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Achievable Transmission Rates and Self-Interference Channel Estimation in Hybrid Full-Duplex/Half-Duplex MIMO Relaying

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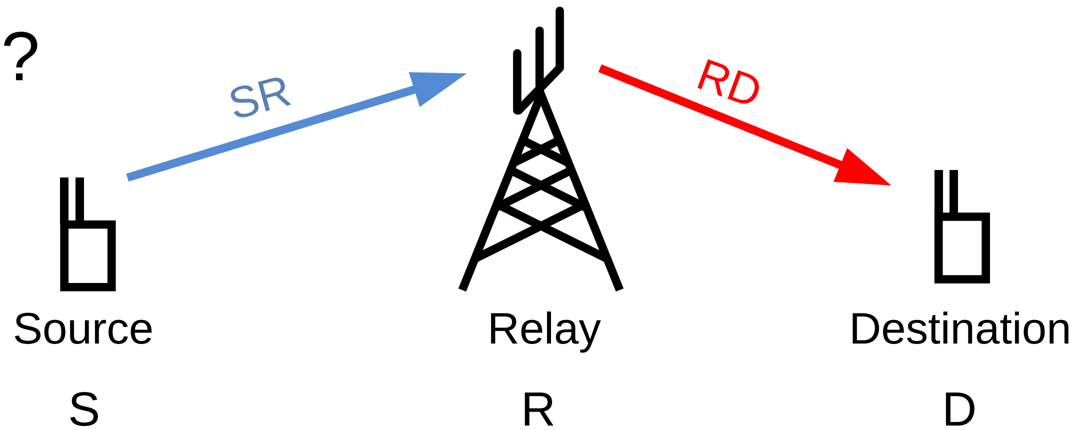
Introduction

- Recent findings, e.g.[1], have clearly shown that inband full-duplex is technically feasible
  - Here we focus on full-duplex relay applications
- The next question is how to best use the full-duplex capability
  - Always transmitting and receiving at the same time, or perhaps choosing the operation mode more wisely?

[1] M. Heino, D. Korpi, T. Huusari, E. Antonio-Rodríguez, S. Venkatasubramanian, T. Riihonen, L. Anttila, C. Icheln, K. Haneda, R. Wichman, and M. Valkama, "Recent Advances in Antenna Design and Interference Cancellation Algorithms for In-band Full-Duplex Relays," *IEEE Communications Magazine*, vol. 53, no. 5, pp. 91-101, May 2015.

Introduction

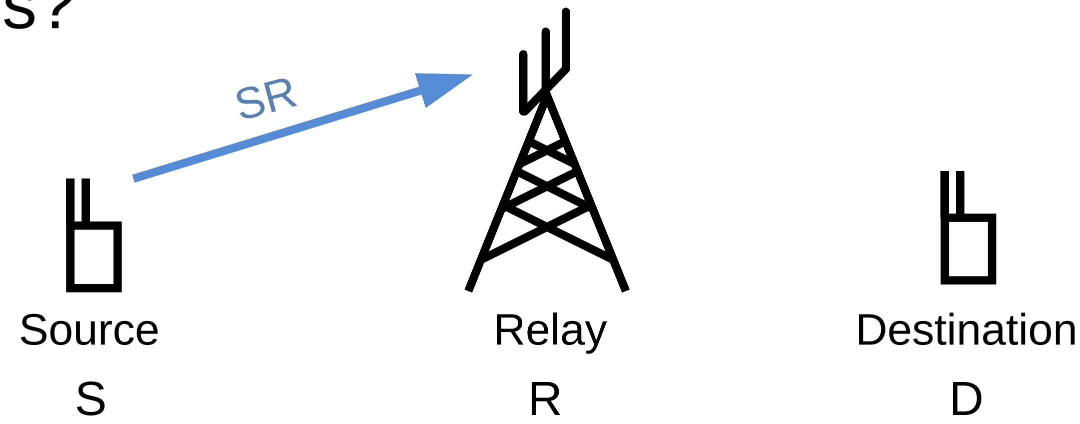
- In this work, we explore this question in a simple two-hop relay system with a full-duplex capable relay (R)
  - What kind of transmission scheme eventually maximizes the end-to-end rate between the source (S) and the destination (D) ?
- Is it this?



Introduction

- Or this?

1.



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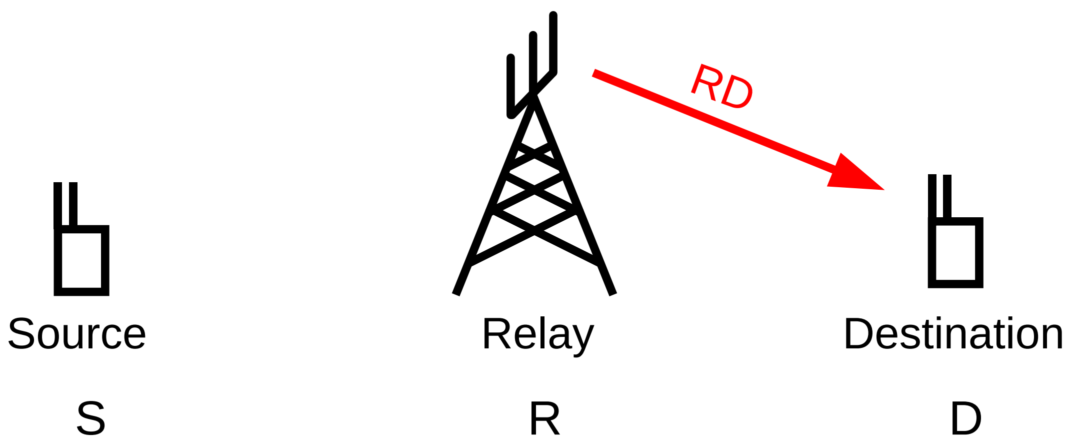


- Or some combination of the two ?

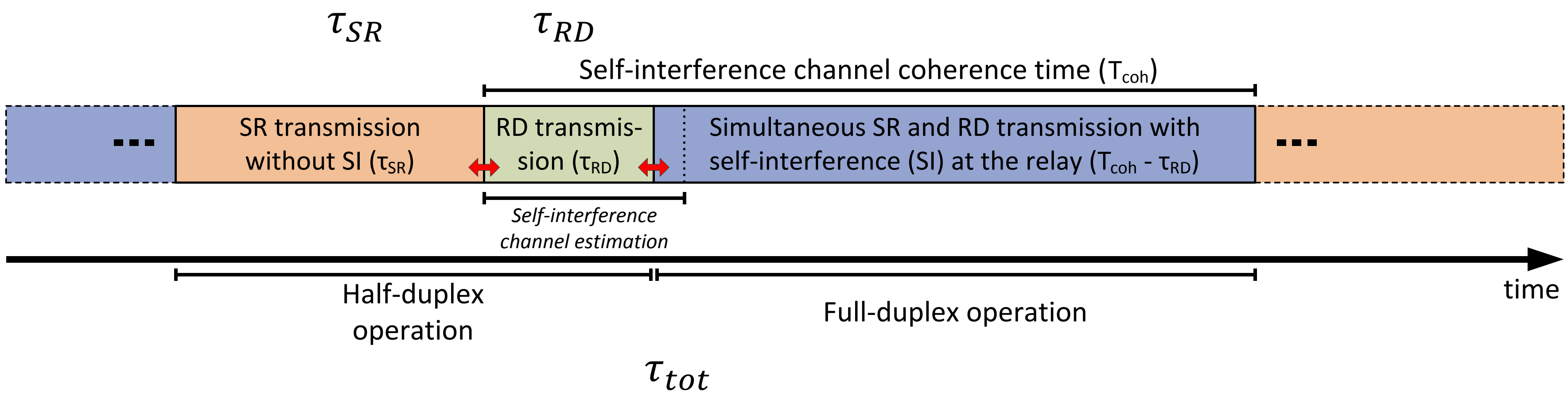
Introduction

- Even though pure full-duplex relaying might be conceptually the most appealing option, many practical issues affect end-to-end performance
- For instance, the SR and RD links might have different path losses, resulting in different SNRs and thus different achievable data rates between the two links
- Also, for accurate self-interference (SI) cancellation, the SI channel must be estimated at some point
  - This is challenging to do if the relay is also receiving a signal, since the useful RX signal acts as noise from SI channel estimation perspective
  - i.e., there are <u>tradeoffs</u>

Proposed scheme

- In this work, we actually propose a scheme that combines the half-duplex and full-duplex approaches
  - The interesting question is whether it performs better than either the pure full-duplex or pure half-duplex scheme
- This can be determined by evaluating the relay system end-to-end performance in different scenarios
  - Taking into account the inherent transmission capability as well as the performance limitations due to SI channel estimation errors and RF component imperfections

Proposed scheme



- The lengths of the different communication modes can be adjusted
- Next we seek to understand what is the optimum partitioning between HD/FD modes, and how does that link to SI channel estimation

Achievable source-to-destination throughput

- The S-D throughput of the system can be expressed as follows:

$$C = \min\left\{\underbrace{\left(\frac{\tau_{SR}}{\tau_{tot}}\right)C_{SR}^{HD} + \left(\frac{T_{coh}-\tau_{RD}}{\tau_{tot}}\right)C_{SR}^{FD}}_{\text{Source-to-relay}},\ \underbrace{\left(\frac{\tau_{RD}}{\tau_{tot}}\right)C_{RD}^{HD} + \left(\frac{T_{coh}-\tau_{RD}}{\tau_{tot}}\right)C_{RD}^{FD}}_{\text{Relay-to-destination}}\right\}$$

Source-to-relay   *Relay-to-destination*

- τ_{SR}, and τ_{RD}, are the times spent in HD mode, T_{coh} is the SI channel coherence time and $\tau_{tot} = T_{coh}+\tau_{SR}$
- The time ratios determine the proportion of time spent in each mode during the relaying procedure
- The achievable end-to-end rate is determined by the smaller of these two rates (S-R, R-D)

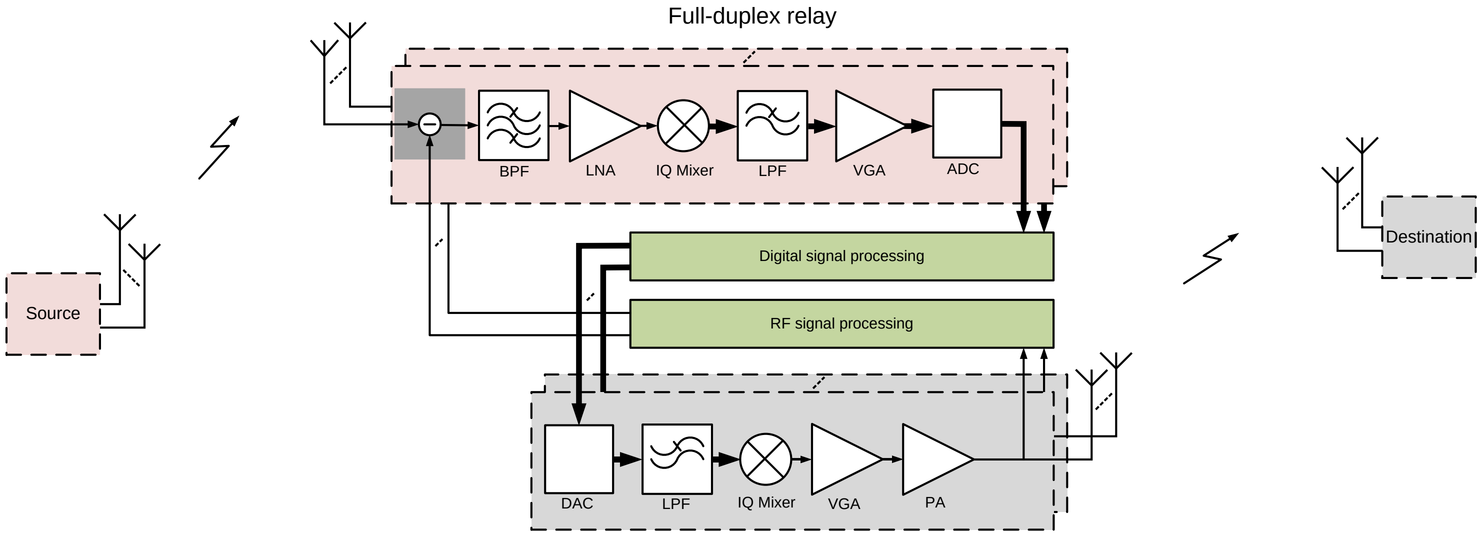
Achievable source-to-destination throughput

- The rate expressions are here calculated using the well-known Shannon-Hartley theorem, i.e.,

$$C_x^y = \sum_{i=1}^{N_x} \log_2\left(1 + sinr_{i,x}^y \lambda_{i,x}^2\right)$$

- Here, $x \in \{SR, RD\}$, $y \in \{HD, FD\}$, N_x is the number of spatial streams, $sinr_{i,x}^y$ is the signal-to(-interference-plus)-noise ratio, and $\lambda_{i,x}$ is the ith singular value of the channel matrix
- The SINR is defined by the received signal power, noise power and in the FD relay also by the SI cancellation performance
    - This is greatly affected by the presence of the source-to-relay transmission during SI channel estimation
    - More detailed SINR expressions available in the paper

Numerical evaluations

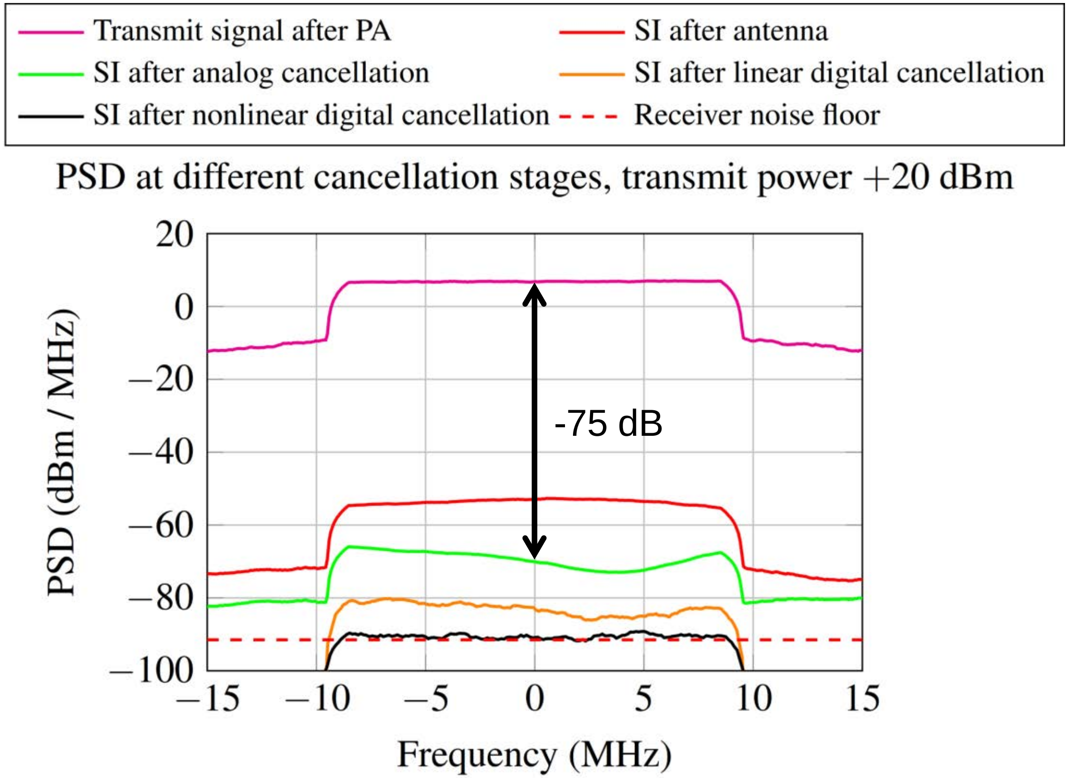


Parameter	Value
Signal bandwidth	12.5 MHz
Waveform	OFDM
Number of TX antennas at the source	2
Number of RX/TX antennas at the relay	2/2
Number of RX antennas at the destination	2
SNR per receiver at the relay, SNR_R	15 dB
SNR per receiver at the destination, SNR_D	20 dB

Parameter (cont.)	Value
Total transmit power of the relay	20 dBm
Analog SI attenuation at the relay	70 dB
IRR at relay (TX & RX)	25 dB
Relay TX PA IIP3	18 dBm
Relay RX ADC bits	12
SI channel estimation sample size at the relay	5000
SI channel coherence time	1 ms

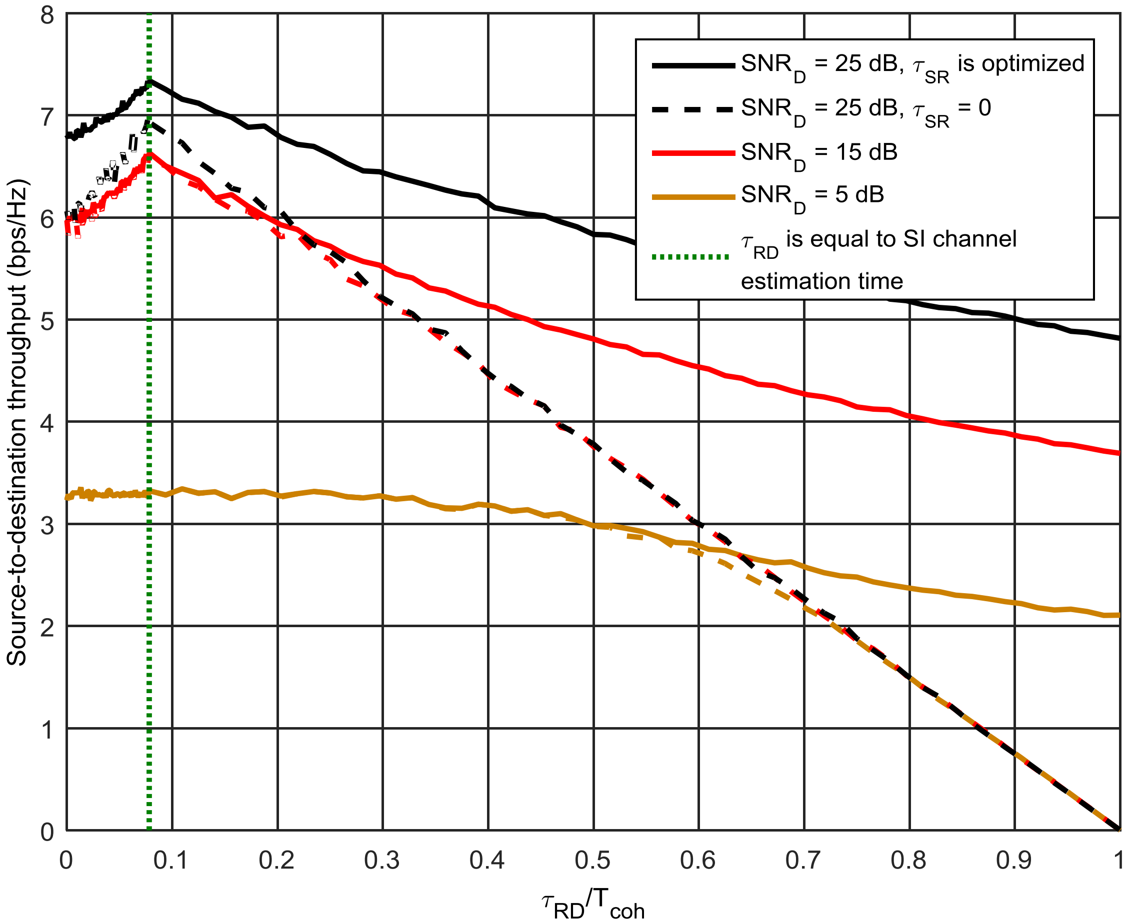
- Widely linear digital canceller is adopted at the relay to cancel the SI in the digital domain
  - Can process the IQ mismatch but not PA induced nonlinear distortion

Side-step: Reference RF measurements



- These measurements were done using a novel relay antenna design and a self-adaptive RF canceller
- Approximately 75 dB of total analog SI cancellation was achieved
- The measurements were done with an LTE waveform at 2.47 GHz and a transmit power of +20 dBm

Numerical evaluations



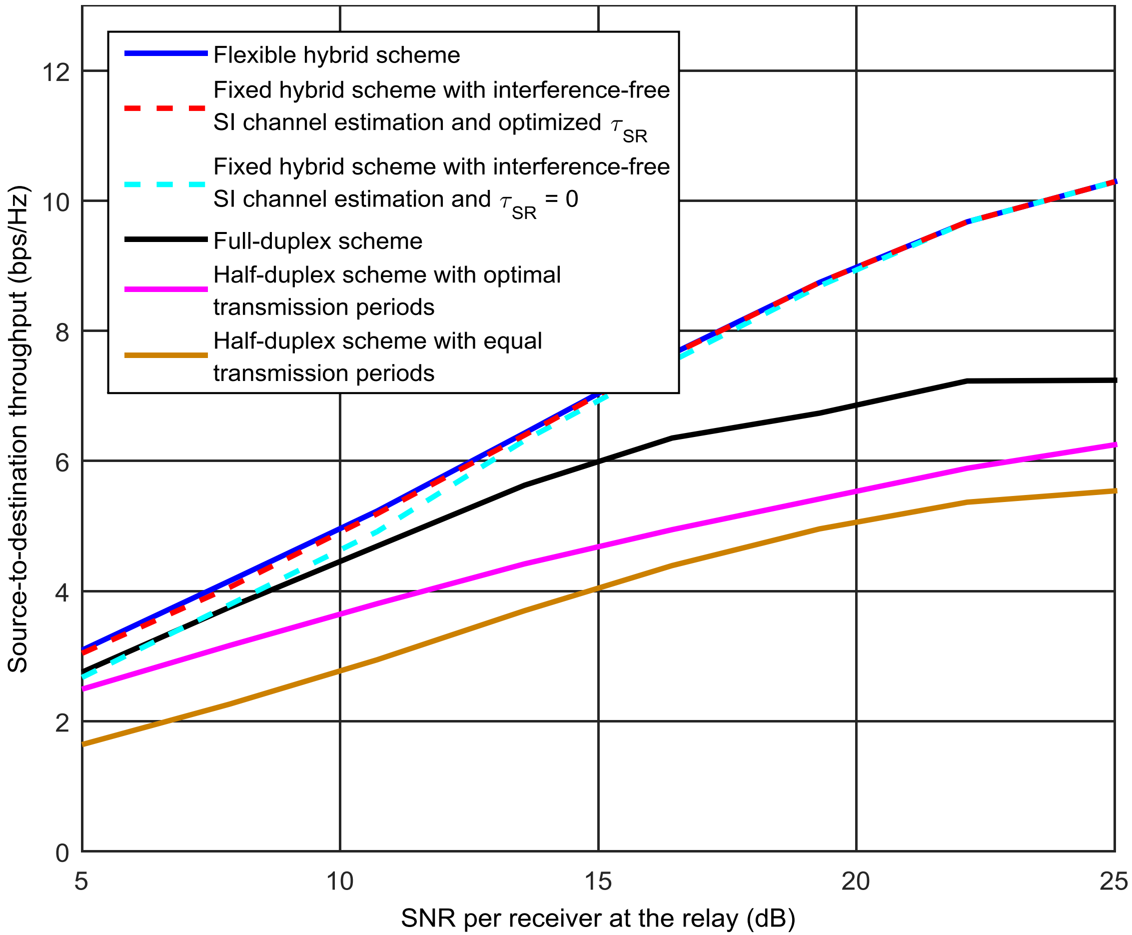
Here SNR at relay, SNR_R, fixed at 15 dB

- Throughputs for the ***proposed scheme*** with different RX signal strengths at the destination
- The length of the HD RD transmission period is varied
- Throughput is maximized when the SI channel can be estimated without interference
- SI channel estimation sample size is fixed (equal to vertical dashed line)

Numerical evaluations

- Next, five different communication schemes are compared:
  - *Flexible hybrid scheme*, which has no limitations on the lengths of the communication periods (as long as $\tau_{RD} \leq T_{coh}$)
  - *Fixed hybrid scheme*, where the value of τ_{RD} is chosen such that it corresponds to the time required for estimating the SI channel
  - *Pure full-duplex scheme*, where $\tau_{SR} = \tau_{RD} = 0$
  - *Pure half-duplex scheme*, where the transmission periods τ_{SR} and τ_{RD} are chosen optimally to maximize the relay-to-destination throughput
  - *Pure half-duplex scheme with equal transmission periods*, where $\tau_{SR} = \tau_{RD}$

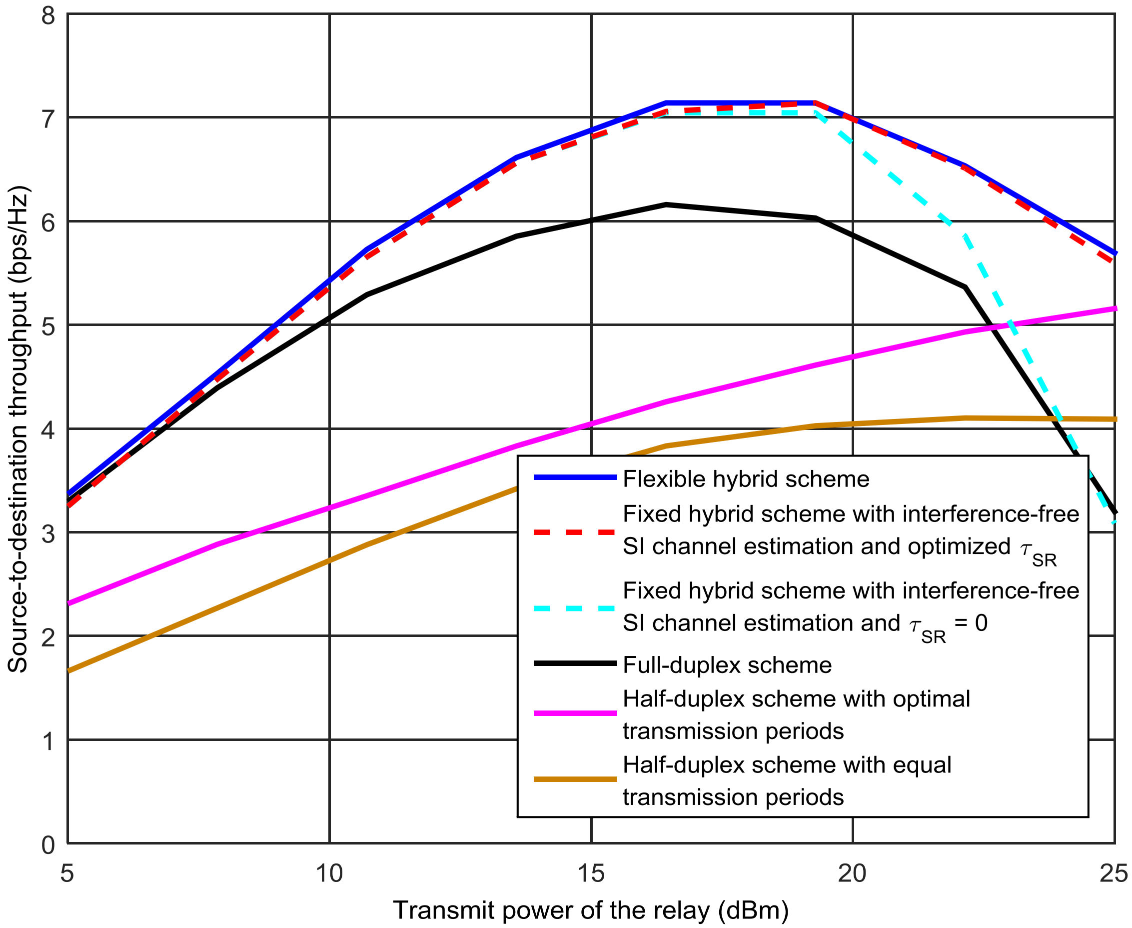
Numerical evaluations



SNR_R

- The flexible and fixed hybrid schemes perform best, thanks to interference-free SI channel estimation
  - It is optimal to choose the length of the HD RD period to match the length of the SI channel estimation period
- With low RX signal power at the relay, also a half-duplex period between source and relay is needed if exactly optimum solution is targeted

Numerical evaluations



- The transmit power has a direct effect on the SINR at the relay due to RF impairments
- With the chosen simulation parameters, 20 dBm is the highest feasible transmit power
- After this, the throughput of the SR link drops too low because widely linear digital canceller cannot anymore suppress all remaining SI

Conclusion

- Both half- and full-duplex communication periods are needed to maximize the throughput of a two-hop link
- In particular, the full-duplex relay should estimate its SI channel during a half-duplex period
- These findings help in optimizing the deployment of full-duplex MIMO relays in future mobile networks

Thank you !

Questions ?