Preliminary Performance Benefit of Single-Hop OFDMA Relay in IEEE802.16

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Gamini Senarath, Wen Tong, Peiying Zhu, Mo-Han Fong
Hang Zhang,Jianglei Ma, G.Q Wang and Dave Paranchych
Nortel
3500 Carling Avenue
Ottawa, Ontario, K2H 8E9

Voice:613-763-1315

Fax:613-765-7723

E-mail:wentong@nortel.com

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Purpose:

To present the benefit of Fixed Relay and Mesh to enhance IEEE802.16e performance.

Statement of Problem

Non-uniform coverage is a fundamental limit of adaptive coding modulation based IEEE802.16e-like shared channel systems.

- MS located away from base receive a lower data rate in average and, therefore, services cannot be offered uniformly across the coverage area.
  - For FUSC case
    - Downlink: 31% of users have less than 0 dB C/I.
    - Uplink: 42% users have less than 0 dB C/I.
- Highly unfair throughput distribution if Equal Time Slot Round Robin (ETSRR) or Proportional Fairness (PF) scheduling is used.
- Layer 2 scheduling can be done so as to deliver equal throughput (EQT) to all the users but has a severe penalty on capacity
  - For FUSC case
    - Downlink: 50% hit.
    - Uplink: 80% hit (i.e. reduces to 20%)
- In addition, users may experience different delays depending on their location because low rate users cannot empty their buffers as fast as the high rate users.

Different Relaying Configurations

- Fixed Relaying or Mobile Relaying
  - Limited to two hops vs using multiple hops
- Diversity options that can be applied
  - Use long-term trends → HHO
    - choose the best path (direct or relay)
    - track only LogNormal
  - Use selection diversity → FBSS for temporal fading gain
    - can be used only for nomadic and slow moving mobiles (< 20 km/hr).
    - Relay path vs direct path (also known as multi-hop diversity)
    - Relay path vs another relay path (also known as multi-route diversity)
  - Use Diversity Combining →MDHO
    - applicable to all the speeds
    - Relay path vs direct path (also known as multi-hop diversity)
    - Relay path vs another relay path (also known as multi-route diversity)
- Type of Antennas used
  - Omni vs directional antenna for relays
- Relay Types:
  - Analogue repetition
  - Decode and forward
  - Decode, store, schedule and forward

Relay vs. MDHO Solution

MDHO (Macro-Diversity Handoff)	**Fixed Relay**
Improves Coverage Significantly	Improves Coverage Significantly
Uses two time resource units (from two BSs) for MDHO users – can impact capacity	Uses two time resource units for MDHO users – but link gain is higher and this shown to improve capacity
Dynamic BS – BS co-ordination required (e.g. scheduling)	BS-BS co-ordination not required except for hand off.
Additional backhaul capacity required.	Not required unless FBSS is used.
Additional hardware resources needed at the BTSs for MDHO	Additional sites with power supply and additional relay units are required
Smooth make before break handover naturally provided.	Fast make before break handover solution is required for delay sensitive services
BS synchronization required	BS synchronization required. However, relays may be used to s[illegible]
Pilot measurements are used for BS and hand off decisions	Relays are required to provide Downlink pilots and IDs for relay to MS dynamic path loss measurements.

Simulation Assumptions/Parameters

- **Relay antenna pattern and placement**
  - Relay Antenna to BS: (1) Omni or (2) 60 degree antenna facing BS
  - Relay Antenna to MS: Omni_directional antennas
  - Relay Placement:
    - 3 relay per sector, d meters away from BS
      - d = k* BS_to_BS distance (i.e. 3 * cell_radius)
    - d meter away from the base
- **Tx Power, Path loss and shadowing**
  - Beam Tx power = 15 watts (i.e. 41.76 dBm = 60.2 dBm (FCC EIRP limit) – 1.5 dB (MTS HLD margin) – 18.76 dB (Antenna Gain)).
  - Relay Tx power is 3 watts, MS max. Tx. power = 600 mw.
  - Base Height = 34 m; Relay Height = 12.5 m (above roof top) and 4 m (below roof-top).
  - **Base to Relay path loss:** 802.16 Type C
  - **Relay to MS path loss: See later chart**
  - **Shadowing:** BM – 10 dB, uncorrelated for initial results,
    - RM: 4 dB for above roof top model
  - T**emporal fading is not modeled, shadowing is modeled.**
    - This means average C/I is used to evaluate data rate..

Relay and MDHO Modeling

– **Simplest in-band OFDM/TDM relay mode**

- **Downlink:**
  - BS to MS time slot : Interference at MS only from BSs
  - BS to Relay time slot : Interference at Relay only from BSs
  - Relay to MS time slot : Interference at MS only from Relays
- **Uplink:**
  - MS to base or MS to Relay time slot :

    (the design can be such that base or relay receive in separate time slots across the network or both base and relay can receive in the same time slot independent of the other bases/relays)
  - Relay to Base time slot

– **2-way MDHO with a 3 dB threshold & a simple MDHO gain evaluation:**

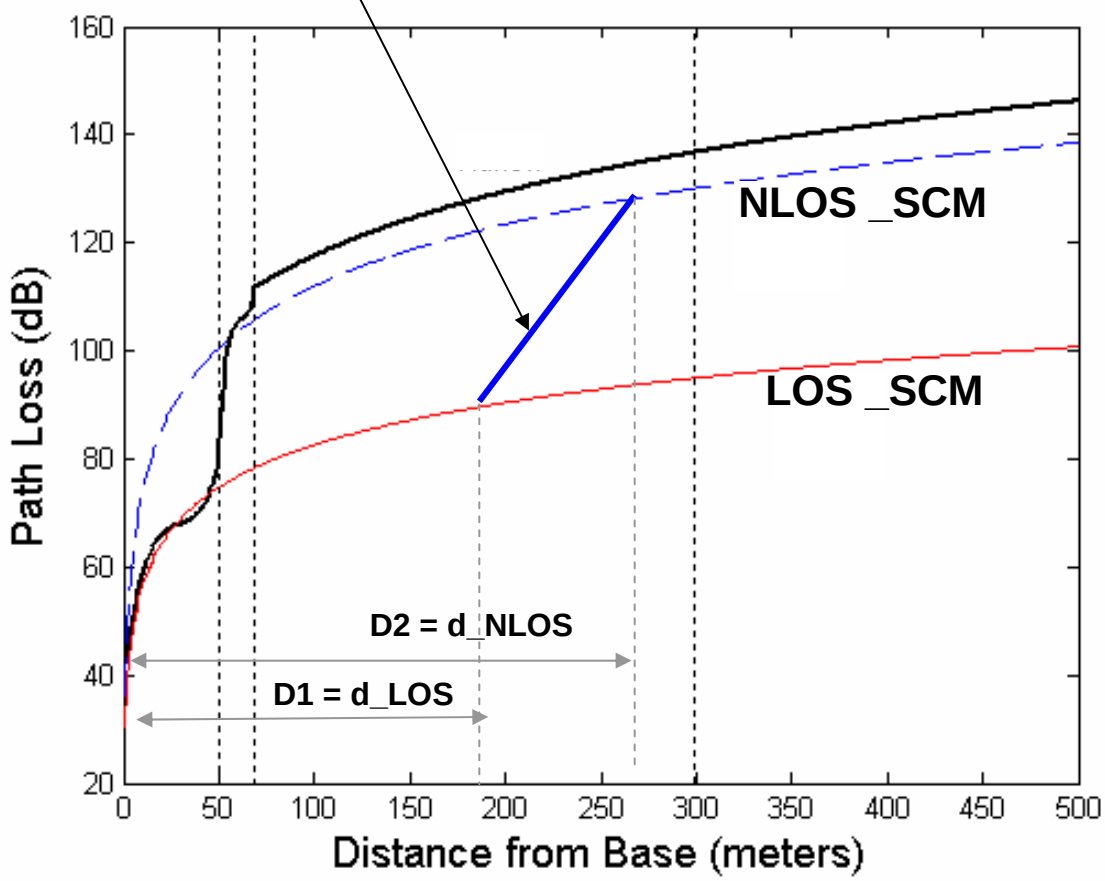
- **For DL MDHO**

  C/I = (C1 + C2) / (C3 + C4 + … + Cn)
- **For UL MDHO**

  C/I = (C1/C2+C3+..Cn) + (C2/C1+C3+C4+..Cn) ;

Generic Model Path Loss Model of Relay to MS

Generic Model uses SCM model when d < d1 and d > d2.
Uses linear Interpolation for Transition Period.

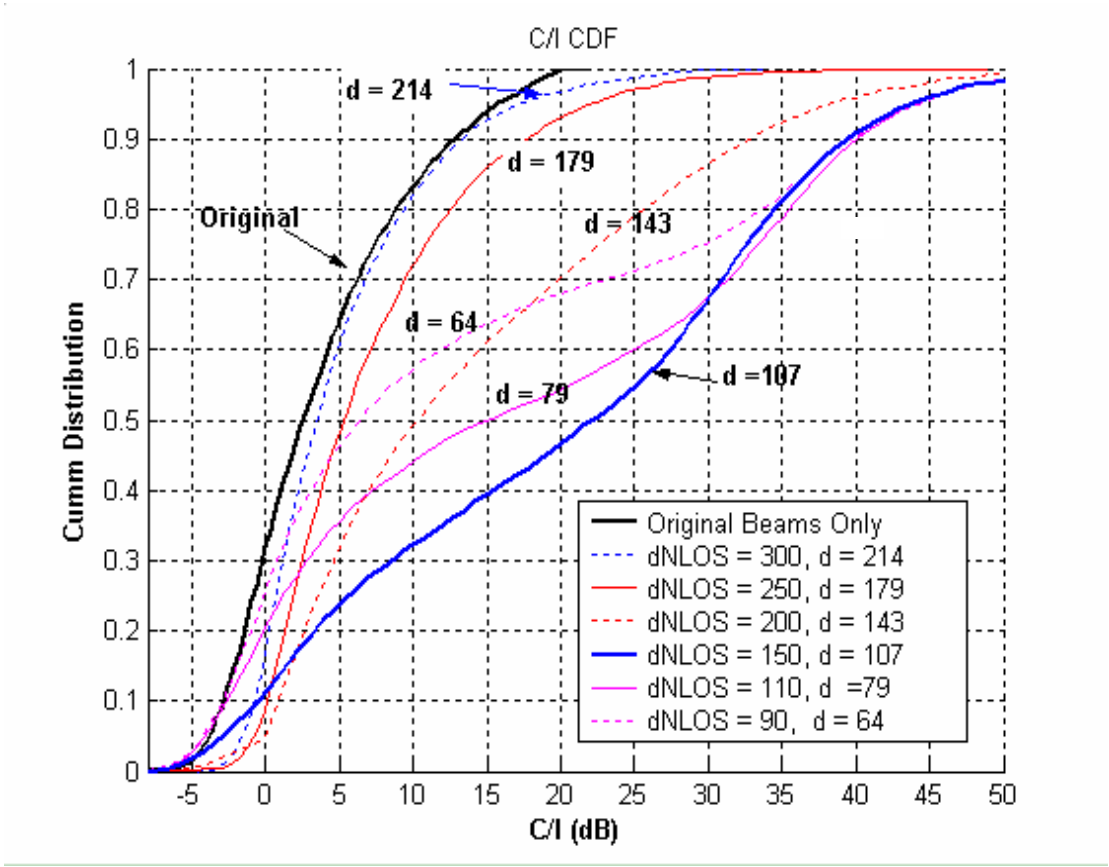


Relay Positioning for Optimum Coverage

- **Relay path loss models have a LOS component and a NLOS component which can be used for effective isolation among relays in relay position planning.**
- **Relay height impacts LOS distance of the relay and relay path loss model.**
- **The following parameters may be carefully selected to provide best coverage**
    - Base to relay distance (d_r),
    - LOS distance (d_los) and NLOS distance (d_Nlos) of the relay
        - if this is controllable, i.e., by changing relay height
    - Number of relays (Nr)
  - Minimize gaps which are not covered by the bases
  - Minimize overlapping of relay coverage area

Optimization of Relay Positioning

CDF Curves for Relay only case



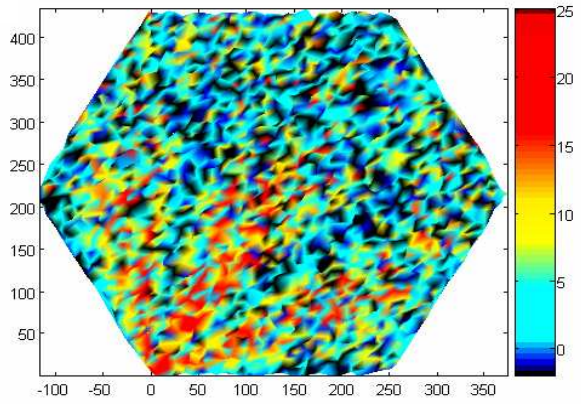
- **General trends are similar to case with no shadowing.**
- **For large d values, curves with and without shadowing are similar.**
- **For small d values, a small difference observed in the middle and top sections of the CDF when shadowing is applied**

Coverage Comparison

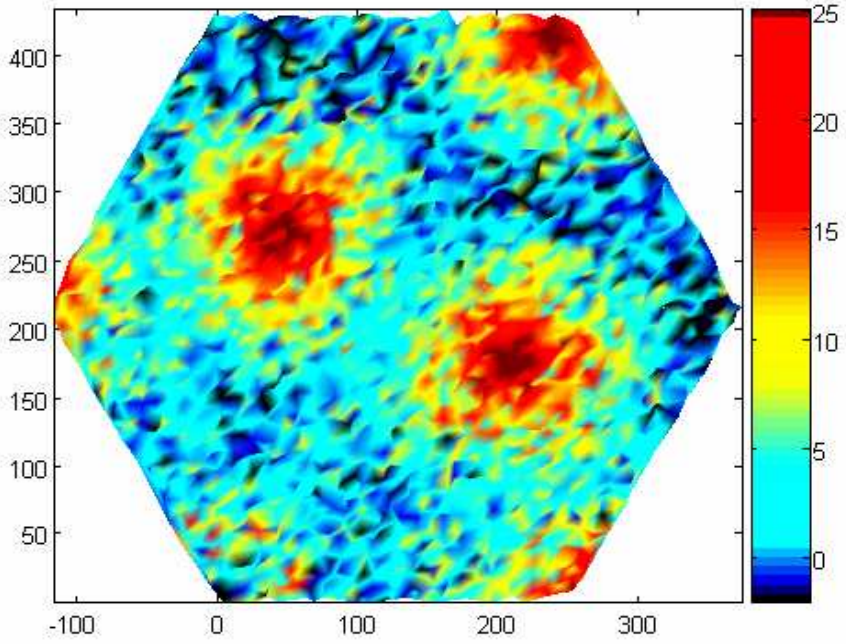
r = 275 m, k = 0.367

Percentage of coverage holes (black and dark blue) has been reduced significantly.

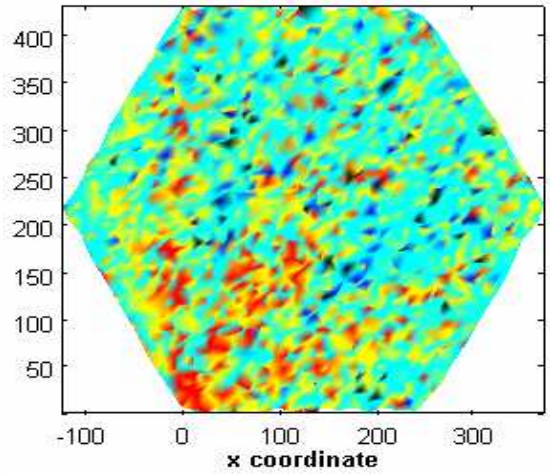
AAS(SDMA)



Relay Only



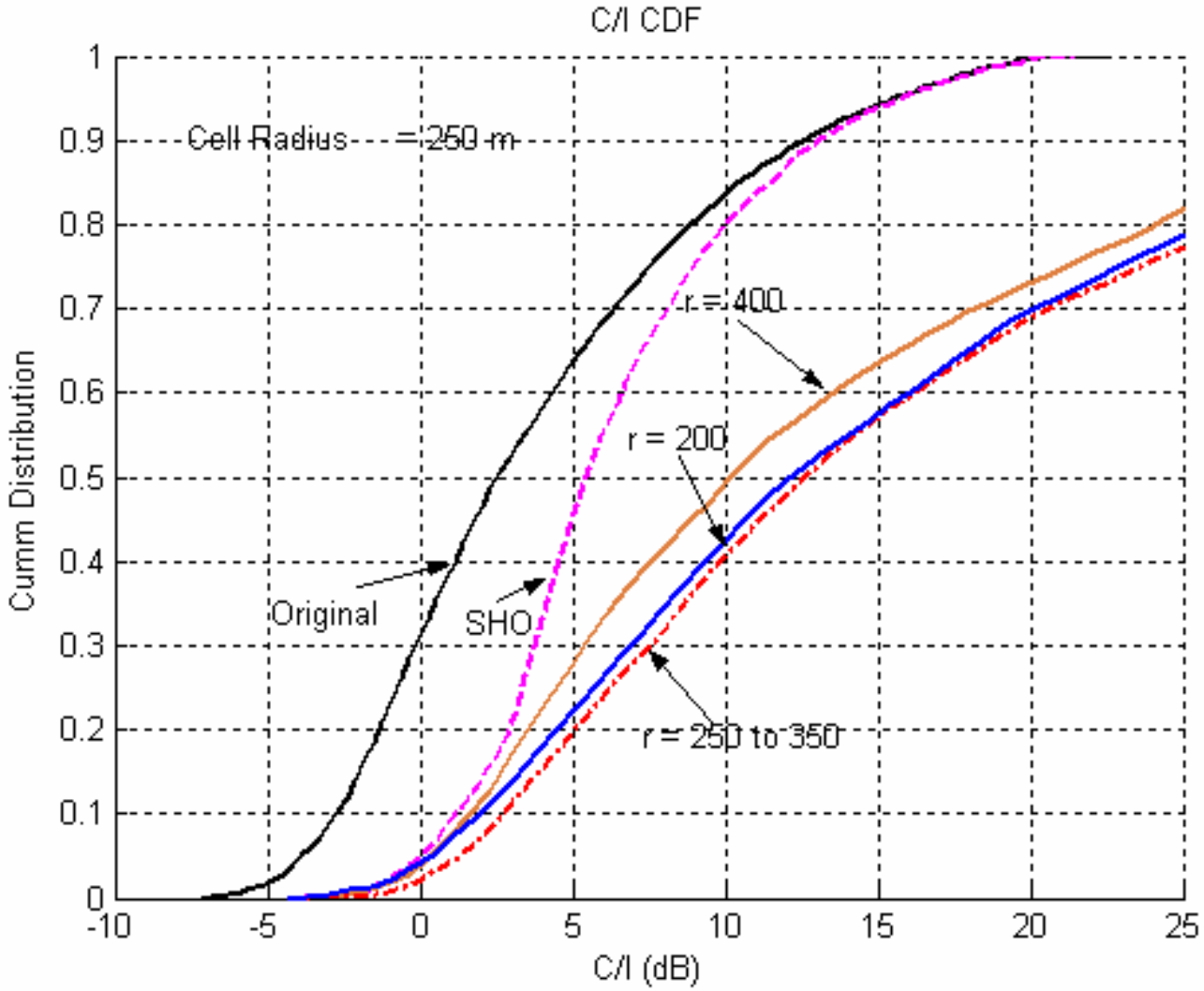
SDMA+MDHO



- **MDHO reduces percentage of coverage holes (black and dark blue) significantly. The improvement is seen in lower C/I areas and at the cell edge. Relays provide higher C/I gains even at the cell edge (previous chart).**
- **Both relay and MDHO uses more time slots to get this improvement. 2-way MDHO use 2 time slots. Relay may not need 2 time slots as base to relay can be sent at a higher AMC level.**

Coverage Impact from Relay to BS Distance

- Relay in the beam boundary (Edge Relay)

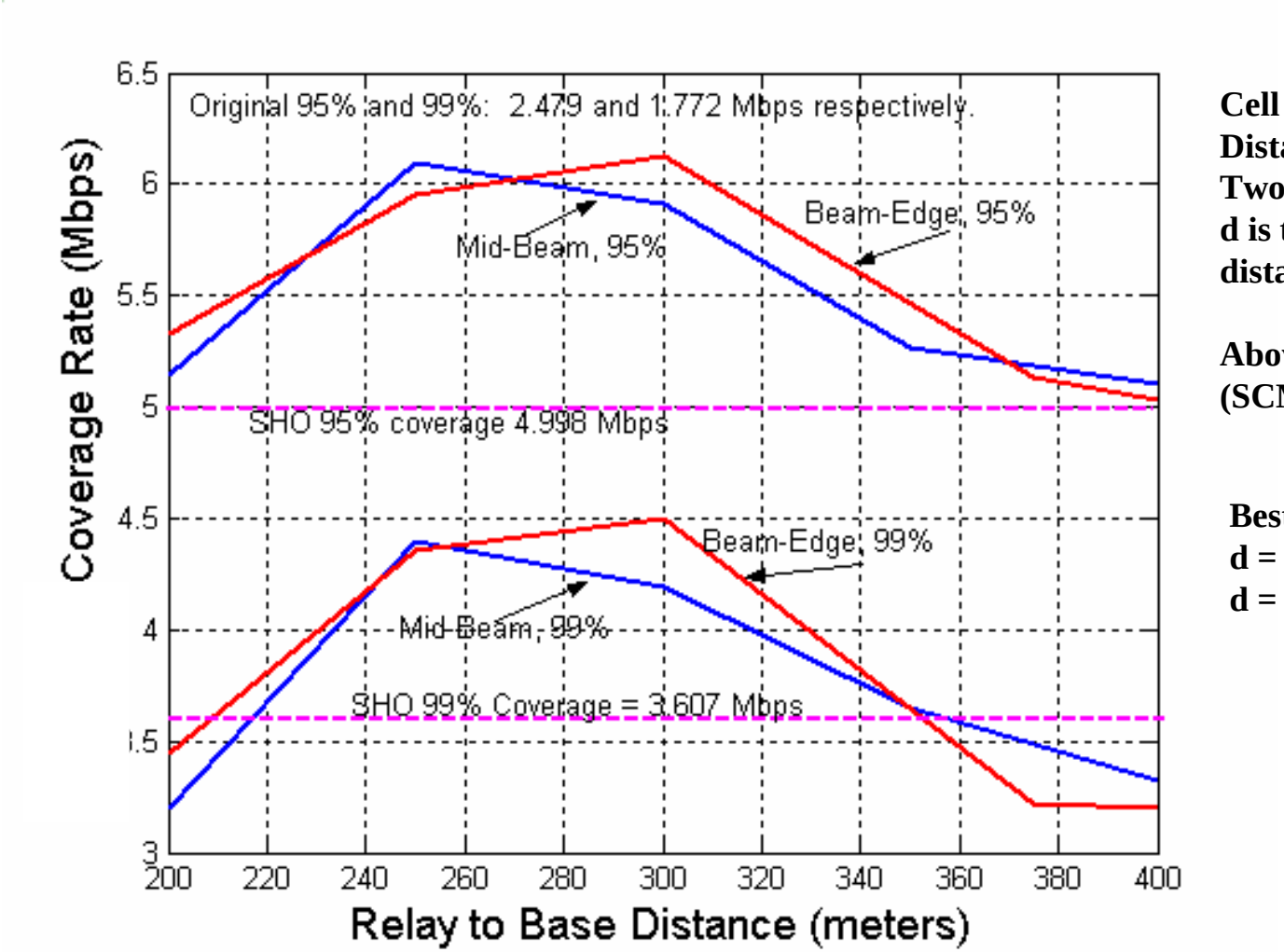


Cell Radius = 250 m
BS to BS Distance = 750 m
Edge Relay, PM3
d1 = 50 m, d2 = 70 m

Best Relay Position
r = 250 to 350 m

Coverage Comparison

(Relay at the middle vs Relay at the Edge)



Cell Radius = 250 m
Distance between Two BTSs = 750 m
d is the relay to base distance.

Above Roof Top Model (SCM) is used.

Best Position
d = 300 m for Edge Relays
d = 250 for Center Relays

Observations

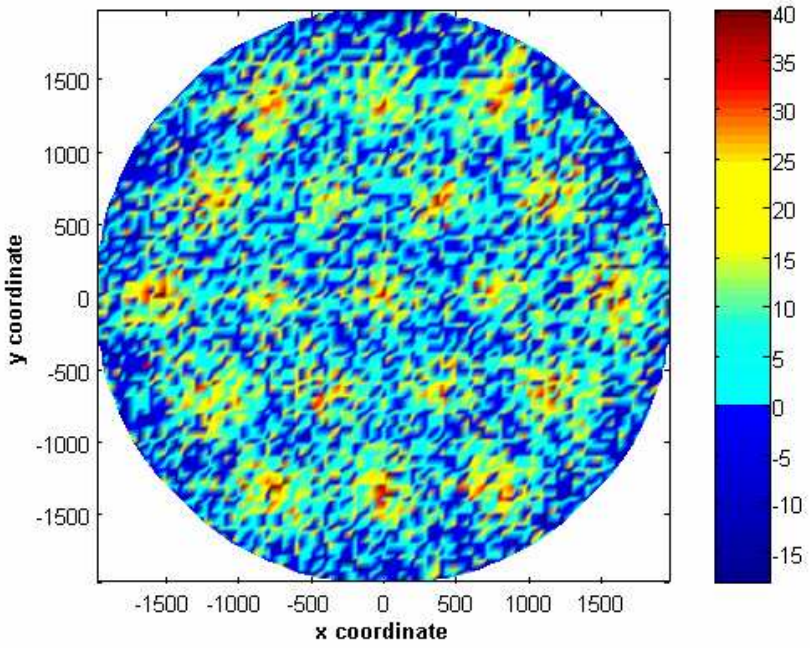
- **Impact of Shadowing:**
  - For large d (relay NLOS distance) values, curves with and without shadowing are similar. For small d values, a small difference observed in the middle and top sections of the CDF when shadowing is applied
  - 99% coverage increases by up to 0.3 dB when shadowing is applied
- **The LOS distance(d1) and NLOS distance (d2) significantly impact the performance.**
  - There is an optimum LOS distance: from 79 m to 200 m
  - Results agree well with the previous relay geometry analysis which indicated the existence of an optimum relay coverage distance of 100 m
  - Relay coverage is higher than MDHO for larger d_LOS values. For smaller d_LOS MDHO has a slightly higher coverage.
- **Relay to base distance significantly impact relay coverage.**
  - Optimum distance is between 250-300 m

Summary for DL One-Hop Relay

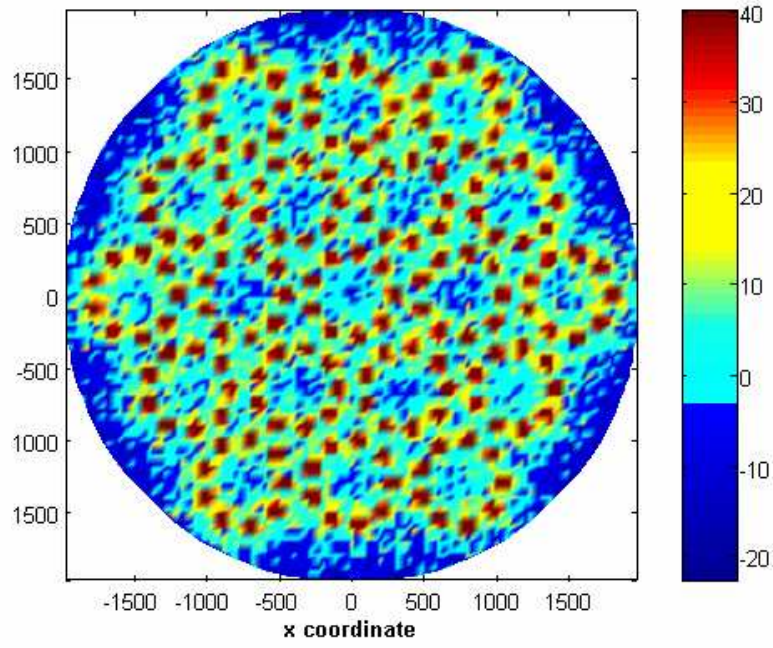
- **Relays provide a significant capacity gains in addition to the coverage improvement.**
  - EQT capacity gain is 55% to 170%.
  - Round Robin EQT capacity gain is 25% to 150%.
  - Fairness decreased when relay users are provided with two time slots
  - Relay selection scheme would change this result
    - in these results, relay is selected when its signal is better than the direct path.
  - Providing network wide equal resources increases capacity as well as fairness significantly under several propagation conditions and therefore is the preferred round robin option for relays.
- **MDHO expects to provide larger gains for delay sensitive services.**

Uplink Relay Performance
- with Shadowing

No Relay

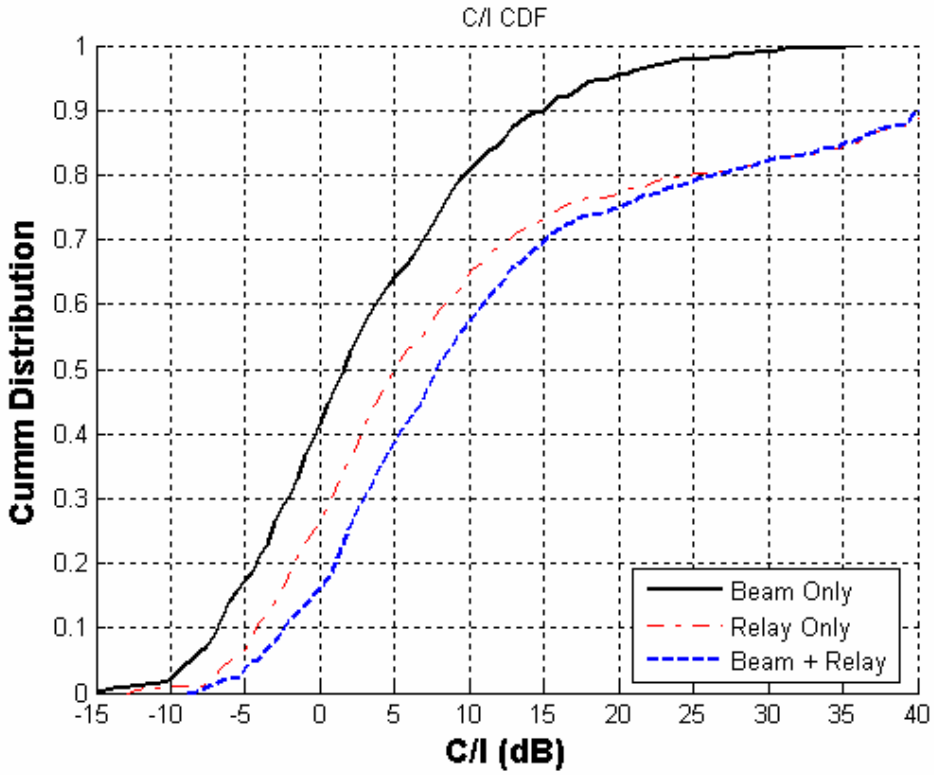


Relay Only



- **Relay placement is very complementary to each other.**
- **Significant improvement in coverage from relays (see C/I cdf in next chart).**

Uplink Relay Impact with Shadowing



- **The larger impact for the uplink (than downlink) is attributed to the mobile transmit power limitation.**

Impact of Noise:

- **All the C/I curves shifted left. 99% coverage numbers degraded (beams by 2.1 dB from -10.4 dB to -12.5 dB; Relay by 3.3 dB (from - 4.2 dB -7.5 dB)**
  - C/I improvement in low C/I areas is smaller than the results with 'Interference Limited' assumption (5 dB 99% coverage gain compared to 6.2 dB gain).
- **Still significant improvement from relays.**

Transmit Power Gain of MS

- **Mode 2 uplink coverage is a critical issue**
  - 99% C/I coverage = **-12.5 dB**
- **2-way MDHO slightly improves single user coverage but degrades multi-user coverage and capacity for delay tolerant services**
  - 99% C/I coverage = **-9.8 dB (2.7 dB improvement)**
  - Round Robin EQT capacity – negligible impact with RRETS-PB
- **Relay improves coverage and capacity significantly.**
  - 99% C/I coverage = **-7.5 dB (5.0 dB improvement)**
  - Round Robin EQT capacity significantly increased (6 mbps/beam to 10.7 Mbps)

Relay provides HUGE coverage and capacity gains for uplink.
MDHO can also provide higher gains for delay sensitive services.

Summary for UL One-Hop Relay

- **Relays provide significant capacity gains in addition to the coverage improvement**
  - EQT capacity improved by 82%
  - Round Robin EQT capacity improved by 76%.
  - Fairness of round robin schemes are not impacted by the proportion of time slots provided to relay users. However, providing network wide equal resources increases capacity significantly.
- **We used a worse case propagation scenario for relays.**
  - **For favorable propagation scenarios a higher gain can be achieved with relays (150m < NLOS distance < 250m).**
- **Power management may increase coverage and capacity even without relays. Therefore, coverage and capacity need to be evaluated under power management schemes in order to assess the benefit from relays (future work).**
- **MDHO expects to provide larger gains for delay sensitive services**