Achievable Rate Regions and Self-interference Channel Estimation in Hybrid Full-Duplex/Half-Duplex Radio Links

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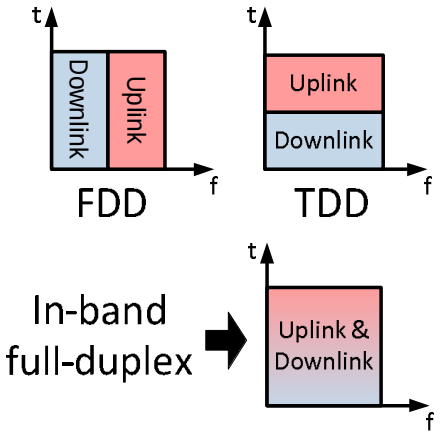
Outline

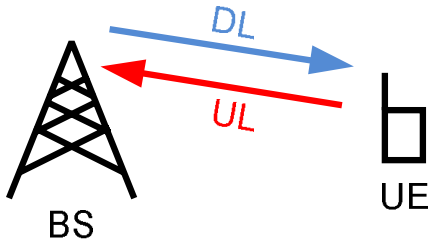
- Introduction
- Flexible hybrid transmission and channel estimation
- Achievable rates and waveform simulations
- Numerical results and discussion
- Conclusions

Introduction

- Hot research area: in-band *full-duplex* communications; a novel 5G paradigm in the field of wireless communications
- The basic idea: simultaneous transmission and reception ("STAR") reusing the same frequency bands
  - Possible by cancelling the full-duplex transceiver's own transmit signal which is *self-interference* (SI) for reception
- In this work: the practical throughput gain of full-duplex (FD) communications
- An important aspect: throughput requirements are usually *asymmetric* between downlink (DL) and uplink (UL)



- full-duplex operation could double spectral efficiency in the best case
  - no residual SI
  - DL/UL = 1/1



- focus: a single-cell system comprising a base station (BS) and a mobile user (UE)

Flexible hybrid transmission scheme

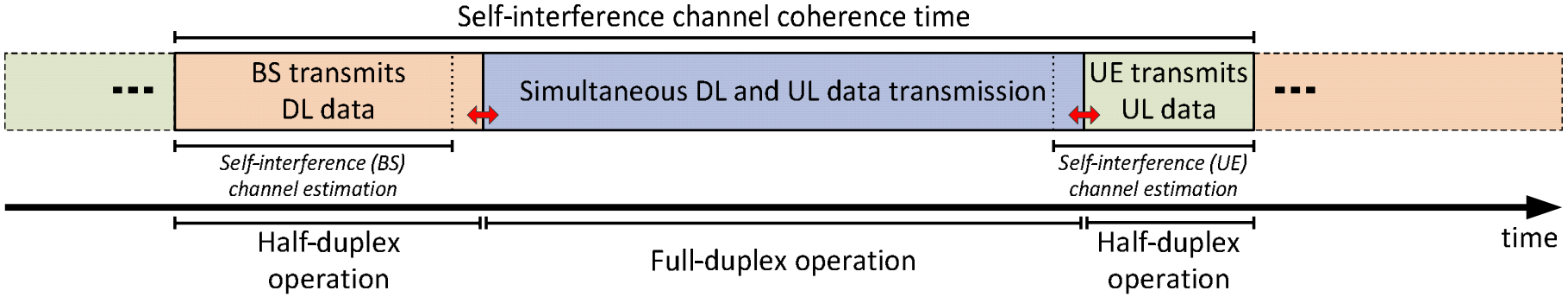
- Fixed continuous full-duplex operation is not necessarily optimal for the overall rate (!)

- In this work, a hybrid FD/HD transmission scheme is analyzed
  - Two-way full-duplex transmission occurs only part of the time
  - In addition, the BS and UE are allowed to transmit alone in their half-duplex (HD) phases

- Benefits:

  1) This type of a flexible frame structure allows for balancing of the downlink and uplink data rates

  2) Now both the BS and the UE have a silent period for estimating their SI loopback channels
  - An accurate estimate is crucial for efficient SI cancellation



Achievable rates

- The respective downlink and uplink data rates can be written as

$$C_{DL} = \alpha_{DL} C_{DL}^{HD} + (1 - \alpha_{DL} - \alpha_{UL})\, C_{DL}^{FD}$$

$$C_{UL} = \alpha_{UL} C_{UL}^{HD} + (1 - \alpha_{DL} - \alpha_{UL})\, C_{UL}^{FD}$$

  - α_{DL} is the proportion of time when only the BS is transmitting
  - α_{UL} is the proportion of time when only the UE is transmitting
  - C_{DL}^{HD} and C_{UL}^{HD} are the rates over the downlink- and uplink-only half-duplex periods
  - C_{DL}^{FD} and C_{UL}^{FD} are the rates over the full-duplex period

- The rates during the half-duplex transmission periods depend only on transmit power, channel conditions, receiver noise floor etc. (the usual factors)

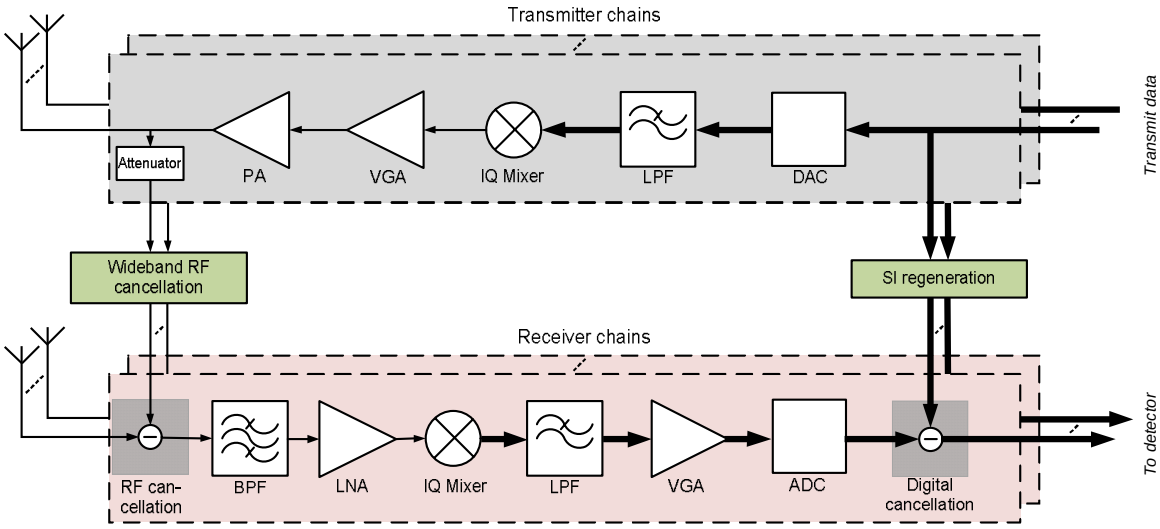
- The rates during the full-duplex transmission period depend also on the achieved cancellation performance, i.e., the amount of residual SI
  - The efficiency of SI cancellation is in turn determined by whether or not the SI loopback channel can be estimated when the other communicating party is silent

Evaluating achievable rates

- System performance is assessed by plotting achievable rate regions
  - Transmission performance shown separately for downlink and uplink as well as all of their ratios
- The numerical values for the rates are obtained with *realistic waveform simulations*

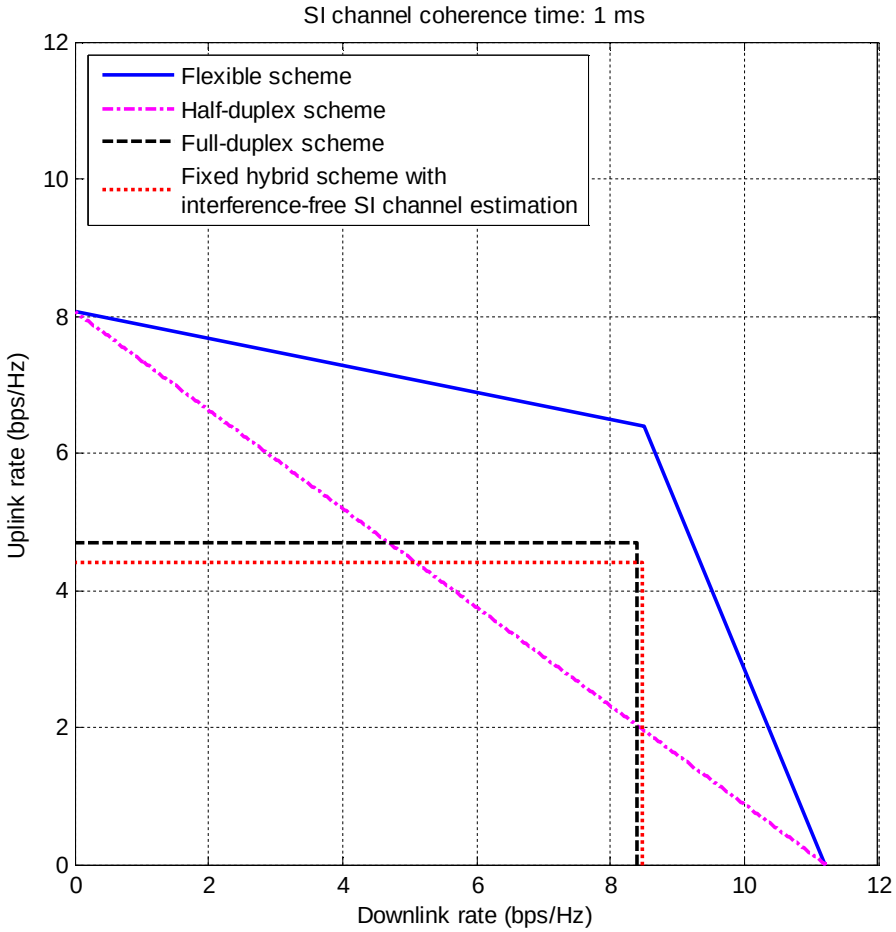
- Determining the rates with full waveform simulations ensures that
  - the received signal's effect on the SI cancellation accuracy is implicitly included in the results
  - the rate under full-duplex operation is realistic because all the prominent (analog RF) circuit impairments are explicitly modeled

Parameter	BS value	UE value
Signal bandwidth	12.5 MHz	
Number of antennas (TX/RX)	4/4	2/2
PA gain	27 dB	22 dB
Total transmit power	20 dBm	15 dBm
SNR per receiver	10 dB	15 dB
Analog SI attenuation	70 dB	65 dB
ADC bits	12	12
Parameter estimation sample size	10 000	7500



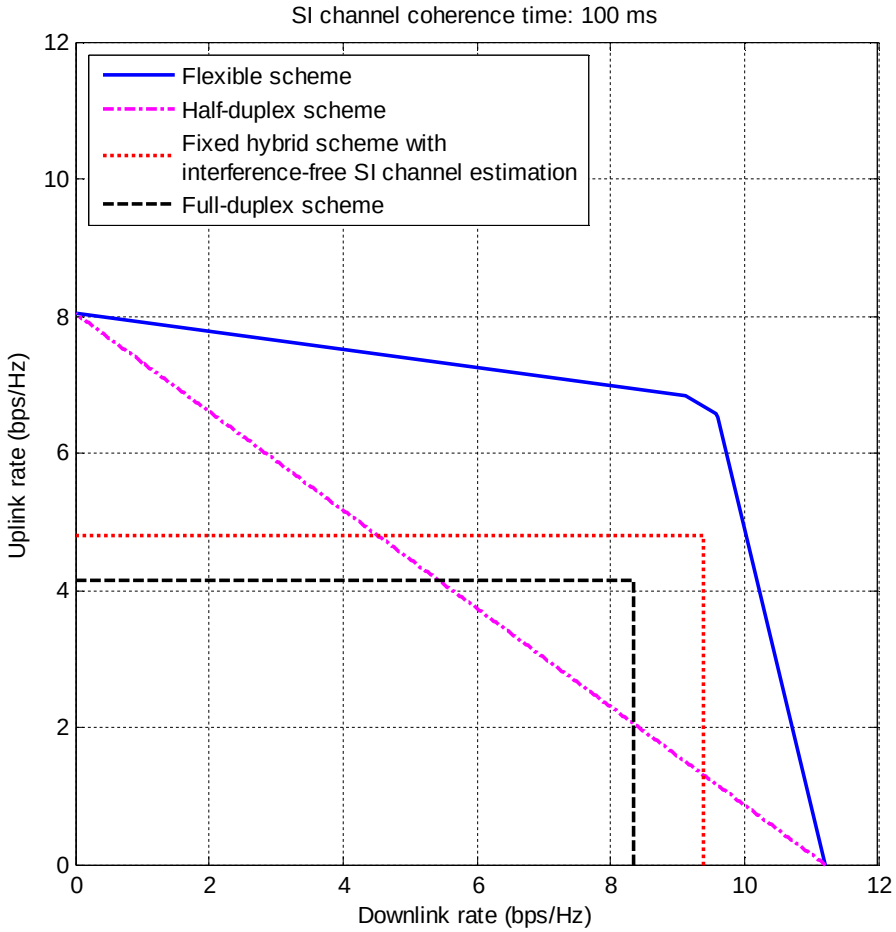
Simulation parameters and the used in-band full-duplex transceiver model (simplified illustration)

Numerical results 1



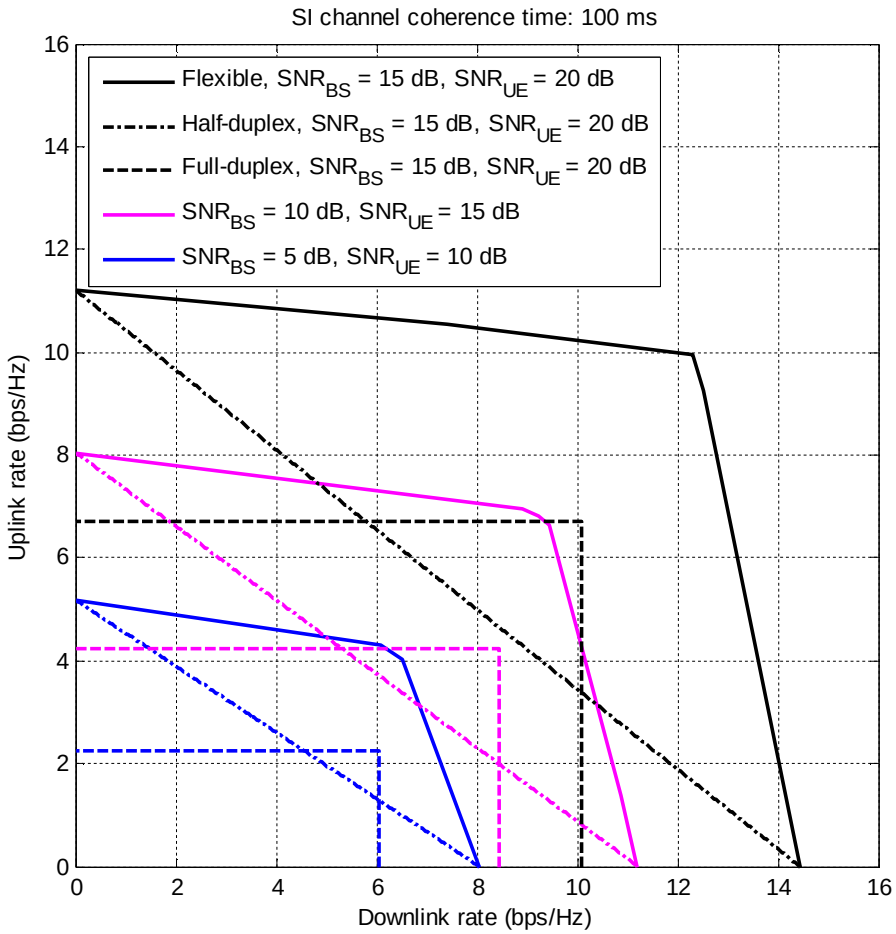
- Rate regions are shown in the figures for four different schemes:
  - *The flexible hybrid scheme* proposed herein where the lengths of the uplink-only (α_{UL}), downlink-only (α_{DL}) and full-duplex periods can be freely adjusted
  - *A half-duplex scheme* where $\alpha_{UL} + \alpha_{DL} = 1$, i.e., there is no full-duplex operation
  - *A full-duplex scheme* where $\alpha_{UL} = \alpha_{DL} = 0$, i.e., simultaneous transmission and reception occurs continuously all the time
  - *A fixed hybrid scheme with interference-free SI channel estimation*, where α_{UL} and α_{DL} are always set to match the length of the SI channel estimation period
- The flexible scheme achieves the best rates in both uplink and downlink
- With such a short SI channel coherence time, it does not pay off to have interference-free SI channel estimation

Numerical results 2



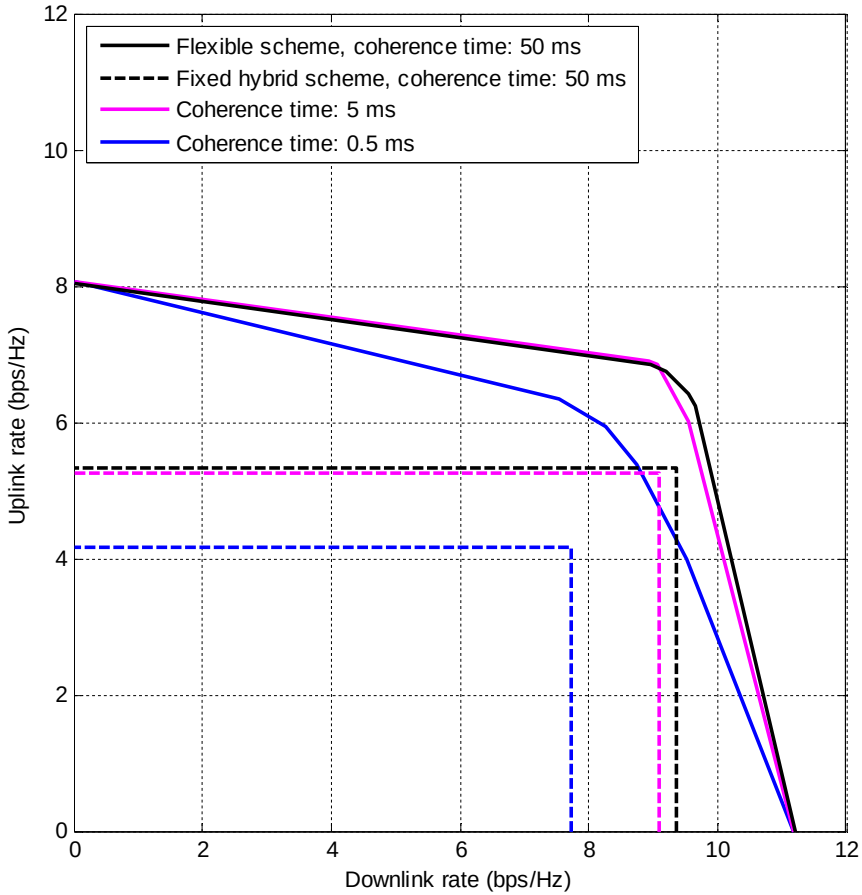
- With a longer SI channel coherence time, the flexible scheme again outperforms the other schemes
- However, now the fixed hybrid scheme with interference-free SI channel estimation performs much better
- With a slowly changing SI channel, the penalty of interference-free SI channel estimation is quite small
  - Continuous full-duplex operation still does not pay off

Numerical results 3



- Rate regions for three different schemes and three different SNR values at the UE and the BS
- A higher SNR for the signal of interest potentially means more interference for SI channel estimation
- However, based on this figure, it seems that it is actually still better to have as high SNR as possible
  - Improved SI cancellation performance cannot by any means compensate for the weaker signal of interest
- Also, the flexible hybrid scheme still outperforms the reference schemes, regardless of the SNR level
  - It can adjust the lengths of the different transmission periods to maximize the rate

Numerical results 4

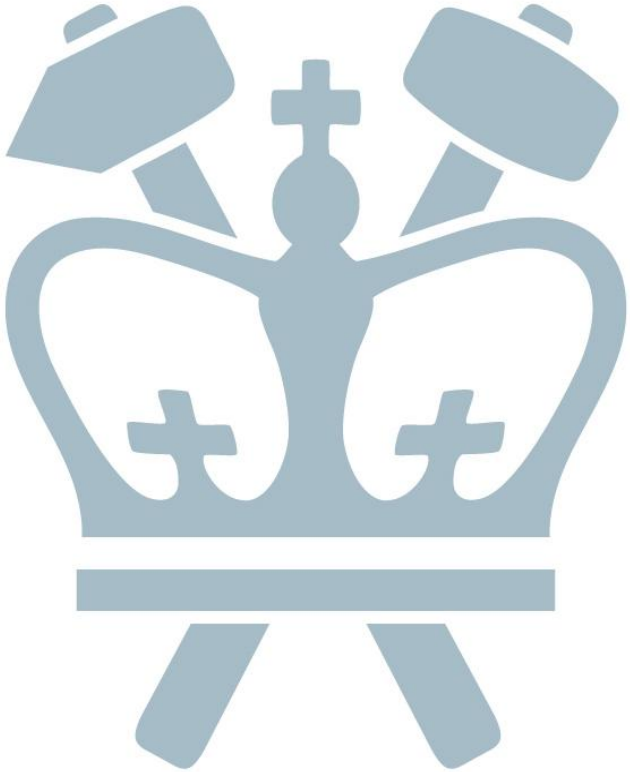


- This figure shows the rate regions for two different schemes with different SI channel coherence times
- The basic observation is that a shorter coherence time renders lower achievable rate
  - The SI channel estimate is valid for a shorter period of time and more resources are needed to estimate it repeatedly
- Also, with the longer coherence times, the fixed hybrid scheme can almost match the flexible scheme
  - The optimal solution is to estimate the SI channel without interference

Conclusion

- In general, continuous full-duplex communication does not maximize rates in a cellular network
- Separate half-duplex periods help in adjusting the rates between uplink and downlink, and also in obtaining a more accurate self-interference channel estimate
- Inclusion of half-duplex periods with adjustable lengths results in significantly broader achievable rate regions, providing especially high gains with asymmetric downlink/uplink rate requirements
- Adjusting the ratio between uplink and downlink data rates is an important feature in practical cellular networks, as requested rates are typically significantly higher in the downlink direction

Thank you



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