physical impact to the access point in 5G NR causes a bottleneck in the system. As multicast can quickly propagate the identical messages to the area covered by the signal without increasing costs, it is considered to be an important solution to large-scale data communication problems.

The latency of 5G NR multicast schemes is always less in the network layer than in the application layer. Multicasting does not only save the communication resources but also speeds up the computational load of the servers, which increases the capacity of 5G NR systems [10].

However, a 5G system includes multicast features and it is ideal for multicast transmissions. With the above advantages, massive MIMO multicasting systems can become promising enablers for the 5G NR [11].

*2.2. Architecture for Opportunistic Massive MIMO-NOMA.* In massive MIMO systems, we find that 5G often creates a good opportunity to make use of NOMA technology for additional gain [12]. When the distance between the multicast group members and the BSs is sufficiently large, the users with different levels of path loss can be grouped into NOMA and non-NOMA by using beamforming. This scenario employing the opportunistic NOMA and massive MIMO is illustrated in Figure 1 and is discussed below.

An important advantage of NOMA is to improve the capacity by applying user pairing so that the users with poor channel conditions gain greater transmit power [13]. However, this may cause the common phenomenon of intercell interference (ICI) in the MIMO system [14] because the cell-edge users experience an improvement in the transmission power, and they will encounter interference from the nearby cells [15]. Therefore, it is important to implement an interference cancellation aided null space method in the NOMA scheme to achieve channel orthogonality between multicast users and unicast users [16].

In addition, under the MIMO-NOMA architecture, data communications serve different users with different power levels, resulting in some users receiving multiple layers of signals and signal interference [17]. The SIC technology decodes different layers of data for users to obtain their own and this is helpful to improve the performance of the MIMO-NOMA system in a hybrid multicast scenario [18]. Figure 2 shows the method for eliminating the interference between the groups.

The MIMO channel model is critical when we evaluate the performance of our proposed system. For practical consideration, we use the 3D propagation channel model, which is detailed as follows.

*2.3. 3D Massive MIMO Channel Model.* The channel model takes into account the downlink transmission of a

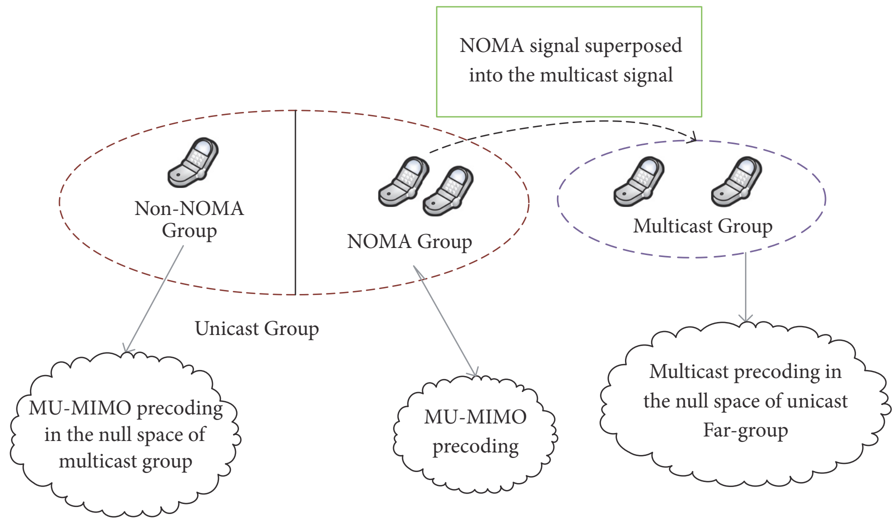


Figure 2: Methods of interference cancellation.

MU-MIMO channel system with $N$ antennas at the BS and $K$ single-antenna users ($K \leq N, K, N \in \mathbb{N}_+$) in a Non-Line-of-Sight (NLOS) condition. It is given by [19]

$$\mathbf{G}_{ch} = \mathbf{HD}, \tag{1}$$

where $\mathbf{G}_{ch} = [\mathbf{g}_{ch,1}, \mathbf{g}_{ch,2}, \ldots, \mathbf{g}_{ch,K}]$ denotes the channel matrix, whose element $\mathbf{g}_{ch,k} \in \mathbb{C}^{N\times 1}$ ($k = 1, 2, \ldots, K$) represents the channel vector between the BS and the $k$th user. $\mathbf{D} = \operatorname{diag}\{\sqrt{\beta_1}, \sqrt{\beta_2}, \ldots, \sqrt{\beta_K}\}$ is the large-scale channel matrix, where $\beta_k = \kappa d_k^{-\gamma}\zeta_k$. $\zeta_k$ stands for the log-normal shadow fading factor, $\gamma$ indicates the path loss exponent, and $d_k$ represents the distance between the BS and the $K$th user; the constant value $\kappa$ is decided by the antenna characteristics and carrier frequency.

The correlation is cited because the massive MIMO antenna has a larger scale than the conventional MIMO. In the massive MIMO system, the channel matrix is given by $\mathbf{H} = [\mathbf{H}_1, \mathbf{H}_2, \ldots, \mathbf{H}_K]$ and the vector $\mathbf{H}_k \in \mathbb{C}^{N\times 1}$ ($k = 1, 2, \ldots, K$) is given by [20]

$$\mathbf{H}_k^H = \mathbf{Z}\mathbf{R}_k\mathbf{v}_k. \tag{2}$$

where $\mathbf{Z} \in \mathbb{C}^{N\times N}$ denotes the constant mutual coupling matrix decided by the antenna array configuration, $\mathbf{R}_k$ represents the steering matrix, and $\mathbf{v}_k$ is the Gaussian stochastic factor.

The forms of $\mathbf{R}_k$ and $\mathbf{v}_k$ depend on the antenna array configuration. For ease of description, a steering vector function can be defined as $\mathbf{a}(\theta)$.

In the rectangular antenna array scenario, the $k$th user has $A_k$ different azimuths of arrival (AoAs) written as $\theta_{k,i}$ and elevations of arrival (EoAs) described by $\phi_{k,i}$. The column steering vectors in $\mathbf{R}_k = [\mathbf{r}_{k,1}, \mathbf{r}_{k,2}, \ldots, \mathbf{r}_{k,A_k}]$ are described by

$$\begin{aligned}\mathbf{r}_{k,i} &= \frac{1}{A_k} \times \operatorname{vec}\left[\mathbf{a}(\theta_{k,i}) \otimes \mathbf{a}(\phi_{k,i})^T\right] = \frac{1}{A_k} \times \operatorname{vec}\Big\{\Big[1, \\ &\quad e^{(j2\pi d/\lambda)\sin\theta_{k,i}}, e^{(j2\pi d/\lambda)2\sin\theta_{k,i}}, \ldots, e^{(j2\pi d/\lambda)(N-1)\sin\theta_{k,i}}\Big] \\ &\quad \otimes \Big[1, e^{(j2\pi d/\lambda)\sin\phi_{k,i}}, e^{(j2\pi d/\lambda)2\sin\phi_{k,i}}, \ldots, \\ &\quad e^{(j2\pi d/\lambda)(N-1)\sin\phi_{k,i}}\Big]\Big\},\end{aligned} \tag{3}$$

where the function of vec(·) is defined as the vectorization of matrix.

We model the hybrid multicast system for the opportunistic massive MIMO-NOMA system in the following chapters.

## 3. Hybrid Multicast Transmission for Opportunistic Massive MIMO-NOMA

*3.1. User Grouping.* For the grouping method [21], we define $\mathbf{g}_m = [g_1, g_2, \ldots, g_k]$ for the $m$th group, where

$$g_k = \begin{cases} 1 & \text{the } k\text{th user subjects to the } m\text{th group,} \\ 0 & \text{otherwise.} \end{cases} \quad (k = 1, 2, \ldots, K), \tag{4}$$

and the users' number of is given by $K_m$ with $\sum_m K_m = K$.

*3.2. Formulation of Multicast.* In this study, the scenario of a local cell multicast is considered and the multicast beamforming vector is given by $\omega_m \in \mathbb{C}^{N\times 1}$ with $\|\omega_m\|^2 = 1$ in the $m$th multicast group. In addition, $s_m$ represents the stochastic information with the unit power that is multicasted in the $m$th group. Therefore, the signal vector of the $m$th group is given as follows:

$$\mathbf{x}_m = \sqrt{p_m}\omega_m s_m, \tag{5}$$

where $p_m$ represents the transmission power. With all the groups sharing the spectrum, the channel input-output relationship at $j$th user can be presented as

$$\begin{aligned} y_{m,j} &= \widehat{\mathbf{g}}_{m,j}^H \mathbf{x}_m + \sum_{n \neq m}^{M} \widehat{\mathbf{g}}_{m,j}^H \mathbf{x}_n + z_{m,j} \\ &= \sqrt{p_m} \widehat{\mathbf{g}}_{m,j}^H \omega_m s_m + \sum_{n \neq m}^{M} \sqrt{p_n} \widehat{\mathbf{g}}_{m,j}^H \omega_n s_n + z_{m,j}, \end{aligned} \tag{6}$$

where $z_{m,j}$ represents the additive zero-mean Gaussian noise with variance $\sigma^2$. Then the signal-to-interference-plus-noise ratio (SINR) obtained by the $j$th user in the $m$th group is

$$\mathrm{SINR}_{m,j} = \frac{p_m \left| \widehat{\mathbf{g}}_{m,j}^H \omega_m s_m \right|^2}{\sum_{n \neq m}^{M} p_n \left| \widehat{\mathbf{g}}_{m,j}^H \omega_n s_n \right|^2 + \sigma^2}. \tag{7}$$

The publication [21] reports that the relationship between the transmission power and $N$ is $p_m = \rho_m(E/N)$, where $\rho_m \in [0, 1]$ is the power ratio and $E$ is the transmission power. If the CSI is known by the BS, it can be a feasible way to deal with the multicast problem by applying the max-min fairness (MMF) as follows:

$$\mathscr{P}: \max_{\{\omega_m, \rho_m, \mathbf{m}\}} \quad \min_{0 \leqslant m \leqslant M} \min_{\forall j \in \mathscr{K}_m} \frac{\rho_m (E/N) \left| \widehat{\mathbf{g}}_{m,j}^H \omega_m s_m \right|^2}{\sum_{n \neq m}^{M} \rho_n (E/N) \left| \widehat{\mathbf{g}}_{m,j}^H \omega_n s_n \right|^2 + \sigma^2} \tag{8a}$$

$$\textbf{s.t.} \quad \left\| \omega_m \right\|^2 = 1, \quad \forall m \tag{8b}$$

$$\sum_{m=0}^{M} \rho_m \leqslant 1, \quad \rho_m \in [0, 1] \tag{8c}$$

$$\mathbf{m} = [m_1, m_2, \ldots, m_K], \quad m_k \in \{0, 1, \ldots, M\}, \ k \in \{1, 2, \ldots, K\} \tag{8d}$$

$$\mathscr{K}_m = \{k \mid m_k = m\}. \tag{8e}$$

*3.3. Asymptotic Optimal Multicast Beamforming.* We can solve the multicast problem $\mathscr{P}$ by an asymptotic solution [22] and get the following theorem.

**Theorem 1.** *$\omega_m^*$, $\rho_m^*$, and SINR are the asymptotic solution of the beamforming vector, power ratio, and minimum SINR, respectively, and they are given by*

$$\omega_m^* = \alpha_m \sum_{j \in \mathscr{K}_m} \frac{\widehat{\mathbf{g}}_{m,j}^H}{\beta_j}, \quad \forall m, \tag{9a}$$

$$\alpha_m = \left( N \sum_{j \in \mathscr{K}_m} \beta_j^{-1} \right)^{-1/2}, \tag{9b}$$

$$\rho_m^* = \frac{\sum_{j \in \mathscr{K}_m} \beta_j^{-1}}{\sum_{k=1}^{K} \beta_k^{-1}}, \quad \forall m, \tag{10}$$

$$\mathrm{SINR}_m^{\infty} = \frac{E}{\sigma^2 \sum_{k=1}^{K} \beta_k^{-1}}, \quad \forall m. \tag{11}$$

According to **Theorem 1**, when $N \to \infty$, the SINR is not related to the user grouping scheme but is related to both the total number of users and the massive channel.

*3.4. Hybrid Unicast/Multicast Transmission.* By multiplying $\mathbf{\Omega}_0$ and the transmit vector, MU-MIMO linear precoding can be achieved, where $\mathbf{\Omega}_0 \in \mathbb{C}^{N \times K_0}$ denotes the precoding matrix and $K_0$ represents the users' number in group 0.

The block diagonalization (BD) precoding algorithm is detailed in [23]. It aims to remove the interuser interference and this process ensures that the interferences from other users are located in the null space.

For the multicast group, we use the beamforming scheme, and for the unicast group, we use the MU-MIMO linear precoding formed by the BD scheme.

*3.5. User Selection with Opportunistic Massive MIMO-NOMA.* Unicast users are grouped into NOMA and non-NOMA. Hybrid unicast/multicast schemes provide the opportunity to make use of the NOMA technology to increase the throughput. In the following situations, it is possible to make use of NOMA. First, the path loss of multicast group users is large. Second, the user of the unicast group who is on a beam with a certain user of the multicast group belongs to the NOMA group. Finally, the power that is transmitted by BS aimed at the unicast user is lower than the power aimed at the multicast user. Moreover, by appropriately adapting the first opportunity, NOMA can also be applied in our proposed model when most users in the multicast group have a large path loss, as shown in Figure 3.

Two criteria of user selection are proposed for the NOMA group. Once the users meet both at the same time, NOMA technology can be applied in this system.

**Input:**

All user data configurations, $U_{\text{data}}$

**Initializtion:**

Indices of the NOMA group user, **Index** = [ ]; Indices of the multicast group user, **Index1** = [ ]; Indices of the pre-NOMA group user, **Index2** = [ ];

**Selection:**

Estimating the distance from the base station to every user by $U_{\text{data}}$.
Estimating the path loss based on the distance. The path loss is recorded in the vector $\mathbf{M}_{pl}$
for $i = 1 : K$
  if $\mathbf{M}_{pl}(i) > pl_1$
    $\mathbf{Index1} = [\mathbf{Index1}, i]$;
  end
  if $\mathbf{M}_{pl}(i) < pl_2$
    $\mathbf{Index2} = [\mathbf{Index2}, i]$;
  end
end
Some users are selected from **Index2** as NOMA group users; these selected users need to be in the same beam as a certain user in **Index1**. **Index** shows all the indices of the NOMA group users.

**Output:**

Return the indices of the NOMA group users, **Index**.

Algorithm 1: Selection algorithm for NOMA group users.

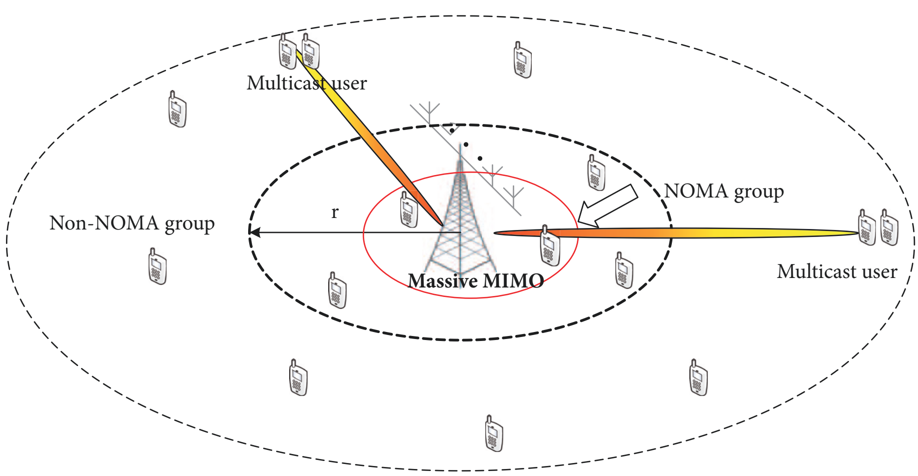


Figure 3: Opportunistic NOMA scheme.

(1) NOMA group users should be able to receive strong multicast signals. We choose a path loss $pl_1$, which is used as a threshold. We define an area based on $pl_1$ so that users outside the area involve a maximum number of multicast group members.

(2) The signal of the multicast users should not experience too much interference by the NOMA group users. We define another area based on a path loss threshold $pl_2$ so that the users inside the area are preselected with minimum interference.

The users of the unicast NOMA are usually paired and the number of non-NOMA users is equal to the number of NOMA users in the paired scheme [24]. However, we are investigating a multicast scenario in this study; therefore, the number of NOMA and non-NOMA users can be different [25]. The proposed grouping algorithm is **Algorithm 1**.

*3.6. Projection Matrix.* In our proposed system, the null space scheme for the interference cancellation [26] is applied to eliminate the interference between the unicast groups and multicast groups. The process of intergroup interference cancellation is clearly demonstrated in Figure 4. Since the NOMA group signal is superimposed on the multicast group signal and the NOMA group power is very small, their intergroup interference can be ignored. At the same time, the superposition channel matrix of the NOMA group and multicast group generates the projection matrix of the non-NOMA group by the null space method and the signal interference of the non-NOMA group with the other groups is then eliminated by mapping the channel matrix of the non-NOMA group signal to the projection matrix.

We assume that the joint channel matrix $\mathbf{G}_{\overline{\text{Non}}} = [\mathbf{G}_{\text{NOMA}}, \mathbf{G}_{\text{Multi}}]$, $\mathbf{G}_{\overline{\text{NOMA}}} = \mathbf{G}_{\text{Non}}$, $\mathbf{G}_{\overline{\text{Multi}}} = \mathbf{G}_{\text{Non}}$, and

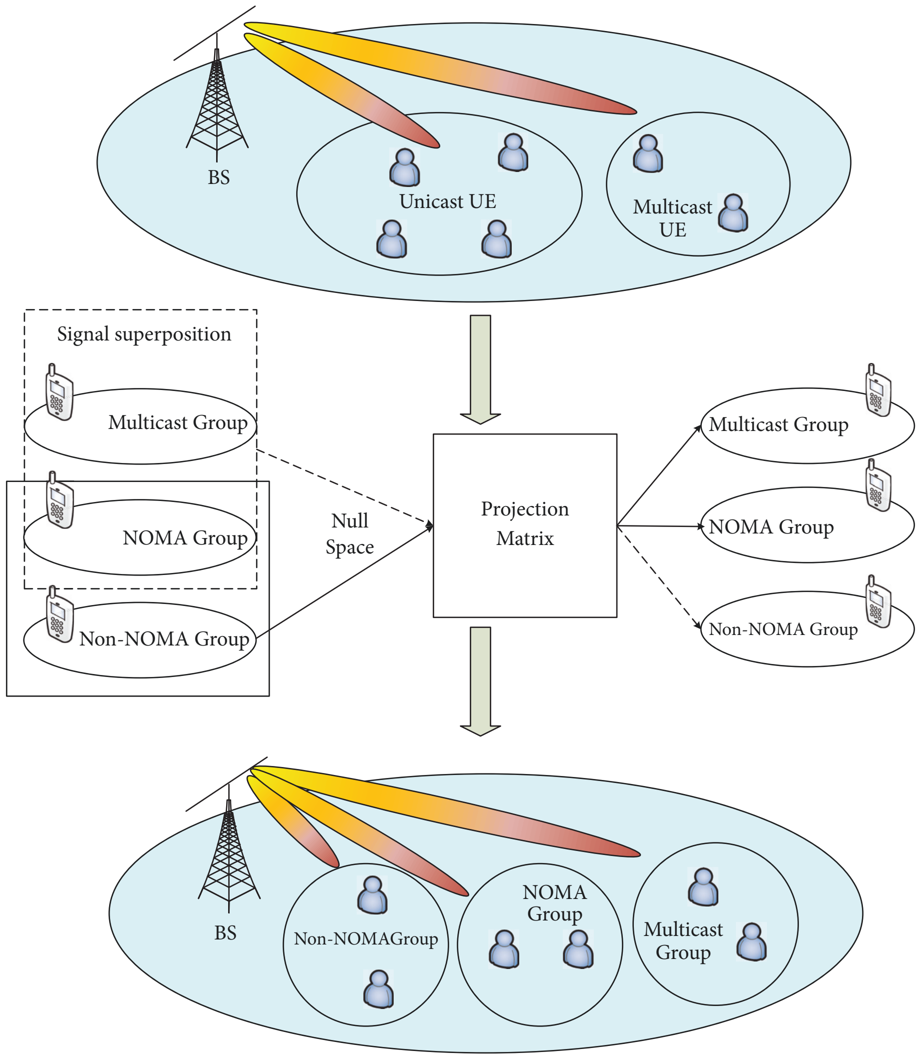


FIGURE 4: Null Space Interference Cancellation.

the channel grouping matrix $\mathbf{G}_m = [\mathbf{g}_{m,1}, \mathbf{g}_{m,2}, \ldots, \mathbf{g}_{m,K_m}, ]$, $(m = \text{Non}, \text{NOMA}, \text{Multi})$. The projection matrix $\mathbf{J}_m$, $(m = \text{Non}, \text{NOMA}, \text{Multi})$ of the $m$th group can be given by the following formulas by using an SVD:

$$\mathbf{G}_{\overline{m}} = \mathbf{U}_{\overline{m}} \mathbf{\Lambda}_{\overline{m}} \mathbf{V}_{\overline{m}}, \tag{12}$$

$$\mathbf{J}_m = \mathbf{V}_{\overline{m}}^{0} \left(\mathbf{V}_{\overline{m}}^{0}\right)^{H}, \tag{13}$$

where $\mathbf{U}_m$, $\mathbf{V}_m$, and $\mathbf{\Lambda}_m$ are SVD factor matrices. $\mathbf{U}_{\overline{m}} \in \mathbb{C}^{N\times N}$, $\mathbf{V}_{\overline{m}} \in \mathbb{C}^{(K-K_m)\times(K-K_m)}$, and $\mathbf{\Lambda}_{\overline{m}} \in \mathbb{C}^{N\times(K-K_m)}$. The subspace for the column vector space of $\mathbf{V}_{\overline{m}}$ is represented by $\mathbf{V}_{\overline{m}}^{0} \in \mathbb{C}^{(K-K_m)\times N}$. After multiplying the projection matrix $\mathbf{J}_m$, the $\mathbf{G}_m$ is transformed into $\widehat{\mathbf{G}}_m$ and the $\mathbf{g}_{m,j}$ is transformed into $\widehat{\mathbf{g}}_{m,j}$ at the same time, where $\mathbf{G}_m$ denotes the channel matrix of the $m$th group and $\mathbf{g}_{m,j}$ represents the channel vector of the $j$th user in the $m$th group.

By effectively eliminating the signal leakage from each group, the performance of the hybrid multicast/unicast transmission is guaranteed after the manipulation.

*3.7. Opportunistic Massive MIMO-NOMA System Model.* According to the full view of the system, the interference cancellation can be presented by the following system formula:

$$\begin{aligned}
\mathbf{Y} &= \sqrt{P}\mathbf{G}\mathbf{J}\omega\mathbf{S} + \mathbf{z}, \text{ and} \\
\mathbf{z} &= \left[\mathbf{z}_{\text{Non}}, \mathbf{z}_{\text{Multi}}\right]^{T}, \\
\mathbf{S} &= \left[\mathbf{s}_{\text{Non}}, \mathbf{s}_{\text{Multi}}\right]^{T} + \left[\mathbf{0}, \mathbf{s}_{\text{NOMA}}\right]^{T}, \\
\omega &= \operatorname{diag}\left(\mathbf{\Omega}, \mathbf{w}_{\text{Multi}}\right), \\
\mathbf{J} &= \left[\mathbf{J}_{\text{Non}}, \mathbf{J}_{\text{Multi}}\right], \\
\mathbf{G} &= \left[\mathbf{G}_{\text{Non}}, \mathbf{G}_{\text{NOMA}}, \mathbf{G}_{\text{Multi}}\right]^{T}, \\
\mathbf{Y} &= \left[\mathbf{y}_{\text{Non}}, \mathbf{y}_{\text{Multi}}\right]^{T}
\end{aligned} \tag{14}$$

where $\mathbf{Y}$ is the received signal of signal $\mathbf{S}$ emitted from the transmitting terminal and $P$ denotes the transmitted power of the transmitting terminal. The precoding

Table 1: Simulation parameters.

| Parameters | Values |
|---|---|
| Scenario | NLOS |
| Frequency | 38GHz |
| Transmit Antenna Height | 36m |
| Receive Antenna Height | 1.5m |
| Number of BS Antenna | 64 to 256 / 128 |
| User Number | $K$=40 |
| Antenna Spacing of Antenna Configuration | 0.5 wave length for horizontal and vertical direction |
| SNR | -10dB to 30dB/ 15dB |
| $Z_1$ | 50 Ω |
| $Z_2$ | 50 Ω |
| $Z_3$ | 50 Ω |
| Transmit Antenna Gain | 25dB |
| Receive Antenna Gain | 13.3dB |
| NOMA Group User Number | 10 / 1 to 10 |

matrix $\omega$ and projection matrix $\mathbf{J}$ can handle the signal $\mathbf{S}$, and $\mathbf{z}$ can be described as the White Gaussian Noise. In addition, matrix $\mathbf{w}_{\text{Multi}}$ is denoted by $\mathbf{w}_{\text{Multi}} = (1/\lambda)[\widehat{\mathbf{g}}^*_{\text{Multi},1}, \widehat{\mathbf{g}}^*_{\text{Multi},2}, \ldots, \widehat{\mathbf{g}}^*_{\text{Multi},K_{\text{Multi}}}]$, where $\lambda$ represents the normalization factor to ensure $\omega_m = (1/\lambda)\sum_{j=1}^{K_m} \widehat{\mathbf{g}}^*_{\text{Multi},j}$ and $\mathbf{\Omega}$ represents the precoding matrix used by the unicast users.

*3.8. Received Signal Model for Opportunistic Massive MIMO-NOMA.* We assume that $\eta(0 < \eta < 1)$ is used to represent the transmission power factor of the $m$th group.

$$\mathbf{y}_{\text{Multi}} = \sqrt{P}\mathbf{G}_{\text{Multi}}\mathbf{J}_{\text{Multi}}\mathbf{w}_{\text{Multi}}\left(\mathbf{s}_{\text{Multi}} + \mathbf{s}_{\text{NOMA}}\right) + \mathbf{z}_{\text{Multi}} \quad (15)$$

$$\mathbf{y}_{\text{Non}} = \sqrt{P}\mathbf{G}_{\text{Non}}\mathbf{J}_{\text{Non}}\mathbf{\Omega}\mathbf{s}_{\text{Non}} + \mathbf{z}_{\text{Non}} \quad (16)$$

$$\begin{aligned}\mathbf{y}_{\text{NOMA}} &= \eta\sqrt{P}\underbrace{\mathbf{G}_{\text{NOMA}}\mathbf{J}_{\text{Multi}}\mathbf{w}_{\text{Multi}}\mathbf{s}_{\text{Multi}}}_{\text{SIC}} \\ &\quad + \eta\sqrt{P}\mathbf{G}_{\text{NOMA}}\mathbf{J}_{\text{Multi}}\mathbf{w}_{\text{Multi}} \\ &\quad \cdots\left(\mathbf{G}_{\text{NOMA}}\mathbf{J}_{\text{Multi}}\mathbf{w}_{\text{Multi}}\right)^{\text{BD}}\mathbf{s}_{\text{NOMA}} + \mathbf{z}_{\text{Multi}}\end{aligned} \quad (17)$$

In (17), $(\cdot)^{(\text{BD})}$ represents the BD precoding of the matrix. The proposed system can separate the data and transmit them to the respective users by SIC and provide high-speed transmission for non-NOMA users; it also provides multicast services for users. As a result, this proposed system significantly increases the spectrum efficiency.

## 4. Simulation Results

In this chapter, we describe the computer simulations that were conducted to study the performance of the proposed system. The detailed simulation parameters are listed in Table 1.

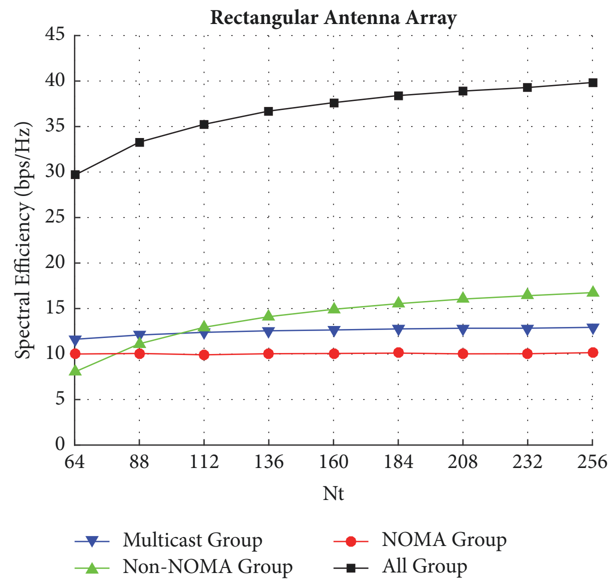


Figure 5: Comparison of spectral efficiency among different groups (antenna array: rectangular; SNR: 15).

*4.1. Comparison of NOMA, Non-NOMA Precoding, and Multicast Beamforming.* The performance of the NOMA, non-NOMA precoding, and multicast beamforming methods is evaluated based on the channel model. The channel model becomes less independent from the viewpoint of space. To compare the multicast beamforming and MU-MIMO linear precoding, BD precoding is selected for the non-NOMA users. The number of users in the non-NOMA group, the NOMA group, and the multicast group is 20, 10, and 10, respectively.

The spectrum efficiency of multicast beamforming and BD precoding for a rectangular antenna array is shown in Figure 5. For the convenience of observation, the total spectrum efficiency is given as “all group”. Generally, the NOMA group has 10% power of the multicast group and its signal is superimposed on that of the multicast group; therefore, the spectrum efficiency is better for the non-NOMA group.

A similar phenomenon is observed in Figure 6, which illustrates the changes in the spectrum efficiency using a cylindrical antenna array.

Figure 7 illustrates the changes in the spectrum efficiency with increasing signal-to-noise ratio (SNR). The maximum number of group users can be raised in this system and the transmission power and interference can be minimized as well. In addition, this figure also illustrates that the spectrum efficiencies are lower without a null space than with a null space. Therefore, it is clear that the null space strategy plays a crucial role in removing the cross interference and improving the system performance.

A similar phenomenon is observed in Figure 8, which illustrates the changes in the spectrum efficiency using the cylindrical antenna array. Although the change trend is the same, the spectrum efficiency is clearly lower for the cylindrical antenna array than for the rectangle antenna array.

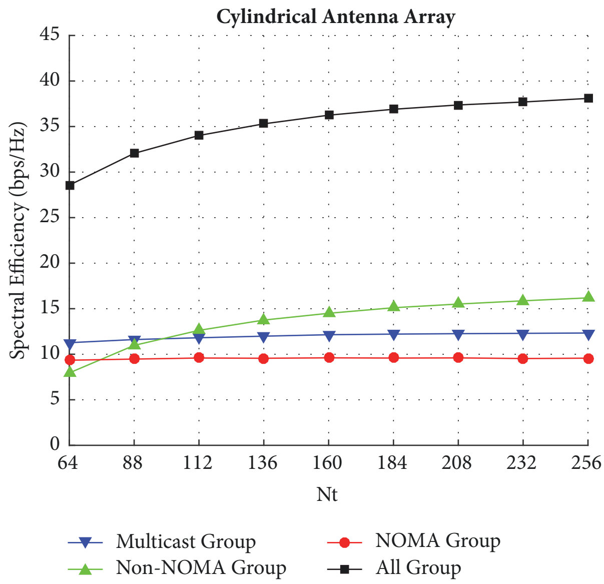


FIGURE 6: Comparison of spectral efficiency among different groups (antenna array: cylindrical; SNR: 15.).

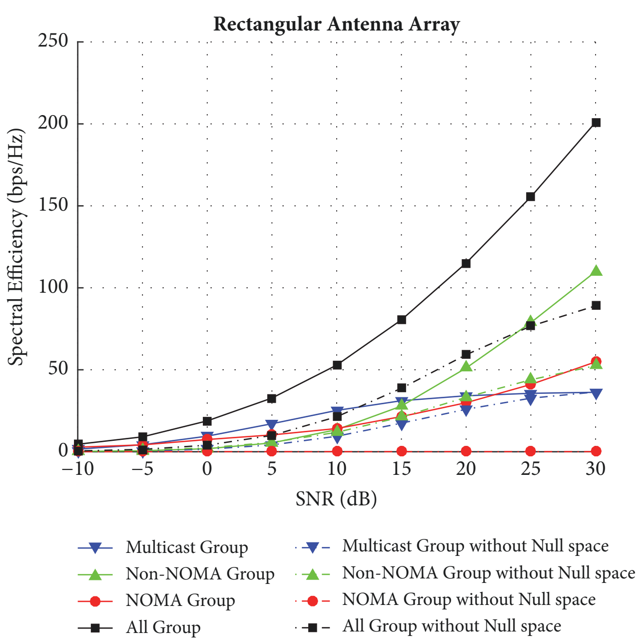


FIGURE 7: Comparison of spectral efficiency among different groups (antenna array: rectangular; antenna number: 128.).

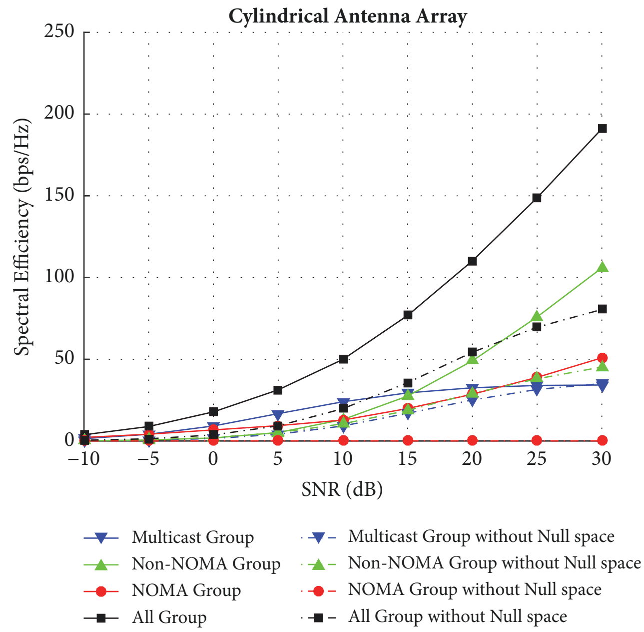


FIGURE 8: Comparison of spectral efficiency among different groups (antenna array: cylindrical; antenna number: 128.).

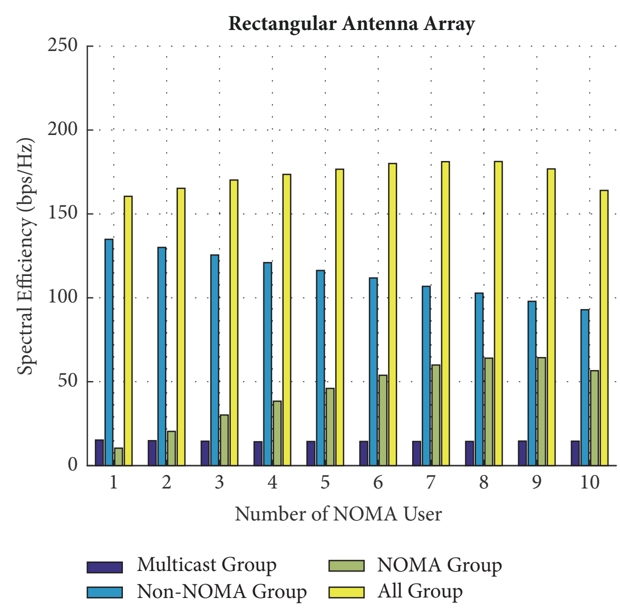


FIGURE 9: Grouping strategy analysis (SNR: 15; antenna number: 28; number of multicast group users: 10; number of non-NOMA group users: 29 to 20; number of NOMA group users: 1 to 10).

*4.2. Analysis of the Opportunistic Massive MIMO-NOMA Strategy.* With the number of users remaining at 30, the balance between the non-NOMA group users and NOMA group users has been illustrated in Figure 9. The results show that the even spectrum efficiency improves with an increasing number of NOMA group users; however, when the number of NOMA users exceeds a certain value, the spectrum efficiency begins to decrease.

The NOMA group users can receive multiple layers of the signal with a high SNR. They use the SIC to decode the different layers of data. From this respect, the NOMA users have a better opportunity to achieve a high data rate. However, a NOMA user may have only one data layer although many layers can be decoded. In other words, a NOMA user usually receives and decodes the data of other users, which is not useful to the user. Even worse, a NOMA user may require large computational resources for the SIC scheme.

In Figure 9, the pseudo-NOMA spectral efficiency denotes the total (all layers) decoded data rate of the NOMA users, including data that are useful and not useful to the decoder. A portion of the pseudo-NOMA spectral efficiency represents the data rate of the NOMA users' own signal, whereas the other portion represents the data rate of the other users' signals. The simulation results clearly reveal that the pseudo-NOMA spectral efficiency is high, although the useful NOMA spectral efficiency is not.

## 5. Conclusion

Group oriented applications are becoming more and more important for future mobile computing. This fact makes it urgent to develop the multicast infrastructure of 5G NR. We accordingly study the integration of NOMA technology and massive MIMO technology to overcome the above challenge. We notice that a practical system is usually a hybrid unicast/multicast system rather than a unique one. Therefore, our scheme utilizes null space based interference cancellation to distinguish the unicast and multicast precoding. Our scheme also superimposes the NOMA user's signal on the multicast users' signal opportunistically in order to improve the spectrum efficiency.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

## References


[1] J. G. Andrews, S. Buzzi, and W. Choi, "What will 5G be?" *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1065–1082, 2014.

[2] Q. Li, R. Q. Hu, Y. Qian, and G. Wu, "Cooperative communications for wireless networks: techniques and applications in LTE-advanced systems," *IEEE Wireless Communications Magazine*, vol. 19, no. 2, pp. 22–29, 2012.

[3] S. Yue, J. Liu, C. Zhai, and Q. Wang, "User pilot scheduling in massive MIMO systems," in *Proceedings of the 2015 International Conference on Wireless Communications and Signal Processing (WCSP)*, pp. 1–5, IEEE, Nanjing, China, October 2015.

[4] Z. Xiang, M. Tao, and X. Wang, "Massive MIMO multicasting in noncooperative cellular networks," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1180–1193, 2014.

[5] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," *IEEE Transactions on Communications*, vol. 61, no. 4, pp. 1436–1449, 2013.

[6] Z. Shi, S. Ma, and H. ElSawy, "Cooperative HARQ Assisted NOMA Scheme in Large-scale D2D Networks," *IEEE Transactions on Communications*, 2017.

[7] X. Liu and X. Wang, "Efficient antenna selection and user scheduling in 5G massive mimo-noma system," in *Proceedings of the IEEE Vehicular Technology Conference*, 2016.

[8] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 186–195, 2014.

[9] E. Karipidis, N. D. Sidiropoulos, and Z.-Q. Luo, "Quality of service and max-min fair transmit beamforming to multiple cochannel multicast groups," *IEEE Transactions on Signal Processing*, vol. 56, no. 3, pp. 1268–1279, 2008.

[10] Z. Xiang, M. Tao, and X. Wang, "Massive MIMO multicasting in noncooperative multicell networks," in *Proceedings of the 1st IEEE International Conference on Communications, ICC 2014*, pp. 4777–4782, 2014.

[11] H. Zhou and M. Tao, "Joint multicast beamforming and user grouping in massive MIMO systems," in *Proceedings of the IEEE International Conference on Communications (ICC '15)*, pp. 1770–1775, 2015.

[12] K. Xiao, L. Gong, and M. Kadoch, "Opportunistic Multicast NOMA with Security Concerns in a 5G Massive MIMO System," *IEEE Communications Magazine*, vol. 56, no. 3, pp. 91–95, 2018.

[13] W. Shin, M. Vaezi, J. Lee, and H. V. Poor, "On the number of users served in MIMO-NOMA cellular networks," in *Proceedings of the 13th International Symposium on Wireless Communication Systems, ISWCS 2016*, pp. 638–642, pol, September 2016.

[14] Z. Ding, F. Adachi, and H. V. Poor, "Performance of MIMO-NOMA Downlink Transmissions," in *Proceedings of the GLOBECOM 2015 - 2015 IEEE Global Communications Conference*, pp. 1–6, IEEE, 2015.

[15] B. Rong, X. Qiu, M. Kadoch, S. Sun, and W. Li, *5G Heterogeneous Networks: Self-organizing and Optimization*, Springer, Berlin, Germany, 1st edition, 2016.

[16] W. Shin, M. Vaezi, and B. Lee, "Coordinated beamforming for multi-cell MIMO-NOMA," *IEEE Communications Letters*, vol. 99, no. 1, p. 1, 2016.

[17] S. Sun, B. Rong, and Y. Qian, "Artificial frequency selective channel for covert CDD-OFDM transmission," *Security and Communication Networks*, 2014.

[18] X. Zhang, S. Sun, F. Qi, R. Bo, R. Q. Hu, and Y. Qian, "Massive MIMO Based Hybrid Unicast/Multicast Services for 5G," in *Proceedings of the IEEE Global Communications Conference (GLOBECOM)*, pp. 1–6, December 2016.

[19] K. Zheng, S. L. Ou, and X. F. Yin, "Massive MIMO channels: a survey," *International Journal of Antennas and Propagation*, vol. 2014, Article ID 848071, 10 pages, 2014.

[20] C. Masouros, M. Sellathurai, and T. Ratnarajah, "Large-scale MIMO transmitters in fixed physical spaces: the effect of transmit correlation and mutual coupling," *IEEE Transactions on Communications*, vol. 61, no. 7, pp. 2794–2804, 2013.

[21] K. Xiao, S. Dai, H. Rutagemwa, B. Rong, L. Gong, and M. Kadoch, "A Novel Opportunistic NOMA Scheme for 5G Massive MIMO Multicast Communications," in *Proceedings of the 2017 IEEE 86th Vehicular Technology Conference (VTC-Fall)*, pp. 1–5, Toronto, ON, September 2017.

[22] S. Sun, L. Gong, B. Rong, and K. Lu, "An intelligent SDN framework for 5G heterogeneous networks," *IEEE Communications Magazine*, vol. 53, no. 11, pp. 142–147, 2015.

[23] N. Chen, B. Rong, A. Mouaki, and W. Li, "Self-organizing scheme based on NFV and SDN architecture for future heterogeneous networks," *Mobile Networks and Applications*, vol. 20, no. 4, pp. 466–472, 2015.

[24] C. Zhang and L. Guo, "BD precoding schemes for cognitive MIMO system," in *Proceedings of the 2009 IEEE International Conference on Network Infrastructure and Digital Content, IEEE IC-NIDC '09*, pp. 11–15, 2009.

[25] Z. Chen and X. Dai, "MED Precoding for Multiuser MIMO-NOMA Downlink Transmission," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 6, pp. 5505–5509, 2017.

[26] Z. Zhao, M. Xu, Y. Li et al., "A Non-Orthogonal Multiple Access-Based Multicast Scheme in Wireless Content Caching Networks," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 12, pp. 2723–2735, 2017.