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Throughput and Coverage Analysis of a Multi-Element Broadband Fixed Wireless Access (BFWA) System in the Presence of Co-Channel Interference

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Introduction

- Study builds on IEEE 802.16-2004 (16d) fixed broadband wireless access standard (fixed WiMAX)
- Channel model for fixed WiMAX in urban environments
  - SUI (Stanford University Interim)
  - Site specific model (urban ray tracing)
- Analyse channel and interference behaviour within a WiMAX network
- Work towards achieving high system throughput using the OFDM-wirelessMAN air interface by exploiting sectorised MIMO arrays
- Conclusions

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Background (IEEE 802.16-2004)

- Fixed WiMAX provides a cost-effective wireless network over extensive areas to large number of users; it provides differentiated broadband service
- The IEEE 802.16-2004 standard defines three PHY layer air-interface techniques
- The 256-FFT OFDM solution is favoured by the vendor community, since OFDM improves system performance in non-line-of-sight urban environments
- UK has 3.5GHz licensed band
- WiMAX supports:
  - Adaptive modulation and coding (AMC)
  - Smart antennal techniques

SUI Channel Models (1)

- SUI models are widely used for fixed WiMAX deployment. A total of six models are defined for three typical terrain types

	K factor	τ_{rms}(μs)	Ant. Corre.	Terrain type
SUI-1	Omni: 3.3(90%), 10.4(75%)	0.111	0.7	C
	30º ant.: 14(90%), 44.2(75%)	0.042		
SUI-2	Omni: 1.6(90%), 5.1(75%)	0.202	0.5	C
	30º ant.: 6.9(90%), 21.8(75%)	0.069		
SUI-3	Omni: 0.5(90%), 1.6(75%)	0.264	0.4	B
	30º ant.:2.2(90%), 7.0(75%)	0.123		
SUI-4	Omni: 0.2(90%), 0.6(75%)	1.257	0.3	B
	30º ant.:1.0(90%), 3.2(75%)	0.563		
SUI-5	Omni: 0.1(90%), 0.3(75%), 1.0(50%)	2.842	0.3	A
	30º ant.:0.4(90%), 1.3(75%), 4.2(50%)	1.276		
SUI-6	Omni: 0.1(90%), 0.3(75%), 1.0(50%)	5.240	0.3	A
	30º ant.:0.4(90%), 1.3(75%), 4.2(50%)	2.370		

Type A: hilly terrain with moderate-to-heavy tree densities;
Type C: mostly flat terrain with light tree densities.

SUI Channel Models (2)

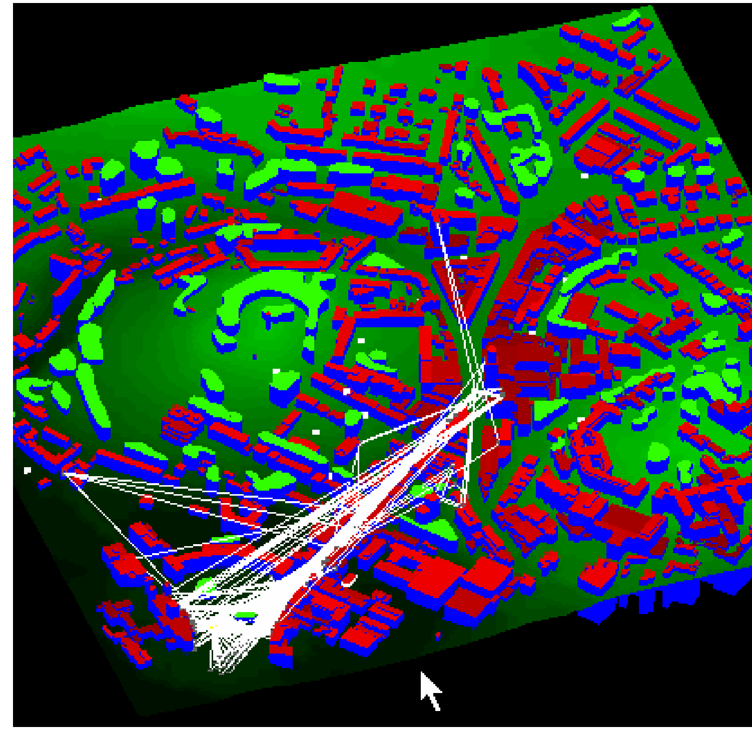
Scenario for SUI channel:

1. Cell size:	7 km
2. BS ant. high:	30m
3. CPE ant. High:	6m
4. BS ant. beamwidth:	120^0
5. CPE ant. Beamwidth:	omni & 30^0
6. Polarization	Vertical
7. Cell coverage	90% with 99.9% reliability

- The SUI approach struggles to support link adaptation studies and is not ideal for calculating the coverage outage probability, since it makes a number of general assumptions (see above)
- To overcome these limitations and assumptions, we use a site specific Ray Tracing (RT) model to analyse the radio channels between each BS and their associated CPEs

Simulation Scenarios

- 3km by 1.8km area covering central Bristol (UK)
- 5 BS placed on tall local buildings (~30m height); each BS uses three 120^{o} sectorised antennas
- 100 CPEs are located at rooftop height (around 6m), and use omni or 30^{o} directional elements
- Consider two MIMO array configurations: 1) Uniform Circular Array (UCA), and 2) Uniform Linear Array (ULA)
- 5MHz channel bandwidth assumed in the 3.5GHz band



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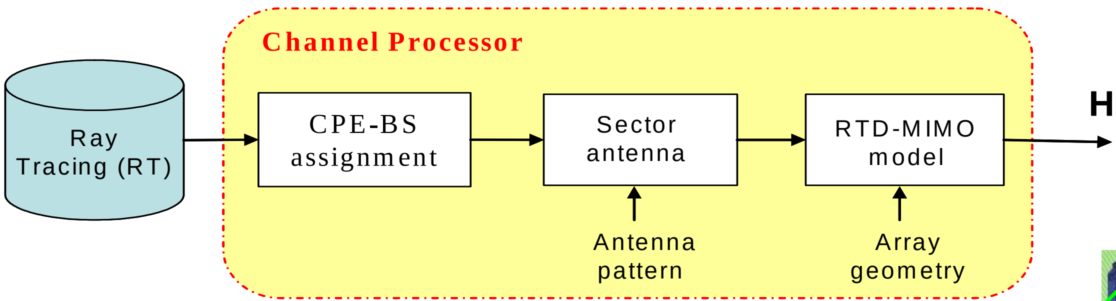
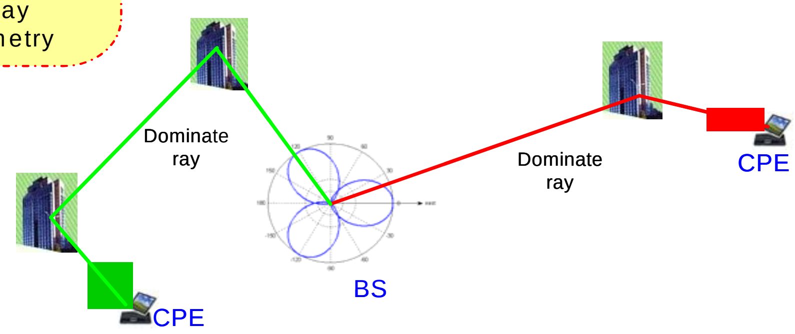
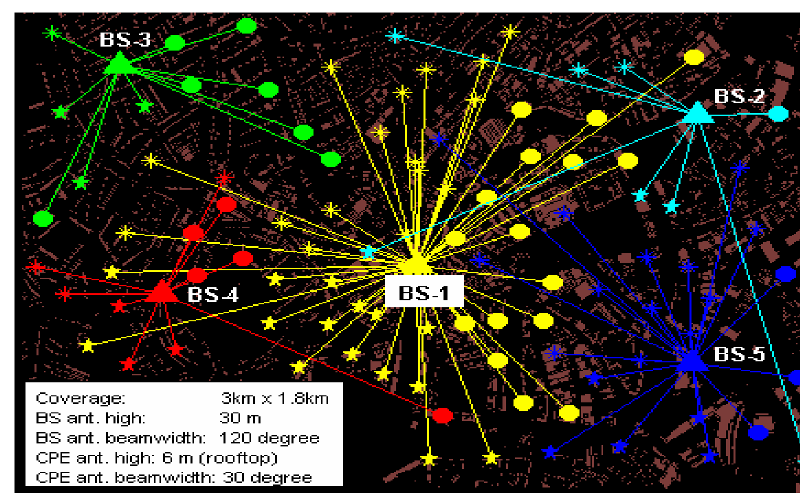
MIMO Channel for Sectorised Multi-BS Network



- Utilises urban geographic data to produce spatial/temporal channel using isotropic element patterns.
- ETSI specified beam patterns are then spatially convolved to model the impact of directional elements
- CPE to BS-Sector assignment and orientation based on strongest path





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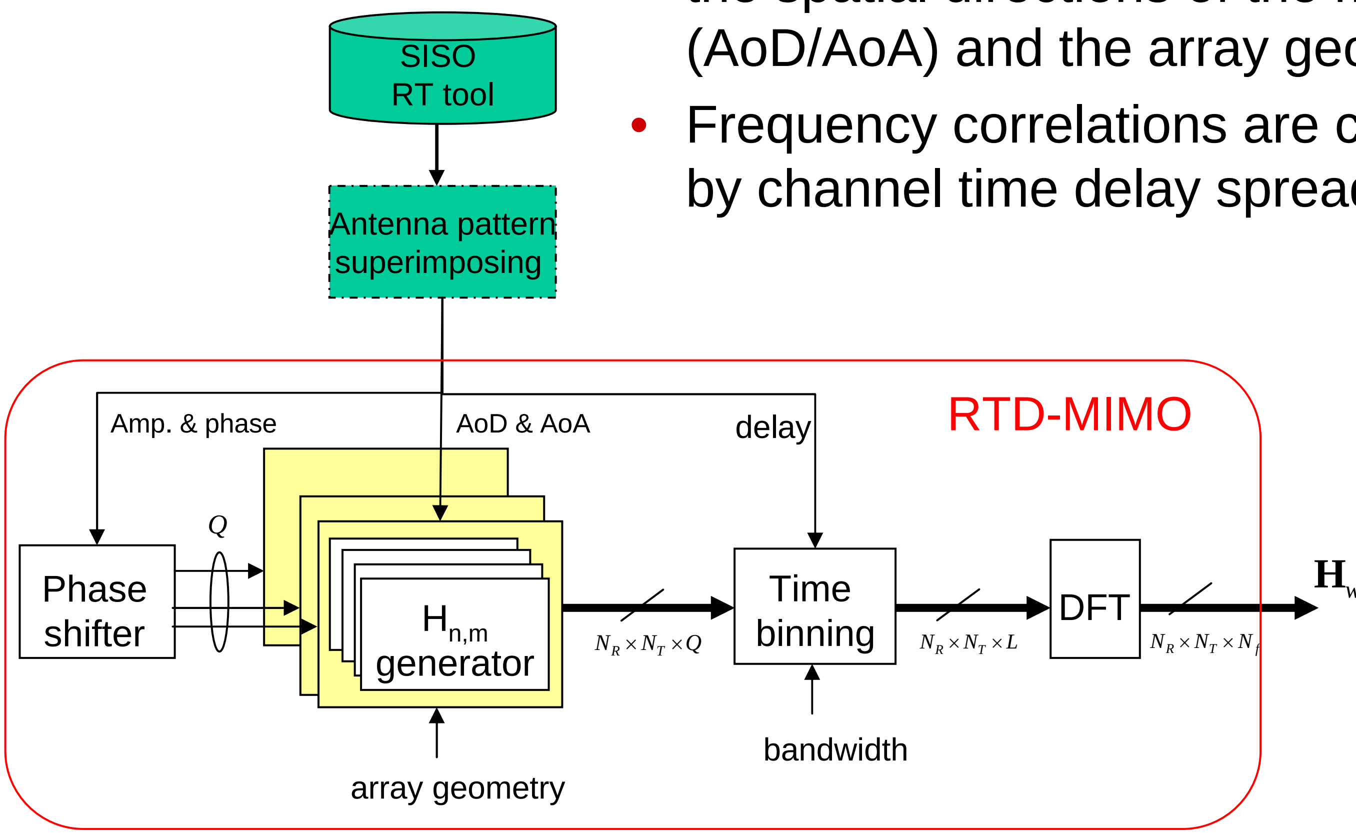
Ray Tracing Deterministic (RTD) - MIMO Channel (1)

- Spatial correlations are determined by the spatial directions of the multipaths (AoD/AoA) and the array geometry
- Frequency correlations are controlled by channel time delay spread.



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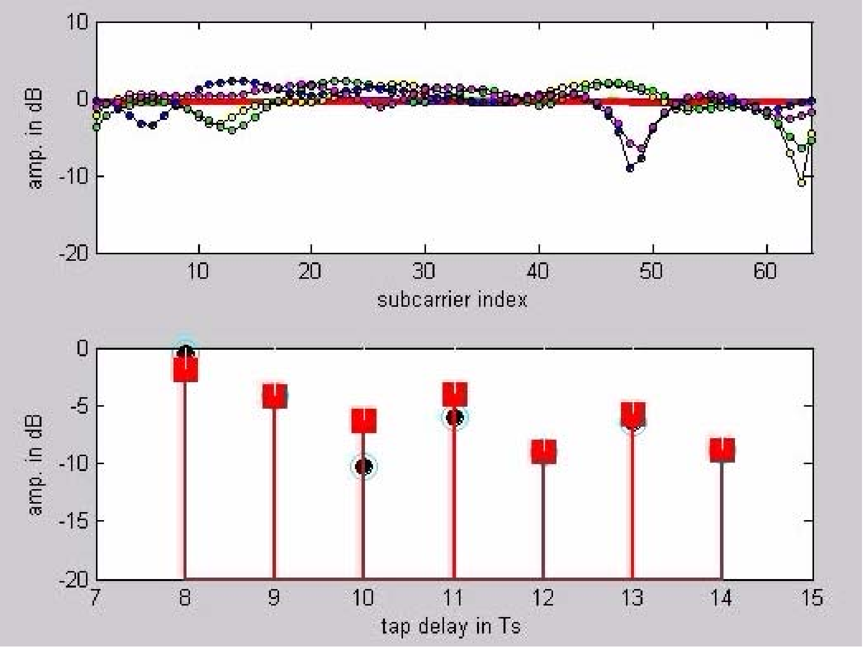
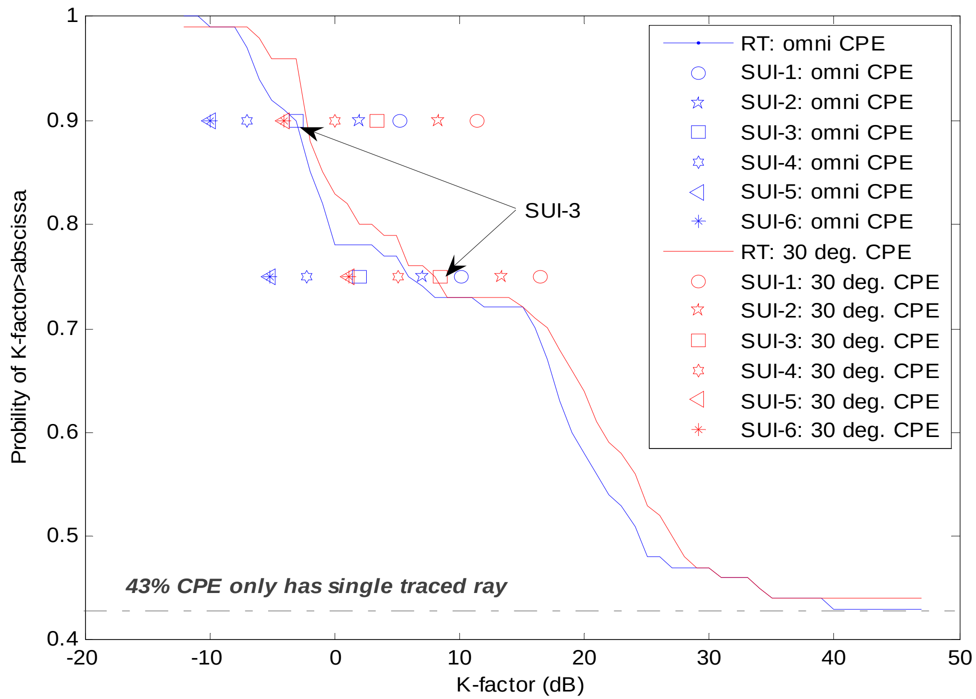
RTD - MIMO Channel (2)

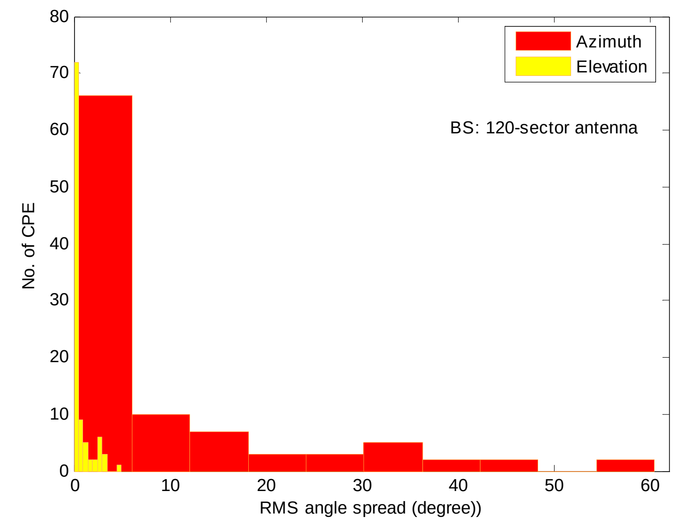
- The plot below shows the time varying Tapped Delay Line weights, and the resulting frequency selective channel responses for the MIMO links
- Each MIMO link suffers individual frequency selective fading



Comparison between RT and SUI model

- The RT results demonstrate that:
  - 73% of users have a very strong dominant ray (a K-factor above 15dB). Simulated area fits the *SUI-3 assumptions* (terrain type B)
  - 30º directional antenna increases the K-factor
  - RMS Angle Spread is much lower in Elevation (compared to Azimuth)





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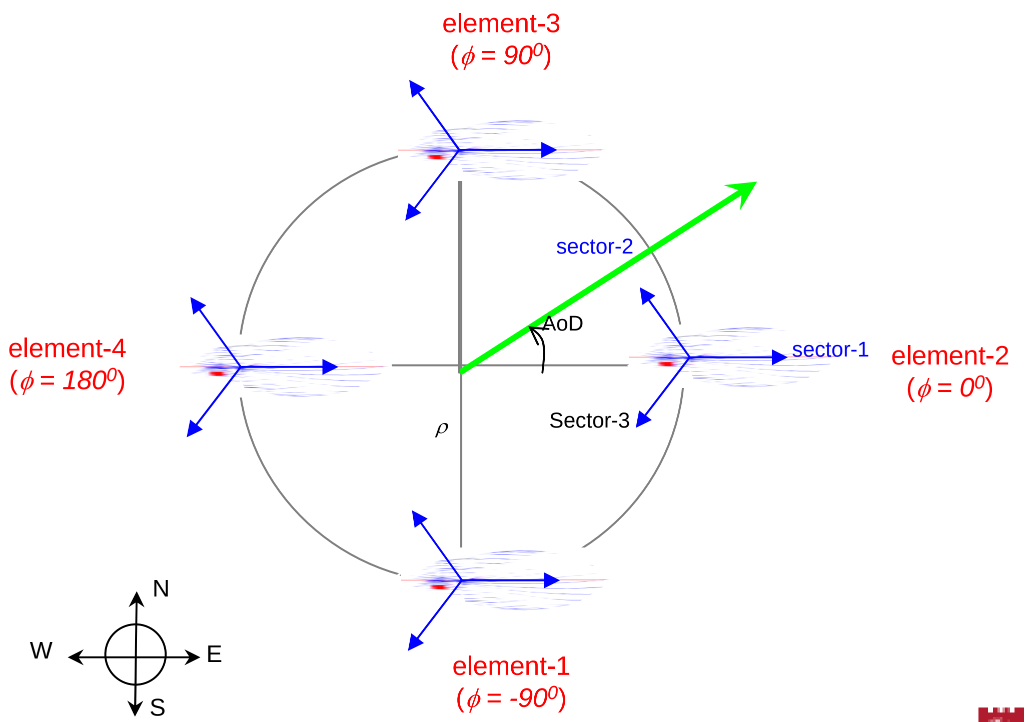
Array Element Geometry

- Higher spatial correlation seen between vertically displaced array elements. Consequently, it is more effective to space MIMO elements in the horizontal plane
- The figure below shows the structure of the MIMO sectorised array



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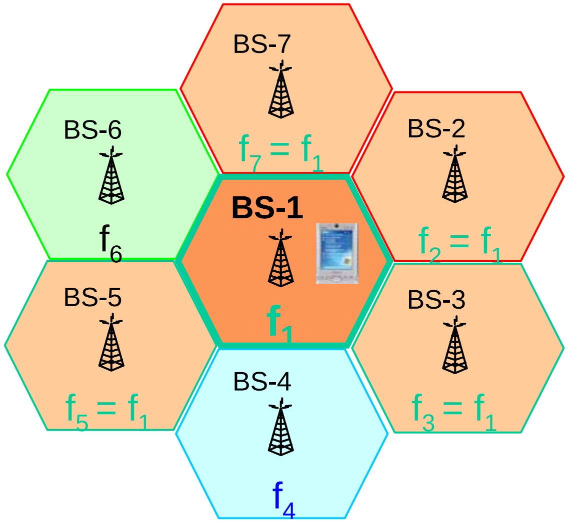
Interference in multi BS environment (1)

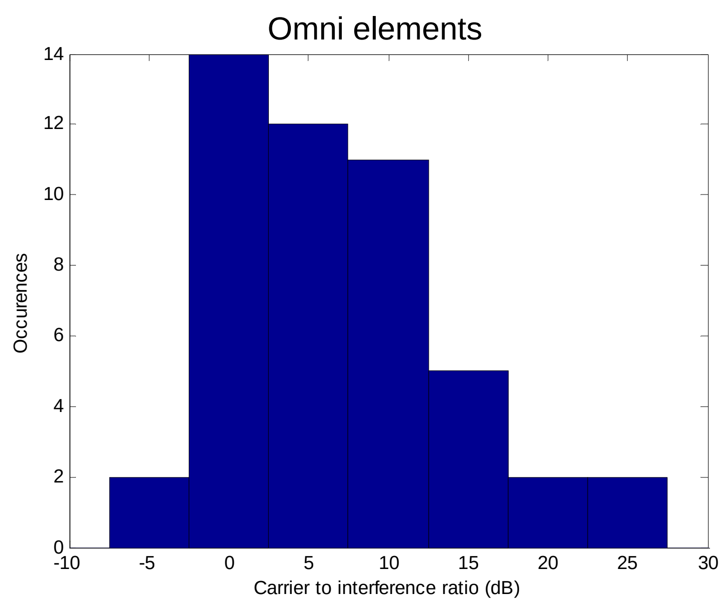
$$C = \log_2 \det\left(I_{N_R} + \frac{SINR}{N_T} \mathbf{HH}^H \right)$$

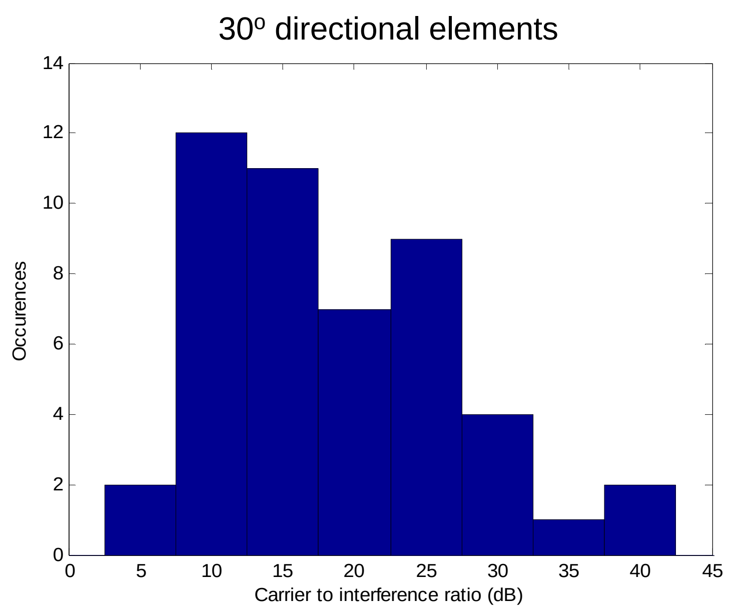
- Co-Channel Interference (CCI) has a harmful effect on capacity (depending on the frequency reuse plan)
- Key challenges include improving throughput, spectrum efficiency and coverage



C/I Distributions

- Systems with directional antenna are likely to ‘see’ high coverage through the use of higher link-speeds
- Performance of Interference Cancellation (IC) depends on the specific channel characteristics





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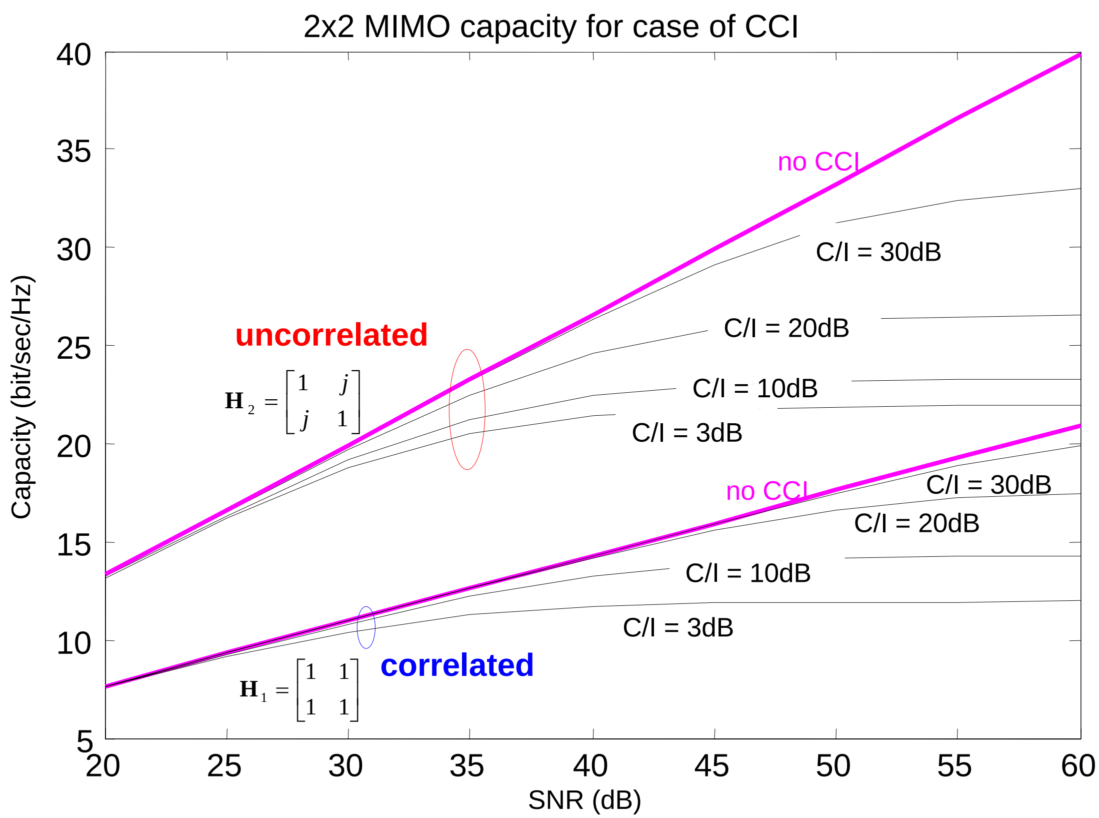
Interference in multi BS environment (2)

- MIMO spatial correlation further reduces capacity



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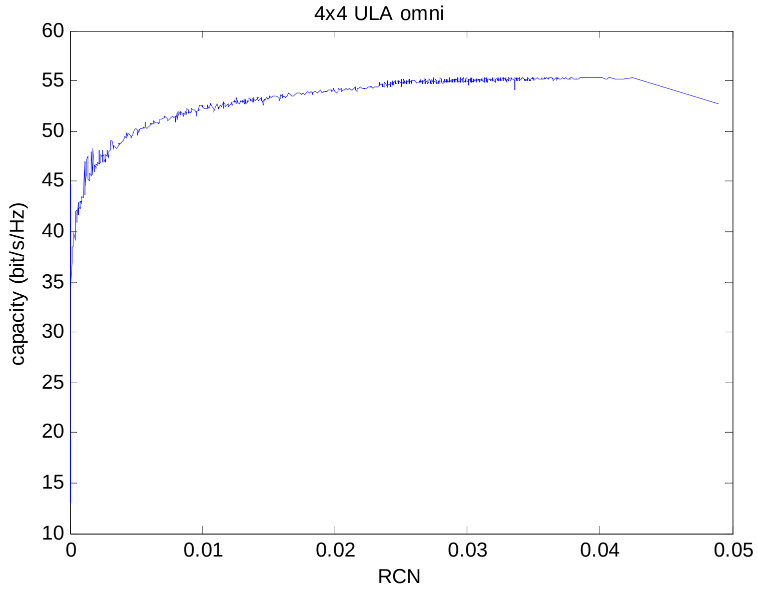
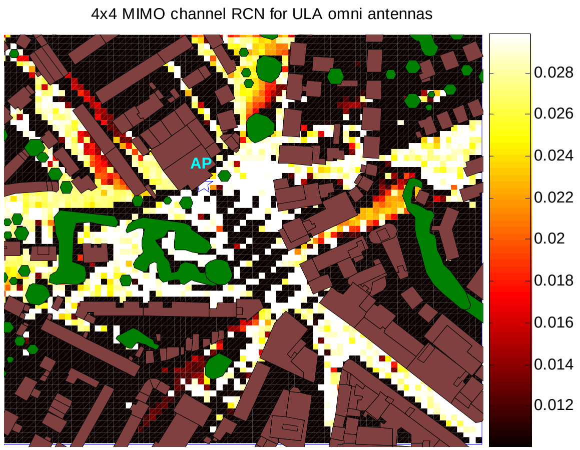
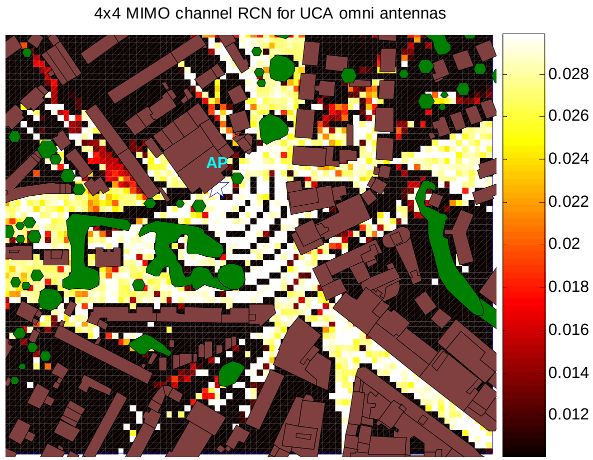
Array Geometry Impact on MIMO Performance

- RCN values quantify MIMO spatial correlation and reflect channel capacity
- ULA geometry works well when the channel is characterized by low correlation
- When MIMO channels are highly correlated, UCA structures outperform their ULA counterparts



RCN: Reciprocal Condition Number
ULA: Uniform Linear Array
UCA: Uniform Circular Array





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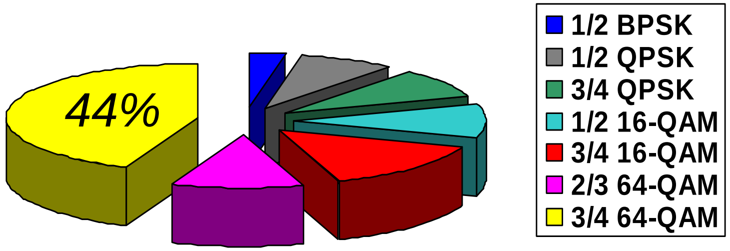
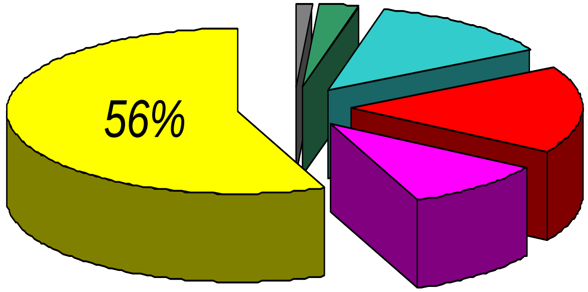
Results Analysis

- In the presence of CCI, there is a trade-off between interference suppression (using narrow beamwidths) and diversity gain (using wider beamwidths).
- We recommend:
  - Wide MIMO element spacings (e.g. 5λ for the BS and 0.5λ for the CPE);
  - Deploying MIMO arrays in the horizontal plane. UCA (4x4 MIMO) works well for open areas.
- Compared to SISO, the sectorised 2x2 MIMO system improved coverage of the highest link speed by 12%. Hence system throughputs are improved by 1.5Mbps.



SISO system throughputs: 11.4Mbps



2x2 MIMO system throughputs: 12.9Mbps

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Conclusions

- Radio channel plays an important role in system evaluation. Our RTD-MIMO can simulate propagation across transition regions, and thus presents a unique insight into system coverage and throughput.
- We have demonstrated WiMAX performance in a practical urban environment, and shown degradation due to path loss, spatial correlation and inference.
- Our results show that:
  - Sectorised antenna system consistently offers higher C/I than omni antenna equivalents. However, they still cannot achieve full coverage and high throughputs on their own
  - Sectorised MIMO arrays offer significant benefits (i.e. the 1.5Mbps improvement seen in this study), even with many LoS channels