Self-Backhauling Full-Duplex Access Node with Massive Antenna Arrays: Power Allocation and Achievable Sum-Rate

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Introduction

- Inband full-duplex communications is quickly becoming reality
  - Several demonstrator implementations already exist
- The next big question is how to best take advantage of it
- In this work, we consider utilizing inband full-duplex capability for self-backhauling in an access node serving mobile users
System model

- Only the access node and the backhaul node are full-duplex capable.
- The access node also has large TX and RX antenna arrays.
- Zero-forcing beam-forming is utilized by the access node to minimize self-interference and multiplex the mobiles.
- The total transmit power of the access node is fixed.
System model

• Assuming uniform channel conditions for the mobiles, it can be shown that the uplink and downlink data rates are:

\[ R_u = U \log_2 (1 + \Gamma_u P_u) \]
\[ R_d = D \log_2 (1 + \Gamma_d P_d) \]

where \( U \) and \( D \) are the numbers of uplink and downlink mobiles, \( P_u \) and \( P_d \) are the corresponding transmit powers.
System model

\[ \Gamma_u = \frac{L_{UE}(N_r - U - M_r^{BH})}{\sigma_n^2 + \alpha P_{AN}} \]
\[ \Gamma_d = \frac{L_{UE}(N_t - N_r - D - M_t^{BH})}{D \sigma_n^2} \]

- \( L_{UE} \) is the path loss between AN and the UEs
- \( N_r / N_t \) denote the number of AN RX/TX antennas
- \( M_r^{BH} / M_t^{BH} \) are the numbers of received/transmitted backhaul streams
- \( \sigma_n^2 \) is the noise floor in all the receivers
- \( \alpha \) is the overall SI cancellation performance of the AN
- \( P_{AN} \) is the total transmit power of the AN
System model

- The backhaul data rates are of similar form, and they can be written as:

\[ R_{uBH} = M_t^{BH} \log_2 \left(1 + \Gamma_u^{BH} (P_{AN} - P_d)\right) \]
\[ R_{dBH} = M_r^{BH} \log_2 \left(1 + \Gamma_d^{BH} P_d^{BH}\right) \]

where \( P_d^{BH} \) is the transmit power of the backhaul node
System model

$$\Gamma_u^{BH} = \frac{L_{BH} (N_t - N_r - D - M_t^{BH})}{M_t^{BH}}$$

$$\Gamma_d^{BH} = \frac{L_{BH} (N_r - U - M_r^{BH})}{M_r^{BH} (\sigma_n^2 + \alpha P_{AN})}$$

- $L_{BH}$ is the path loss between AN and BN
Transmit power optimization

• The objective is then to maximize the sum-rate, subject to the following constraints:
  – The uplink and downlink data rates are within the backhauling capabilities of the access node
  – The uplink and downlink transmit powers are lower than or equal to a predefined limit
  – The ratio between the uplink and downlink data rates is as defined by a parameter \( \rho \)

• Basically, the optimization is done by choosing the highest transmit powers that fulfill all of the constraints
Transmit power optimization

- Utilizing the rate expressions and the aforementioned constraints, we obtain the following optimal transmit powers:

\[ P_d^* = \min\{P_d^I, P_d^{II}, P_d^{III}, P_d^IV\} \]

\[ P_u^* = \frac{(1 + \Gamma_u P_d^*) \frac{\rho D}{U}}{\Gamma_d} \]

\[ P_d^I = \frac{(1 + \Gamma_d^{BH} P_d^{BH})^{M_t^{BH}}}{\Gamma_d} - 1 \]

\[ P_d^{II} = \frac{\Gamma_u^{BH} P_AN - (1 + \Gamma_d P_AN)^{M_t^{BH}}}{\Gamma_u^{BH} + \Gamma_d \frac{\rho D}{M_t^{BH}} (1 + \Gamma_d P_AN)^{M_t^{BH}} - 1} + 1 \]

\[ P_d^{III} = \frac{(1 + \Gamma_u P_{UE}^{BH})^{\frac{\rho D}{U}}}{\Gamma_d} - 1 \]

\[ P_d^{IV} = P_{AN} \]
Numerical results

Next, we evaluate the optimal transmit powers and the corresponding sum-rates numerically, using the given parameter values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of access node TX/RX antennas</td>
<td>200/100</td>
</tr>
<tr>
<td>Number of DL/UL mobiles</td>
<td>10/10</td>
</tr>
<tr>
<td>Number of DL/UL backhaul streams</td>
<td>12/6</td>
</tr>
<tr>
<td>Receiver noise floor</td>
<td>-90 dBm</td>
</tr>
<tr>
<td>Transmit power of the access node</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Maximum transmit power of the mobiles</td>
<td>25 dBm</td>
</tr>
<tr>
<td>Transmit power of the backhaul node</td>
<td>40 dBm</td>
</tr>
<tr>
<td>Amount of SI cancellation in the access node</td>
<td>-100 dB</td>
</tr>
<tr>
<td>Path loss between the access node and the mobiles</td>
<td>-90 dB</td>
</tr>
<tr>
<td>Path loss of the backhaul link</td>
<td>-80 dB</td>
</tr>
<tr>
<td>Ratio between UL and DL data rates</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Numerical results

- Since certain approximations were made when deriving the aforementioned expressions, the analytically obtained results are compared with the results of numerically optimizing the original problem → good match
- It can be observed that at least 18 parallel spatial streams are needed for backhauling the downlink data with the lower SI cancellation levels
- Then, the highest sum-rate is achieved already with 85 dB of total SI cancellation
  - This is already reachable today
Numerical results

- Here, the same curves are drawn with respect to the ratio between uplink and downlink data rates, as well as with different path losses for the mobiles.
- There is an optimal data rate ratio, which depends on the path loss.
- The optimal ratio is obtained when both the DL and UL transmit powers are at their maximum.
  - With any other data rate ratio, either the UL or DL transmit power must be limited below the maximum value to fulfil all the constraints.
Conclusion

• Sum-rate maximizing transmit powers for a self-backhauling full-duplex access node were analytically derived
  – The given constraints ensured the self-backhauling capability

• With careful selection of transmit powers, full-duplex self-backhauling is feasible
  – However, the traffic ratio should be quite symmetric to obtain the highest sum-rates
Thank you!

- Questions?