Power Allocation of Full-Duplex Transmission in Wireless OFDM Networks

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Abstract

In this paper, we consider a three-node wireless OFDM network, which consists of two half-duplex uplink and downlink terminal nodes and one full-duplex base station node. The full-duplex capability of the base station allows it to transmit to and receive from the terminal nodes simultaneously across multiple subcarriers. In this case, the downlink transmission may suffer from the inter-node interference generated from the uplink terminal node. We aim to maximize the sum-rate of the uplink and downlink transmissions through subcarrier power allocation.

1. Introduction

In this paper, we consider three-node wireless OFDM network with full-duplex capable base station that can transmit to and receive from two different nodes simultaneously over multiple subcarriers [1]. In this scenario, there are two unidirectional transmissions, i.e., uplink transmission from uplink transmitter to base station, and downlink transmission from base station to downlink receiver. Also, the downlink receiver suffers from the inter-node interference generated from the uplink transmitter. We aim to maximize the sum-rate of the uplink and downlink transmissions through subcarrier power allocation. We first formulate the subcarrier-level power allocation problem as a convex optimization problem and develop a solution using the Lagrangian dual optimization technique.

2. Sum-Rate of Full-Duplex Transmissions

We consider a single-cell three-node wireless OFDM network that consists of one full-duplex base station (BS) and two half-duplex terminals for uplink (U) and downlink (D), respectively, as shown in Fig. 1. Using the full-duplex capability, the base station can transmit to node D while receiving from node U at the same time. We assume that the self-interference at the BS can be successfully suppressed below the noise power level by exploiting various interference cancellation techniques.

We assume that there are N subcarriers, and for each subcarrier i (1 ≤ i ≤ N), we denote by \(\mathcal{H}_U^i\), \(\mathcal{H}_D^i\), and \(\mathcal{H}_I^i\) the normalized channel gain (with respect to the noise power) of the uplink (U→BS), the downlink (BS→D), and the inter-node link (U→D), respectively. Also, let \(P_U^i\) and \(P_D^i\) denote the power allocation of node U and BS to each subcarrier i. We assume that the total transmission power of the base station and the uplink node are constrained by \(P_{BS}\) and \(P_U\), respectively. Let \(R_U^i\) denotes the maximum achievable uplink rate. Also, given \(R_U^i\), let \(R_D^i\) denote the maximum achievable downlink rate. We assume that the base station and the uplink node transmit at rate \(R_D^i\) and \(R_U^i\), respectively. The following lemma provides the subcarrier sum-rate \(R_s^i = R_U^i + R_D^i\).

**Lemma 1.** Given the channel gains \(\mathcal{H}_U^i\), \(\mathcal{H}_D^i\), and \(\mathcal{H}_I^i\), and the uplink and downlink powers \(P_U^i\) and \(P_D^i\), the subcarrier sum-rate \(R_s^i\) can be calculated as

\[
R_s^i = 1_{\{\mathcal{H}_U^i > \mathcal{H}_I^i\}} \left( \log \left( 1 + P_U^i \mathcal{H}_U^i \right) + \log \left( \frac{1 + P_D^i \mathcal{H}_D^i}{1 + P_U^i \mathcal{H}_I^i} \right) \right) + 1_{\{\mathcal{H}_I^i > \mathcal{H}_U^i\}} \min \left( \log \left( 1 + P_U^i \mathcal{H}_U^i \right) + \log \left( 1 + P_D^i \mathcal{H}_D^i \right) \right).
\]

**Proof:** The maximum achievable uplink rate can be easily obtained as \(R_U^i = \log \left( 1 + P_U^i \mathcal{H}_U^i \right)\), which is the capacity of the uplink channel by Shannon’s well-known formula. For the downlink, we can consider the following two cases depending on the relationship between \(\mathcal{H}_U^i\) and \(\mathcal{H}_I^i\):

- **Case1)** \(\mathcal{H}_U^i > \mathcal{H}_I^i\)

Since the maximum achievable uplink rate is larger than the capacity of inter-node link, i.e.,\(R_U^i > \log \left(1 + P_U^i \mathcal{H}_I^i \right)\), the downlink node is unable to decode the uplink signal. In this case, the downlink node should decode the downlink signal in the presence of the interference (the uplink signal), and the SINR becomes \(\frac{P_D^i \mathcal{H}_D^i}{1 + P_U^i \mathcal{H}_I^i}\). Thus the maximum achievable downlink rate \(R_D^i\) is

\[
R_D^i = \log \left( 1 + \frac{P_D^i \mathcal{H}_D^i}{1 + P_U^i \mathcal{H}_I^i} \right).
\]


Then the sum-rate $R_s^i$ for $H_U^i > H_i^i$ is given as

$$ R_s^i = \log \left(1 + P_u^i H_U^i \right) + \log \left(1 + \frac{P_d^i H_D^i}{1 + P_u^i H_i^i} \right) $$

(3)

Case 2) $H_U^i \leq H_i^i$

We can consider a virtual multiple access channel, which consists of the downlink and the inter-node link, i.e., the base station and the uplink node are two transmitters and the downlink node is a receiver. Assume that the base station and the uplink node transmit at rate $C_D$ and $C_I$, respectively. The achievable region of $(C_D, C_I)$ can be obtained [2] as

$$ C_D \leq \log \left( 1 + P_u^i H_D^i \right), $$

(4)

$$ C_I \leq \log \left( 1 + P_u^i H_i^i \right), $$

(5)

$$ C_D + C_I \leq \log \left( 1 + P_u^i H_i^i + P_d^i H_D^i \right). $$

(6)

Since the (virtual) signal transmitted on the inter-node link is the uplink signal, we have $C_I = R_U^i$. Depending on $R_U^i$, we have two subcases for $R_D^i$ as follows:

Case 2-1) $R_U^i \leq \log \left( 1 + \frac{P_d^i H_D^i}{1 + P_u^i H_i^i} \right).$

The downlink node can first decode the uplink signal by treating it as signal and the downlink signal as interference. In this case, the SINR becomes $\frac{P_d^i H_D^i}{1 + P_u^i H_i^i}$, so the uplink rate should be lower than $\log \left( 1 + \frac{P_d^i H_D^i}{1 + P_u^i H_i^i} \right)$. Once the uplink signal is decoded, the downlink node can subtract it from the aggregate received signal. Since only the downlink signal and the noise are left, the maximum achievable downlink rate can be written as

$$ R_D^i = \log \left( 1 + P_d^i H_D^i \right), $$

(7)

which is the maximum achievable downlink rate without interference. Then the sum-rate $R_s^i$ is given by

$$ R_s^i = \log \left( 1 + P_u^i H_U^i \right) + \log \left( 1 + \frac{P_d^i H_D^i}{1 + P_u^i H_i^i} \right). $$

(8)

Case 2-2) $\log \left( 1 + \frac{P_u^i H_U^i}{1 + P_d^i H_D^i} \right) < R_U^i \leq \log \left( 1 + P_u^i H_i^i \right)$

In contrast to the previous case, the downlink node is unable to decode the uplink signal in the presence of the downlink signal as interference. Since the sum of $C_D$ and $C_I$ is upper bounded by (6), we simply have

$$ C_D \leq \log \left( 1 + P_d^i H_D^i \right). $$

(9)

Then the maximum achievable downlink rate is given as

$$ R_D^i = \log \left( 1 + P_u^i H_U^i + P_d^i H_D^i \right) - R_U^i, $$

(10)

and the corresponding sum-rate $R_s^i$ is

$$ R_s^i = \log \left( 1 + P_u^i H_U^i + P_d^i H_D^i \right). $$

(11)

Note that in case 2-1, (8) < (11), and in case 2-2, (11) < (8). Thus in each case, the sum-rate $R_s^i$ is the minimum of (8) and (11), which can be written as

$$ R_s^i = \min \left( \log \left( 1 + P_u^i H_U^i \right) + \log \left( 1 + P_d^i H_D^i \right), \right. \log \left( 1 + P_d^i H_D^i \right). $$

(12)

Finally, combining the results of (3) and (12), we can obtain $R_s^i$ as in (1). We can show that $R_s^i$ is a concave function. Due to limit of space, we omit the proof.

3. Sum-Rate Maximization

Given the maximum achievable sum-rate $R_s^i$ for each subcarrier $i$, we formulate the sum-rate maximization problem as

$$ \begin{align*}
\text{maximize} & \quad \sum_{i=1}^{N} R_s^i \\
\text{subject to} & \quad \sum_{i=1}^{N} P_u^i \leq P_u \\
& \quad \sum_{i=1}^{N} P_d^i \leq P_{BS}.
\end{align*} $$

Since the above problem is a convex optimization problem, we can solve it via Lagrangian dual optimization.

4. Conclusion

In this paper, we considered the subcarrier power allocation problem of full-duplex transmission in a three-node OFDM network to maximize the sum-rate of uplink and downlink transmissions.

5. Reference


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