

# In-Band Full Duplexing

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# Outline

- 1 Introduction
- 2 In-Band Full-Duplexing (IBFD)
- 3 Toward a High Level Taxonomy

## Modes of Channel Operation

- Simplex
- Duplexing
  - Half-duplex(TDD)
  - Full-duplex
    - Out-band
    - In-band

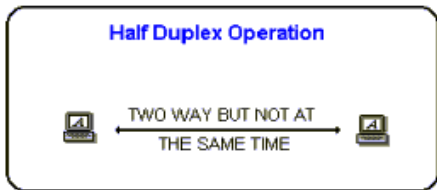
# Simplex

- Data in a simplex channel is always one way.
- An example of simplex is Television, or Radio.



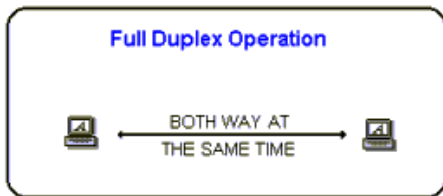
## Half-duplex(TDD)

- A half-duplex channel can send and receive, but not at the same time.
- An example of half-duplex is talk-back radio, and CB Radio (Citizens Band).



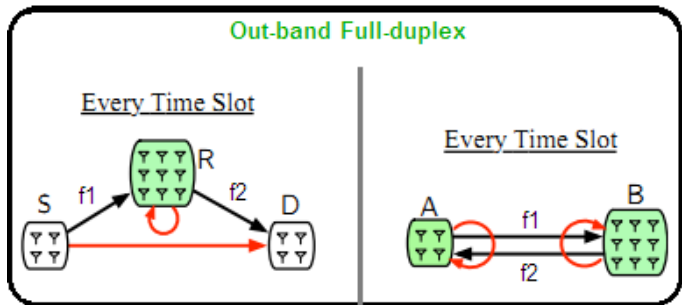
## Full-duplex

- Data can travel in both directions simultaneously. There is no need to switch from transmit to receive mode like in half duplex.
- An example can be a consumer which uses a cable connection to not only receive TV channels, but also the same cable to support their phone and Internet surfing.



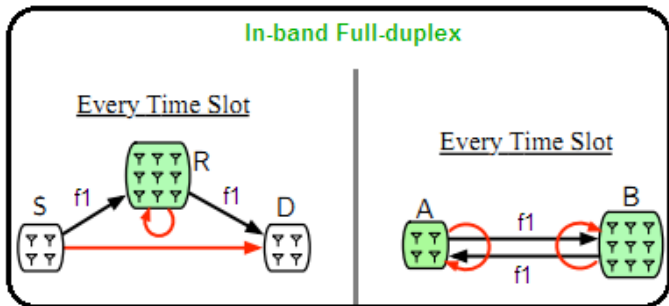
## Out-band full-duplex (FDD)

- Data can travel in both directions simultaneously, but in the separated frequency bands (frequency-division-duplexing (FDD)).



## In-band full-duplex

- Data can travel in both directions simultaneously, and in the same frequency band.





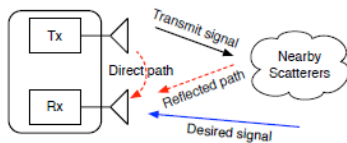
## Comparison of Modes of Channel Operation

Disadvantages Mode of channel		Non simultaneously	Spectrum efficiency loss	Self- interference
		Half-duplexing	✓	✓
Full-duplexing	Out-band		✓	
	In-band			✓

- In-band full-duplex (IBFD) operation has emerged as an attractive solution for **increasing the throughput** of wireless communication systems and networks.

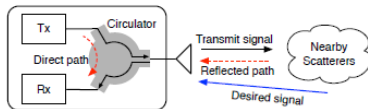
## Antenna Design of IBFD

- Separated antenna



(a) Separate-antenna full-duplex

- Shared antenna



(b) Shared-antenna full-duplex

Source: [1]

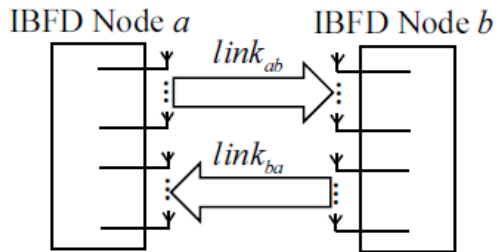
## Self Interference

- Simultaneous transmission and reception in a single frequency band can cause the transmitted signals to loop back to their receive antennas.
- Self-interference refers to the interference that a transmitting IBFD terminal causes to itself, which interferes with the desired signal being received by that terminal.

## Topologies of IBFD terminals at the network level

- Bi-directional Full-duplex(BFD)
- Full-duplex Relay(FDR)
- Full-duplex Cellular (FDC)

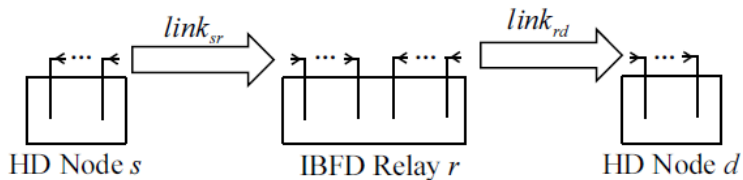
## Bi-directional Full-duplex(BFD)



(a) Bi-directional Full-duplex (BFD)

Source: [2]

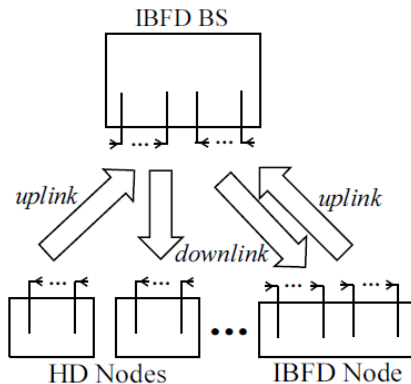
## Full-duplex Relay(FDR)



(b) Full-duplex Relay (FDR)

Source: [2]

## Full-duplex Cellular (FDC)



(c) Full-duplex Cellular (FDC)

## Criteria for Classification of Research Works on IBFD

- Topologies of terminals at the network level
  - Bi-directional Full-duplex(BFD)
  - Full-duplex Relay(FDR)
  - Full-duplex Cellular (FDC)
- Effect in network layers
  - Physical layer (e.g. self interference management)
  - MAC layer (e.g. carrier assignment, scheduling)
  - Network layer (e.g. multi radio network)
- Wireless network types
  - Cellular Networks
  - Relay Networks
  - Cognitive Radio Networks
  - Heterogeneous Networks
  - Energy Harvesting Networks



## Classification of Research Works on In-band full-duplex

- Interference Cancellation methods in IBFD (Providing in-band full-duplexing)
- Modelling of interference cancellation
  - Ideal Self-IC Scheme
  - Imperfect Self-IC
- Resource Allocation with in-band full-duplexing in different networks
  - Cellular Networks
  - Relay Networks
  - Cognitive Radio Networks
  - Heterogeneous Networks
  - D2D communications
  - Energy Harvesting Networks

## References

- 1 A. Sabharwal, P. Schniter, D. Guo, D. Bliss, S. Rangarajan, and R. Wichman, In-band full-duplex wireless: Challenges and opportunities, 2013.
- 2 D. Kim, H. Lee, and D.-K. Hong, A Survey of In-band full-duplex transmission: From the perspective of PHY and MAC layers, 2015