TAMPERE UNIVERSITY OF TECHNOLOGY

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

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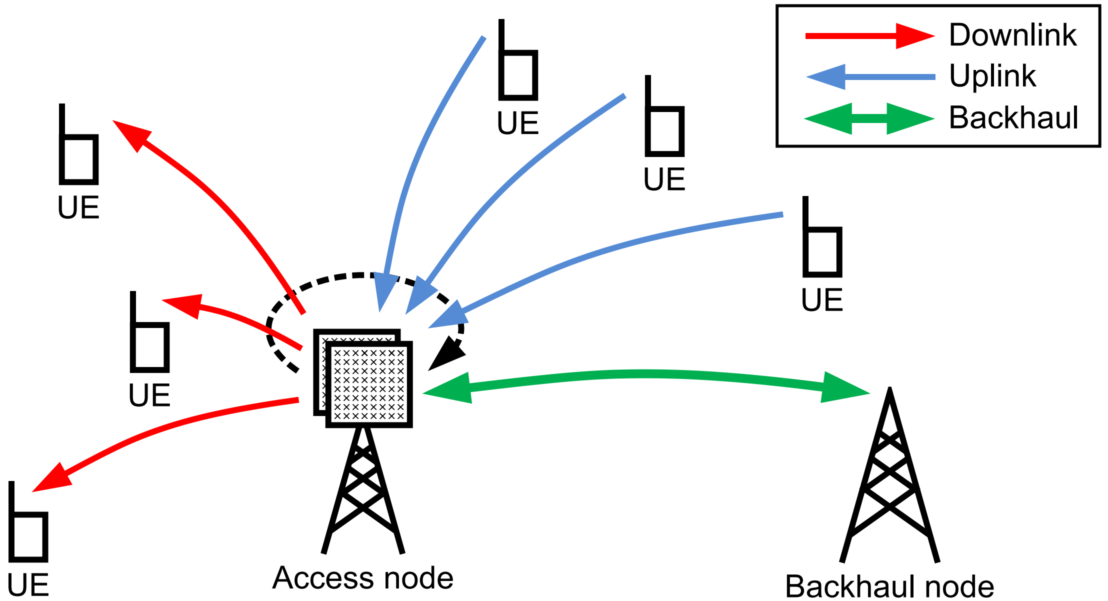
Introduction

- 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
- σ_n^2 is the noise floor in all the receivers
- α 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:

$$R_u^{BH} = M_t^{BH} \log_2\left(1 + \Gamma_u^{BH}(P_{AN} - P_d)\right)$$
$$R_d^{BH} = M_r^{BH} \log_2\left(1 + \Gamma_d^{BH} P_d^{BH}\right)$$

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 (ρ)*
- 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:

$$P_d^* = \min\{P_d^{I}, P_d^{II}, P_d^{III}, P_d^{IV}\}, P_u^* = \frac{(1+\Gamma_u P_d^*)^{\frac{\rho D}{U}}}{\Gamma_d},$$

$$P_d^{I} = \frac{\left(1+\Gamma_d^{BH} P_d^{BH}\right)^{\frac{M_r^{BH}}{D}} - 1}{\Gamma_d},$$

$$P_d^{II} = \frac{\Gamma_u^{BH} P_{AN} - (1+\Gamma_d P_{AN})^{\frac{\rho D}{M_t^{BH}}-1}\left[1+\left(1-\frac{\rho D}{M_t^{BH}}\right)\Gamma_d P_{AN}\right]+1}{\Gamma_u^{BH} + \Gamma_d \frac{\rho D}{M_t^{BH}}(1+\Gamma_d P_{AN})^{\frac{\rho D}{M_t^{BH}}-1}},$$

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

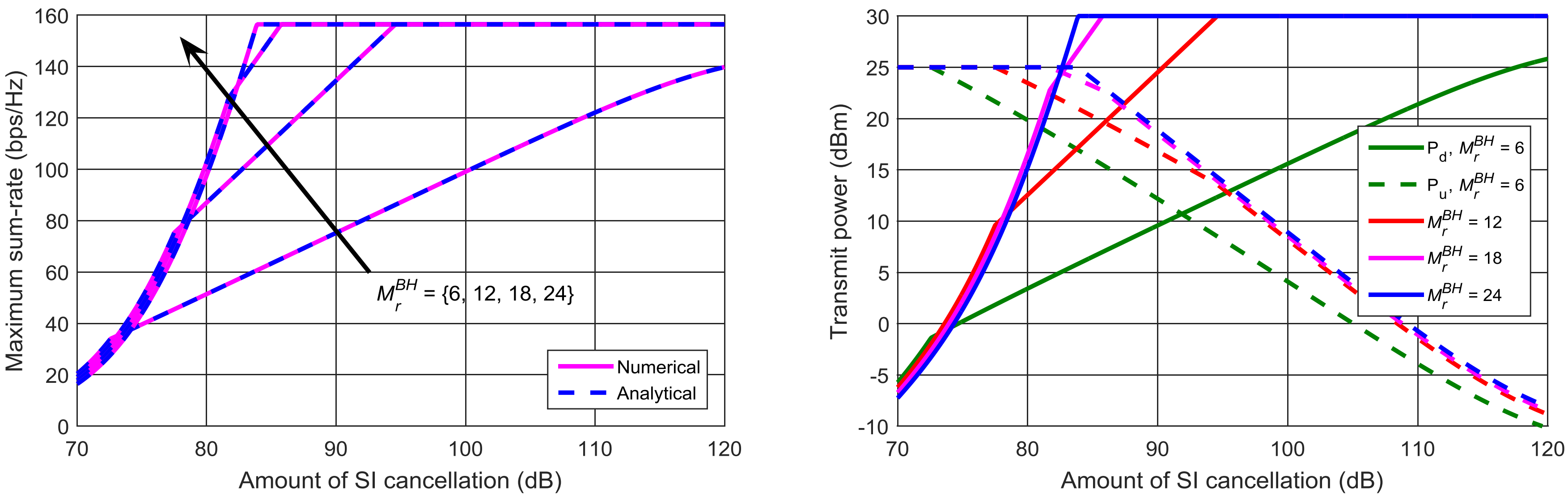
$$P_d^{IV} = P_{AN}$$

Numerical results

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

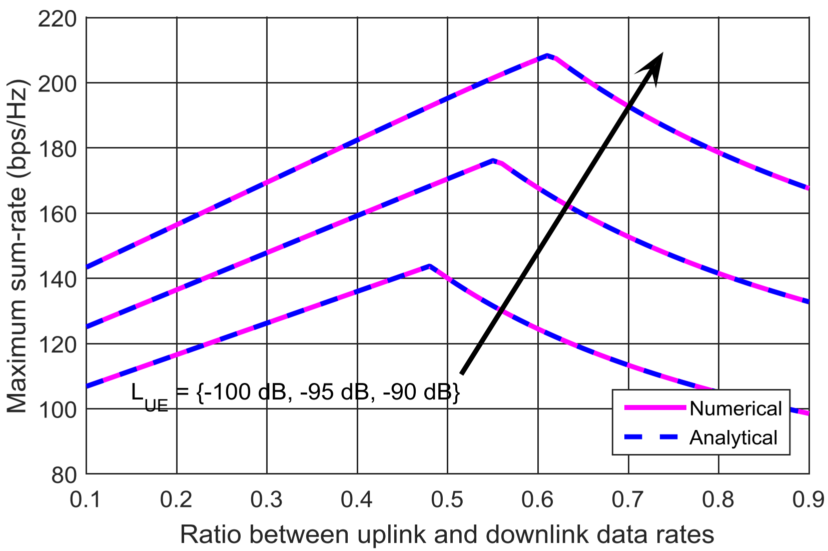
Parameter	Value
Number of access node TX/RX antennas	200/100
Number of DL/UL mobiles	10/10
Number of DL/UL backhaul streams	12/6
Receiver noise floor	-90 dBm
Transmit power of the access node	30 dBm
Maximum transmit power of the mobiles	25 dBm
Transmit power of the backhaul node	40 dBm
Amount of SI cancellation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

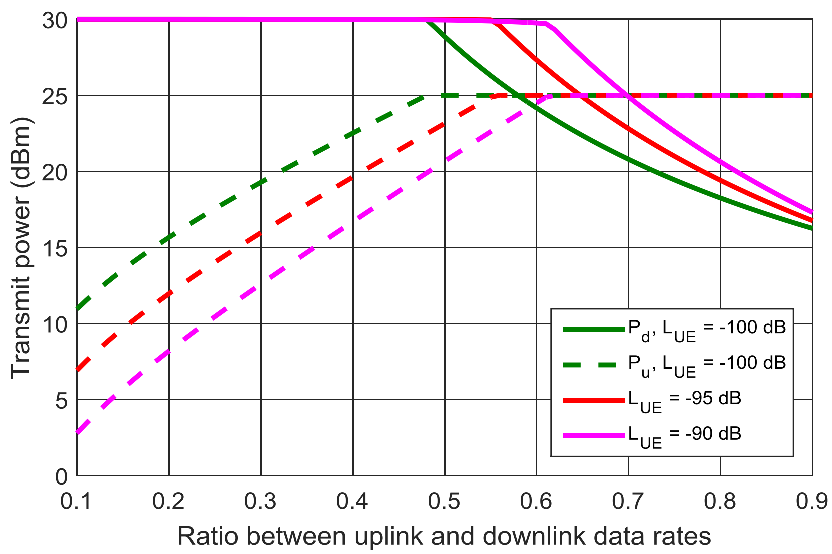
Numerical results



- 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?