Full-Duplex Communications for Wireless Links with Asymmetric Capacity Requirements

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Half-Duplex Asymmetric Links

Asymmetries between downlink and uplink throughput requirements are

- common in wireless systems, reflecting usage patterns (e.g., video streaming)
- inherent in wireless protocols (e.g., acknowledgements, control or training)

$$C_{\mathrm{d,HD}} = W \log_2\left(1 + \frac{\delta P_{\mathrm{d,HD}}}{N_0 W}\right)$$

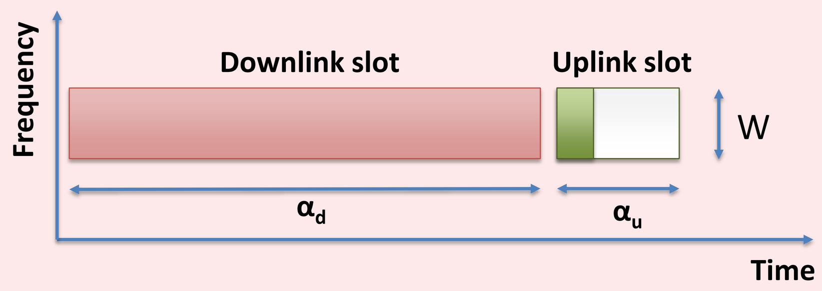
$$C_{\mathrm{u,HD}} = W \log_2\left(1 + \frac{\delta P_{\mathrm{u,HD}}}{N_0 W}\right)$$

Goal: maximize the sum capacity

➡ transmit at the maximum allowed power

Practical constraints impose a lower bound on the uplink resource usage:

- in **Time-Division Duplex:**



1. Guard intervals
2. Minimum length of the uplink slot

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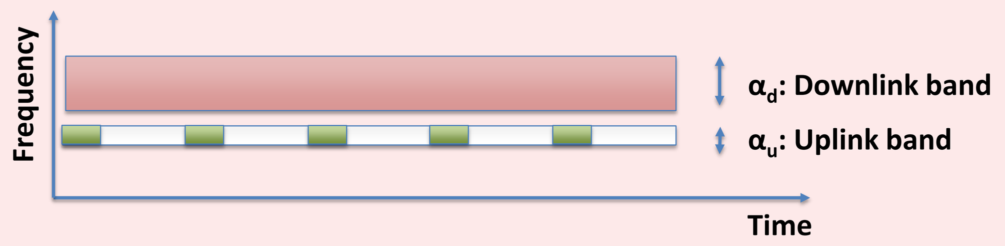
- in **Frequency-Division Duplex:**



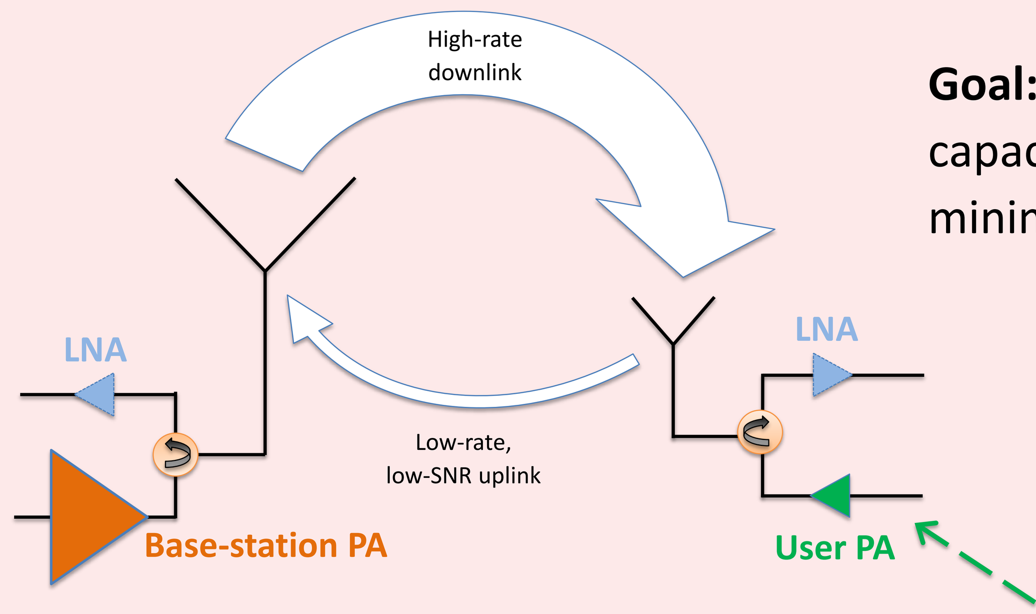
1. Guard bands
2. Minimum width of the uplink band

The actual user uplink traffic may be **much smaller** than the given lower bound

Not possible to adjust the resources to reflect the traffic asymmetry
➡ **significant resource waste**

Power Allocation for Full-Duplex Asymmetric Links

Full-Duplex: Simultaneous transmission of the low-rate uplink and reception of the high-rate downlink in the same frequency band



Goal: maximize the downlink capacity, while maintaining a required minimum capacity on the uplink

Decrease the transmit power on the uplink reduces self-interference

Depending on the degree of the asymmetry

$$C_{\mathrm{d,FD}} = W \log_2\left(1 + \frac{\delta P_{\mathrm{d,FD}}}{N_0 W + \beta P_{\mathrm{u,FD}}}\right)$$

$$C_{\mathrm{u,FD}} = W \log_2\left(1 + \frac{\delta P_{\mathrm{u,HD}}}{N_0 W + \beta P_{\mathrm{d,FD}}}\right)$$

β: self-interference cancellation factor

No α_d and α_c : downlink and uplink channels are active concurrently

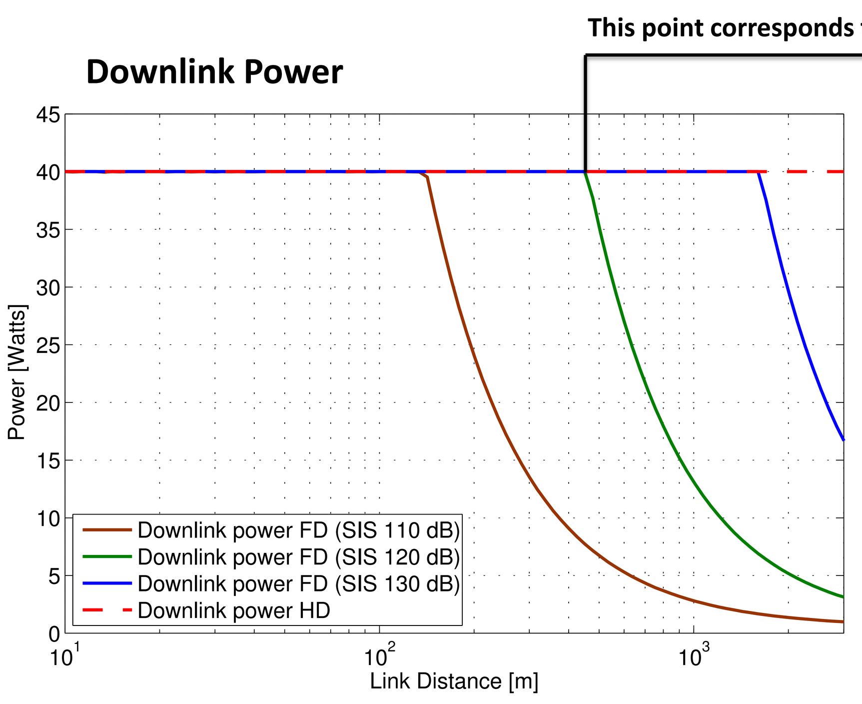
No guard bands, no guard intervals ➡ **no overhead, no latency**

The reduction in the uplink power additionally provides:

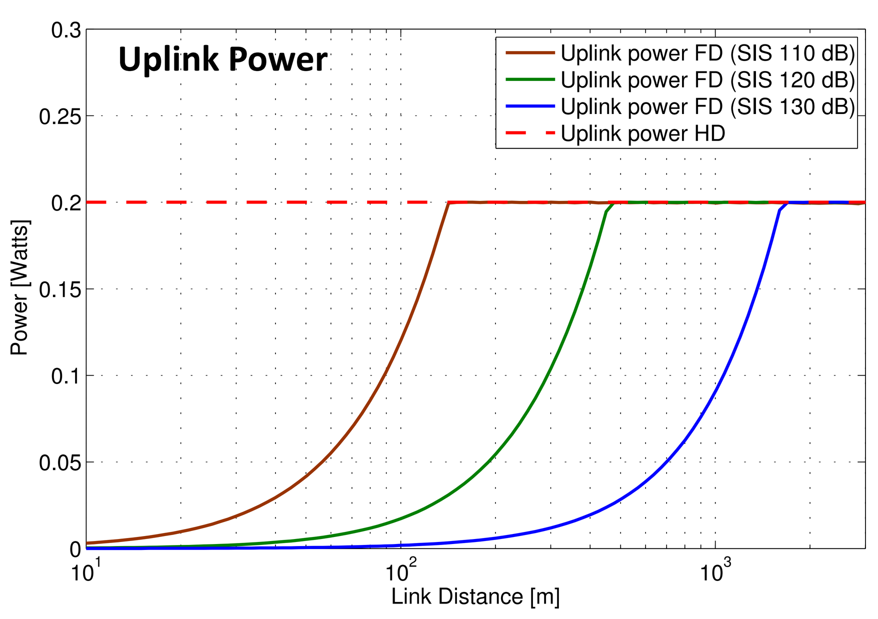
- **increased battery life**
- **reduced inter-cell interference**

Simulation Results for an LTE System

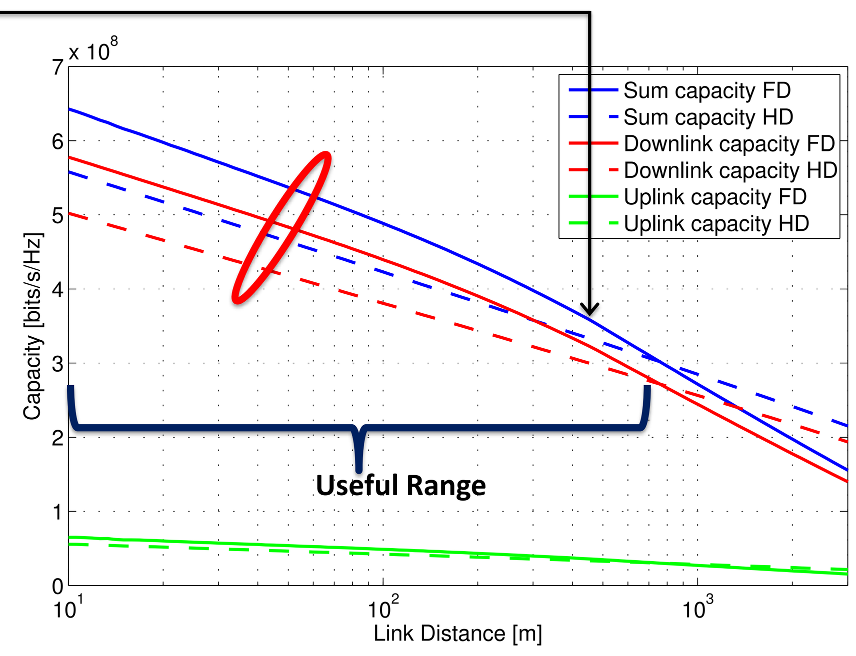
Transmit Power Comparison



- Half-duplex transmits always at max power
- In full-duplex, the transmit power of the user terminal is kept as low as possible
- For larger link distances the user terminal saturates at its max power, thus requiring the downlink power to decrease as well



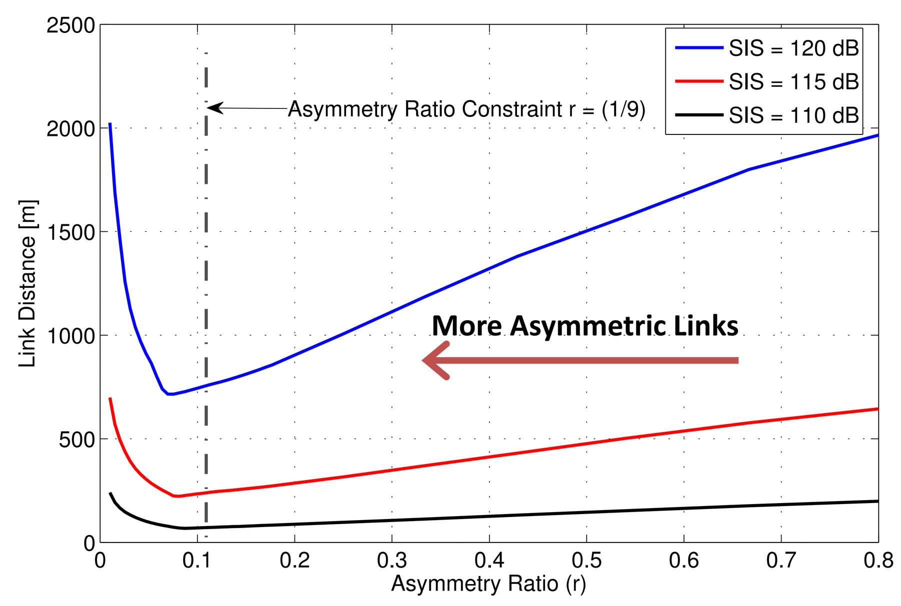
Capacity Comparison



- Power allocation allows full-duplex to keep a gain over half-duplex for a useful range of link distances.
- In this figure the actual data asymmetry is **the same as** the asymmetry constraint (1/9). This corresponds to the "worst" case for full-duplex in terms of the useful range over half-duplex (i.e., the point where full-duplex capacity crosses half duplex capacity occurs in the smallest possible link distance)

Bandwidth (W)	20 MHz
Center frequency (f_0)	2.35 GHz
Self-interference suppression	90–130 dB
Link distance	10–3000 m
Asymmetry ratio constraint (r)	1/9
Downlink transmit power range (P_d)	23 dBm to 46 dBm
Uplink transmit power range (P_u)	-20 dBm to 23 dBm

Full-Duplex Useful Range



- Full-duplex shows great behaviour for symmetric links, in terms of the range where the capacity is higher than half-duplex
- The benefits of full-duplex diminish as the link becomes more asymmetric
- However, when the actual uplink traffic is lower than the **imposed lower bound**, full-duplex can save the spectral resources that half-duplex wastes
- After this "break" point, the more asymmetric the link becomes, the better for full-duplex

Full-duplex can use power allocation as an extra knob ➡ any constraint is "tuned down" to the actual data asymmetry, increasing the overall spectral efficiency

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