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Electromagnetic Simulation Software

Simulation of Beamforming using FD-MIMO for LTE-Advanced Pro in an Urban Small Cell

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Introduction

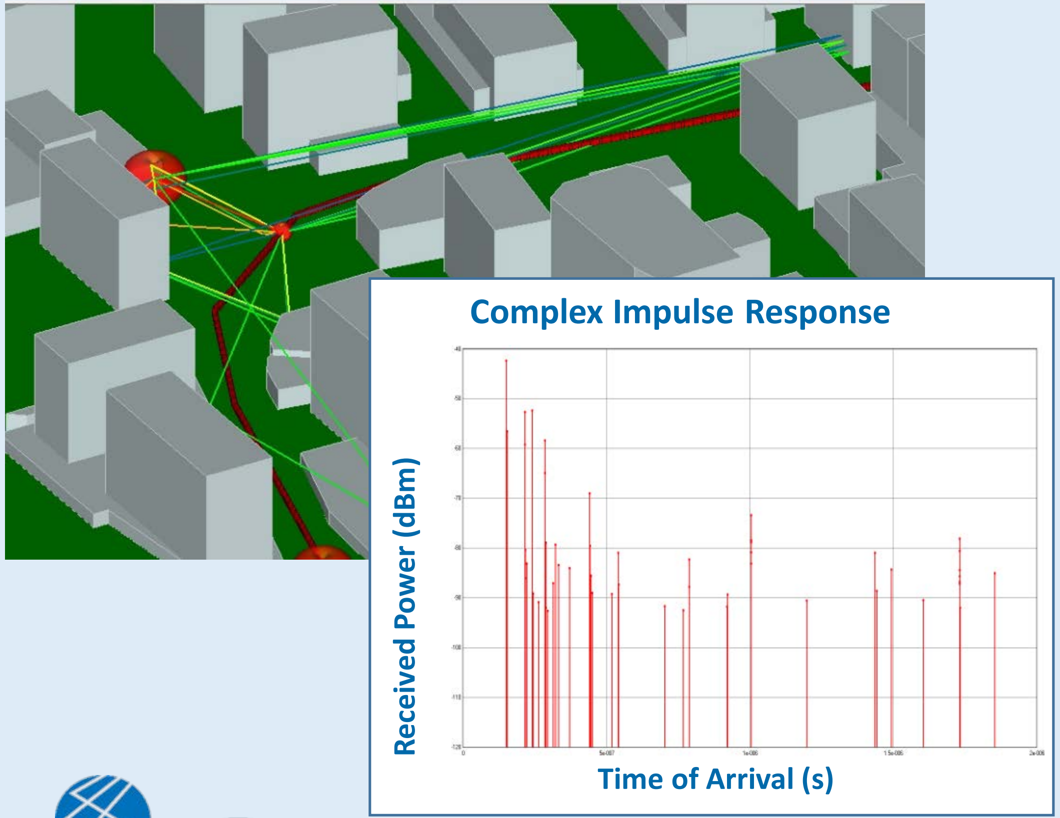
- FD-MIMO is a promising new technology in LTE-A Pro
- This presentation shows how Remcom's Wireless InSite® MIMO can be used to predict performance for FD-MIMO systems in an urban small cell
  - Wireless InSite MIMO provides an innovative and optimized capability for high-fidelity predictive simulation of complex channel characteristics
  - We extend these results to evaluate SINR and throughput for several different beamforming methods
  - The result is a tradeoff of MIMO methods and throughput for a sample planning scenario, demonstrating the value of high-fidelity simulation

Simulating FD-MIMO in Wireless InSite

- Wireless InSite predicts MIMO channels with complex multipath
  - 3D ray-tracing provides accurate channel data, with angle, phase and polarization

- MIMO optimizations:
  - Simulates large MIMO systems with minimal increase to run-time
  - Yet retains detailed polarization, phase and gain across all antenna pairs

Propagation Paths for channel between 1 transmit/receive MIMO antenna pair



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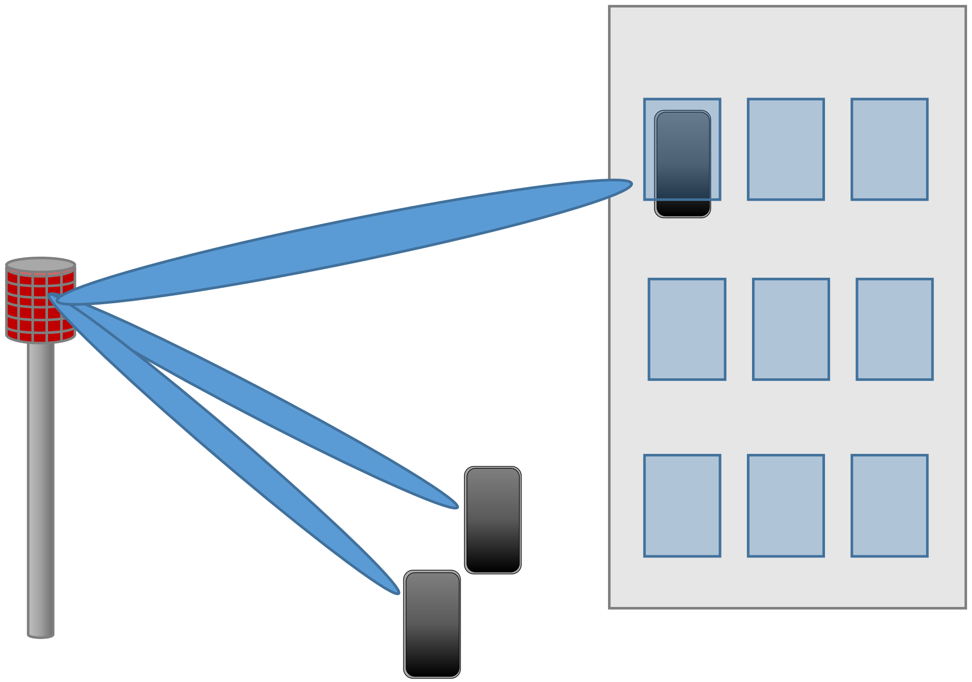
Full-Dimension MIMO (FD-MIMO)

- What is FD-MIMO?
  - LTE-A Pro allows up to 64 antennas
  - “Full-dimension” refers to arrays in both vertical and horizontal directions, allowing for creation of 3D beams
  - Beamforming directs signal to UE, increasing its SINR while reducing interference to others
  - Increases spectral efficiency and total throughput of a small cell

Beamforming with FD-MIMO



Other Key Technologies in this Demo

- Cooperative MultiPoint (CoMP)
  - Base stations coordinate on scheduling/beamforming to minimize inter-cell interference, and potentially even combine signals (joint processing)
  - Becomes even more critical with beamforming, particularly at cell edge

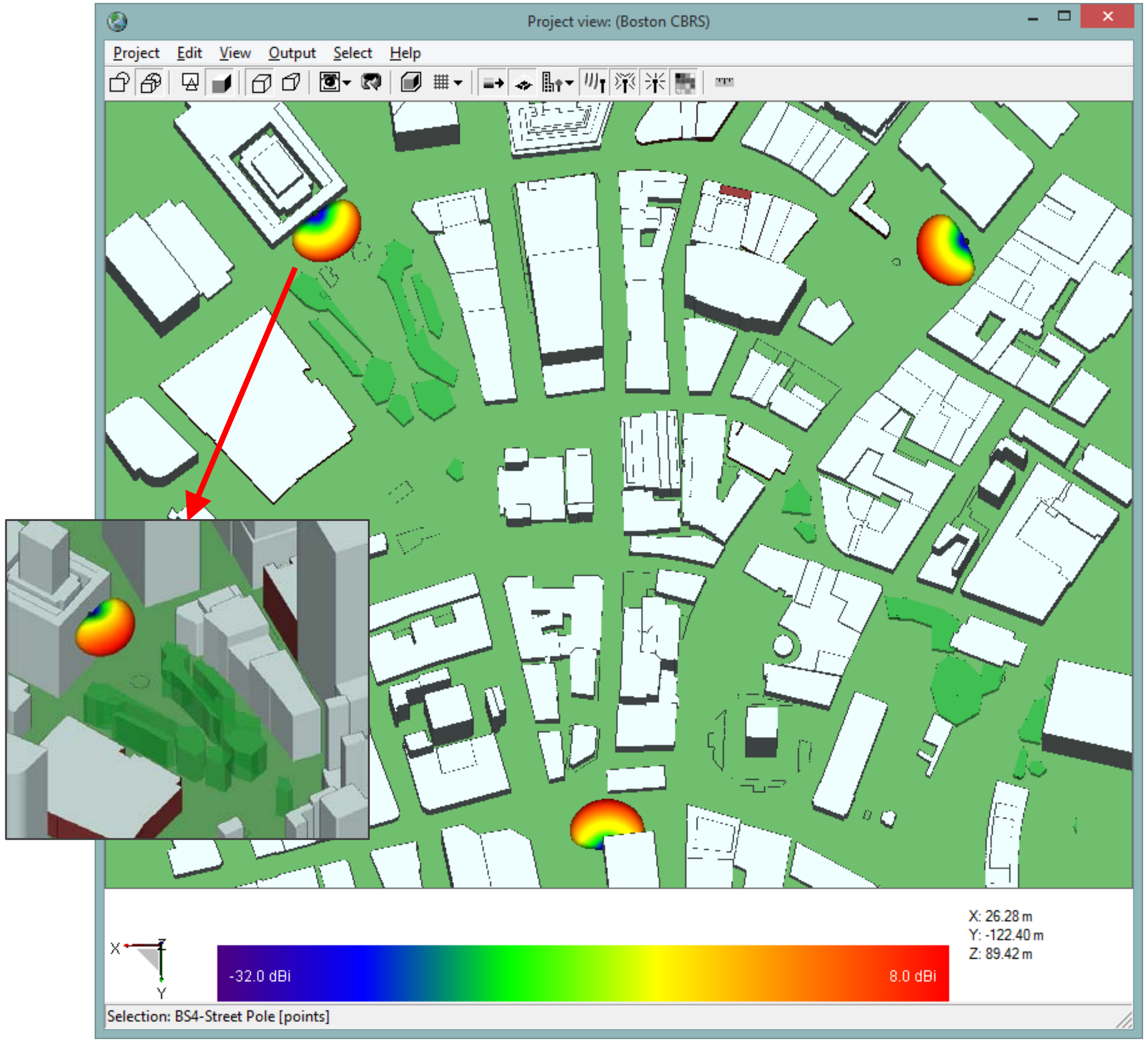
- 256 QAM (added in LTE-A R12)
  - Increases potential throughput, and small cells with beamforming more likely to achieve SINR required to be able to use it

- New spectrum becoming available, such as Citizens Broadband Radio Service (CBRS, 3.5 GHz) unlicensed bands, and future mmwave bands increase available spectrum for these technologies

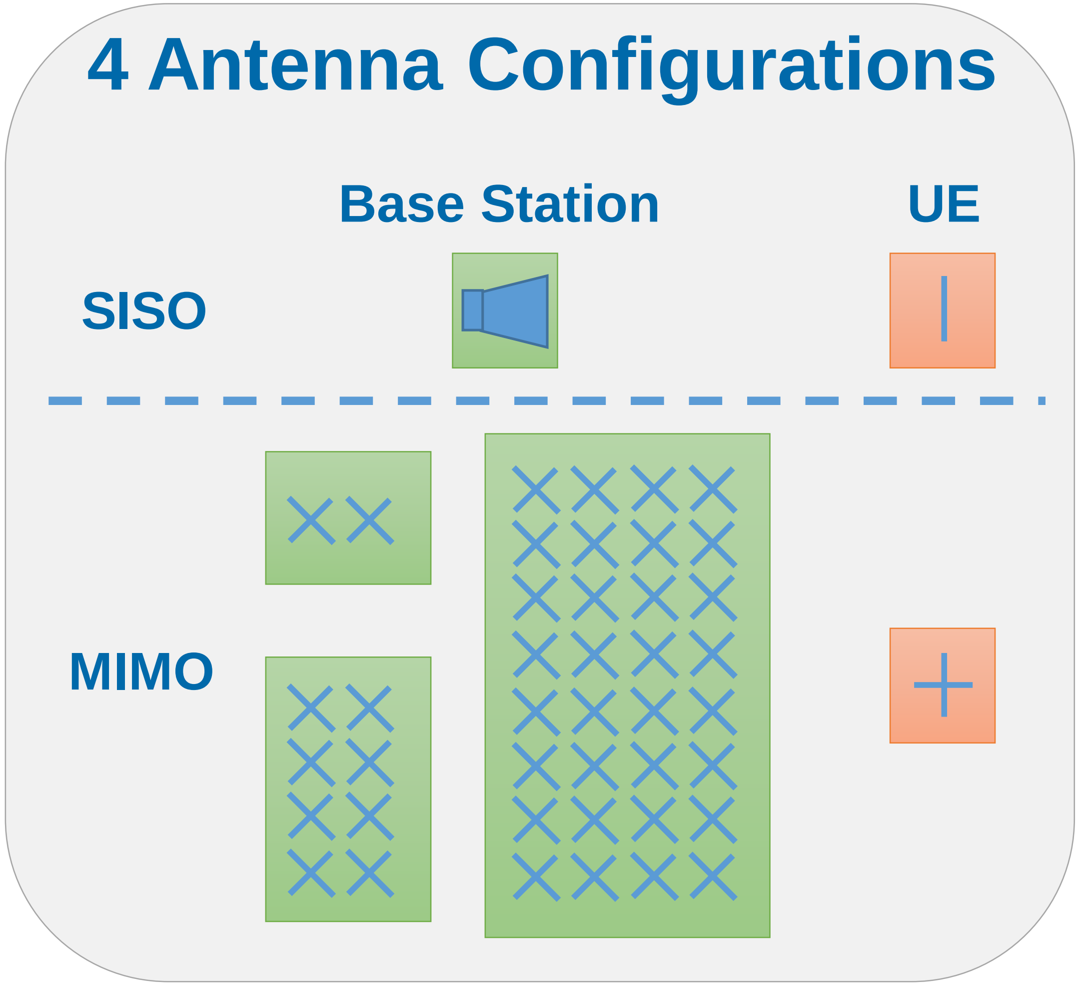
Demonstration: FD-MIMO in Boston

- 3 small cell base stations in downtown Boston
  - 2 on lampposts (15m height)
  - 1 (left) placed 50m up on building to propagate over trees in square

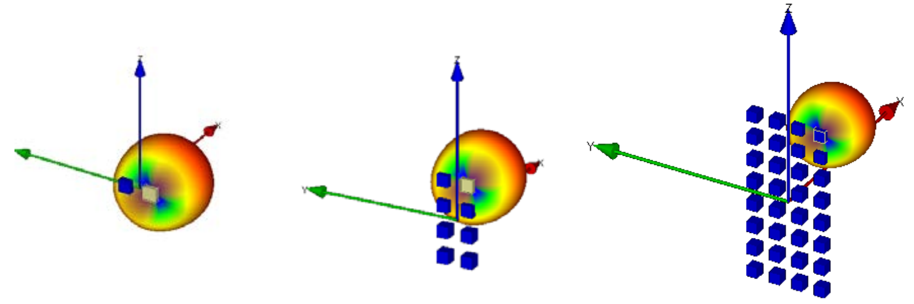
- Using new spectrum to augment existing coverage
  - Frequency: CBRS
  - 20 MHz (3.55-3.57 GHz)



Antennas for SISO & MIMO Scenarios



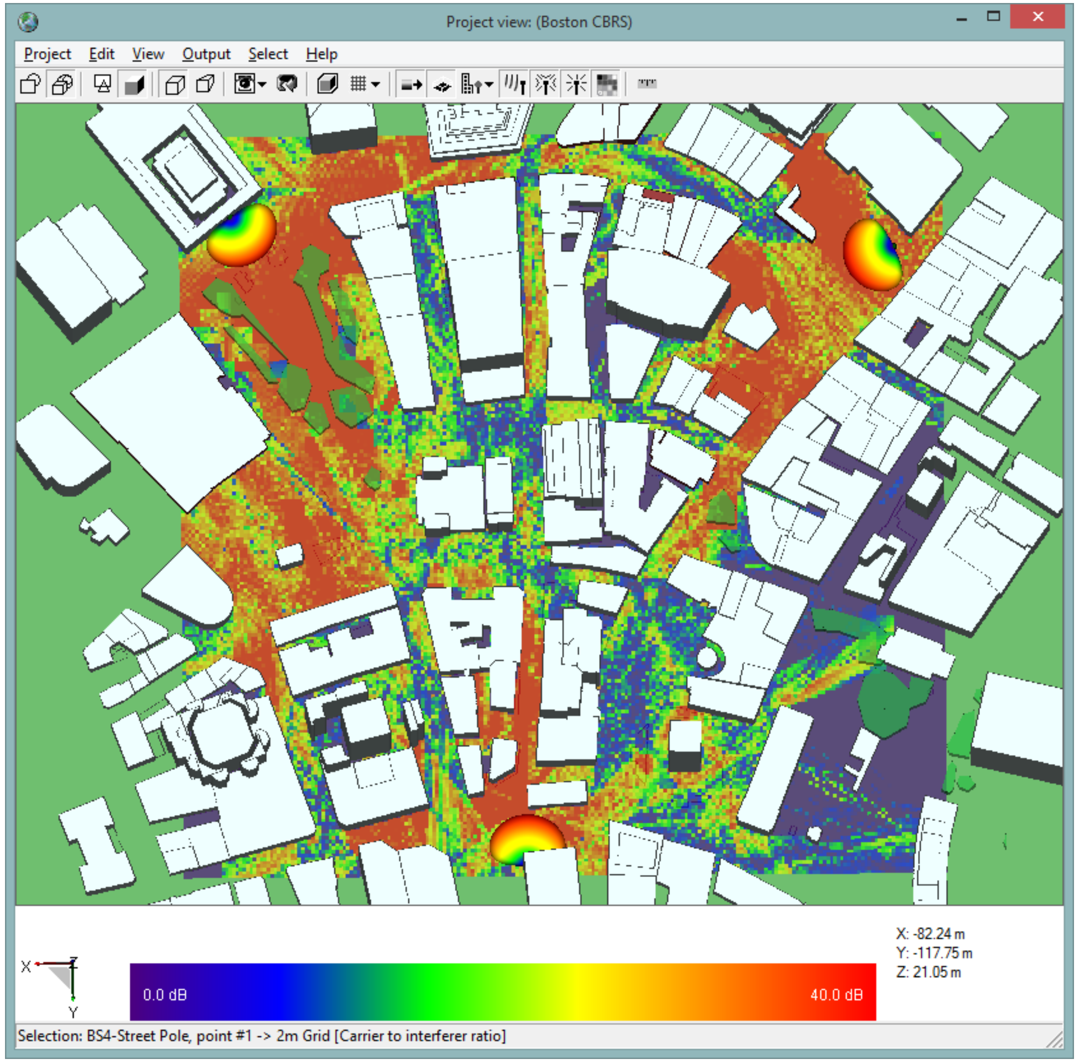
- 4 scenarios for base station antennas:
  - Baseline SISO: sector horns
  - MIMO, 4 elements (2 xpol patch)
  - MIMO, 16 elements (8 xpol)
  - MIMO, 64 elements (32 xpol)



- User equipment (UE)
  - 1 isotropic antenna for SISO
  - 2 xpol isotropics for MIMO cases

SISO Baseline: SINR

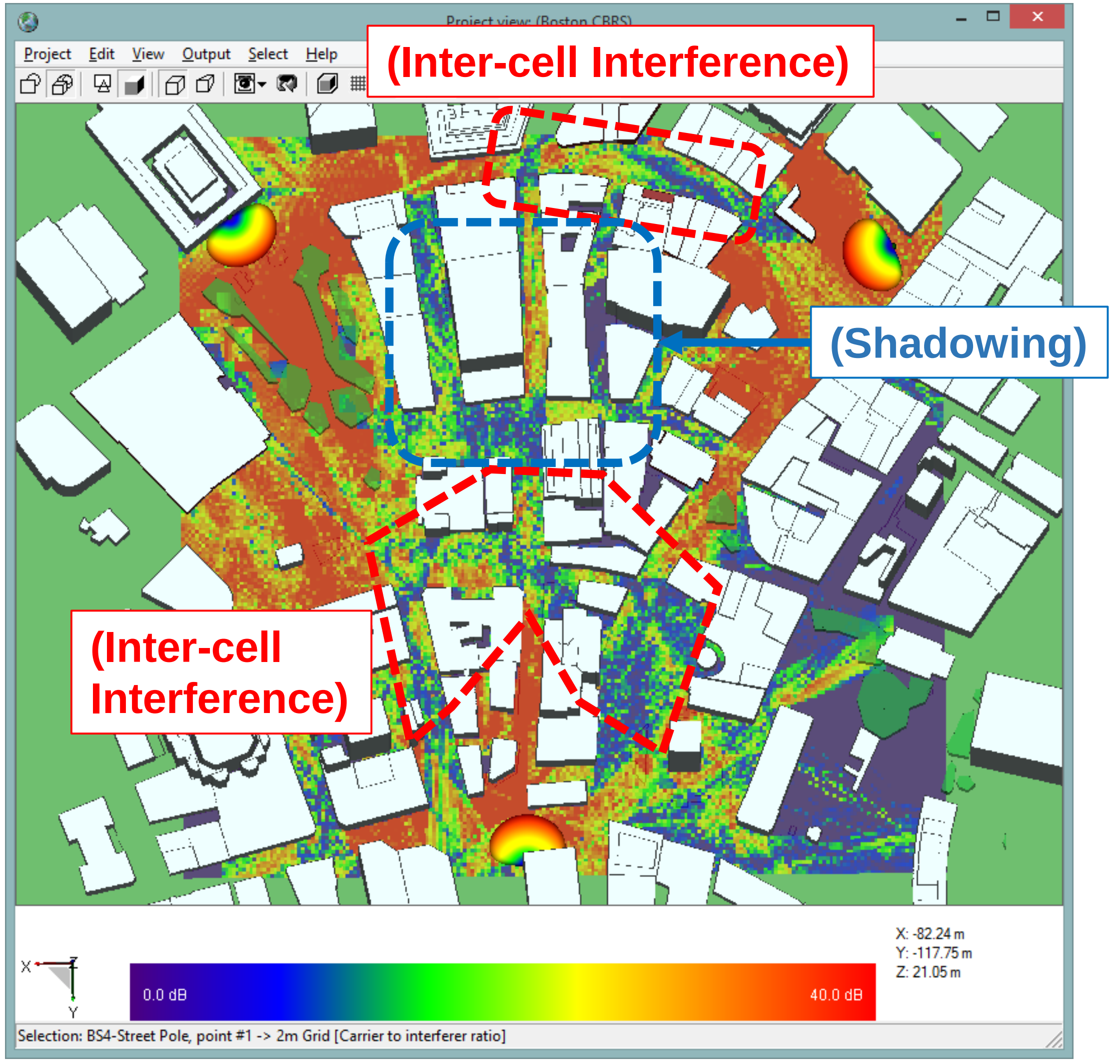
- All base stations set up with a sector horn; UE grid with isotropic antennas
- Calculated SINR accounting for:
  - Ambient noise, -168dBm/Hz [2]
  - Interference from other base stations
- SINR field map shows good coverage over most of area
  - Some areas of shadowing and interference



SISO Baseline: Shadowing & Interference

- Inter-cell interference occurs at cell edges between base stations (shown in red)

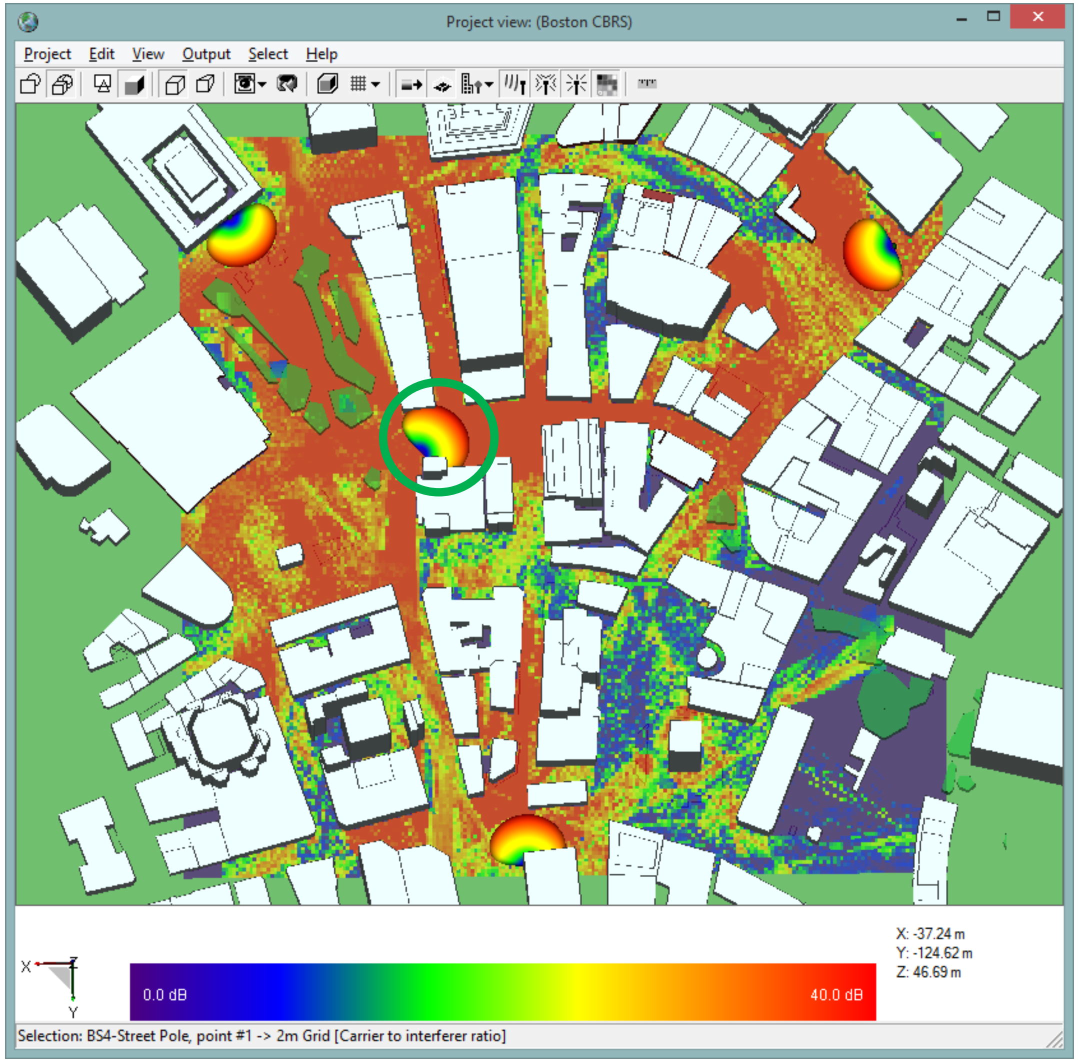
- Shadowing by buildings in center of base stations (blue)



4^{th} Base Station Reduces Shadowed Areas

- Added 4^{th} base station to improve shadowed area (green circle)
  - Ignored inter-cell interference
  - Assume different bands or use of inter-cell interference coordination

- Successfully reduces much of the shadowed area in top middle



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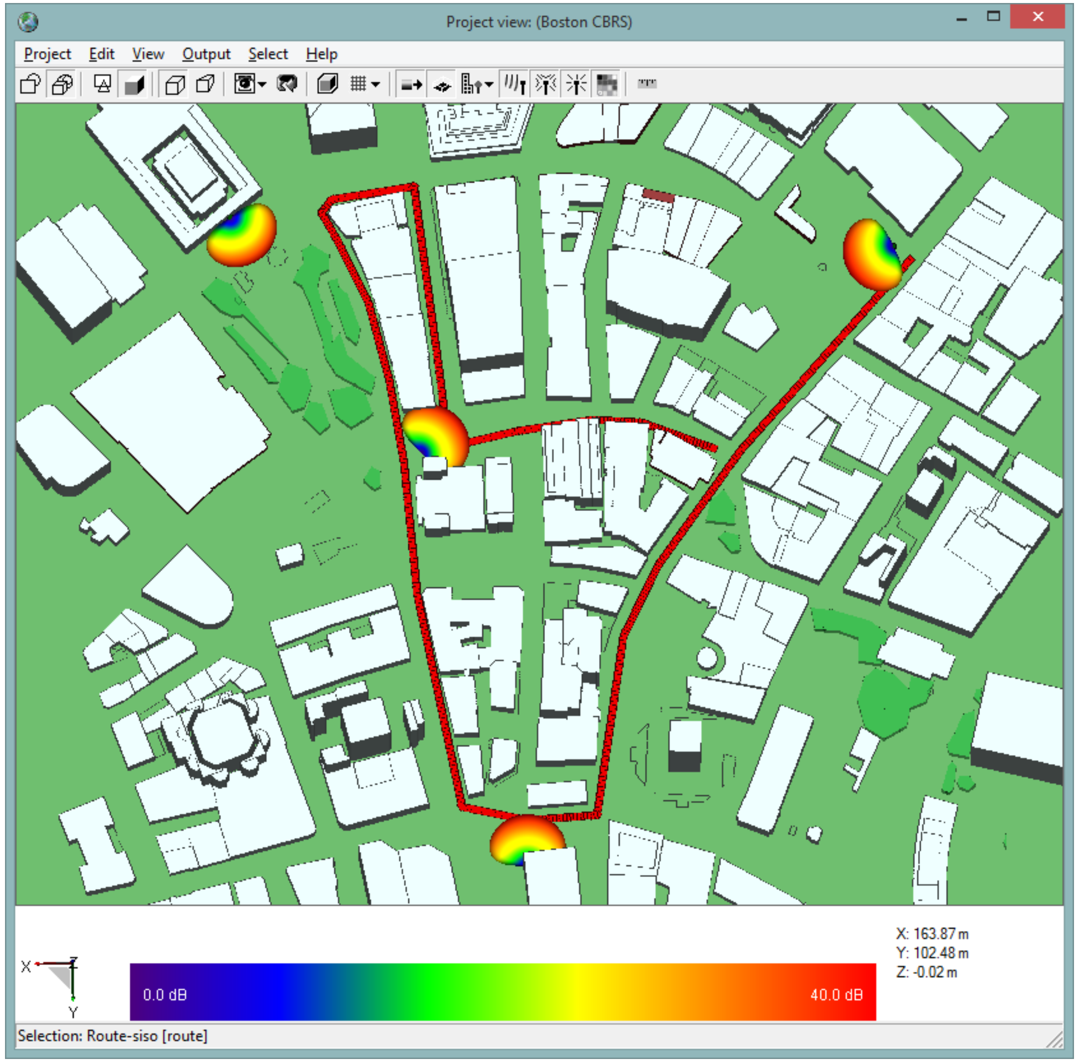
SISO Throughput for 20 MHz Component Carrier

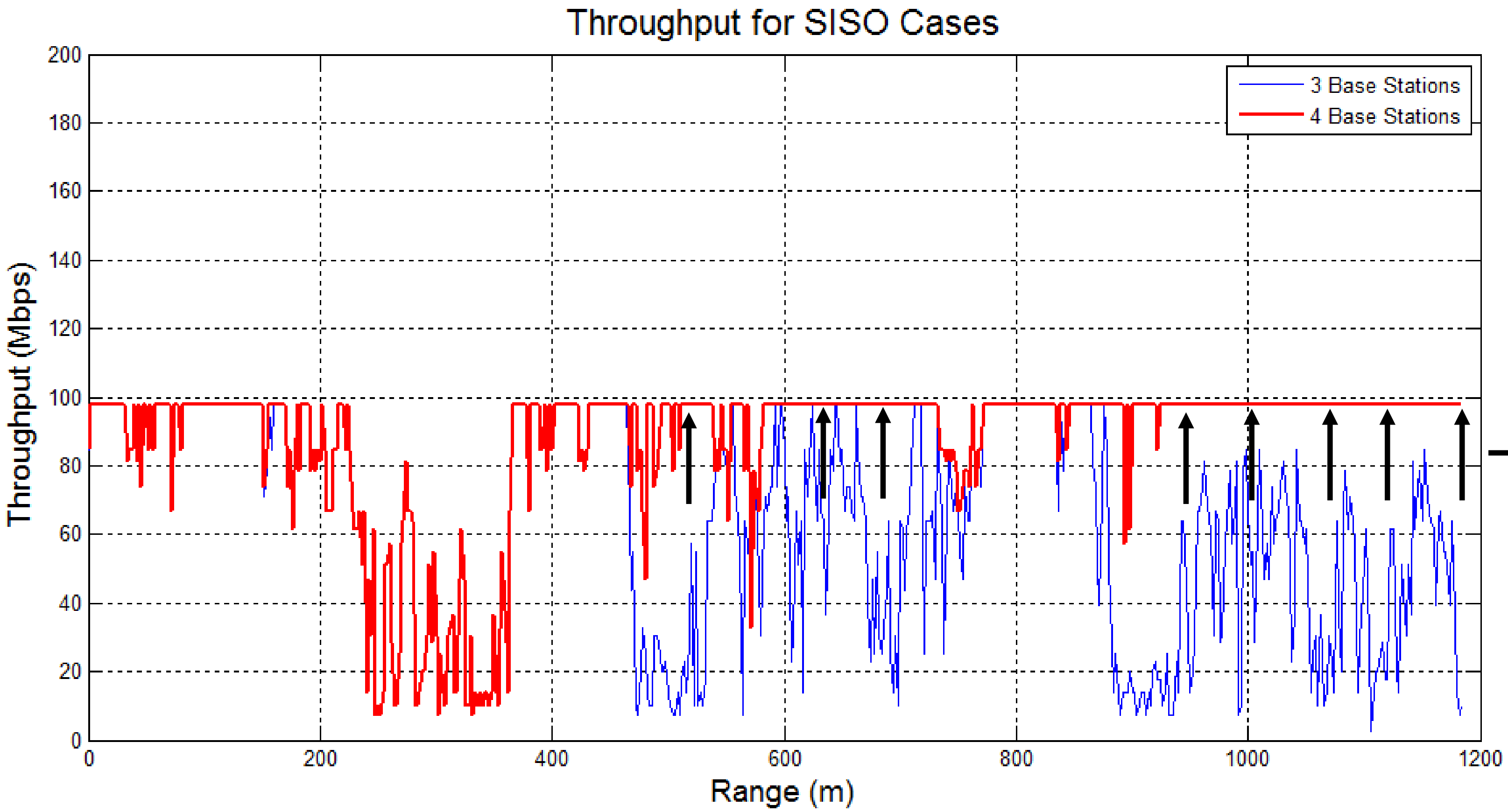
- Defined UE route through scene
  - Passes by each base station
  - Includes shadowed areas overcome by 4th base station

- Calculated LTE-A Pro throughput
  - Lookup tables devised based on SINR and 3GPP Rel 13 transport block size tables [3]
  - 256 QAM highest throughput for 20 MHz: 97.9 Mbps



Throughput along Route

Results show that when 4th base station added (red line), more of route achieves max 256-QAM throughput



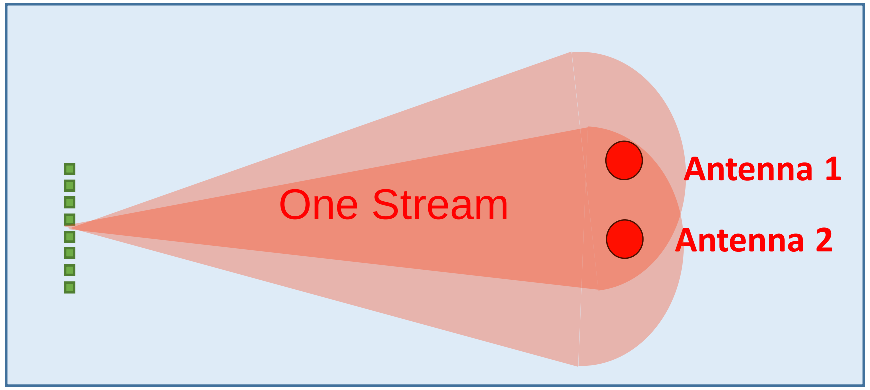
Throughput increases

MIMO Beamforming & Spatial Multiplexing

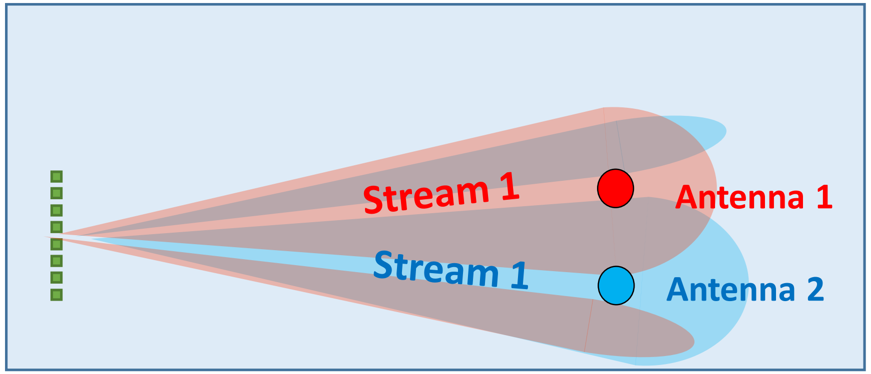
- Evaluated 3 MIMO techniques:
  - Singular Value Decomposition (SVD)
    - Creates isolated data streams to each Rx antenna (spatial multiplexing)
  - Max. Ratio Transmission (MRT)
    - Creates beam maximizing gain to a receiving antenna
    - Directed beams to both UE antennas and combined (Max Ratio Combining)
  - Zero Forcing (ZF)
    - Creates beam to antenna while minimizing interference to others (allows stream to each UE antenna)

- Applied these for a single user at each position to predict coverage for grid and route (SU-MIMO, *not* MU-MIMO)

MRT/MRC: Beams Combined



Zero Forcing & SVD: Multiple Streams



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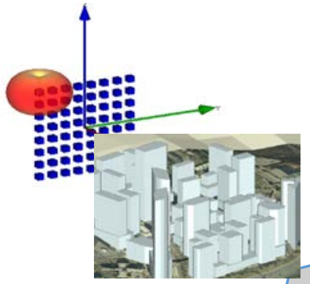
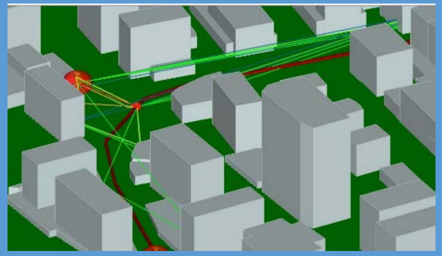
Simulations & Prototypes Used in Study

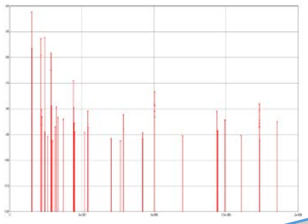
Scenario Inputs



Wireless InSite Simulations



Complex H-Matrix



(Wireless InSite Future Capability)

Prototype Algorithms:

- Beamforming weights
- SINR for MIMO streams
- MIMO throughput

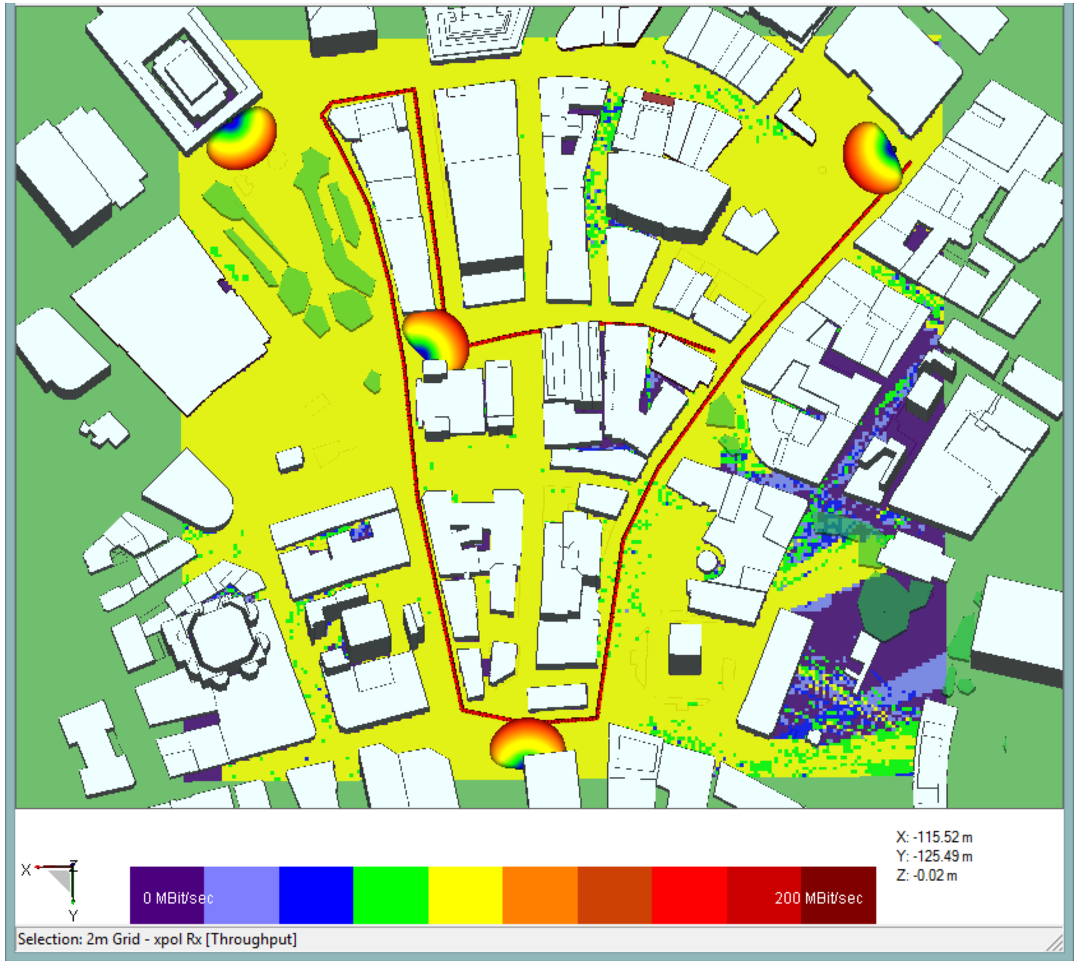
SINR & Throughput

Process:

- Wireless InSite MIMO: predict complex H-matrices
- Prototype code for SINR & MIMO methods (MRT & ZF scripts from [4])
- Prototype calculations: MIMO streams, SINR, throughput

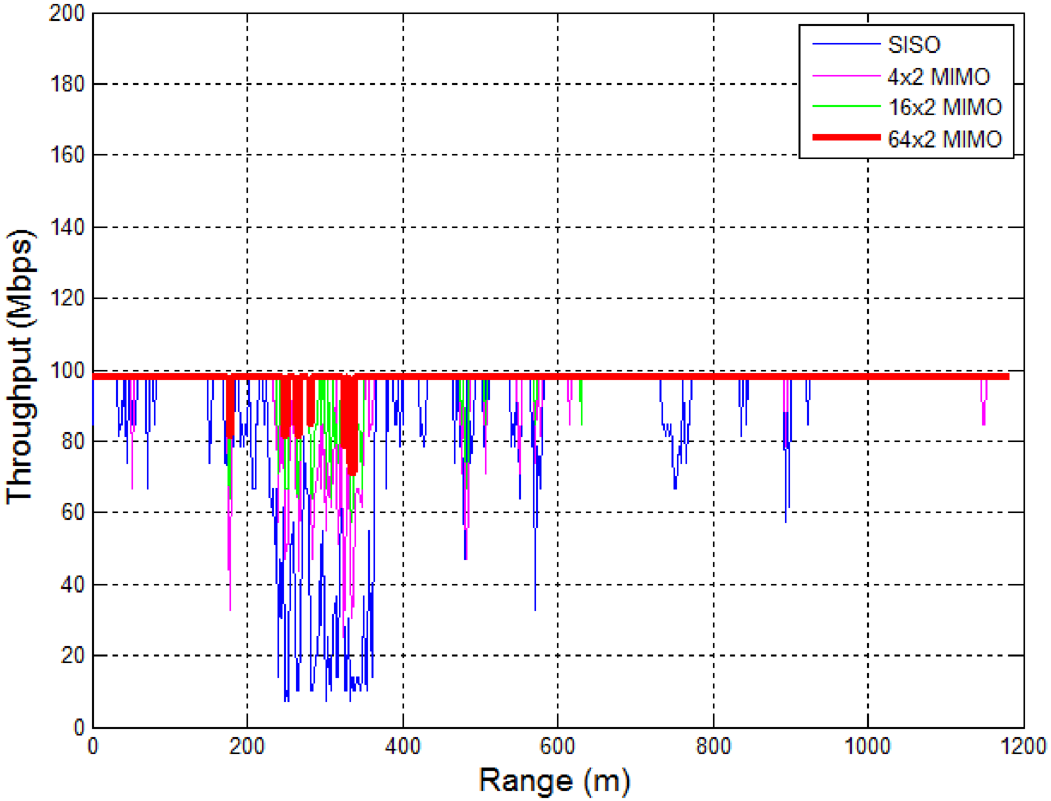
Throughput using MRT-MRC Beamforming

64x2 Scenario: Throughput w/MRT Beamforming



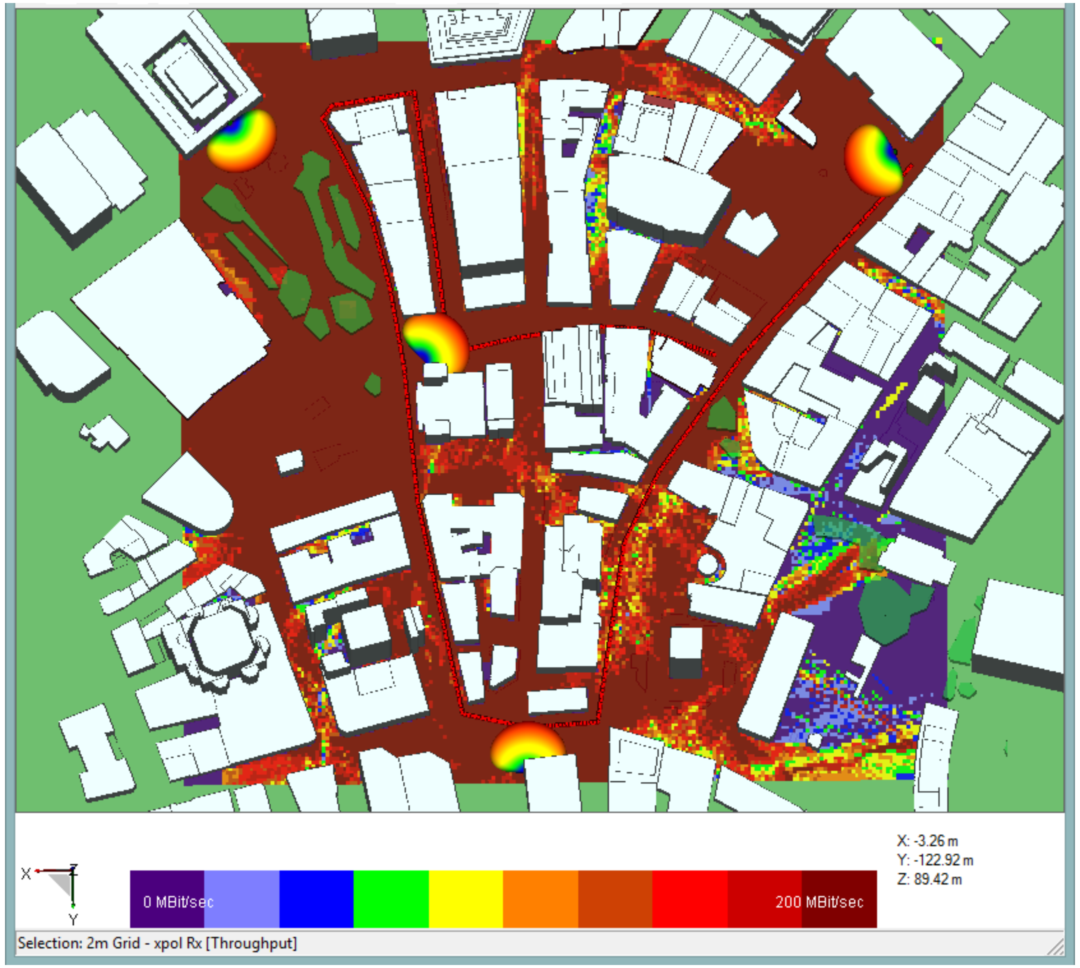
MRT-MRC Beamforming

- 64x2 (red) achieves max throughput over most of area



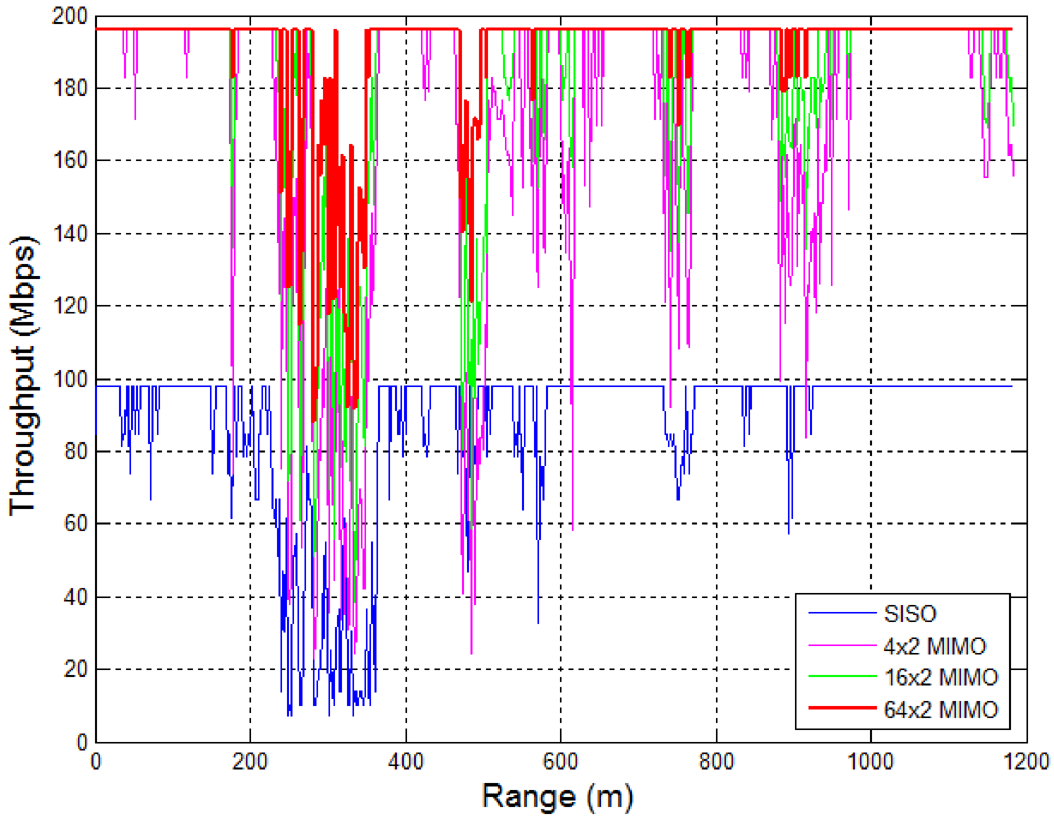
Throughput using ZF Beamforming

64x2 Scenario: Throughput w/ZF Beamforming



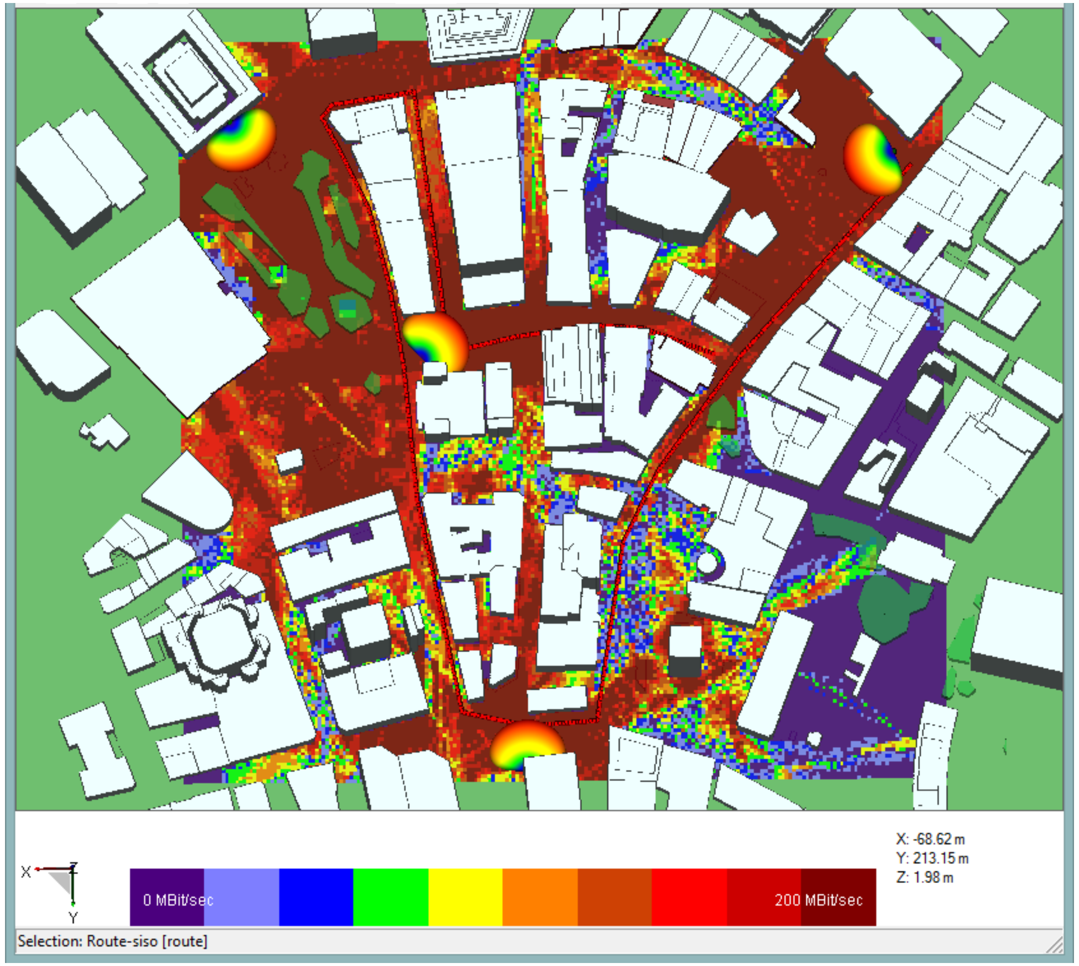
ZF Beamforming

- 64x2 (red) generates 2 successful streams, achieving 100-200 Mbps



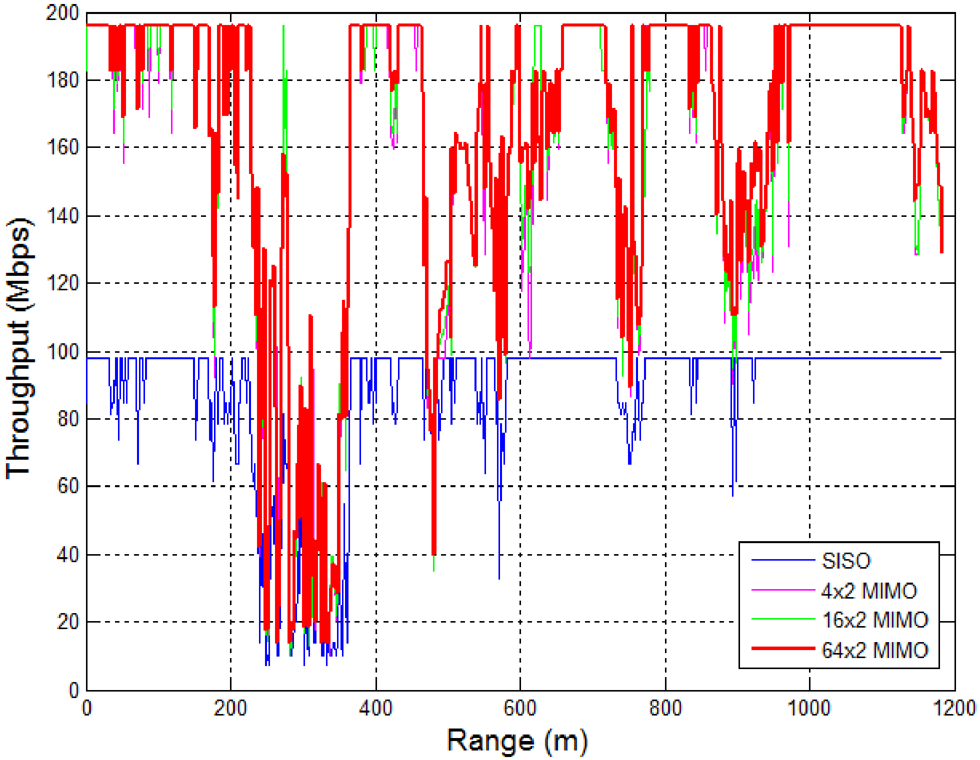
Throughput using SVD Spatial Multiplexing

64x2 Scenario: Throughput with SVD



SVD Spatial Multiplexing

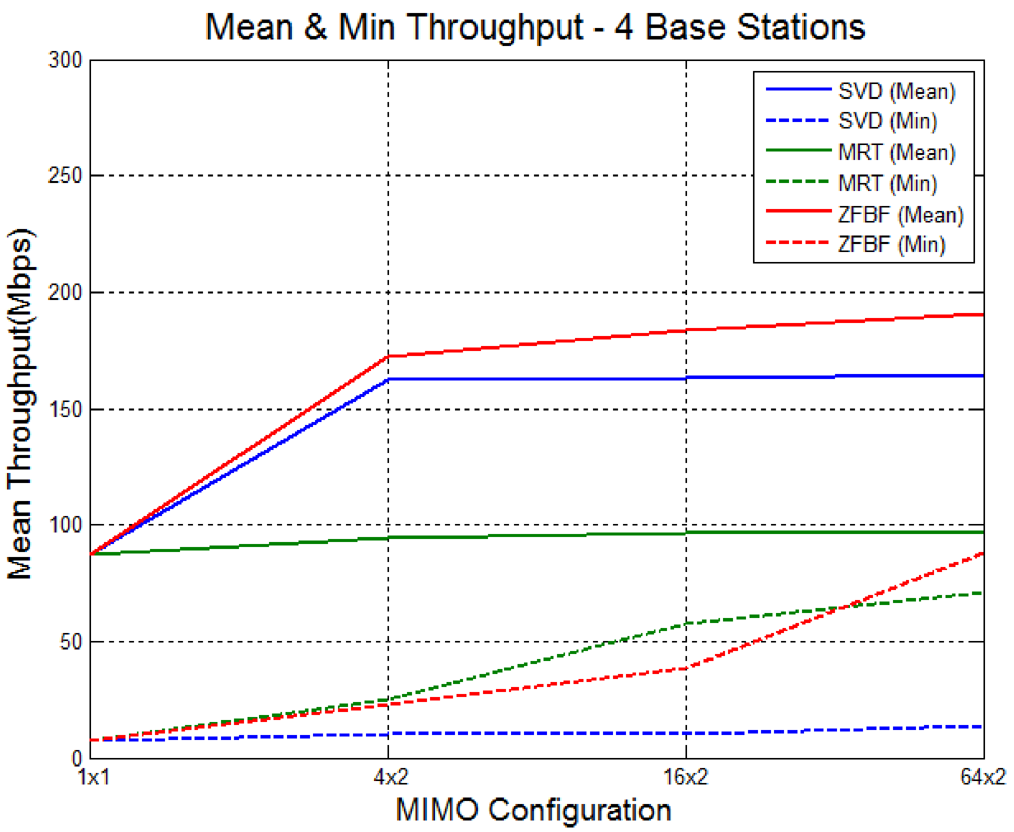
- Mostly > 100Mbps (2 streams)
- Inter-cell interference drops throughput in several places



Comparing MIMO Methods & Configurations

- Plot shows comparison of mean and minimum throughput along route

- Observations
  - SVD increased 86% over SISO on average, but continued to have significant dropouts
  - MRT 16x2 and 64x2 had only small improvement to mean, but beamforming eliminated dropouts
  - ZFBF more than doubled mean throughput and also eliminated dropouts



Built-in Optimizations Made Study Possible

- Recorded run times on high-end desk-top workstation
- Results show only 2-4 x increase in run-time for 64x2 FD-MIMO, making simulations for this demo very feasible

Scenario	MIMO Configuration	Run Time (min)
Route (593 points), 4 Base Stations	1x1 (SISO)	8.6
	4x2	9.0
	16x2	10.6
	64x2	17.1
Field Map (47,515 Points) , 4 Base Stations	1x1 (SISO)	33
	4x2	31
	16x2	48
	64x2	119

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Conclusions

- Used Wireless InSite MIMO to demonstrate efficient method for predicting detailed channel characteristics for FD-MIMO scenario in downtown Boston
- Used prototype calculations planned for a future version to compute beamforming, SINR for MIMO streams, and throughput
- Results showed impact of inter-cell interference and some benefits to each of the beamforming approaches for the sample scenario
- Study provides insight into MIMO throughput for FD-MIMO, and demonstrates value of MIMO simulations in assessing performance

References

[1] H. Ji, et. al., “Overview of Full-Dimension MIMO in LTE-Advanced Pro,” IEEE Communications Magazine, Volume 55, Issue 2, pages 176-184, October 20, 2016.

[2] R. Beck, “Results of Ambient RF Environment and Noise Floor Measurements Taken in the U.S. in 2004 and 2005,” World Meteorological Organization Report, CBS/SG-RFC 2005/Doc. 5(1), March 2006.

[3] “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 13),” 3GPP TS 36.213 V13.6.0 (2017-06).

[4] E. Björnson, M. Bengtsson, and B. Ottersten, “Optimal Multiuser Transmit Beamforming: A Difficult Problem with a Simple Solution Structure”, IEEE Signal Processing Magazine, Vol. 31, No. 4, 2014, pp. 142-148. Also available arXiv:1404.0408v2 [cs.IT] 23 Apr 2014.

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