Where are the Relay Capacity Gains in Cellular Systems?

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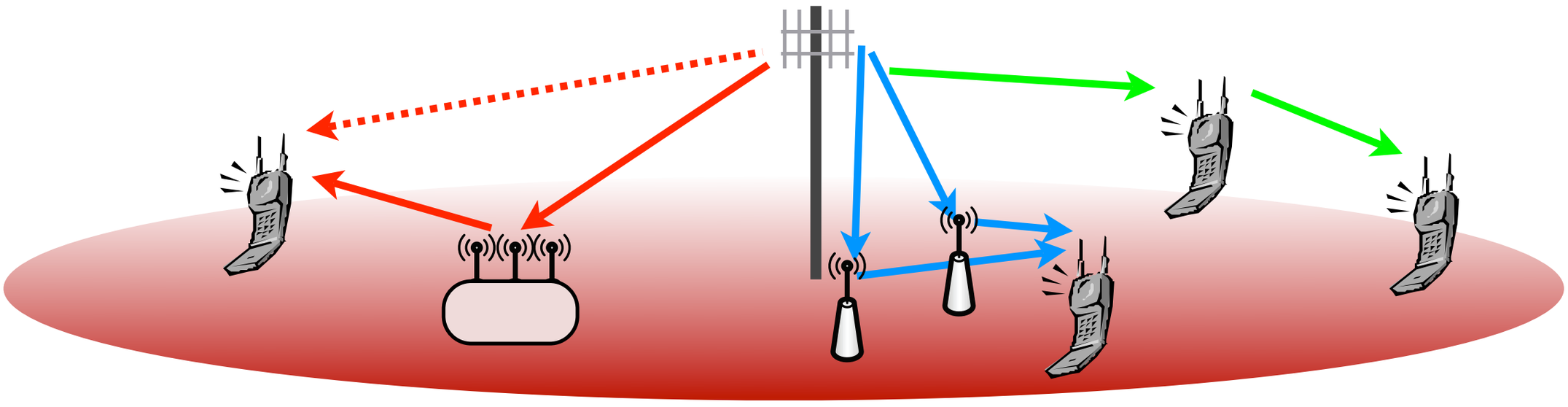
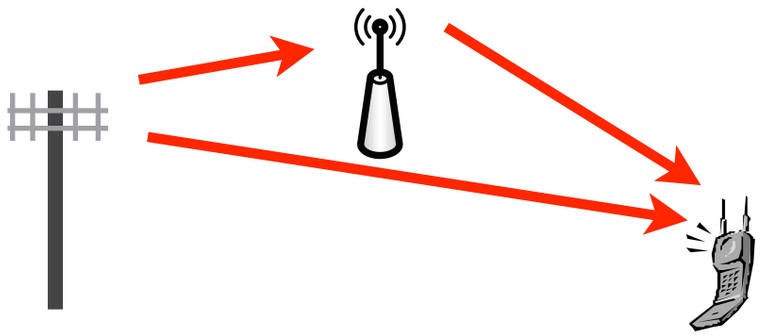
Introduction to Relays



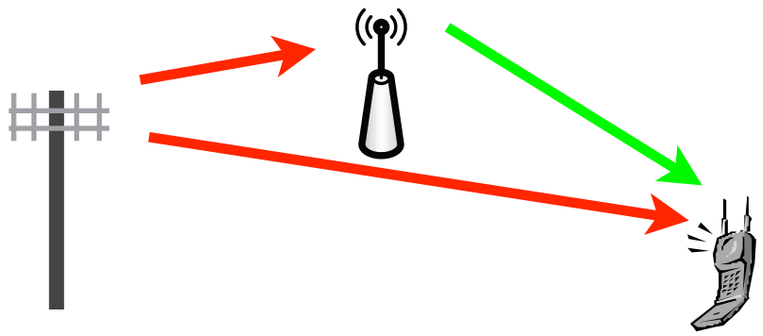
- Relays assist communication
  - May be fixed (infrastructure), mobile (bus) or cooperative (other users)
  - Single antenna, multiple antennas, multiple relays, multiple users
- Main purpose of relays
  - Coverage (large-scale effects), diversity (small-scale) [?], and capacity [??]

Types of Relays

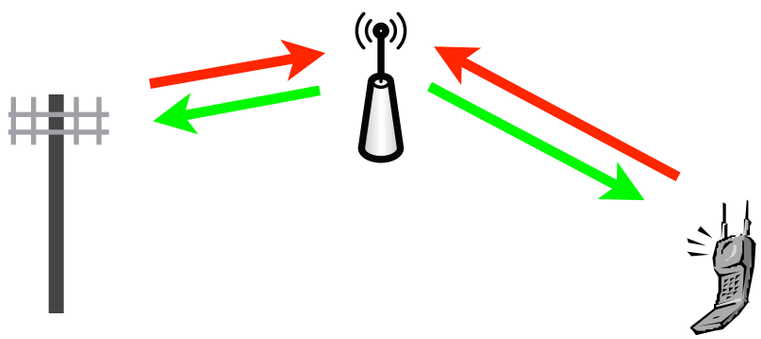
1st time-slot
2nd time-slot



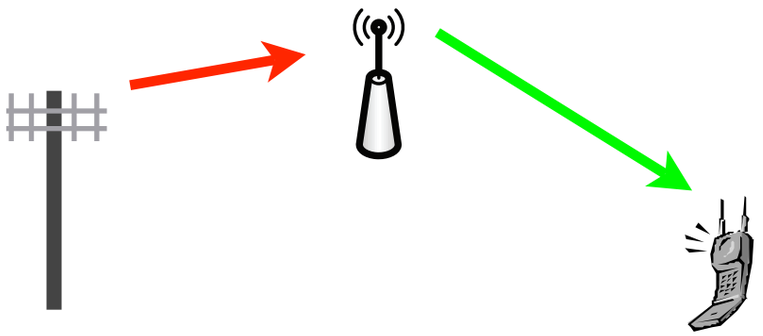
One-way
full duplex



One-way
half duplex

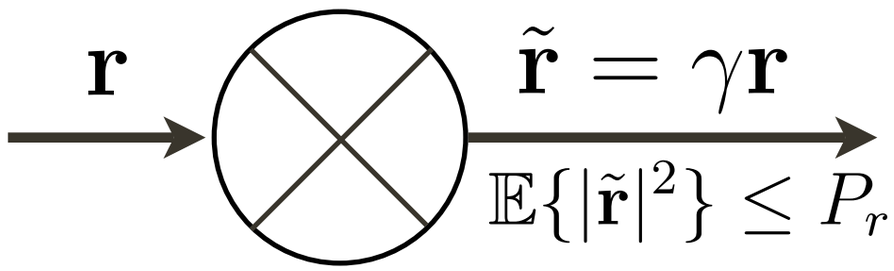


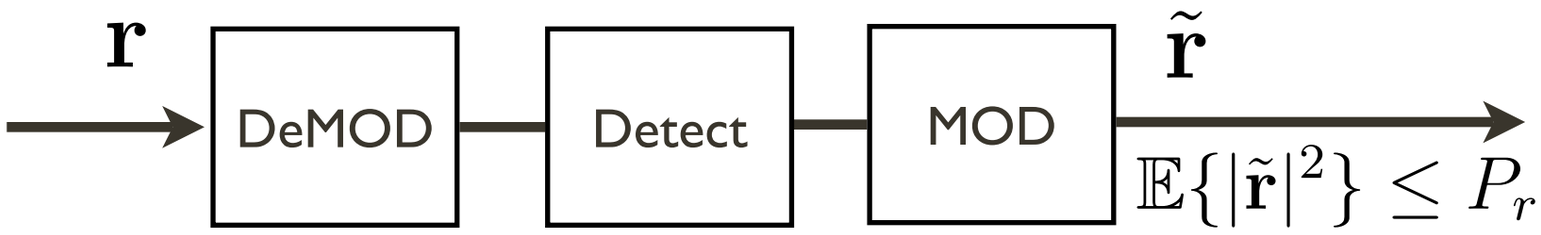
Two-way
half duplex

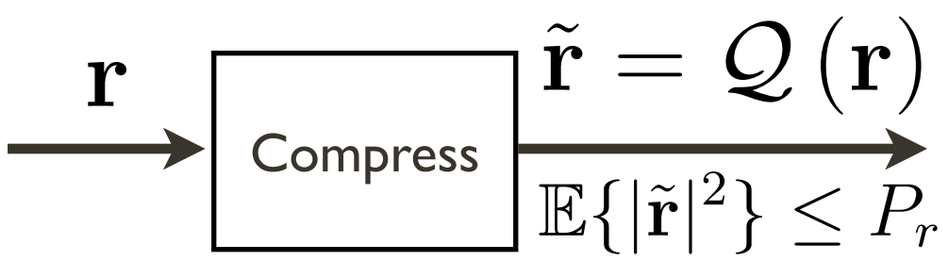


One-way
multi-hop

Relay Operation

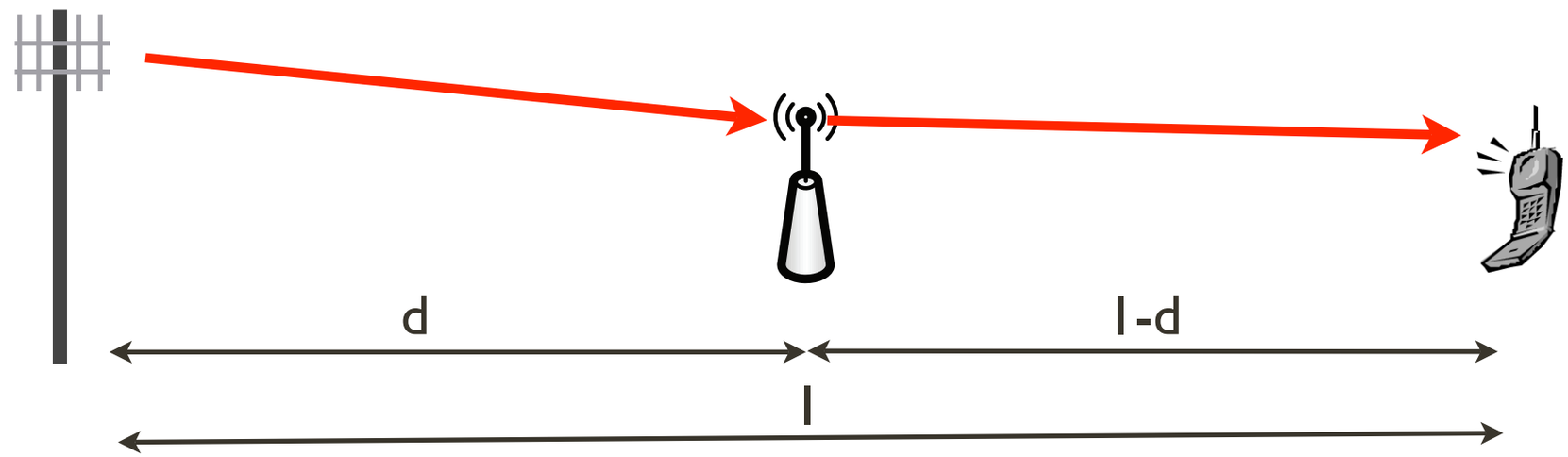






- Amplify-and-forward
  - Relay scales RX signal
  - Seems practical; less interest in standards
- Decode-and-forward
  - Relay decodes RX signal
  - Very practical
- Compress-and-forward
  - Relay compresses RX sig
  - Receiver decodes with partial information
  - Less industry interest

Expected Gains of Relays



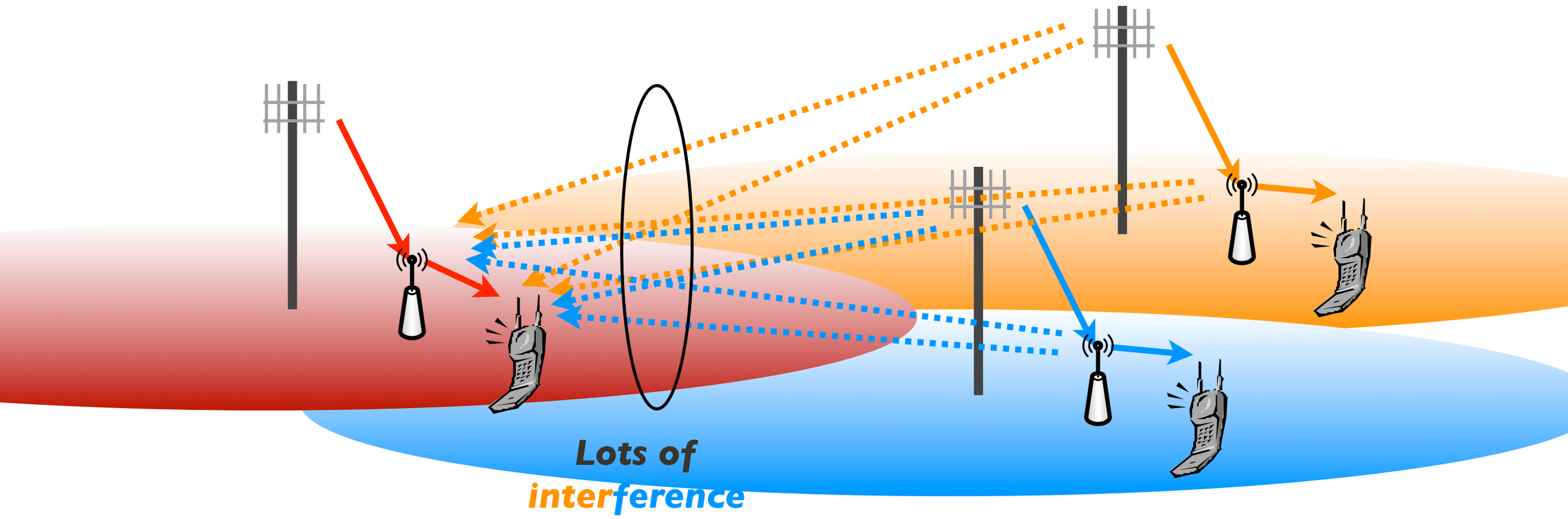
Linear system: full-duplex relay, no fading & same transmit powers [KraEtAl05]

$$R_{\text{relay}} - R_{\text{direct}} = \log(1 + k\ P) - \log(1 + P) \rightarrow \log(k) \triangleq \Delta R_{\infty} \quad \text{as } P \rightarrow \infty$$

- The maximum capacity gain over the direct transmission
  - As $d \rightarrow 0, \Delta R_{\infty} = 2$ bps/Hz (DF is the best)
  - As $d \rightarrow 1, \Delta R_{\infty} = 1$ bps/Hz (CF is the best)
  - If $d = 0.5\ , \Delta R_{\infty} = \log(1 + 2^{\alpha}) \approx \alpha$ bps/Hz $\quad \alpha \in [2, 5)$ path-loss exponent

Capacity gains of relays are modest (there is diversity as well)

Cellular Systems Interference Limited



- Relay deployments 7% indoor coverage improv. [DoppEtAl08]
- 30% improvement in outage SINR w/ fast PC [SreEtAl02]
- Better uplnk coverage, 10% rate improvement 3GPP [IrmDie08]
- 6% rate improvement downlink LTE-A [LinEtAl09]

With interference, capacity gains seem to reduce further

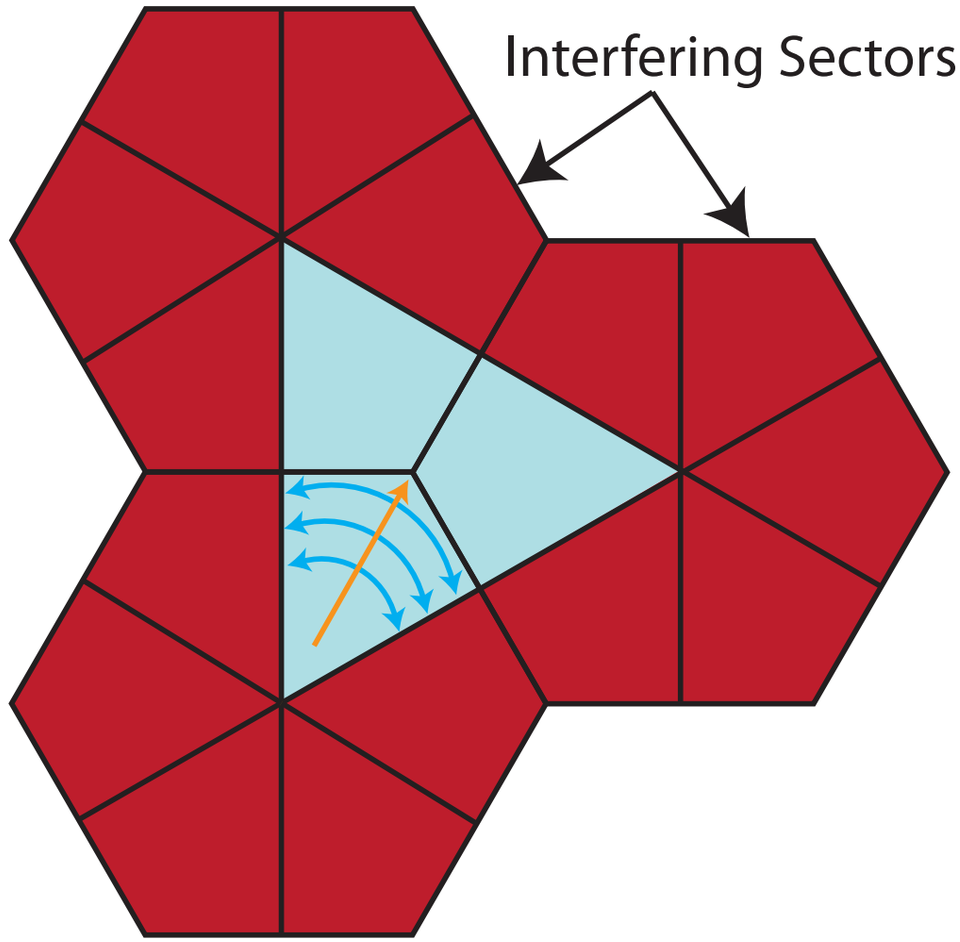
Purpose of this Talk


(1) Discuss performance of different relaying strategies


(2) Suggest some solutions to make relays better


Compare with no relay & coordinated transmission (via DPC)

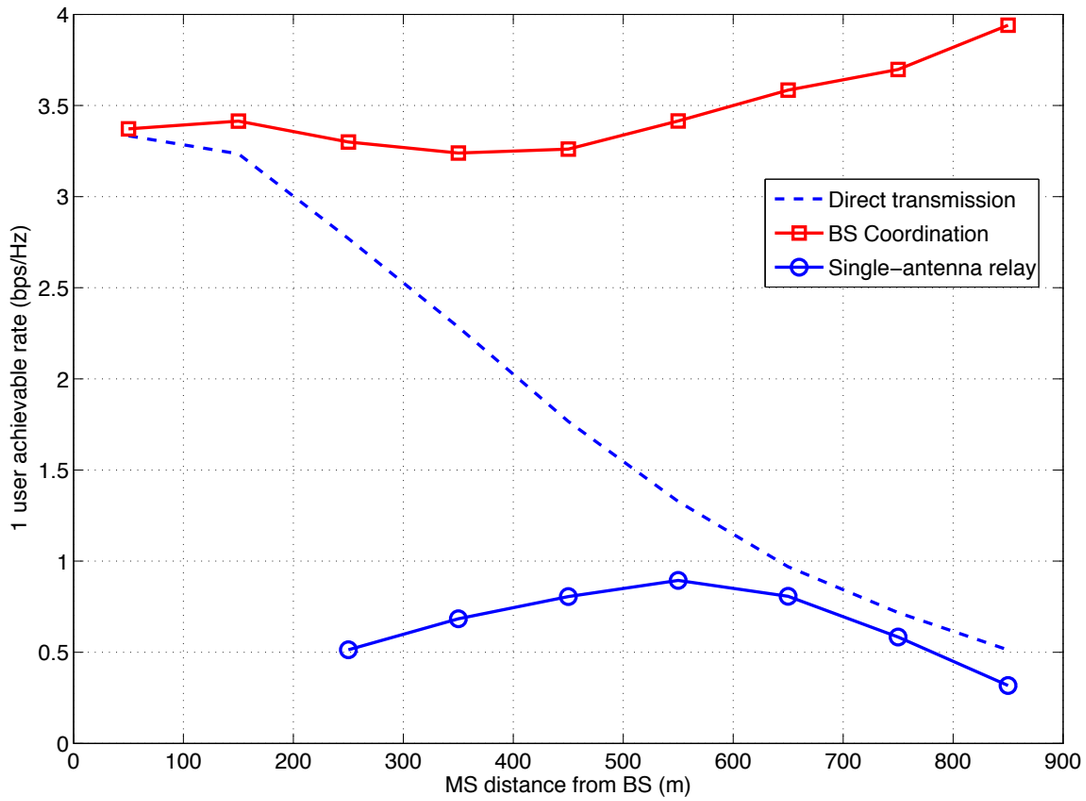
Simulation Framework



- Channel
  - IEEE 802.16j Type E channel model
  - 46 dBm base station transmit power
  - 37 dBm relay transmit power
  - 24 dBm mobile transmit power
- Configuration
  - 3 cells, 6 sectors per cell, 1 antenna UE
- Compute throughput on ring
- Switch from direct to relay link as move from BTS [ring based]

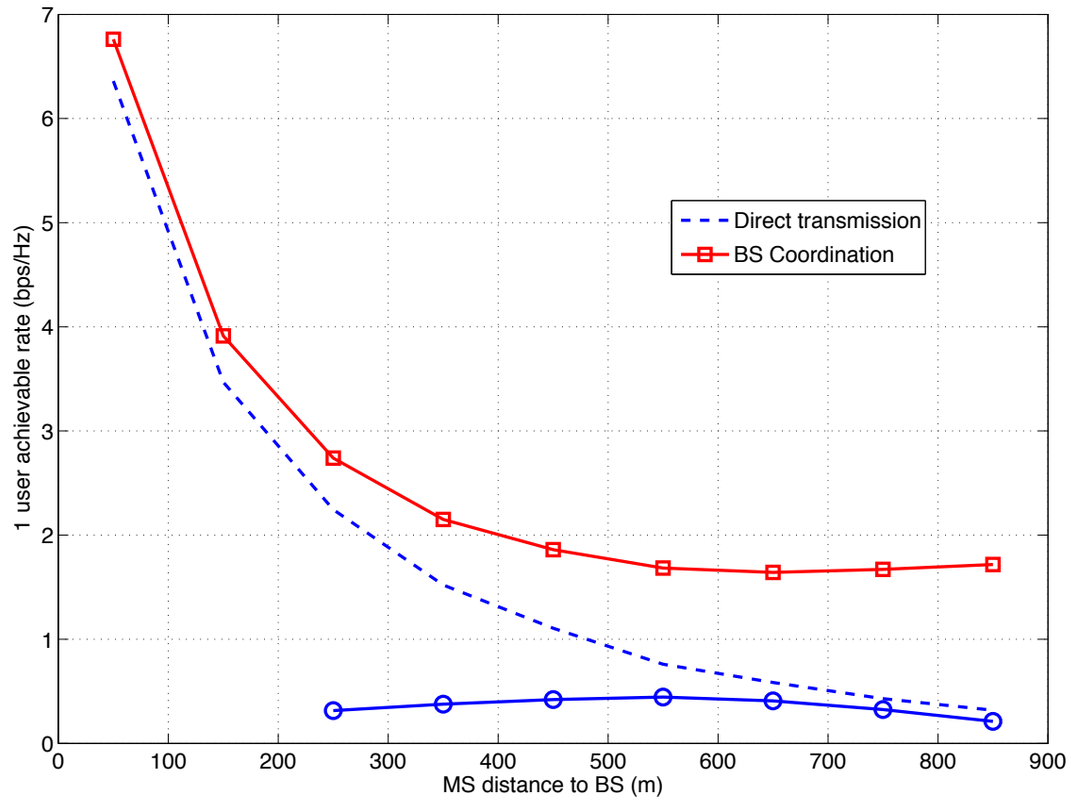
Relay Performance

Downlink (DL)



- **BS-RS interference limited**

Uplink (UL)

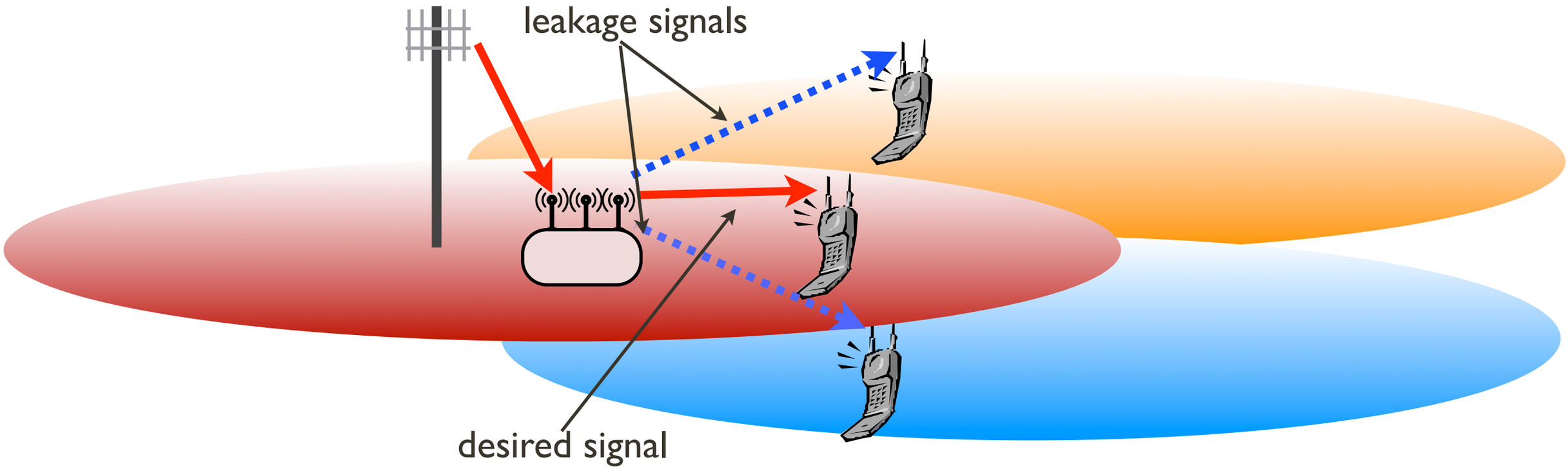


- **BS-RS interference limited**

Half duplex relay, ignore direct link, DF, optimum time sharing

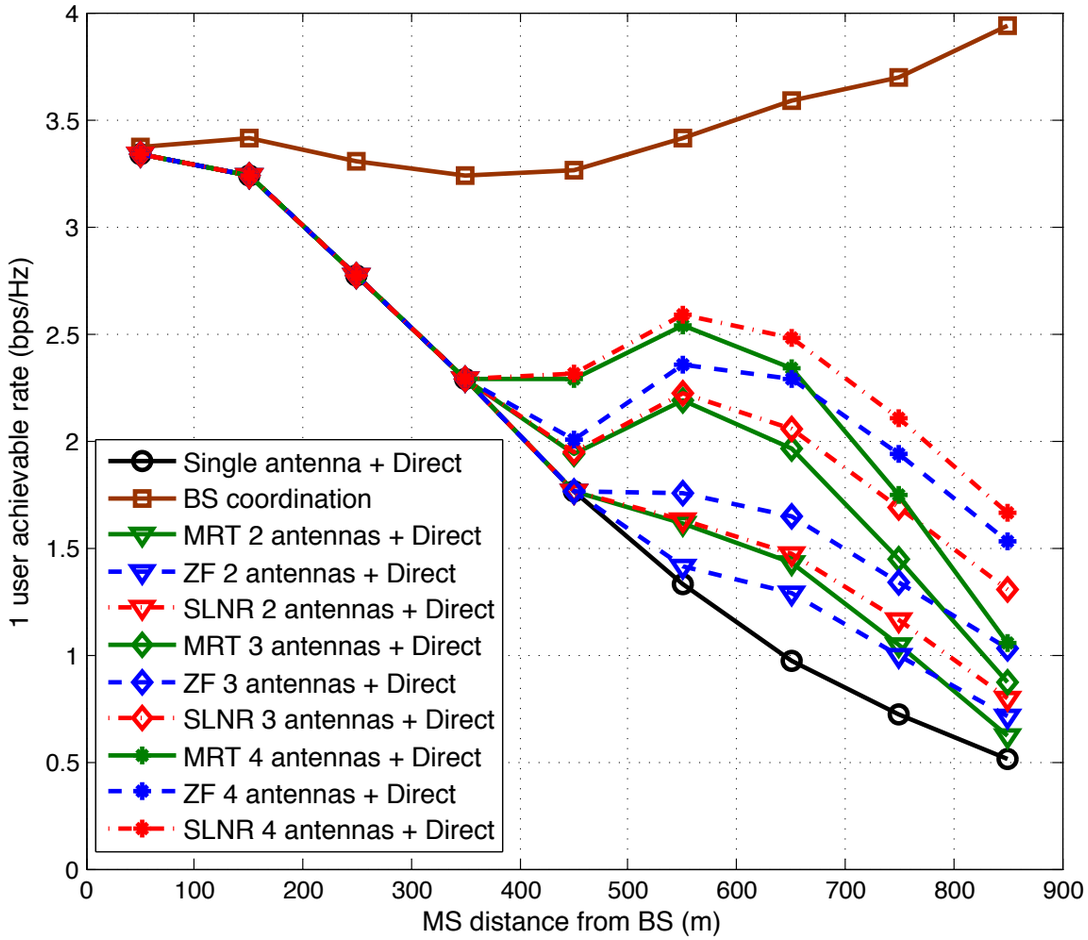
No gain from a single relay (ouch!!!)

Add Multiple Antennas

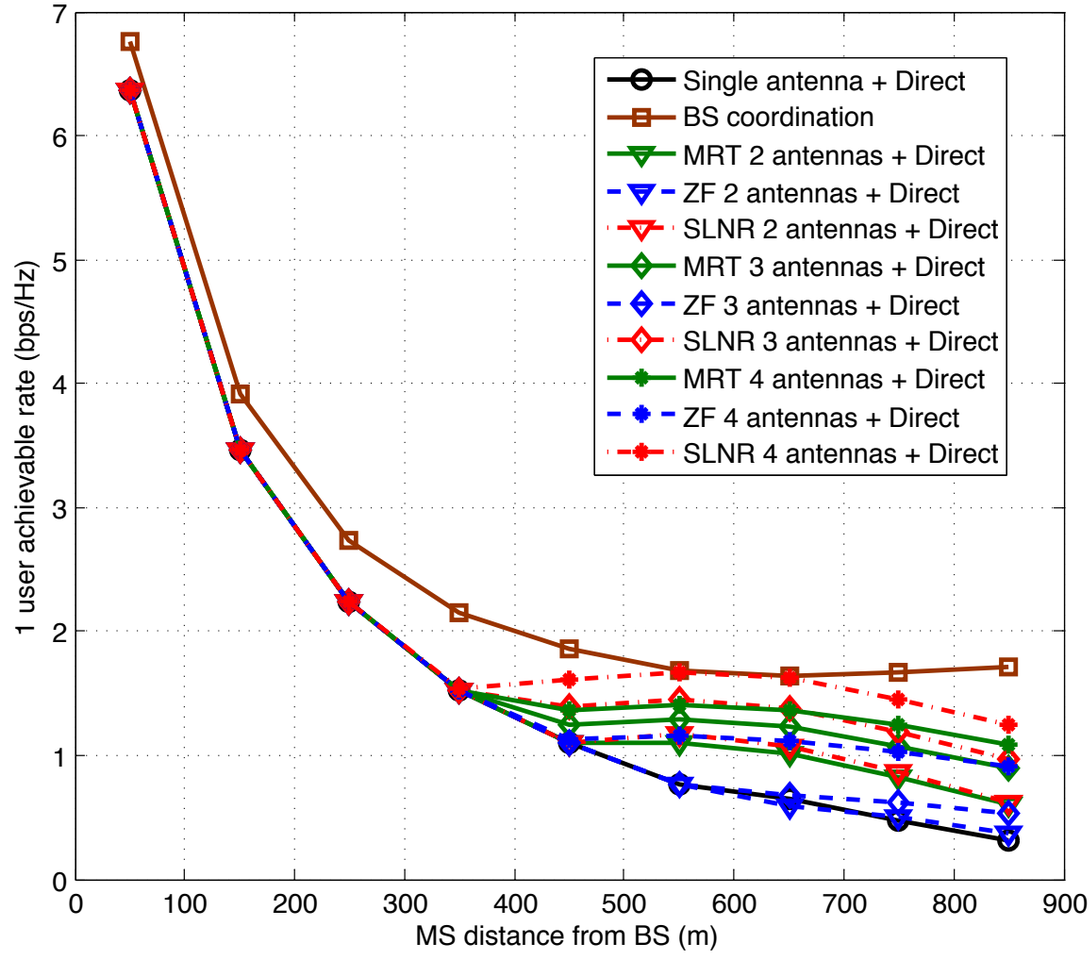


- First phase: Receive MMSE RX receive filter
- Second phase: TX beamforming (BF) at relays
  - MRT (max. ratio trans.): maximizing desired signal power to its own user
  - ZF (zero-forcing): minimizing sum of leakage powers to other users
  - SLNR (signal-to-leakage-plus-noise ratio): balancing MRT & ZF (like MMSE)

One-Way Relay with Antennas



Downlink (DL)

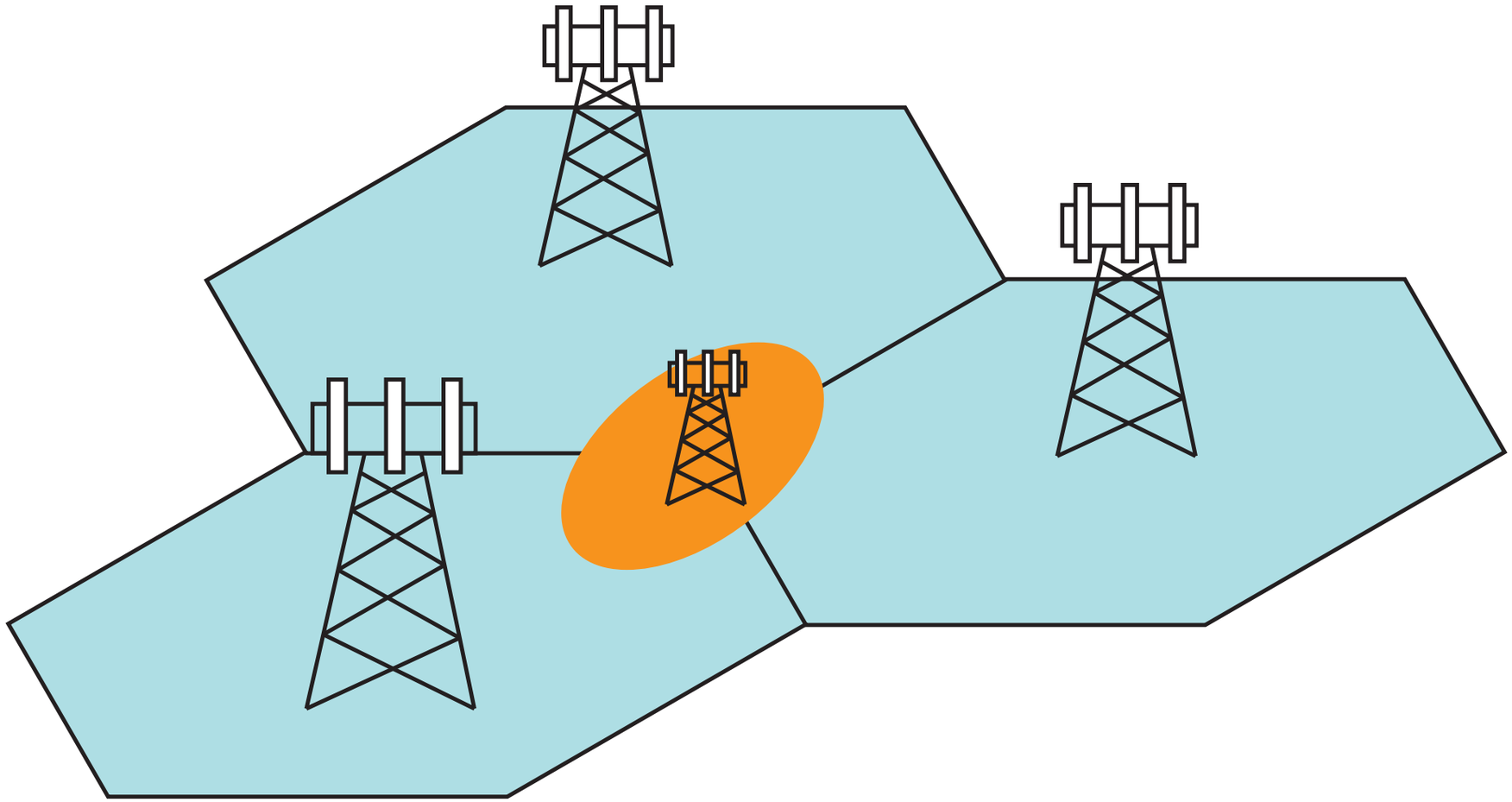


Uplink (UL)

- Using multiple antennas at relays provide significant gains
  - Better than direct trans./single-ant. relays from half of cell radius to cell-edge
- Interference cancellation is good only for DL cell-edge users

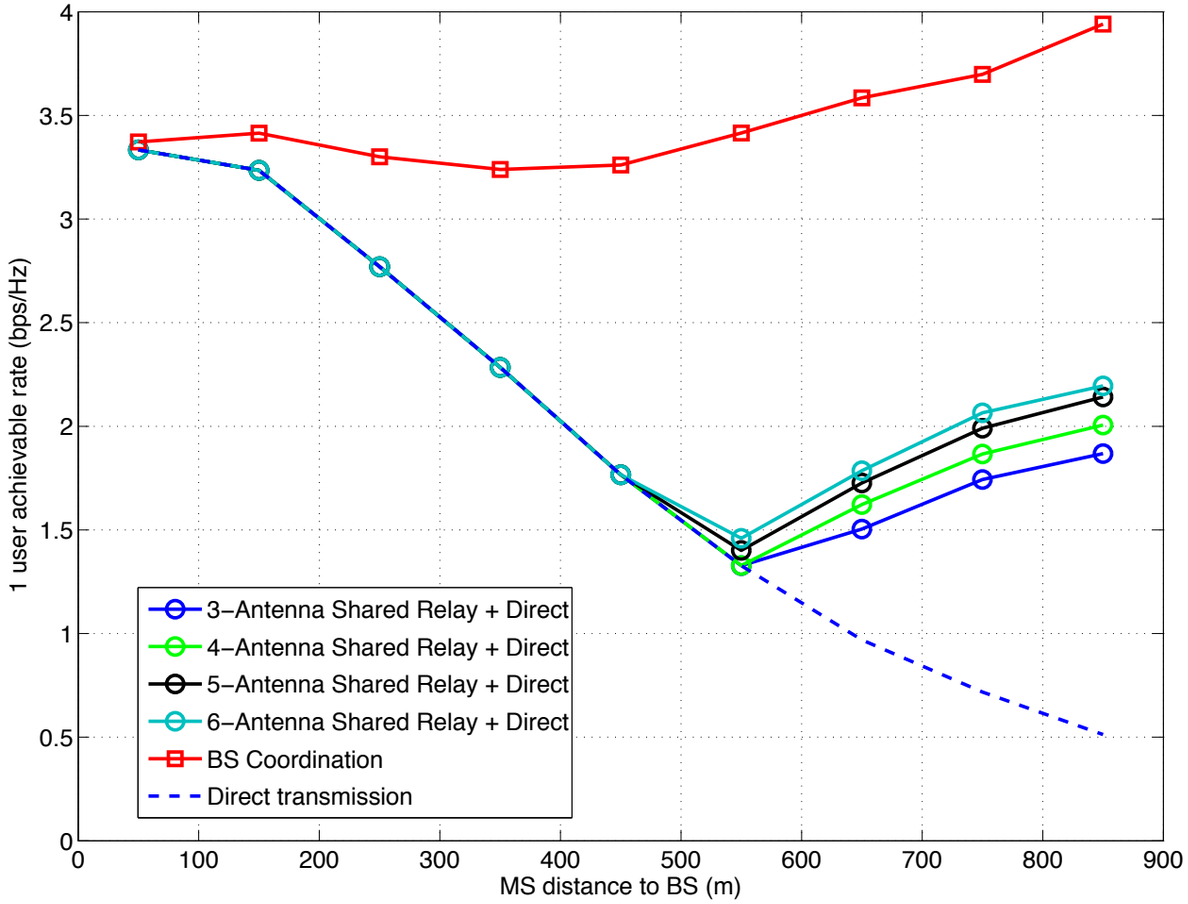
Enhanced relay functionality reduces gap to full coordination

Shared Relaying

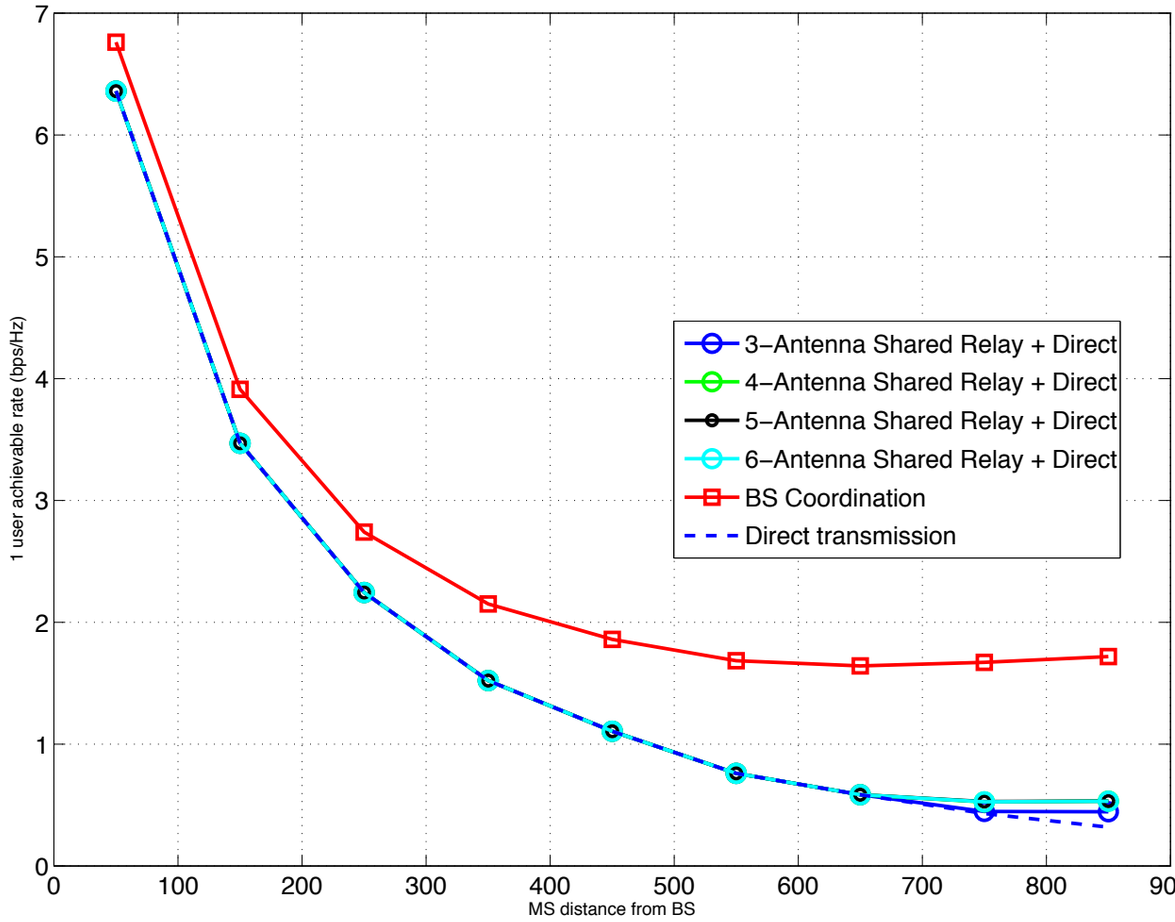


- Multi-antenna relay placed at cell intersection [PetEtAl09]
  - Relay shared among multiple base stations
  - Inter-cell interference removed through MU-MIMO techniques
  - Performs a decode and forward operation

Shared Relay Performance



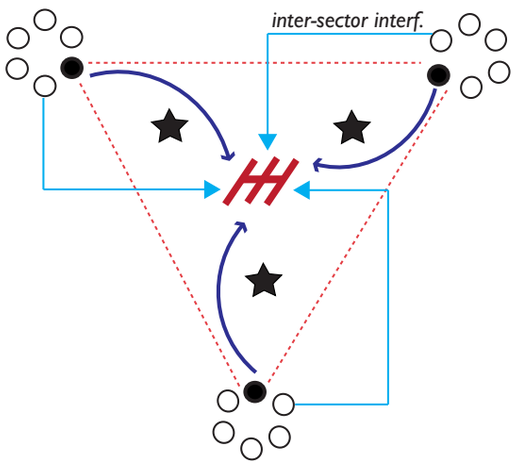
Downlink



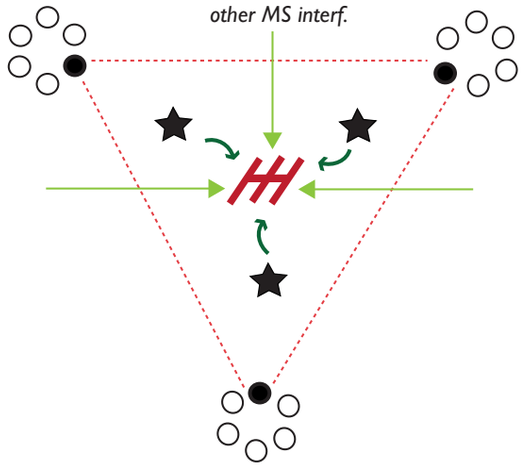
Uplink

Enhanced relay functionality reduces gap to full coordination

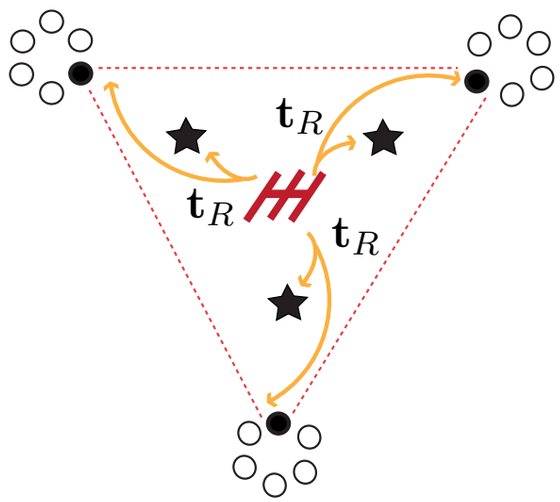
Two-Way Shared Relay



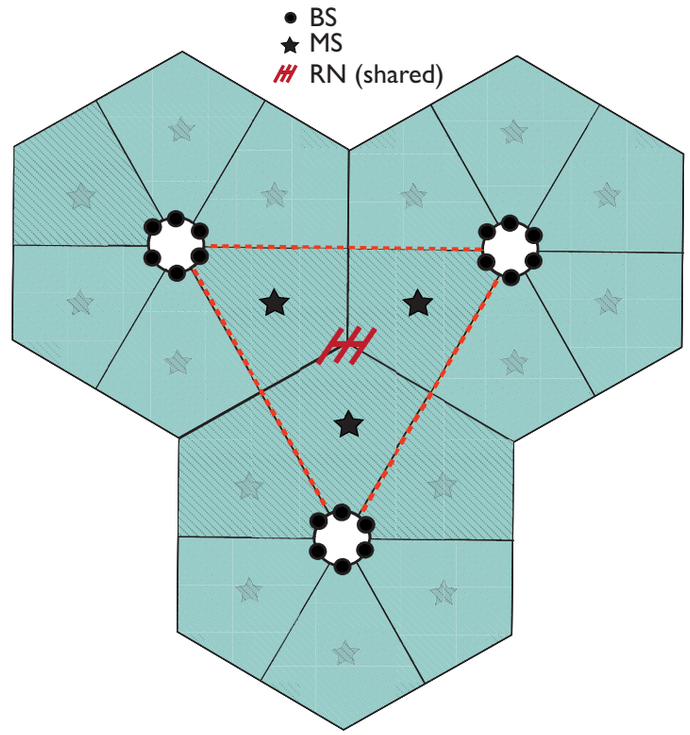
phase I



phase II



phase III

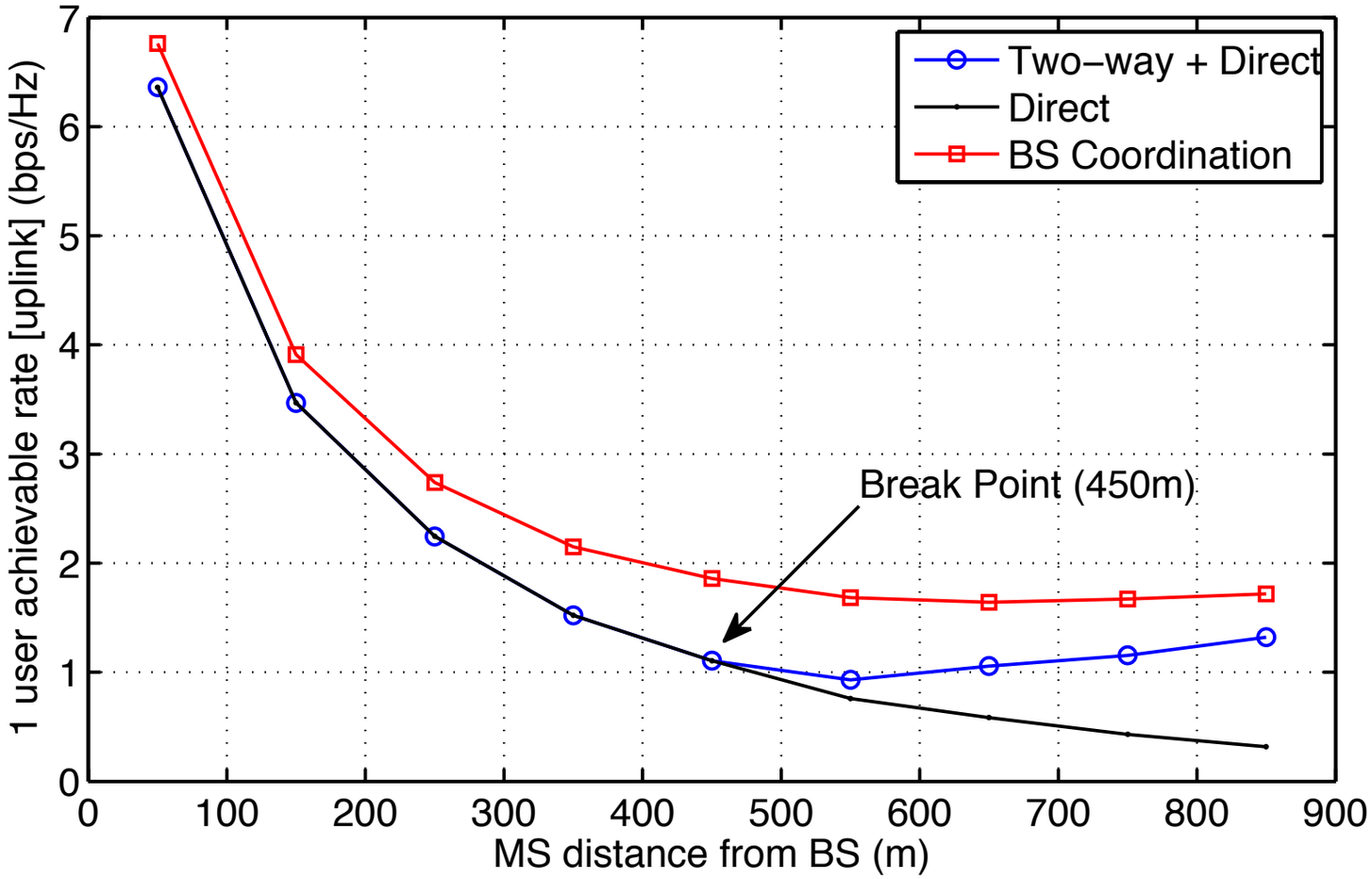


Cellular Topology

Concept

- Phase I: Relay decodes BS signals under inter-sector interference
- Phase II: Relay decodes MS signals under other MS interference
- Phase III: UL/DL power control + spatial orthogonalization via block diag.
- A single superposition of UL + DL signals is transmitted by relay

Two-Way Shared Relay Uplink



$$R_{UL}(\gamma) \;=\; \frac{1}{3}\min\{R_{UL}^{(II)}, R_{UL}^{(III)}\}$$

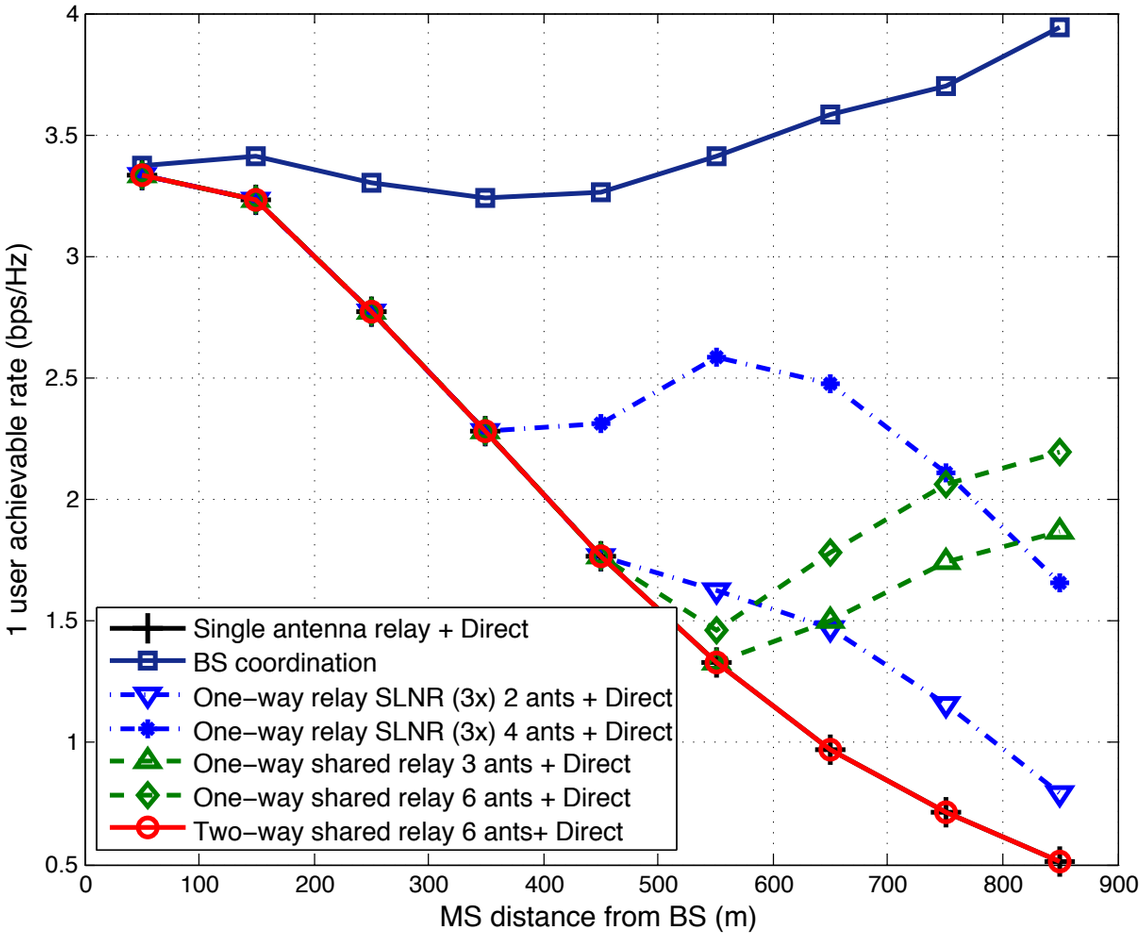
in presence of MS interference

w/ block diagonalization

Performance

- Performance is reduced due to inter-sector and inter cell MS interference
- Direct transmission is preferred unless MS closer to shared relay
- Optimal time-share with phase III is also assumed (not shown in equation)

Downlink Comparison



Area Spectral Efficiency (ASE)

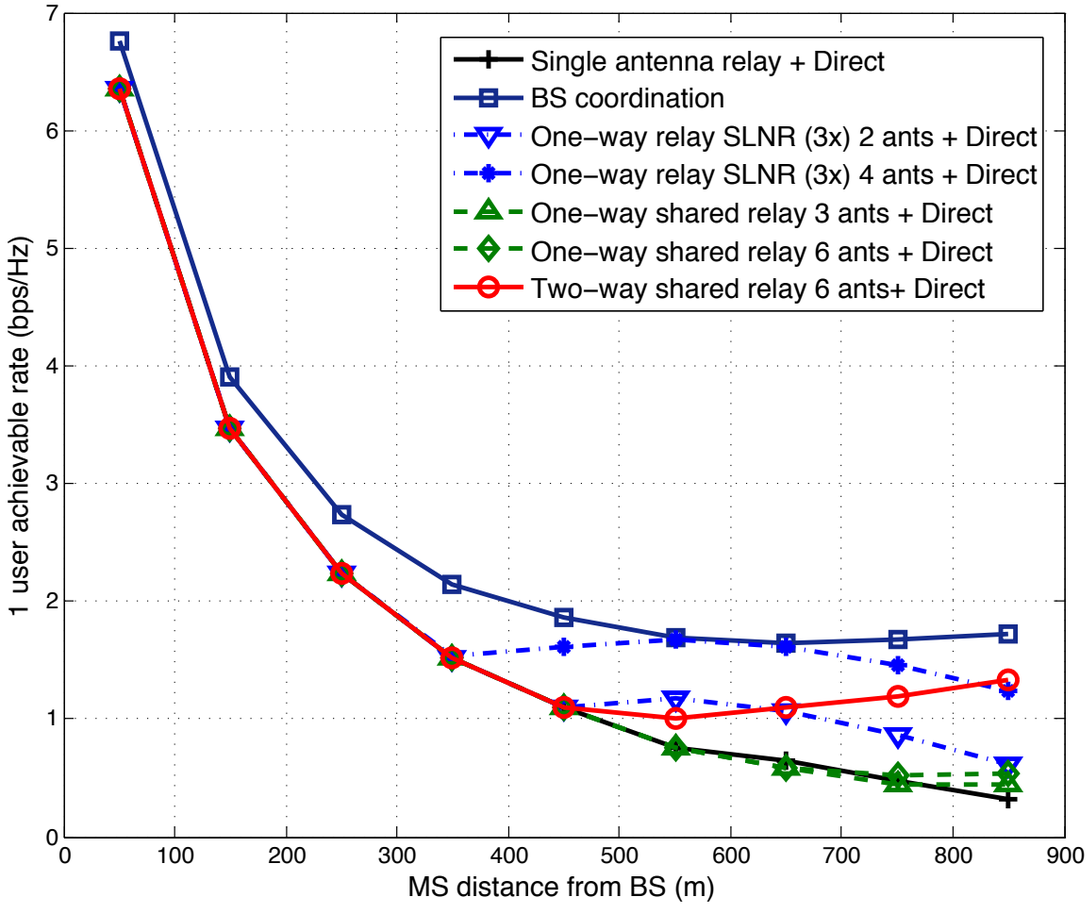
Configurations	ASE (bps/Hz/km^2)
Single-antenna relay + direct	6.99
BS coordination	20.20
One-way SLNR (3x) 2 ants + Direct	8.53
One-way SLNR (3x) 4 ants + Direct	12.68
One-way shared relay 3 ants + Direct	10.31
One-way shared relay 6 ants + Direct	11.44
Two-way shared relay 6 ants + Direct	6.99

One-way shared relay is good for cell-edge users

One-way relay with multiple antennas help more-inner users

Two-way shared relay does not help DL transmission

Uplink Comparison

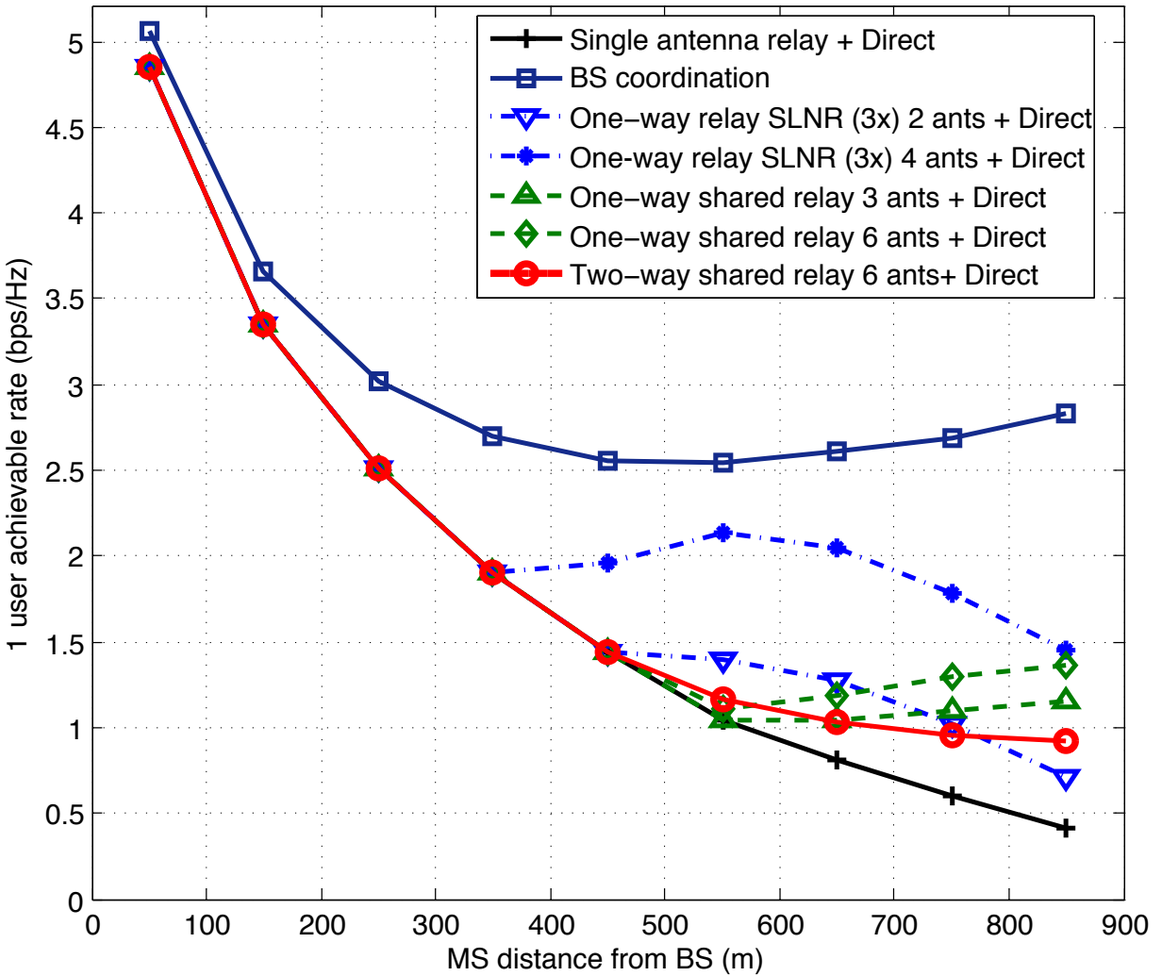


Area Spectral Efficiency (ASE)

Configurations	ASE (bps/Hz/km^2)
Single-antenna relay + direct	4.78
BS coordination	10.61
One-way SLNR (3x) 2 ants + Direct	6.43
One-way SLNR (3x) 4 ants + Direct	9.08
One-way shared relay 3 ants + Direct	4.96
One-way shared relay 6 ants + Direct	5.16
Two-way shared relay 6 ants + Direct	7.58

- Two-way shared relay is good for cell-edge users
- One-way relay with multiple antennas help more-inner users
- One-way shared relay does not help UL transmission

Uplink / Downlink Sum Comparison



Area Spectral Efficiency (ASE)

Configurations	ASE (bps/Hz/km^2)
Single-antenna relay + direct	5.89
BS coordination	15.41
One-way SLNR (3x) 2 ants + Direct	7.48
One-way SLNR (3x) 4 ants + Direct	10.88
One-way shared relay 3 ants + Direct	7.63
One-way shared relay 6 ants + Direct	8.30
Two-way shared relay 6 ants + Direct	7.28

Two-way shared relay is not as good as one-way shared relay

Where are the Capacity Gains?

- Not here: Relays that neglect interference
  - They arguably suck even without interference

- Here: Relays that deal with interference
  - Multiple antennas improve mid-range cell performance
  - Multiple antenna shared relay improves edge of cell performance
  - Combination of relay strategies seems very attractive

- Future work: Two-way, relay selection, power control

References

[DoppEtAl08] K. Doppler, C. Wijting, and K. Valkealahti, "On the Benefits of Relays in a Metropolitan Area Network", VTC 2008.

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[PetEtAl09] S. W. Peters, A. Y. Panah, K. T. Truong, and R. W. Heath, Jr., ``Relaying Architectures for 3GPP LTE-Advanced," EURASIP Journal on Advances in Signal Processing, special issue on 3GPP LTE and LTE Advanced, vol. 2009, Article ID 618787, 14 pages, doi:10.1155/2009/618787, 2009.

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