Power Allocation in 5G mmWave Networks with Massive MIMO and Block Diagonalization

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Abstract. In this paper, we consider an energy-efficient downlink power allocation problem of a massive multiple-input multiple-output (MIMO) system in cellular networks. We propose a new technique that uses block diagonalization (BD) precoding with massive MIMO in 5G networks that employs millimeter wave (mmWave) channel matrix to reduce the level of interference. A power allocation algorithm is then introduced by increasing the energy efficiency (EE) of the system to obtain optimal downlink power values using sequential quadratic programming (SQP) algorithm. The results reveal that using BD reduces the interference level and hence, increases the energy.

Keywords: Energy-efficiency, power allocation, Massive MIMO, Block diagonalization, millimeter-wave.

1. Introduction

One promising innovation for future five generation wireless tele-communication is using massive MIMO with small cells networks that has attracted parts of investigate consideration as of late [1-3]. It has been stated that energy efficiency (EE) is progressed by overlaying current foundation by a layer of small cells (SCs) or utilizing massive MIMO at the BSs. Several research works were investigated for heterogeneous massive MIMO with block diagonalization (BD) precoding to mitigate signals interferences as in [4-7]. Other researchers illustrated that performance of MIMO antenna in milli-meter wave (mmWave) channel matrix [8-9] is enhanced through building for recommended simulator which is pertinent for a wide extend with frequencies (500 MHz to 100 GHz) and radio recurrence (RF) transmission capacities (0 to 800 MHz) for milli-meter wave wireless tele-communication systems. A comprehensive survey of large mmWave multi-user channel was introduced in [10] for expansive multiuser MIMO networks with commonsense RF equipment limitations to induce the alluring however infeasible full-complexity zero-force (ZF) precoding with low-complexity cross breed PZF techniques. A mmWave simulation work in [11] considered the performance of MIMO in a mmWave at 72GHz with a 32 component antenna array with Zero-Forcing strategies to support multi-users with higher gains. In arrange to extend the generally energy effectiveness of the system.

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we introduce a block diagonalization precoding along with mmWave channel matrix. For the sake of practicality, we have considered the parameters that were introduced in the work of Saleh and R. Valenzuela model [12]. We start to detect the interference mitigation process at the transmitter using BD then apply Saleh and R. Valenzuela model so that channel matrix with massive MIMO systems can eliminate interferences. We have applied our proposed algorithm in a heterogeneous network topology with massive MIMO. Finally, a power allocation algorithm in proposed by maximizing the overall EE using Sequential quadratic programming algorithm (SQP) [16]. To the best of the authors knowledge, rare research works have investigated massive MIMO with BD in 5G mmWave networks.

The other part of this paper is presented as : System model and BD analysis is explained in Section two. Section three introduces the power allocation algorithm that assigns SQP algorithm with BD and mm-wave to find optimal downlink power values. In Section five, simulation results demonstrate the performance of the proposed algorithm. Finally, our work is concluded in Section six.

2. System Model
2.1 Block diagonalization precoding for interference mitigation

We consider a massive MIMO framework as showed up in Fig.1, where a base station with \( N_{BS} \) antennas and \( M_{BS} \) RF chains is assumed to schedule \( K \) user equipment. \( N_{MC} \) is the number of antennas in each small cell. Each mobile station (MS) is prepared with \( N_{MS} \) antennas and \( M_{MS} \) RF chains to support MS as input data at the transmission part. NS is the input data to the precoder which means that total \( K*NS \) data streams are handled. To guarantee the effectiveness communication carried by the constant number of RF chains, Transmitted steams is constrained by:

i) \( K*NS \leq M_{BS} \leq N_{BS} \) for the BS.

ii) \( NS \leq M_{MS} \leq M_{MS} \) for each MS.

As discussed in [4], the precoding matrix is made of two main parts: \( T_k = M_k * B_k \), where \( M_k \) is the preprocessing of multiple users to mitigate interferences whereas \( B_k \) represents the channel parallelization and power allocation.

![Figure 1. Block diagram of block diagonalization](image)

Considering that transmitter has idealize information of the channel state information of \( W_k \), \( M_k \) is chosen in arrange to alter columns lying within the null space of \( H_{r,j} \) (\( j \neq k \)) i.e., \( H_{r,j} M_k = 0 \) for \( j = 1, \ldots, K \) (\( j \neq k \)). We consider this as the BD channel matrix of user \( k \) as :

\[
H_k = \begin{bmatrix} H_{r,1}^T, \ldots, H_{r,k-1}^T, H_{r,k}^T, \ldots \end{bmatrix}^T
\] (1)
2.2 Millimeter wave channel matrix model
Let \( H_k = [h_1, h_2, \cdots, h_K] \) represent the channel matrix among BS and the k user. We present the Saleh-Valenzuela channel model for mmWave tele-communications [11] and [12] so \( h_k \) can be given as:

\[
H_k = g_{2010}g_{3031} (g_{2161}) g_{1153}g_{4672} g_{2016}g_{3031} (g_{2161}) g_{4673} + \sum g_{2010}g_{3031} (g_{3039}) g_{1153} g_{4672} g_{2016}g_{3031} (g_{3039}) g_{4673} g_{3013} g_{3039}g_{2110}g_{2169} (g_{2010}) g_{3031} (g_{2161}) g_{1153} g_{4672} g_{2016}g_{3031} (g_{2161}) g_{4673} g_{3013} \tag{2}
\]

\( \beta_k^{(0)} (\theta_k^{(0)}) \) is assigned to illustrate the LOS part of the k-th user, the total range for \( \beta_k^{(0)} (\theta_k^{(0)}) \) with \( 1 \leq l \leq L \) represent the \( l \)-th NLOS component of the k-th user, where \( L \) is the overall number of NLOS components \( a(\theta) \) is the \( N \times 1 \) array steering vector.

3. Small cells Massive-MIMO system.

3.1 Downlink system model in presence of small cells
The channel vector represent channel characteristics from the BS or small cell to user k is \( H_k \). So \( H_k \) represent channel matrix for mmWave channel matrix, by applying block diagonalization, the channel matrix will be denoted as \( \tilde{H}_k \) for mmWave and block diagonalization. the signal received at the k-th user is:

\[
y_k = \tilde{H}_k W_k u_k + \tilde{H}_k \sum_{i \neq k} W_i S_i + \tilde{H}_{i,k} + n_k
\]

\[= \tilde{H}_k x_k + \tilde{H}_k \sum_{i \neq k} x_i S_i + Z_k \tag{3}\]

where \( u_k \) is the transmit signal with power \( P_k \), \( x_k = W_k u_k \) is the precoded transmitted signal for user k and the complex noise component is represented by \( n_k \).

3.2 Massive MIMO Energy Efficiency.
The energy efficiency of the system can be given as follows:

\[
\text{Energy Efficiency} = \frac{\text{achievable sum rate}}{\text{Total power}} = \frac{R(c)}{P_{\text{total}}} \tag{4}
\]
While the achievable rate $R(c)$ is expressed as follows:

$$R(c) = \sum_{k=1}^{K} \log_2 \left( 1 + \text{SINR}_k \right)$$  \hspace{1cm} (5)

where $\text{SINR}_k$ is the signal-to-interference ratio at user $k$.

The total power consumed w.r.t our proposed system:

$$P_{\text{total}} = \frac{1}{\eta} p_t + p_c + \sum_{k=1}^{K} p_{c,k} + p_{\text{source}}$$

$$= \sum_{k=1}^{K} \left( \frac{p_k}{\eta} + p_c \right) + p_{\text{source}},$$

where $\eta$ is the power amplifier efficiency, $p_t$ is overall power consumption, $p_c$ is the overall power for circuits, $p_{c,k}$ is power consumption at user’s mobile equipment, $p_{c,k}$ is the power consumption at the macro BS and $p_{c,c}$ is the power consumption at small cells. Now, the total achievable sum rate can be expressed as:

$$R(c) = \sum_k \sum_i \log_2 \left( 1 + \tilde{H}_{l,k} P_{l,k} \right)$$

(7)

Where $\tilde{H}_{l,k}$ represent proposed block diagonalization mmWave channel matrix and $P_{l,k}$ represents transmit power. EE is the ratio between the sum-rate and the total consumed power for equal power values to all user as in (5) and can be given as:

$$\text{EE}(p) = \frac{\sum_i \sum_k \log_2 \left( 1 + \tilde{H}_{l,k} P_{l,k} \right)}{P_{\text{total}}}$$

(8)

4. Efficient power allocation using SQP

The BS allocates each transmit antenna MT with diverse sums of power with power allocation values. The SINR at user $k$ is given by:

$$\text{SINR}_k = \tilde{H}_{l,k} P_{l,k}^*$$

(9)

where $P_{l,k}^*$ is the transmit power to user $k$. Then, we able to get the esteem of SINR and the achievable rate for user $k$ from transmitter sources macro base station or one of the three small cells as below:

$$R_{\text{lk}} = \sum_i \sum_k \log_2 \left( 1 + \tilde{H}_{l,k} P_{l,k}^* \right)$$

(10)

4.1 applying SQP algorithm to EE equation.

$$\forall(p, \lambda) = \sum_{k=1}^{K} \log_2 \left( 1 + \text{SINR}_k \right) + \sum_{k=1}^{K} \lambda \left( ( p_k - (p_{\text{max}}^{bs}) ) \right) A + \sum_{k=1}^{K} \lambda \left( ( p_k - (p_{\text{max}}^{sc}) ) \right) B$$

(11)
Where A and B represent \{1,0\} as when A = 0, B = 1 and vice versa that can be changed as it were by the user needs so that user is served by macro base station or by small cells for all k not both, so user can communicate with one source only (unity source) macro base station or one of the three small cells.

Let $\lambda$ is Lagrange Multiplier, we introduce an optimization issue, pointing to maximize the EE with system limitations. An SQP power allocation algorithm is proposed to optimize all parameters around Base station and small cells.

$$
\begin{align*}
\max_{P_{lk}} \sum_{i} \frac{\log_2 (1 + \tilde{h}_{i,k} P_{i,k}^*)}{\sum_{k} \sum_{i} \frac{p_{lk}}{\eta} + p_c}
\end{align*}
$$

Subject to $R_{req} \geq R_{min}$

$$
\sum_{i} \sum_{k} P_{i,k}^* \leq P_{source}^{\text{max}}
$$

Based on our SQP calculation, ready to propose an EE power allocation calculation using Lagrange multiplier method.

4.2 Sequential quadratic programming algorithm

1. Input: Set $\lambda$, $(p_{\text{max,bs}})$ and $(p_{\text{max,sc}})$ $k = 1,\ldots,K$
2. Output: $\{p^*\}$ and $R_k$
3. Initialize: value of power to be $p = p_o$
4. Calculate power allocation values $p_{i,k}$ using SQP
5. Recalculate achievable rate but substitute with optimal power values
$$
\sum_{k} \sum_{i} \log_2 (1 + \tilde{h}_{i,k} P_{i,k}^*)
$$
6. Check convergence: the algorithm stops when $\lambda + 1 < 0$

5. Simulation Results.
In this part, results are obtained to validate our proposed algorithm. The network model consists of macro and small-cells, the working frequency is 60 GHz, $K = 6$, $N_{bs} = 64$ and $N_{sc} = 16$. 


Base station is equipped with 3 small cells and the total number of users \( K=6 \), all parameters values are shown in table 1.

| parameter                                | value          |
|------------------------------------------|----------------|
| Total transmitted power                  | 32 mW (15 dBm) |
| Circuit power consumption                | 40 dBm         |
| RF power amplifier efficiency            | 0.31           |
| Path loss exponent                       | 3.5 dB         |
| Standard deviation of shadowing          | 8 dB           |
| peak-to-average power ratio              | 12             |
| noise power \( \sigma^2 \)              | -108 dBm       |
| Radius of circular coverage              | 400 m          |
| Total number of SCs                      | 3 small cells  |

The next two figures illustrates the Energy Efficiency with and without SQP algorithm in order to validate our results.

Figure 3 shows the values of energy efficiency at different available transmit power (dB) values. We consider two scenarios: The first is the energy efficiency performance obtained with the proposed power values; the second scenario does not include power allocation where power values are distributed equally among users. The results indicate that EE with our proposed SQP algorithm has higher EE values than equal power performance where optimal power values with BD helps in reducing the interference level.
The next two figures illustrate the relation between Energy Efficiency (EE) versus number of users and number of antennas respectively to validate the results with different interference mitigation techniques.

**Figure 4** shows energy efficiency (bits/J) at different SINR values with and without power allocation.

**Figure 5** studies the effect of number of users. It can be easily concluded that the EE values decrease as number of users increase. However, the performance of EE using the proposed algorithm is better than the conventional scenarios.
6. Conclusion

In this paper, we proposed an energy-efficient power allocation for heterogeneous cellular 5G mmWave organize with Massive MIMO and utilizing BD. The energy effective was arranged using the SQP calculation. The simulation comes almost showed up that the proposed algorithm exceed the past researches by accomplishing the foremost extreme EE execution to validate the results with different interference mitigation techniques. The execution of EE moreover can be moved forward with MIMO and small cells topology. Based on the proposed power allocation calculation, we as well imitated and analyzed the penchant of the EE with the particular number of users.

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