PhD Preliminary Exam
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# Spectrum Efficiency for Future Wireless Communications

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# Outline

- Introduction
- Dynamic TDD in Macro Cell Assisted Small Cell Architecture
  - System model
  - SINR distributions and numerical results
  - Half-duplex FDD-like radio resource assignment
  - System level simulations
- Full-Duplex Relaying Systems
  - Motivation
  - System model
  - Resource optimization
  - Numerical results
- Summary and Future Work

# Roadmap

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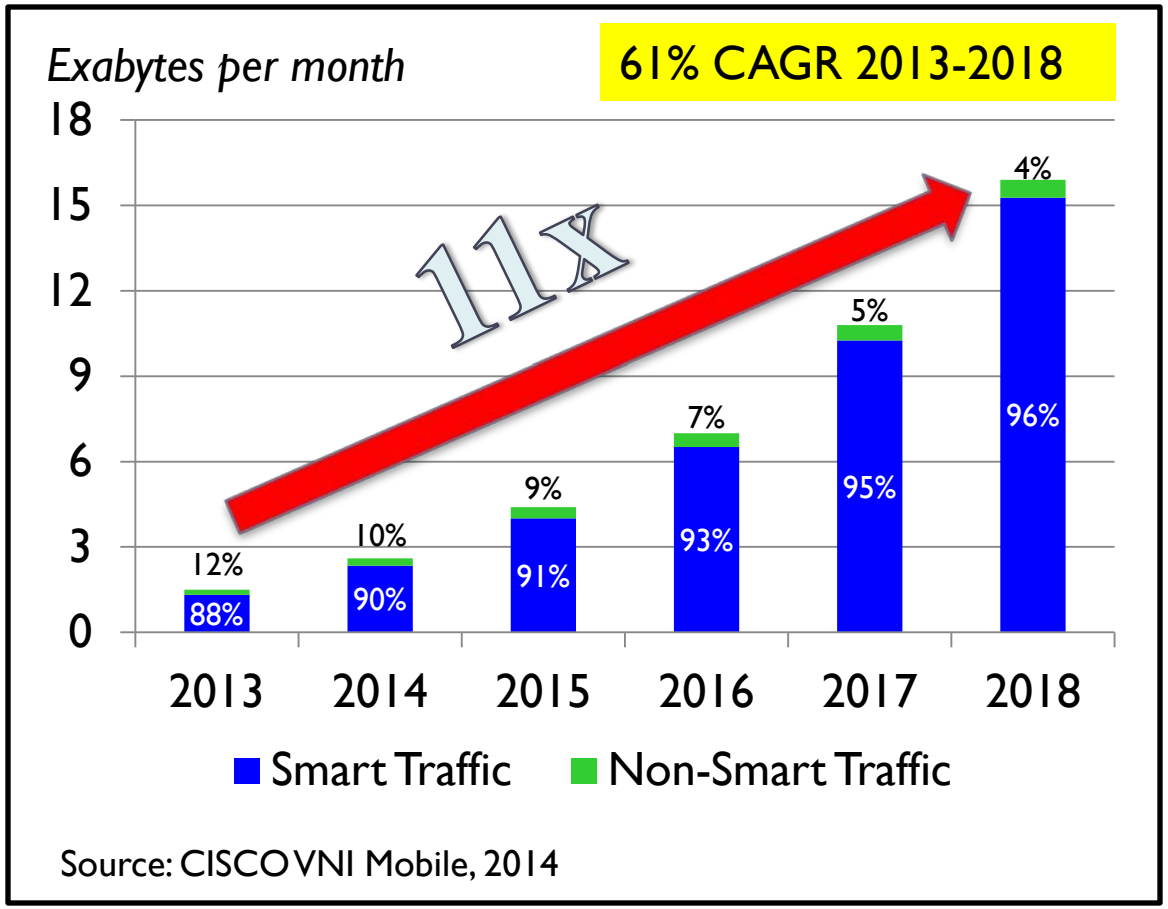
# Introduction

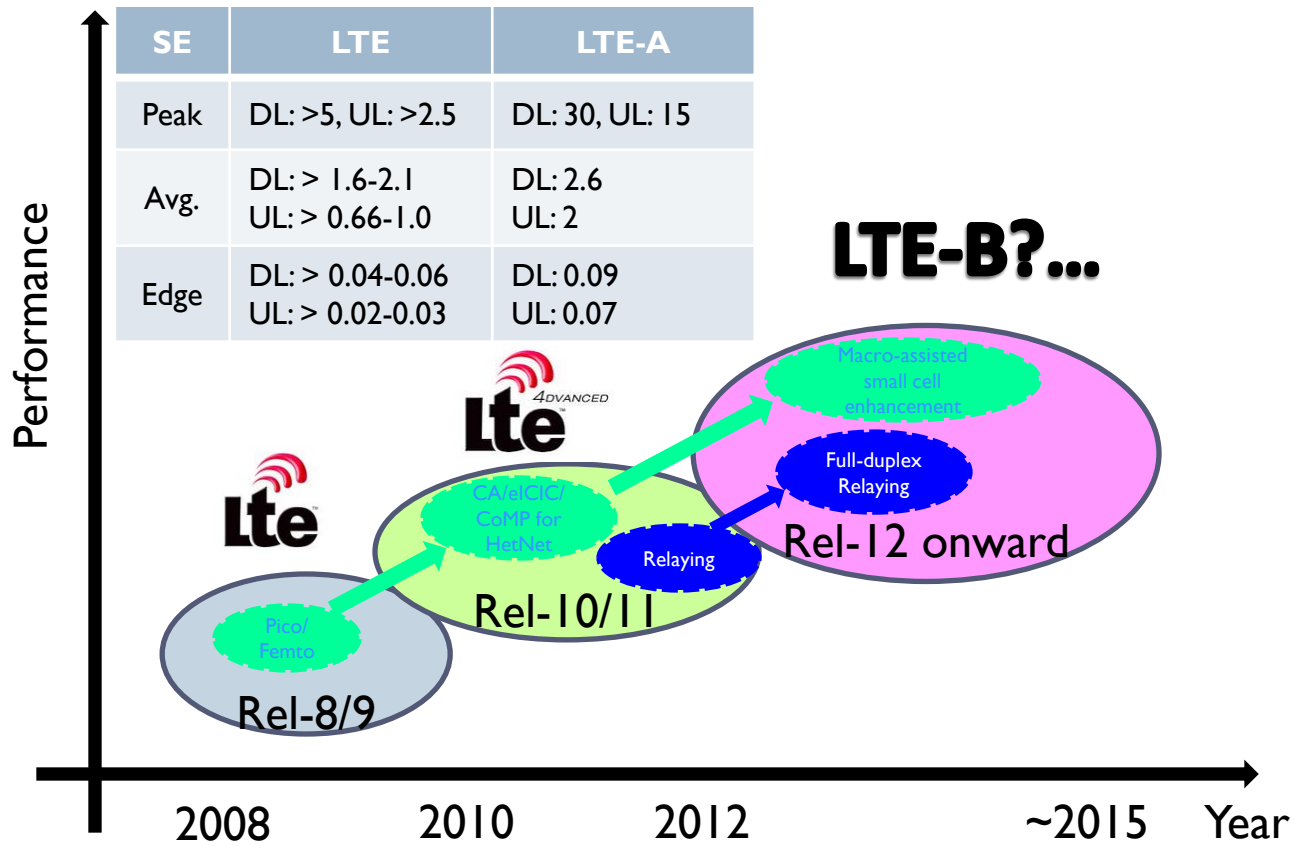
- Globe mobile data traffic, 2013-2018




Continued exponential growth in mobile data traffic driving the need for continued spectrum enhancement in wireless communications

# Introduction (cont.)

- Evolution path for future radio access by 3GPP




| SE | LTE | LTE-A |
|---|---|---|
| Peak | DL: >5, UL: >2.5 | DL: 30, UL: 15 |
| Avg. | DL: > 1.6-2.1<br>UL: > 0.66-1.0 | DL: 2.6<br>UL: 2 |
| Edge | DL: > 0.04-0.06<br>UL: > 0.02-0.03 | DL: 0.09<br>UL: 0.07 |

  - Macro-assisted small cell enhancement
  - Relaying: full-duplex vs. half-duplex

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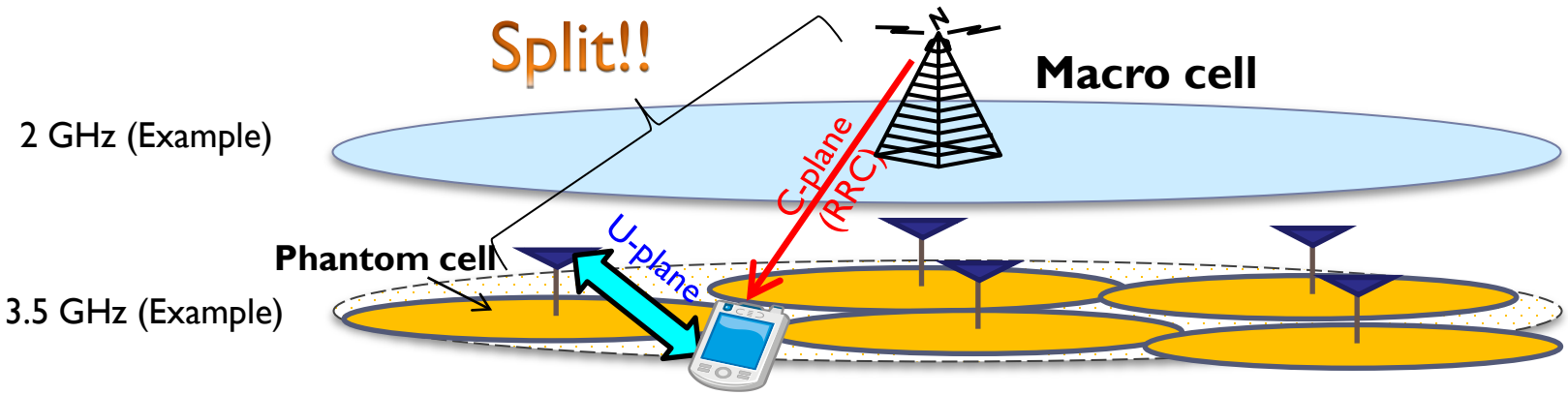
# Macro-assisted small cell architecture

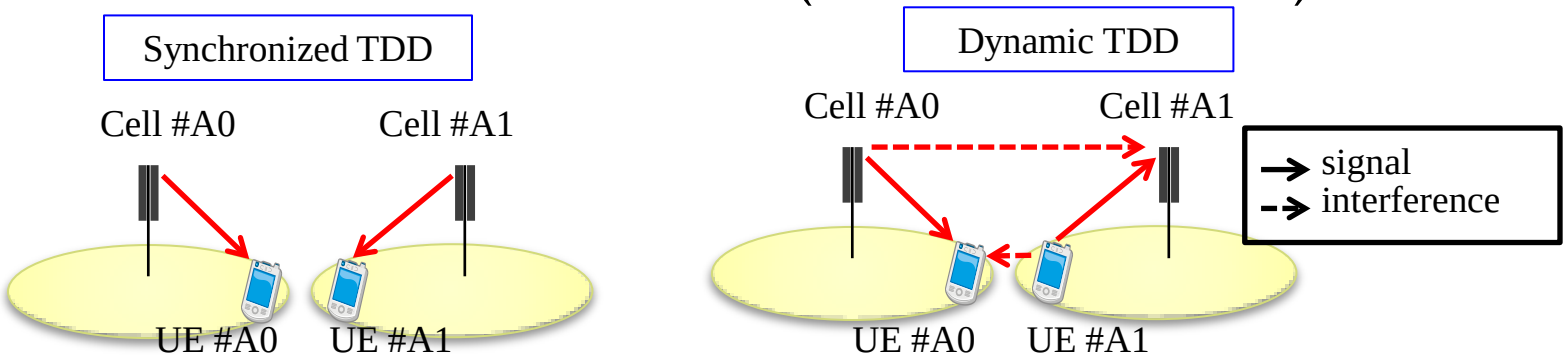
- Phantom cell architecture (one example)
  - A small cell architecture proposed by DOCOMO [Ishii-Kishiyama'12]
  - Objective: provide high system capacity and robust mobility while reducing the cell planning efforts
  - Key feature: Control-plane/User-plane split
    - C-plane: maintains good connectivity and mobility (Macro, lower spectrum)
    - U-plane: provides higher throughput and flexible / cost-energy efficient operations (small cells, higher/wider spectrum bands)
    - Small cells are not configured with cell specific signals/channels (PSS/SSS, CRS, MIB/SIB)



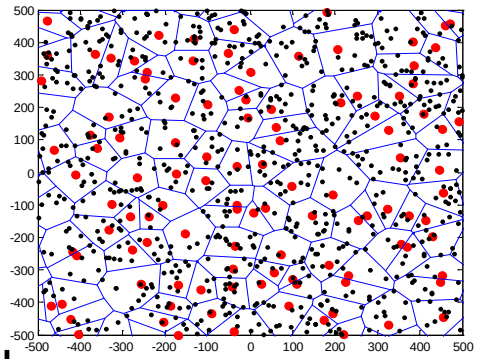

H. Ishii et al., "A Novel Architecture for LTE-B", IEEE Globecom workshop, December 2012

# Dynamic TDD for Phantom cells

- Definition:
  - For each phantom cell, the DL/UL assignment is dynamically changing depending on the traffic, without coordination and time slot synchronization
- Motivation:
  - DL/UL traffic is asymmetric and dynamically variable
  - Complete time synchronization in dense small cells scenario is bothersome
  - Device-to-device (D2D) and small cells may co-exist
- Feasibility:
  - The dynamic DL/UL slot reconfigurations can be easily realized
  - Macro cell can assist the phantom cells regarding interference coordination
- Problem: Inter-cell interference (DL-to-UL/UL-to-DL)



# Performance evaluation methods




- Conventional method: simulations
  - Lack of theoretical analysis
  - General inference can not be drawn
  - Time consuming, especially for large scale networks
- Our goal: analytical expressions
  - Classical hexagon model: less accurate especially for small cells
  - Poisson point process (PPP) model
    - $\Phi_1$ : Base stations (BSs) with density $\lambda_1$
    - $\Phi_2$ : User equipments (UEs) with density $\lambda_2$
  - Dynamic TDD operation (UL probability is $\eta$)
    - $\tilde{\Phi}_1$ : DL active transmitting BSs with density $\tilde{\lambda}_1 = \lambda_1(1-\eta)$
    - $\tilde{\Phi}_2$ : UL active transmitting UEs with density $\tilde{\lambda}_2 = \lambda_1\eta$

# Radio propagation model

- Large scale fading
  - Slope-intercept (in dB) path loss model
  - In linear scale, the path loss is $PL = \frac{K \cdot P}{R^{\delta}}$
- Small scale fading
  - Rayleigh fading for all links
  - Link power gain $H \sim \exp(1)$
- Thermal noise power $N_0$
- Transmit power allocation
  - UL: open loop power control (OLPC)

$$\frac{KP^{\text{tx}}(R)}{R^{\delta}} = \theta \Leftrightarrow P^{\text{tx}}(R) = \frac{\theta R^{\delta}}{K}$$

  - DL: OLPC and fixed power transmission

# SINR distribution

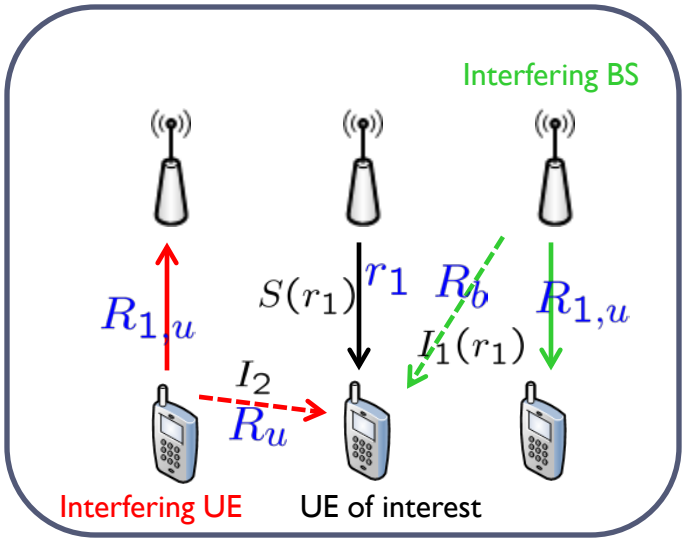
- DL SINR with fixed DL transmit power

$$\Gamma(r_1) = \frac{S(r_1)}{I_1(r_1)+I_2+N_0}$$

where $S(r_1) = K_1 P_1^{\text{tx}} H_1 / r_1^{\delta}$

$$I_1(r_1) = \sum_{b \in \tilde{\Phi}_1 : R_b > r_1} \frac{K_1 P_1^{\text{tx}} H_b}{R_b^{\delta}}$$

$$I_2 \approx \sum_{u \in \tilde{\Phi}_2} \frac{\theta K_2}{K} H_u \left(\frac{R_{1,u}}{R_u}\right)^{\delta}$$




$$\begin{aligned}\mathbb{P}\{\Gamma(r_1) > \gamma\} &= \mathbb{P}\left\{H_1 > \frac{\gamma r_1^{\delta}}{K_1 P_1^{\text{tx}}}[I_1(r_1) + I_2 + N_0]\right\} \\ &= \mathrm{e}^{-sN_0} \mathcal{L}_{I_1(r_1)}(s) \mathcal{L}_{I_2}(s) \Big|_{s=\gamma r_1^{\delta}/(K_1 P_1^{\text{tx}})}\end{aligned}$$

where $\mathcal{L}_X(s) = \mathbb{E}\,\mathrm{e}^{-sX}$ is the Laplace Transform of R.V. $X$

$$\boxed{\mathbb{P}\{R_{1,u} \le x\} = 1 - \exp(-\pi c \lambda_1 x^2),\ x \ge 0,\ c = 1.25}$$

$$\boxed{\mathbb{P}\{\Gamma > \gamma, d_{\min} \le R_1 \le d_{\max}\} = \int_{d_{\min}}^{d_{\max}} \mathbb{P}\{\Gamma(r_1) > \gamma\} f_{R_1}(r_1)\, \mathrm{d}r_1}$$

# Manipulating Laplace transform

$$
\begin{aligned}
\mathcal{L}_{I_1(r_1)}(s) &= \mathbb{E}\left[e^{-sI_1(r_1)}\right] \\
&\overset{(1)}{=} \mathbb{E}\left[\exp\left(-s \sum_{b\in\tilde{\Phi}_1:R_b>r_1} \frac{K_1 P_1^{\mathrm{tx}} H_b}{R_b^{\delta}}\right)\right] \\
&\overset{(2)}{=} \mathbb{E}\left[\prod_{b\in\tilde{\Phi}_1:R_b>r_1} \exp\left(-s\frac{K_1 P_1^{\mathrm{tx}} H_b}{R_b^{\delta}}\right)\right] \\
&\overset{(3)}{=} \mathbb{E}_{\tilde{\Phi}_1}\left[\prod_{b\in\tilde{\Phi}_1:R_b>r_1} \mathcal{L}_{H_b}\left(s\frac{K_1 P_1^{\mathrm{tx}}}{R_b^{\delta}}\right)\right] \\
&\overset{(4)}{=} \mathbb{E}_{\tilde{\Phi}_1}\left[\prod_{b\in\tilde{\Phi}_1:R_b>r_1} \frac{1}{1+s\frac{K_1 P_1^{\mathrm{tx}}}{R_b^{\delta}}}\right] \\
&\overset{(5)}{=} \exp\left[-2\pi\lambda_1(1-\eta)\cdot\int_{r_1}^{\infty}\left(1-\frac{1}{1+s\frac{K_1 P_1^{\mathrm{tx}}}{r^{\delta}}}\right) r\,dr\right] \\
&\overset{(6)}{=} \exp\left[-\pi\lambda_1(1-\eta)(K_1 P_1^{\mathrm{tx}})^{2/\delta} \times s^{2/\delta} G_{2/\delta}\left(\frac{r_1^2}{(K_1 P_1^{\mathrm{tx}})^{2/\delta} s^{2/\delta}}\right)\right]
\end{aligned}
$$

Expectation over the PPP

Expectation over the fading channel

PGFL of PPP

$$\mathcal{L}_{I_2}(s) = \exp\left[-\frac{\eta}{c\,\mathrm{sinc}(2/\delta)}\left(\frac{s\theta K_2}{K}\right)^{2/\delta}\right]$$

# Closed-form expressions

- Unconditional CCDF $(N_0 = 0)$

$$\boxed{\mathbb{P}\{\Gamma > \gamma\} = \frac{\mathrm{e}^{-\pi c \lambda_1 d_{\min}^2 A(\gamma)} - \mathrm{e}^{-\pi c \lambda_1 d_{\max}^2 A(\gamma)}}{A(\gamma)}}$$

$$\begin{aligned} \text{where } A(\gamma) &= 1 + (\gamma^{2/\delta}/c)\Big\{(1-\eta)G_{2/\delta}(\gamma^{-2/\delta}) \\ &+ \eta/\left[\pi\lambda_1 c\,\mathrm{sinc}(2/\delta)\right]\left[\theta K_2/(K K_1 P_1^{\mathrm{tx}})\right]^{2/\delta}\Big\} \end{aligned}$$

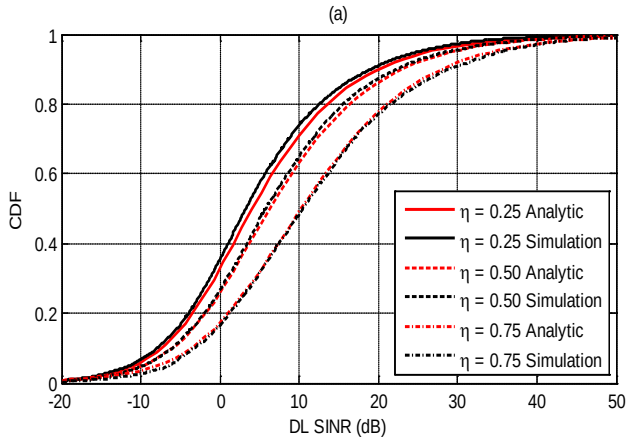
- Special case: $\delta = 4,\ N_0 > 0,\ d_{\min} = 0,\ d_{\max} = \propto$

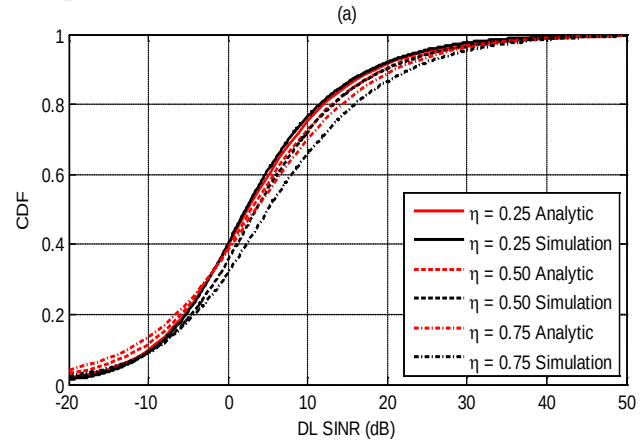
$$\boxed{\mathbb{P}\{\Gamma > \gamma\} = \frac{\sqrt{\pi}}{2\sqrt{B(\gamma)}} \exp\left[\frac{A(\gamma)^2}{4B(\gamma)}\right] \mathrm{erfc}\left(\frac{A(\gamma)}{2\sqrt{B(\gamma)}}\right)}$$

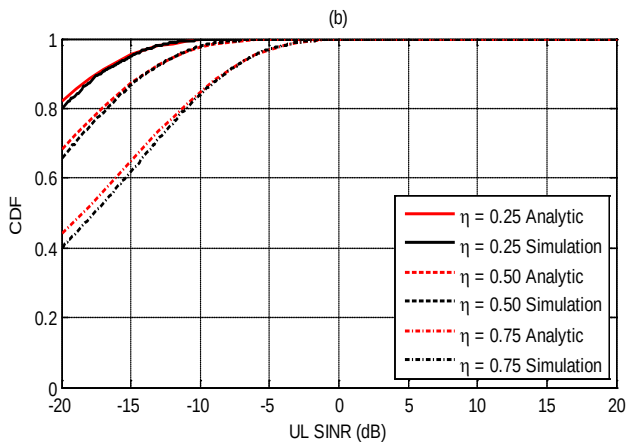
where $B(\gamma) = \gamma N_0/[(\pi\lambda_1 c)^2 K P_1^{\mathrm{tx}}]$

# Numerical results

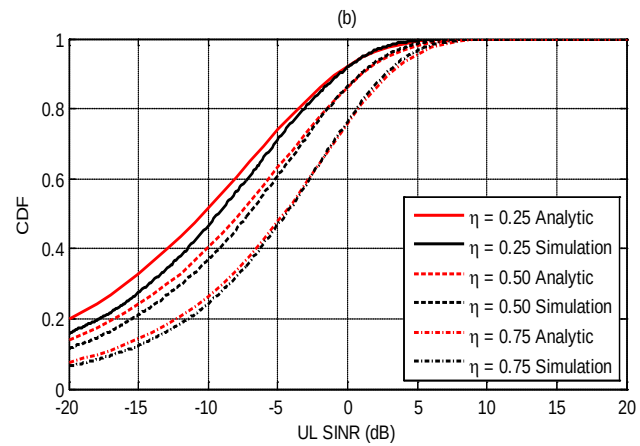
- DL with fixed transmit power




DL TX power = 23 dBm

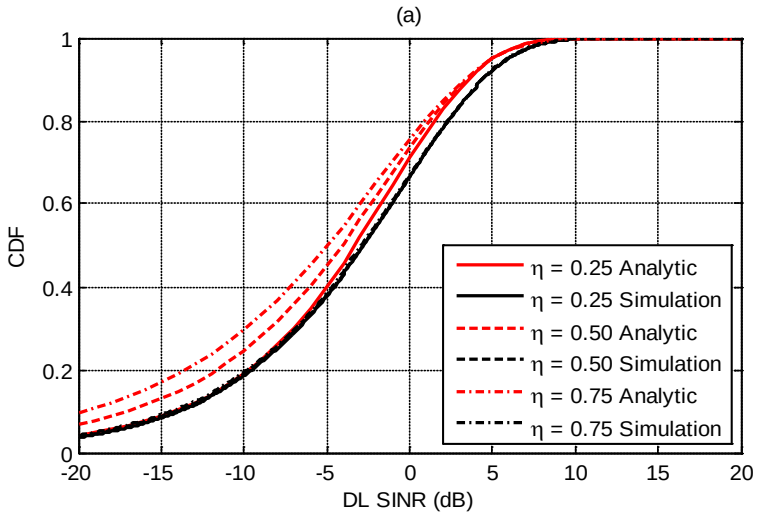


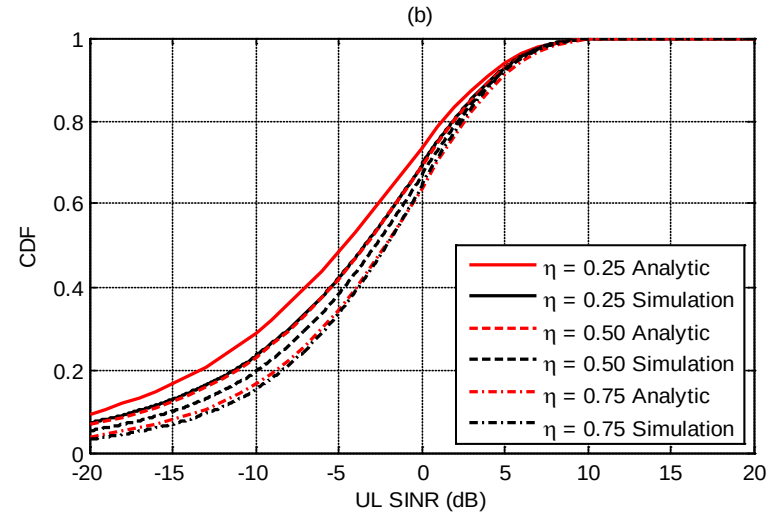

DL TX power = 5 dBm

UL is the bottleneck for dynamic TDD with fixed DL transmit power!

# Numerical results (cont.)

- DL with open loop power control (OLPC)



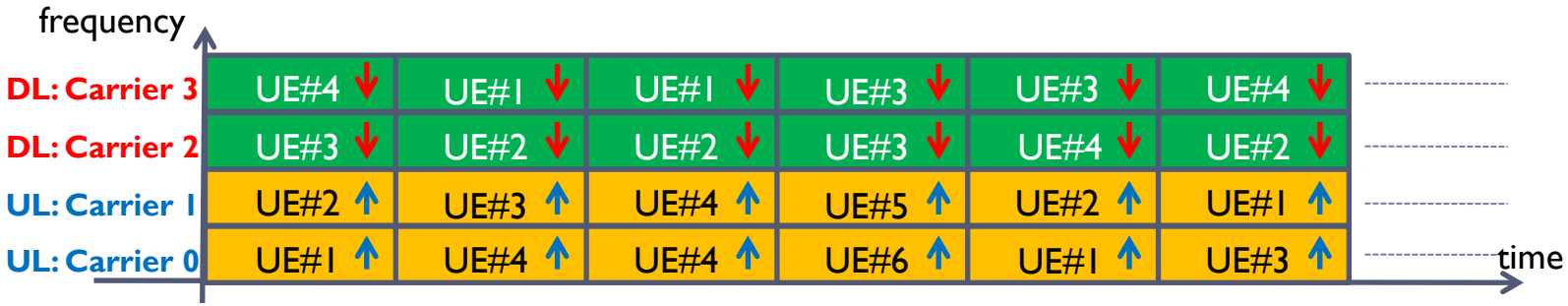




  - Autonomous dynamic DL power control in each phantom cell is feasible and easily implementable
  - With OLPC on DL, the UL SINR performance is improved greatly compared to the fixed DL case
  - With OLPC on DL, the DL throughput suffers due to the DL SINR degradation

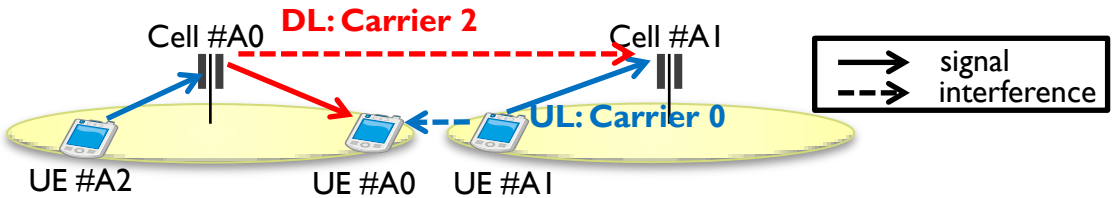
**Need for inter cell interference coordination (ICIC)!**

# Half-duplex FDD-like ICIC

- DL and UL transmissions take place on distinct carriers
- Hybrid of TDD and FDD
  - BSs are full-duplex: DL and UL at the same time slot for different UEs
  - UEs are half-duplex: DL and UL at different time slots (no duplexer needed)
- There may be some spacing needed between the DL and UL carriers, (adjacent channel interference ratio (ACIR))




- DL-to-UL and UL-to-DL interference can be mitigated



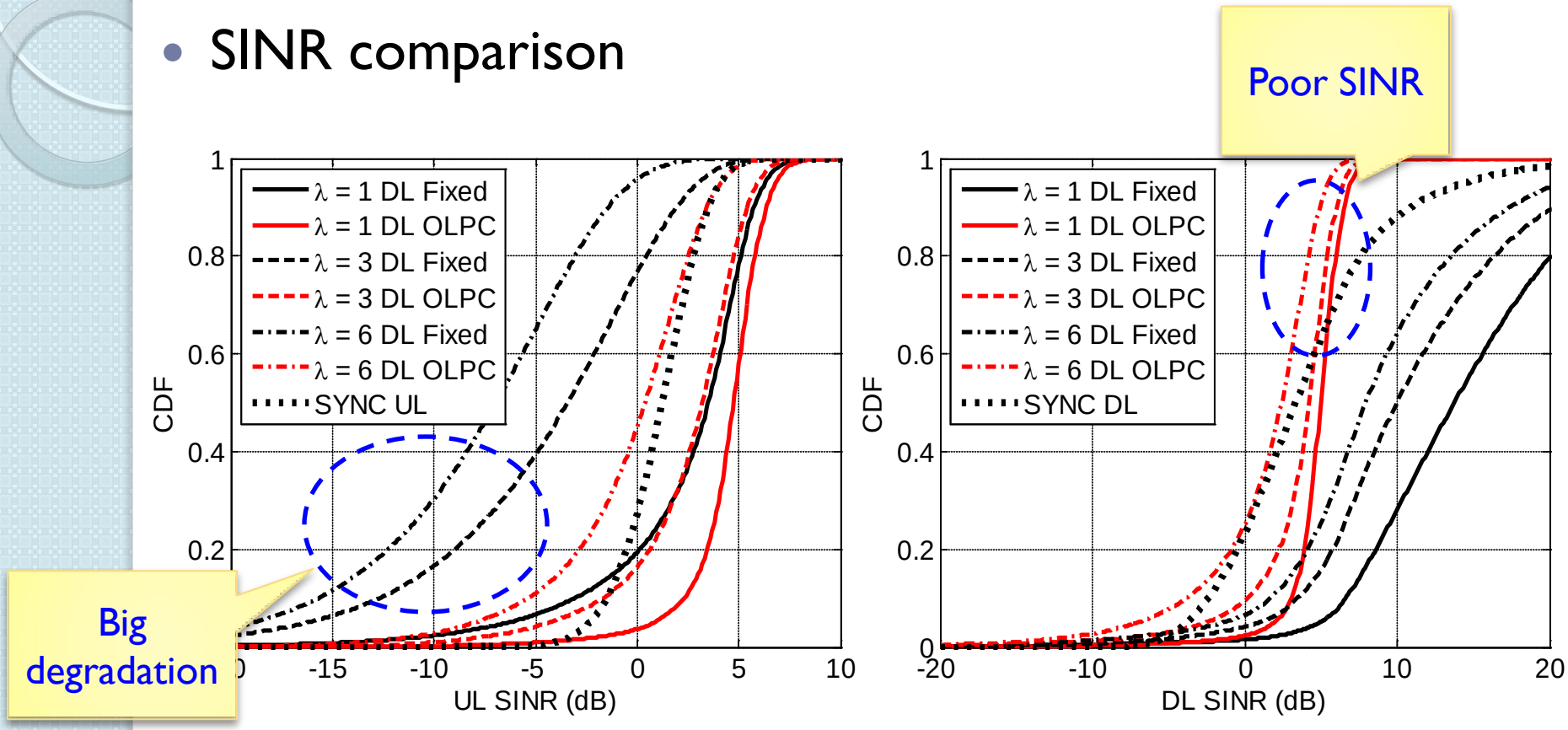
# System level simulation setup

- System deployment
  - 19-macrocell hexagonal (uniform Phantom cells and UEs deployment)
  - No interference between Macro and Phantom cells
- DL and UL transmit power allocation
  - DL: consider both fixed power and OLPC
  - UL: OLPC
- ACIR model: 30/20/10 dB
- Channel model
  - Slow fading: NLoS (Hexagonal cell layout) for Urban Micro (UMi)
  - Fast fading: 6-ray Typical Urban (TU) multipath channel model
- Traffic model: FTP Model 1 with different packet arrival rates
- Simulation scenarios:

| | | |
|---|---|---|
| Without ICIC | | 10 MHz bandwidth is used for each cell |
| With ICIC | Frequency reuse 2 | 2 carriers (5 MHz each), each cell uses one, and two closest neighboring cells use different carriers |
| | Half-duplex FDD-like | 2 carriers (5 MHz each), one for DL and the other for UL |

# Dynamic TDD without ICIC

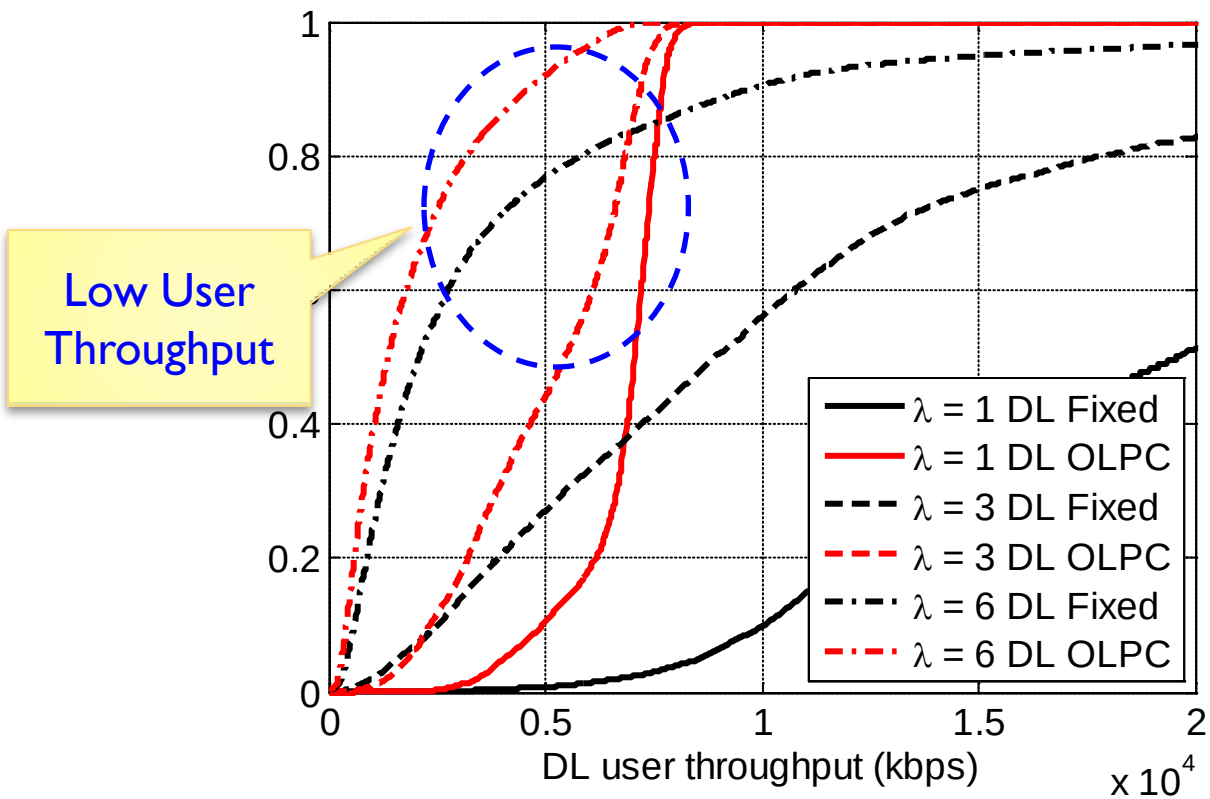
- SINR comparison




  - Synchronized TDD results are used for reference (DL fixed, UL OLPC with full buffer traffic)
  - With DL OLPC, UL SINR is acceptable in dynamic TDD scenario, but DL SINR is degraded compared to the fixed DL case

# Dynamic TDD without ICIC (cont.)

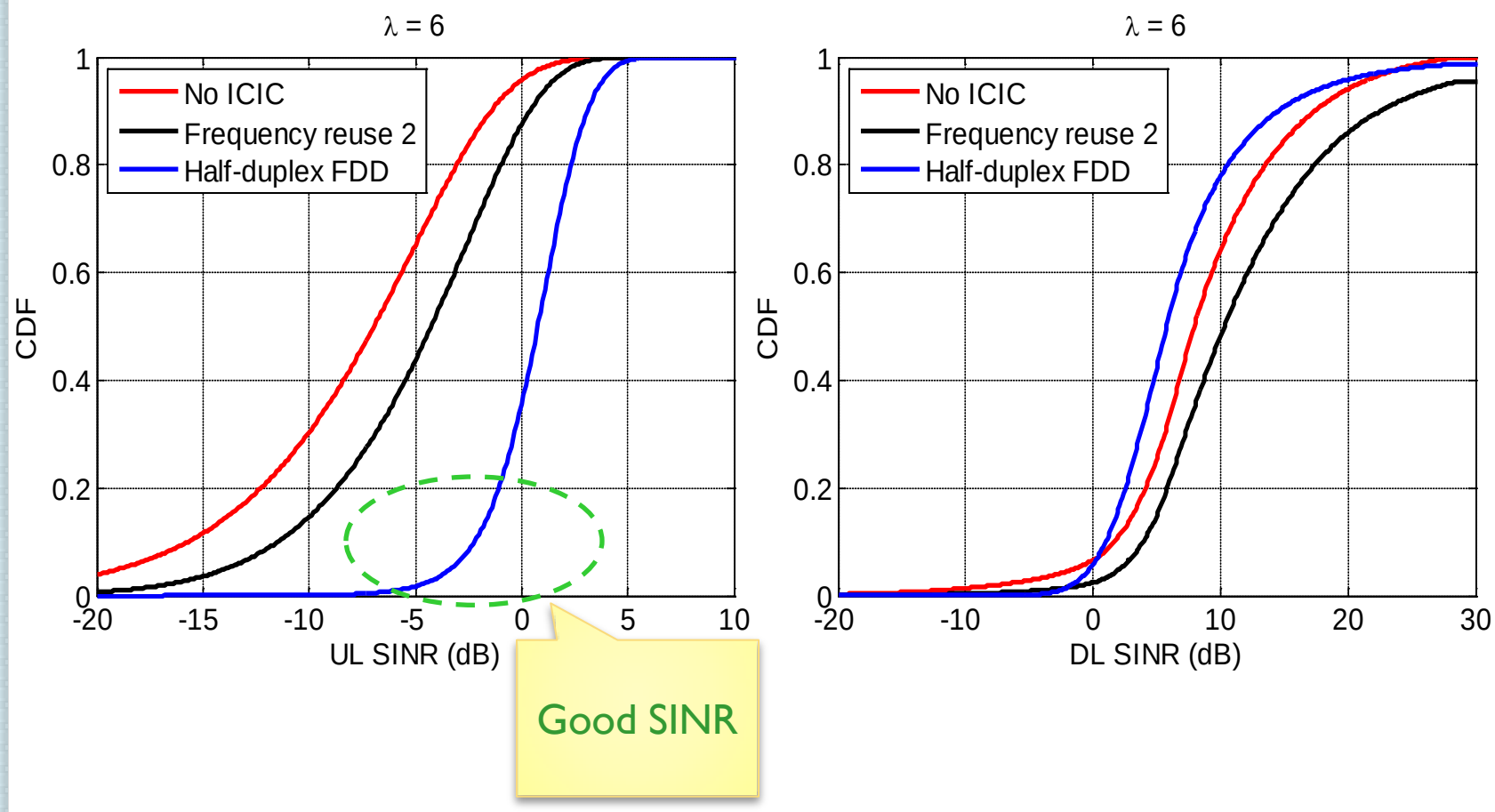
- DL user throughput comparison




  - DL user throughput is degraded significantly by using DL OLPC
  - Dynamic TDD without any interference coordination is problematic in either fixed DL or DL OLPC case!

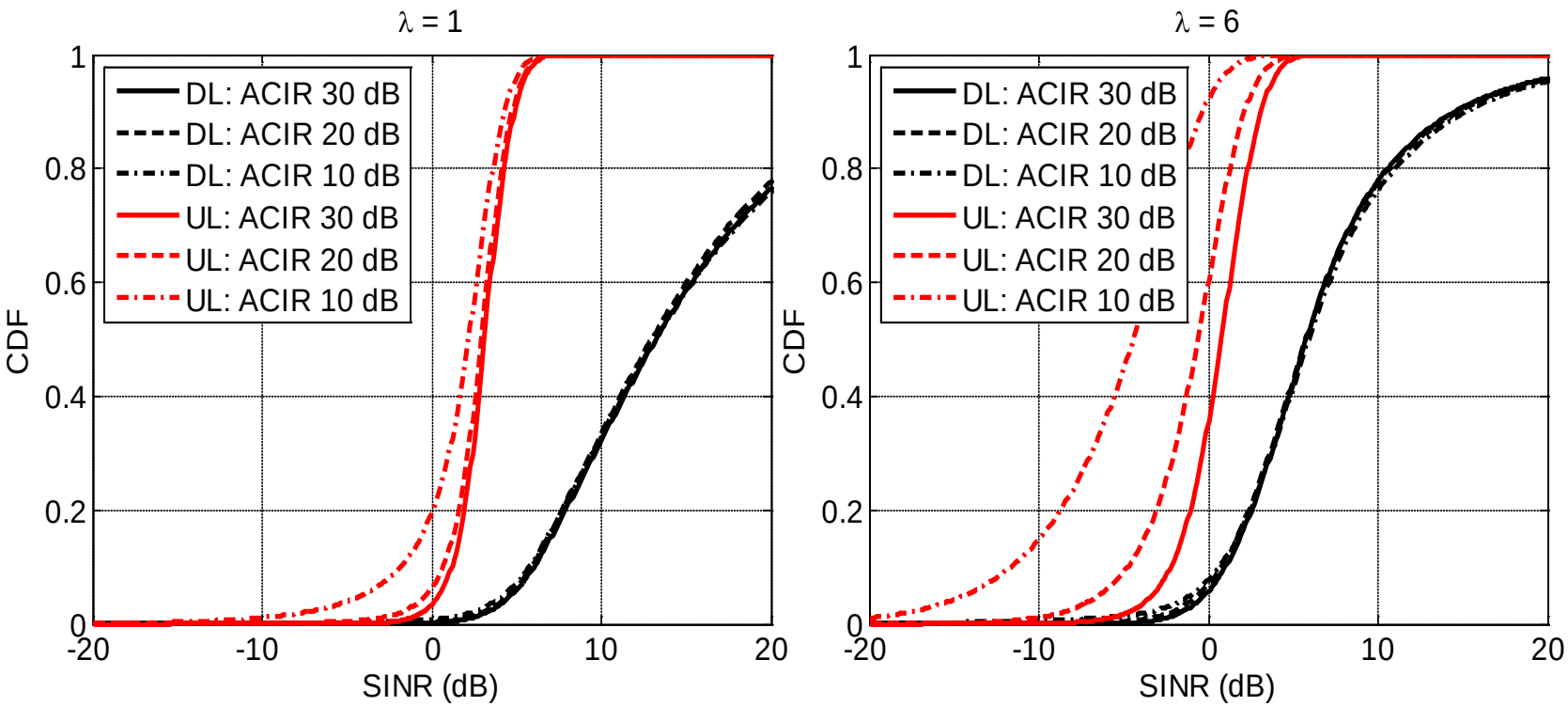
# Dynamic TDD with ICIC

- SINR comparison
  - Half-duplex FDD provides very good UL SINR even with fixed DL



# Dynamic TDD with ICIC (cont.)

- Effect of ACIR
  - Effect on DL SINR is almost negligible under different traffic loads
  - As ACIR decreases, UL SINR is degraded, especially for high traffic load



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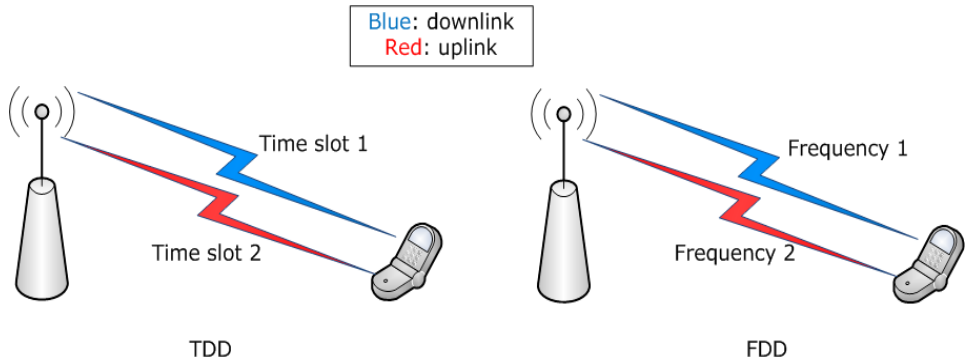
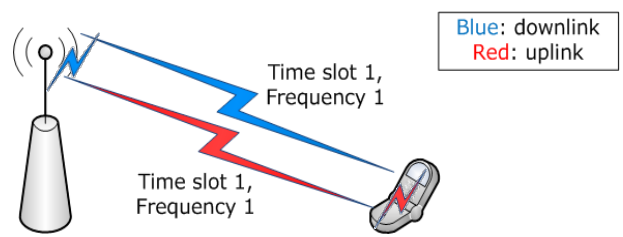
# Motivation

- Current wireless radio




Orthogonal transmission incurs penalty on spectrum efficiency!

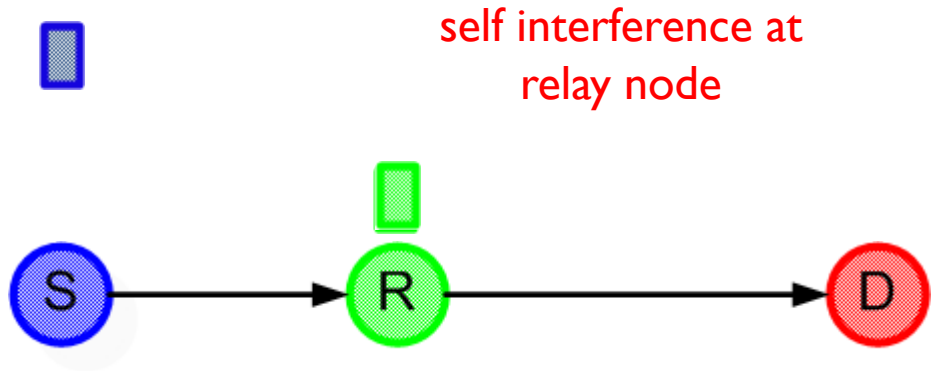
- Full-duplex radio



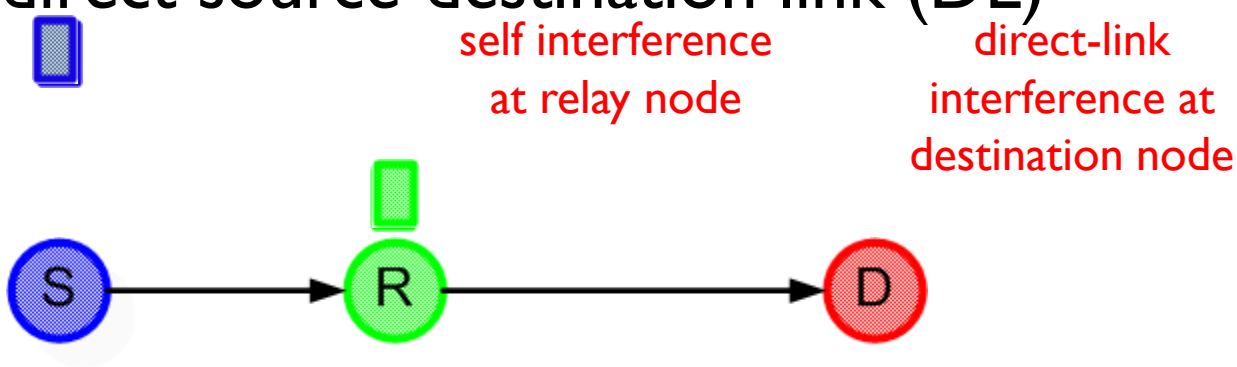

- Self interference
  - Antenna cancellation [Choi-Jain'10]
  - Analog/digital cancellation [Hua-Liang'12] [Li-Murch'12]

# Full-duplex relaying operation

- Without direct source-destination link (NDL)



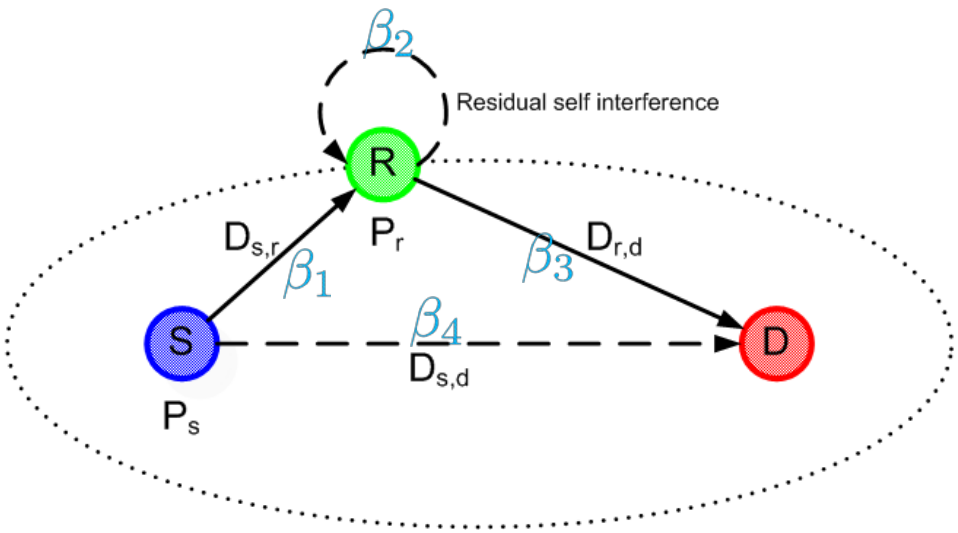

- With direct source-destination link (DL)




- Question: how to allocate transmit power and select relay location?

# System model

- Two-hop full-duplex DF relaying system




$$\beta_1 = G \cdot D_{s,r}^{-\nu}$$

$$\beta_3 = G \cdot D_{r,d}^{-\nu}$$

$$\beta_4 = G \cdot D_{s,d}^{-\nu}$$

$$\gamma_s = \frac{P_s}{\mathcal{N}_0}, \gamma_r = \frac{P_r}{\mathcal{N}_0}$$

$\beta_2$ : self interference level

The outage probability can be derived as [Kwon-Lim'10]:

$$\boxed{P_{outage} = 1 - \frac{1}{\left(1 + \eta \frac{\beta_2}{\beta_1} \frac{\gamma_r}{\gamma_s}\right)\left(1 + \eta \frac{\beta_4}{\beta_3} \frac{\gamma_s}{\gamma_r}\right)} \times \exp\left[-\eta\left(\frac{1}{\beta_1 \gamma_s} + \frac{1}{\beta_3 \gamma_r}\right)\right]}$$

# Transmit power optimization

- Problem formulation
  - Find the optimal transmit SNRs which provide the minimum outage probability, given any relay node location

$$\begin{aligned} \underset{\gamma_s, \gamma_r}{\text{minimize}} \quad & P_{outage}(\gamma_s, \gamma_r) \\ \text{subject to} \quad & \gamma_s > 0, \ \gamma_r > 0 \\ & \gamma_s + \gamma_r = \gamma \ \text{(with sum constraint)} \end{aligned}$$

- Four scenarios considered
  - With/without sum power constraint
  - With direct source-destination link (DL)
  - Without direct source-destination link (NDL)

# Optimal solution (w/o sum constr.)

- Proposition 1: *For relaying systems without direct source-destination link (NDL):*
  - $P_{outage}$ *is a monotonically decreasing function of source SNR* $\gamma_s$
  - *For a given source SNR* $\gamma_s$ *, the optimal relay SNR is given by*

$$\gamma_r^o = \frac{\eta}{2\beta_3} + \sqrt{\frac{\eta^2}{4\beta_3^2} + \frac{\beta_1\gamma_s}{\beta_2\beta_3}}$$

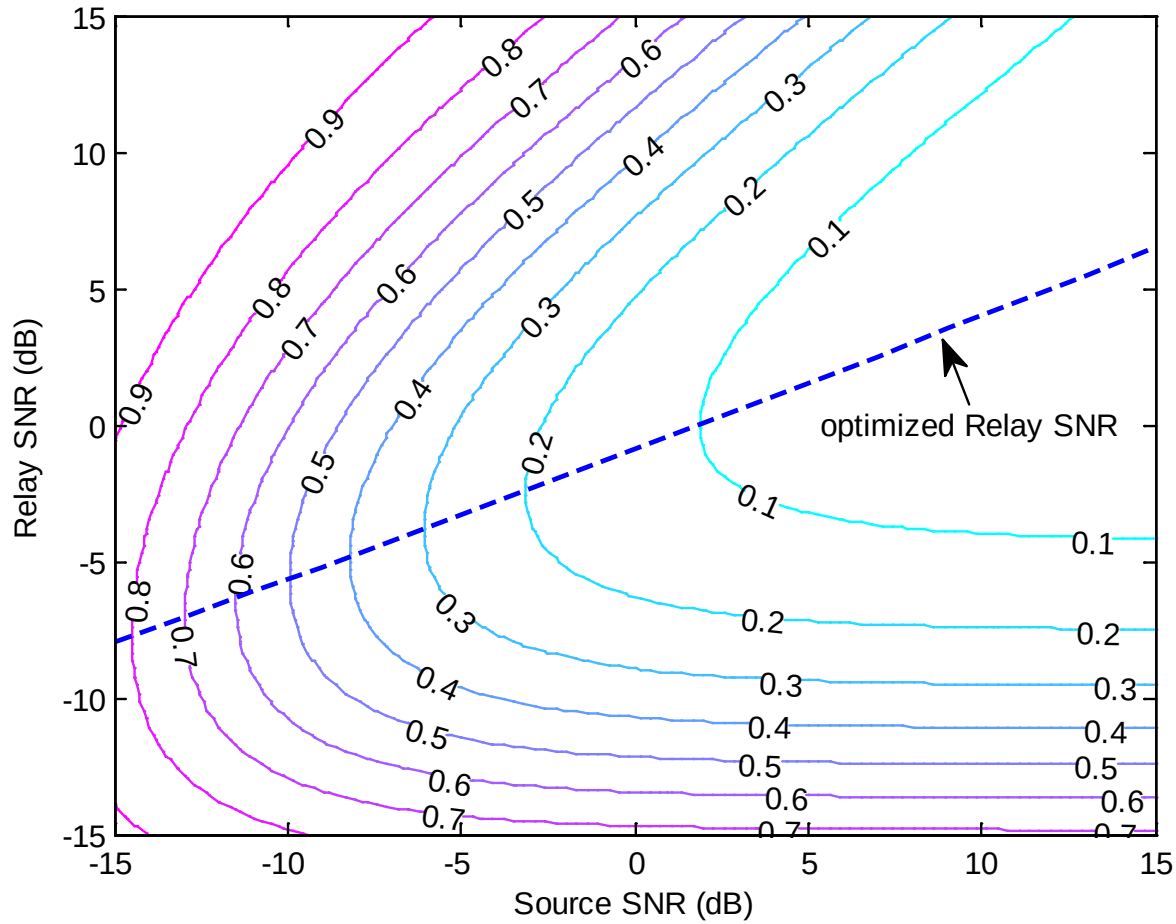
- Proposition 2: *For relaying systems with direct link (DL):*
  - *For a given source SNR* $\gamma_s$ *, the optimal relay SNR is found by solving*

$$\frac{\beta_4}{\beta_3}\gamma_s^2 = \frac{\beta_2}{\beta_1}\gamma_r^2 + \frac{\gamma_r}{\beta_1}\left(1 + \eta^2\frac{\beta_2\beta_4}{\beta_1\beta_3} + \eta\frac{\beta_2}{\beta_1}\frac{\gamma_r}{\gamma_s} + \eta\frac{\beta_4}{\beta_3}\frac{\gamma_s}{\gamma_r}\right)$$

  - *For a given relay SNR* $\gamma_r$ *, the optimal source SNR is found by solving*

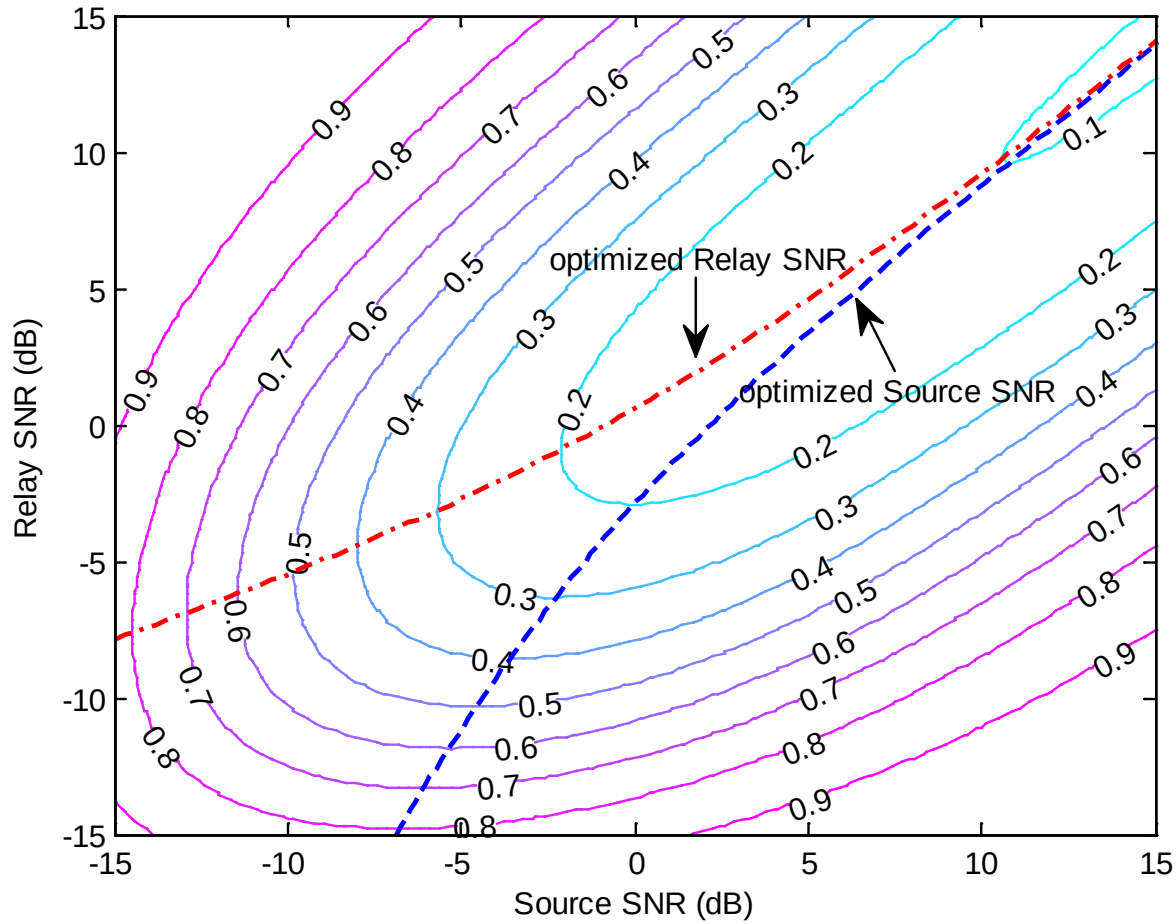
$$\frac{\beta_2}{\beta_1}\gamma_r^2 = \frac{\beta_4}{\beta_3}\gamma_s^2 + \frac{\gamma_s}{\beta_3}\left(1 + \eta^2\frac{\beta_2\beta_4}{\beta_1\beta_3} + \eta\frac{\beta_2}{\beta_1}\frac{\gamma_r}{\gamma_s} + \eta\frac{\beta_4}{\beta_3}\frac{\gamma_s}{\gamma_r}\right)$$

# Numerical results (w/o constr. + NDL)




- ✓ The outage prob. decreases monotonically as the source SNR increases
- ✓ Given any source SNR, there exists a unique optimal relay SNR

# Numerical results (w/o constr. + DL)




- ✓ For a given SNR on one node, there is a optimal SNR on the other node
- ✓ Two optimal curves tend to merge at high transmit SNR

# Optimal solution (with sum constr.)

- Proposition 3: *For relaying systems without direct source-destination link (NDL):*
  - *The unique optimal transmit SNR ratio* $(\rho_\gamma^o = \gamma_s^o/\gamma_r^o)$ *between the source and relay can be found by solving*

$$\beta_1^2\rho_\gamma^3 + \eta\beta_1\beta_2\rho_\gamma^2 - \beta_1\beta_3(1+\beta_2\gamma)\rho_\gamma - \eta\beta_2\beta_3 = 0,\ \rho_\gamma > 0$$

- Proposition 4: *For relaying systems with direct link (DL):*
  - *The unique optimal transmit SNR ratio between the source and relay can be found by solving*

$$\frac{\beta_1}{\beta_3}\rho_\gamma^2 = \frac{\beta_2\gamma + C}{\beta_4\gamma + C},\ \text{where } C = 1 + \eta^2\frac{\beta_2\beta_4}{\beta_1\beta_3} + \eta\frac{\beta_2}{\beta_1}\frac{1}{\rho_\gamma} + \eta\frac{\beta_4}{\beta_3}\rho_\gamma$$

NDL is a special case of DL with $\beta_4 = 0$

# Discussions on NDL results

- General result

$$\beta_1^2\rho_\gamma^3 + \eta\beta_1\beta_2\rho_\gamma^2 - \beta_1\beta_3(1+\beta_2\gamma)\rho_\gamma - \eta\beta_2\beta_3 = 0,\ \rho_\gamma > 0$$

- Without self interference (ideal case)

$$\beta_2 = 0 \Rightarrow \rho_\gamma^o = \frac{\gamma_s^o}{\gamma_r^o} = \sqrt{\frac{\beta_3}{\beta_1}}$$

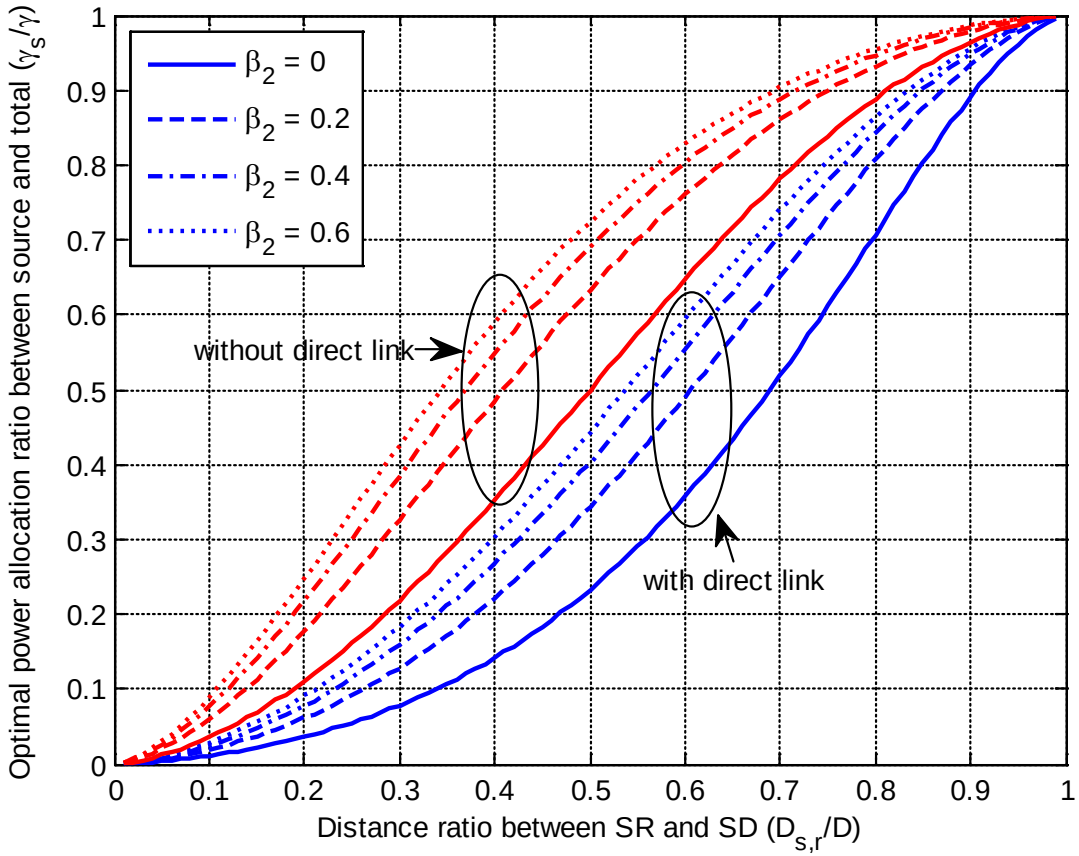
- Perturbation analysis of $\beta_2$ $(\beta_2 \to 0)$

Let $\beta_2 = \epsilon,\ \rho_\gamma = \rho_0 + \epsilon\rho_1$, and plug into the optimal solution

$$\Rightarrow \begin{cases} \beta_1\rho_0(\beta_1\rho_0^2 - \beta_3) = 0 \\ 3\beta_1^2\rho_0^2\rho_1 - \beta_1\beta_3(\rho_1 + \rho_0\gamma) + \eta(\beta_1\rho_0^2 - \beta_3) = 0 \end{cases}$$

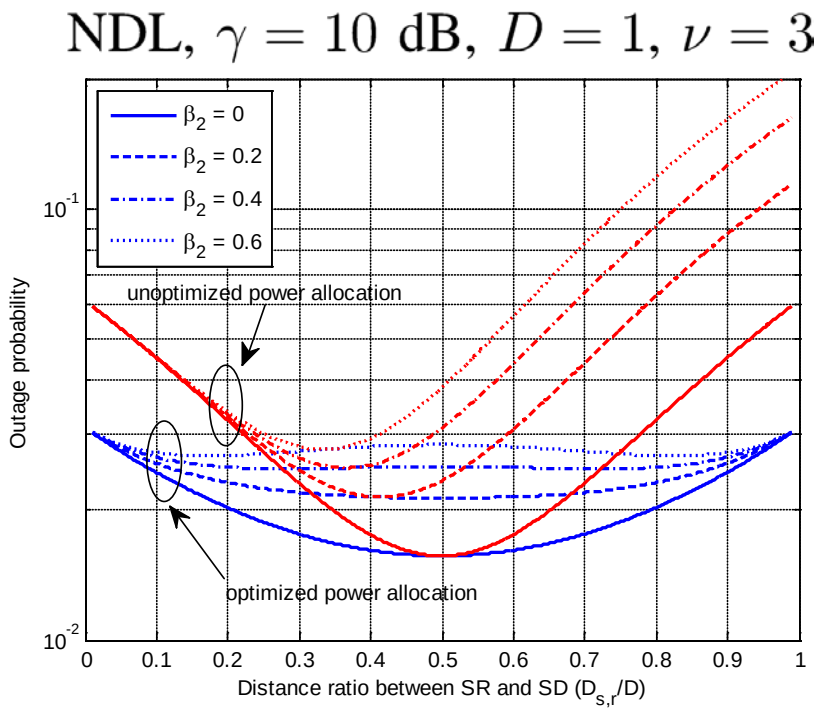
$$\Rightarrow \begin{cases} \rho_0 = \sqrt{\frac{\beta_3}{\beta_1}} \\ \rho_1 = \frac{\gamma}{2}\rho_0 \end{cases} \quad \Rightarrow \boxed{\rho_\gamma = \sqrt{\frac{\beta_3}{\beta_1}}(1 + \frac{\gamma}{2}\beta_2)}$$

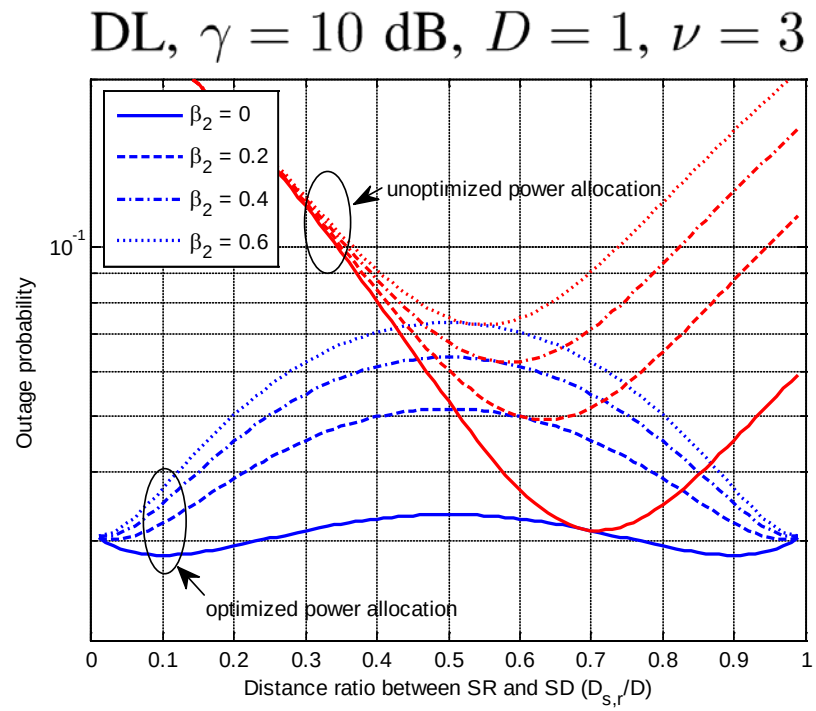
# Opt. power allocation (with constr.)




- ✓ As relay moves towards destination, the optimal source TX power increases
- ✓ As self interference increases, the optimal source TX power increases
- ✓ The optimal source TX power for DL is lower than that for NDL systems

# Outage probability gain (with constr.)




- ✓ Uniform (un-optimized) power allocation between the source and relay is adopted for comparison
- ✓ Optimized transmit power outperforms the un-optimized one universally
- ✓ The source-relay and relay-destination link are more balanced with power optimization at different relay locations

# Relay location optimization

- Problem formulation
  - Find the optimal relay location which provides the minimum outage probability, given any transmit SNRs at the source and relay nodes

$$\begin{aligned} \underset{D_{s,r},D_{r,d}}{\text{minimize}} \quad & P_{outage}(D_{s,r}, D_{r,d}) \\ \text{subject to} \quad & D_{s,r} > 0,\ D_{r,d} > 0 \\ & D_{s,r} + D_{r,d} = D,\ D \geq D_{s,d}. \end{aligned}$$

- Two scenarios
  - With direct source-destination link
  - Without direct source-destination link

# Optimal solution

- Proposition 5: *For relaying systems without direct source-destination link (NDL):*
  - *The unique optimal relay location* $(\rho_D^o = \frac{D_{s,r}^o}{D})$ *can be found by solving*

$$\left(\frac{1-\rho_D}{\rho_D}\right)^{\nu-1} = \frac{\gamma_r}{\gamma_s} + \frac{\beta_2\gamma_r^2}{\gamma_s + \eta\beta_2\gamma_r(\rho_D D)^\nu}, \; 0 < \rho_D < 1$$

- Proposition 6: *For relaying systems with direct link (DL):*
  - *The unique optimal relay location can be found by solving*

$$\left(\frac{1-\rho_D}{\rho_D}\right)^{\nu-1} = \frac{\frac{1}{\gamma_s} + \frac{\beta_2\gamma_r}{\gamma_s+\eta\beta_2\gamma_r(\rho_D D)^\nu}}{\frac{1}{\gamma_r} + \frac{\beta_4\gamma_s}{\gamma_r+\eta\beta_4\gamma_s((1-\rho_D)D)^\nu}}, \; 0 < \rho_D < 1$$

NDL is a special case of DL with $\beta_4 = 0$

# Discussions on NDL results

- General result

$$\left(\frac{1-\rho_D}{\rho_D}\right)^{\nu-1} = \frac{\gamma_r}{\gamma_s} + \frac{\beta_2\gamma_r^2}{\gamma_s + \eta\beta_2\gamma_r(\rho_D D)^{\nu}},\ 0 < \rho_D < 1$$

- Without self interference (ideal case)

$$\beta_2 = 0 \Rightarrow \frac{D_{s,r}}{D_{r,d}} = \left(\frac{\gamma_s}{\gamma_r}\right)^{\frac{1}{\nu-1}}$$

- Perturbation analysis of $\beta_2$

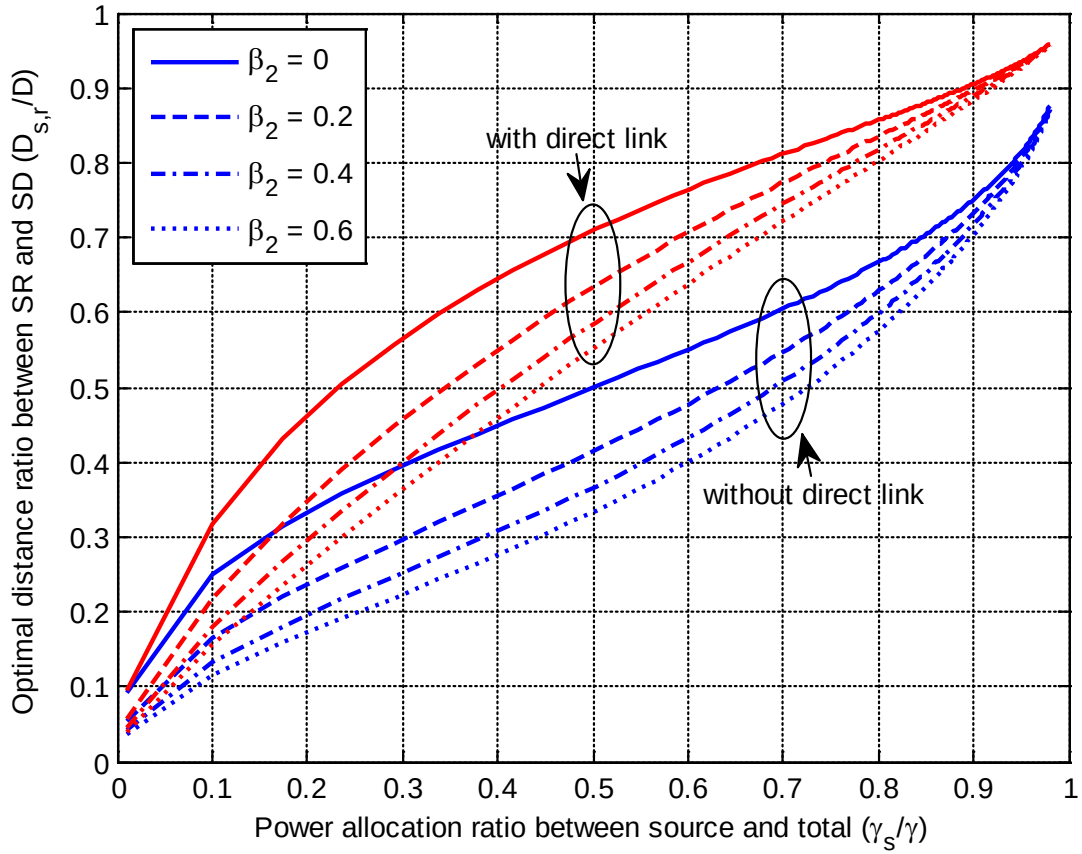
$$\beta_2 \to 0$$

$$\Rightarrow \frac{\gamma_s}{\beta_2} \gg \eta\gamma_r(\rho_D D)^{\nu}$$

$$\Rightarrow \left(\frac{1-\rho_D}{\rho_D}\right)^{\nu-1} = \frac{\gamma_r}{\gamma_s}(1+\beta_2\gamma_r)$$

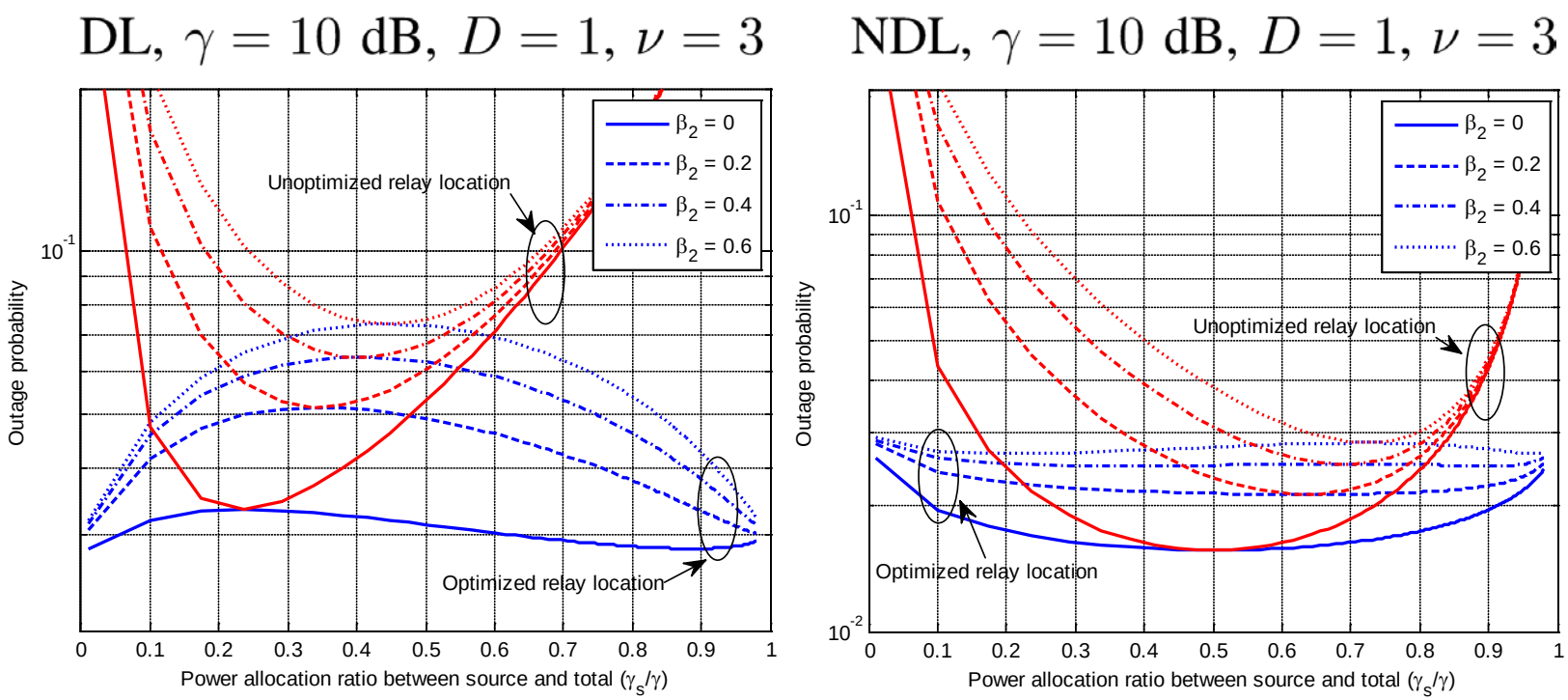
$$\Rightarrow \boxed{\rho_D^o = \frac{1}{1+\left[\frac{\gamma_r}{\gamma_s}(1+\beta_2\gamma_r)\right]^{\frac{1}{\nu-1}}}}$$

# Optimal relay location



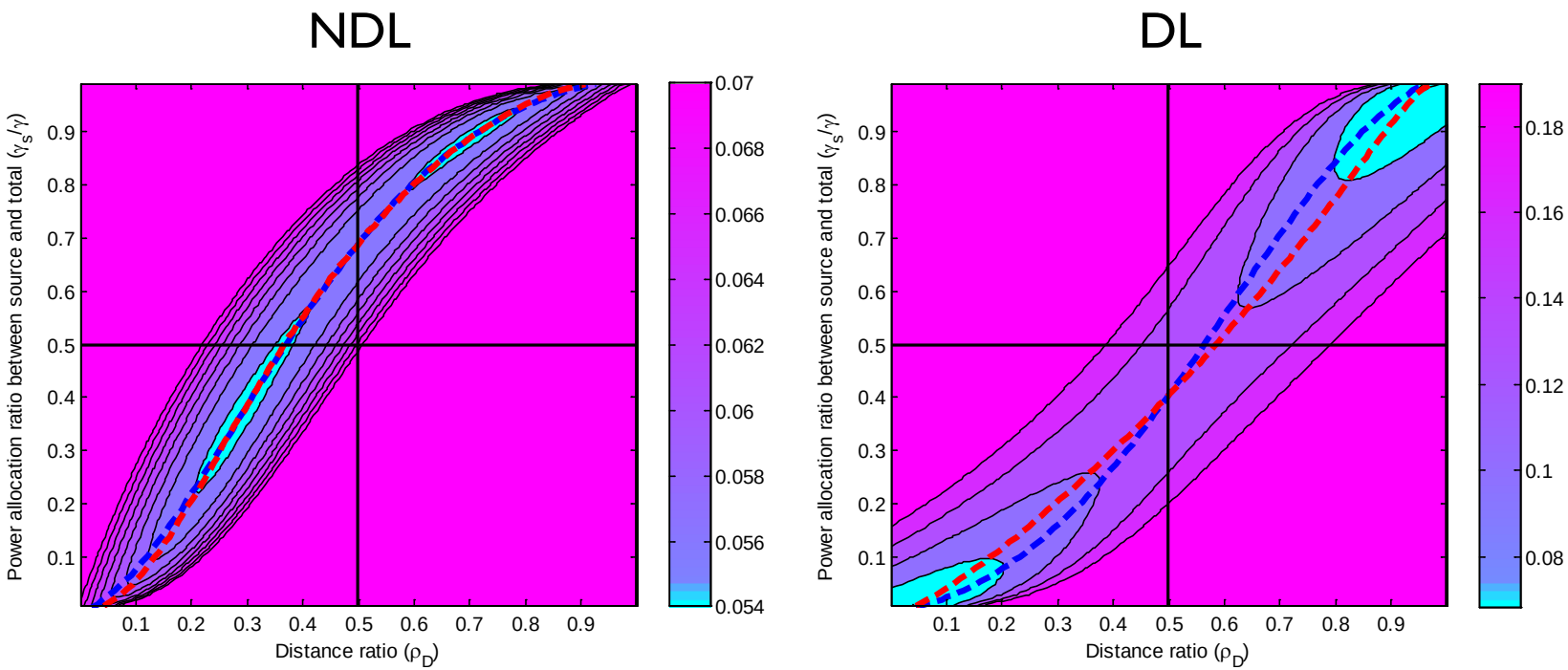

- ✓ As the source transmit power increases, the optimal relay moves to the destination
- ✓ As the self interference increases, the optimal relay moves towards the source
- ✓ The optimal relay for DL systems is closer to the destination compared to NDL

# Outage probability gain



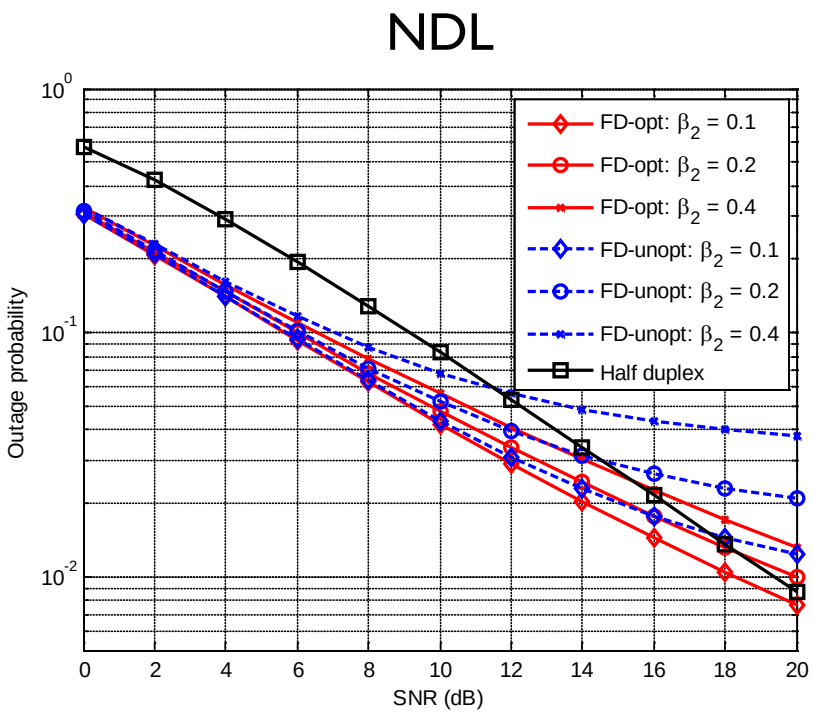

- ✓ Optimized relay location outperforms the un-optimized one universally
- ✓ The outage probability curves for the optimized ones are more flat
- ✓ The source-relay and relay-destination links are more balanced with location optimization

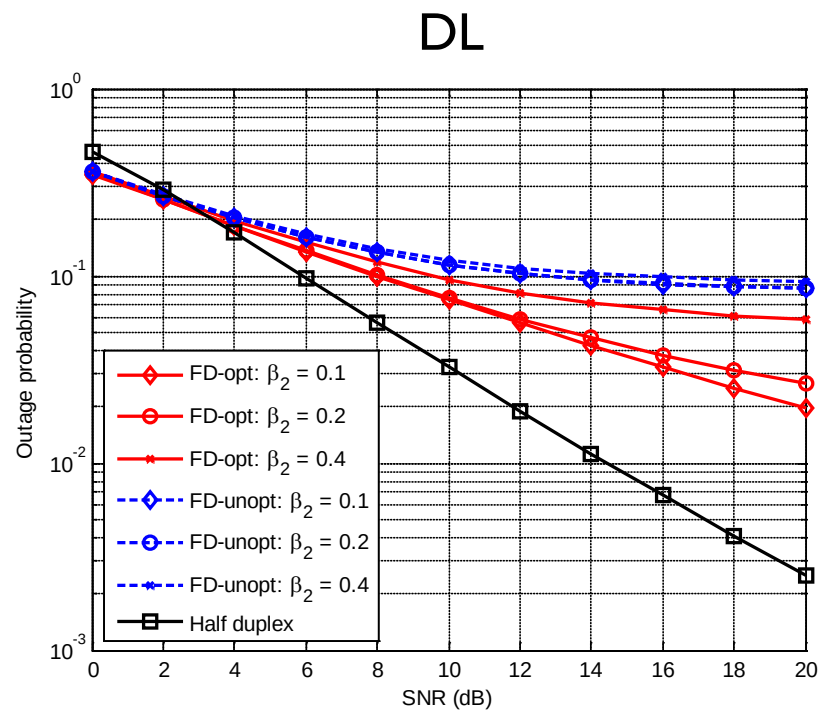
# Benefits of joint optimization




- ✓ Joint optimization can achieve global minimum outage performance
- ✓ Global minimum is not unique, can be achieved by locating the relay either closer to the source or closer to the destination, as long as proper power allocation is conducted

# Full-duplex vs. Half-duplex




- ✓ For NDL systems, full-duplex can achieve comparable outage performance to half-duplex even when the RSI level is high
- ✓ For DL systems, half-duplex outperforms full-duplex

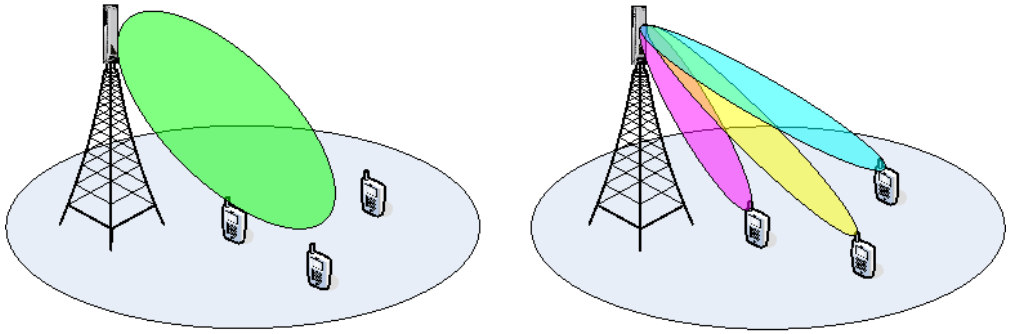
# Roadmap

- Introduction
- Dynamic TDD in Macro Cell Assisted Small Cell Architecture
  - System model
  - SINR distributions and numerical results
  - Half-duplex FDD-like radio resource assignment
  - System level simulations
- Full-Duplex Relaying Systems
  - Motivation
  - System model
  - Resource optimization
  - Numerical results
- Summary and Future Work

# Summary

- Spectrum efficiency enhancement is needed to support the explosive data traffic growth
- Problems in the evolution of future radio access
  - Dynamic TDD in macro-assisted small cell enhancement
    - Network modeling and performance analysis with stochastic geometry
    - Inter cell interference coordination method for dynamic TDD
    - System level simulations
  - Full-duplex relaying systems
    - Optimal resource allocation (transmit power, relay location)
    - Potential performance gain

# Future work

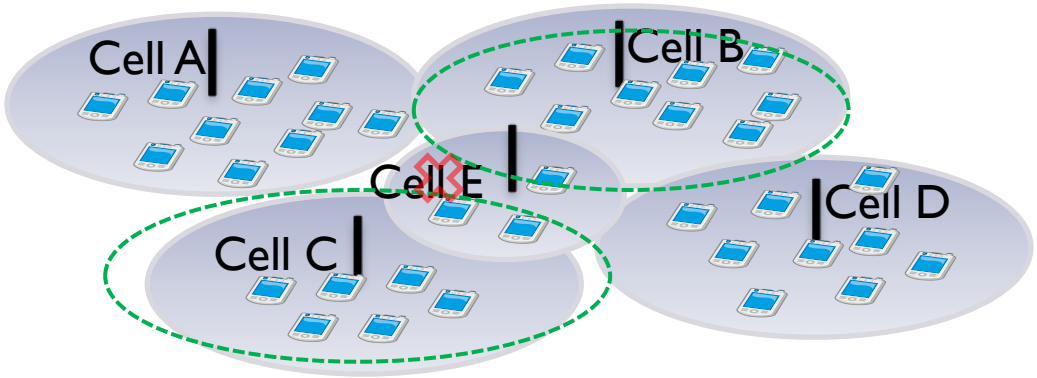


(a) Conventional 2D BF (b) 3D BF

- 3D beamforming
  - What?
    - Control the antenna radiation pattern dynamically in full dimensions
    - Vertical antenna pattern is usually fixed at conventional BSs
  - How?
    - The employment of active antenna systems (AAS) at BSs has been recently approved by 3GPP in 2011
    - Adaptively weighting the elements in a 2D or 3D AAS antenna array
      - ➢ Vertical sectorization/UE-specific 3D beamforming
  - Why?
    - Better cell range control and interference coordination
    - 3D dynamic beamforming is feasible in phantom cell architecture
  - <u>Capacity enhancement scheme</u>
  - <u>Traffic load balancing algorithms</u>

# Future work (cont.)

- Energy efficiency
  - With the high demand in data capacity also comes high energy consumption
  - Energy saving for green wireless communication systems is also of urgent importance
    - <u>Phase 1: Energy efficient cellular network planning</u>
      - Optimized network deployment strategies
    - <u>Phase 2: Energy efficient base station operation</u>
      - Traffic-aware dynamic cell zooming on/off (transmit power adjustment) and cell shaping (3D beamforming)



# Publications

[J1] **B. Yu**, L. Yang and C.-C. Chong, "Optimized Differential GFSK Demodulator," IEEE Transactions on Communications, vol. 59, no. 6, pp. 1497-1501, June 2011

[J2] X. Cheng, **B. Yu**, L. Yang, J. Zhang, G. Liu, Y. Wu, and L. Wan, "Communicating in the Real World: 3D MIMO," IEEE Wireless Communications Magazine, 2014 (accepted)

[J3] **B. Yu**, L. Yang, X. Cheng, and R. Cao, "Resource Optimization for Full-Duplex Decode-and-Forward Relaying," (in preparation)

[J4] **B. Yu**, L. Yang, H. Ishii, and S. Mukherjee, "Dynamic TDD Support in the Enhanced Local Are Architecture," (in preparation)

# Publications (cont.)


[C1] **B. Yu**, L. Yang and C.-C. Chong, "Optimized Differential Bluetooth Demodulator," in Proc. of IEEE Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, November 1-4, 2009.

[C2] **B. Yu**, L. Yang and C.-C. Chong, "Wireless ECG Monitoring over Bluetooth," in Proc. Of IEEE Wireless Communications & Networking Conference (WCNC), Sydney, Australia, April 18-21, 2010.

[C3] **B. Yu**, S. Mukherjee, H. Ishii and L. Yang, "Dynamic TDD Support in the LTE-B Enhanced Local Area Architecture," in Proc. of the 4th IEEE International Workshop on Heterogeneous and Small Cell Networks (HetSNets), Anaheim, CA, December 3-7, 2012.

[C4] **B. Yu**, H. Ishii and L. Yang, "System Level Performance Evaluation of Dynamic TDD and Interference Coordination in Enhanced Local Area Architecture," in Proc. of the 77th IEEE Vehicular Technology Conference (VTC-Spring), Dresden, Germany, June 2-5, 2013.

[C5] **B. Yu**, X. Cheng and L. Yang, "Energy Saving Analysis and Evaluation in the Enhanced Local Area Architecture," in Proc. of IEEE ICC 2013 International Workshop on Small Cell Wireless Networks (SmallNets), Budapest, Hungary, June 9-13, 2013.

[C6] **B. Yu**, L. Yang, X. Cheng, R. Cao, "Transmit Power Optimization for Full-Duplex Decode-and- Forward Relaying," in Proc. of IEEE Global Communications Conference (GLOBECOM), Atlanta, GA, December 9-13, 2013.

[C7] **B. Yu**, L. Yang, X. Cheng, and R. Cao, "Relay Location Optimization for Full-Duplex Decode-and-Forward Relaying," in Proc. of the IEEE Military Communications Conference (MILCOM), San Diego, CA, USA, November 18-20, 2013.

[C8] **B. Yu**, L. Yang, H. Ishii, and X. Cheng, "Load Balancing with Antenna Tilt Control in Enhanced Local Area Architecture," in Proc. of the 79th IEEE Vehicular Technology Conference (VTC-Spring), Seoul, Korea, May 18-21, 2014

# Questions?

*Thank you!*