



Doufexi, A., Tameh, EK., Williams, C., Nix, AR., Beach, MA., & Prado-Miguel, A. (2006). Capacity and coverage enhancements of MIMO WLANs in realistic environments. In *2006 IEEE International Conference on Communications (ICC 2006)* (pp. 4297-4302). Institute of Electrical and Electronics Engineers (IEEE).  
<https://doi.org/10.1109/ICC.2006.255756>

Peer reviewed version

Link to published version (if available):  
[10.1109/ICC.2006.255756](https://doi.org/10.1109/ICC.2006.255756)

[Link to publication record in Explore Bristol Research](#)  
PDF-document

## University of Bristol - Explore Bristol Research

### General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:  
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

# Capacity and Coverage Enhancements of MIMO WLANs in Realistic Environments

Angela Doufexi, Eustace Tameh, Chris Williams, Andrew Nix, Mark Beach, Arantxa Prado

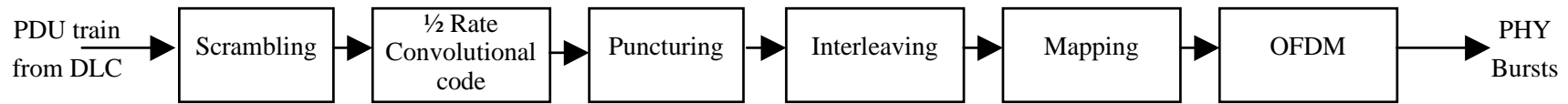
Centre for Communications Research  
University of Bristol, Bristol



# Overview

- Work combines a WLAN physical layer simulator with a 'hotspot' propagation modelling tool.
- MIMO-OFDM solutions are evaluated in terms of coverage and throughput for 2x2 and 4x4 arrays.
- PER and throughput results are produced for a range of *realistic* channel groups.
- Ray modelling is used to determine the SNR and the most appropriate channel type.
- Throughput and PER maps are then generated for a site-specific 'hot spot'.
- Recommendations given for use of MIMO in future standards, such as 802.11n.

# Physical Layer of OFDM based WLANs



- Data is supplied to the physical layer in the form of an input PDU train.
- The data is input to a scrambler that prevents long runs of 1s and 0s.
- The scrambled data is input to a  $\frac{1}{2}$  rate convolutional encoder.
- The puncturing schemes facilitate the use of the code rates:  $\frac{1}{2}$ ,  $\frac{3}{4}$ ,  $\frac{9}{16}$  and  $\frac{2}{3}$ .
- The coded data is interleaved in order to prevent error bursts from being input to the convolutional decode process in the receiver.
- The interleaved data is subsequently mapped to data symbols according to either a BPSK, QPSK, 16-QAM or 64-QAM scheme.
- The OFDM modulation is implemented by means of an IFFT.

# WLAN Physical Layer: Mode Dependent Parameters

Mode	Modulation	Coding Rate R	Bit rate [Mbit/s]
1	BPSK	1/2	6
2	BPSK	3/4	9
3	QPSK	1/2	12
4	QPSK	3/4	18
5 ( 802.11a/g)	16QAM	1/2	24
5 (H/2)	16QAM	9/16	27
6	16QAM	3/4	36
7	64QAM	3/4	54
8 ( 802.11a/g)	64QAM	2/3	48

# Space Time Block Codes and Spatial Multiplexing

- For STBC with 2 Tx antennas, the transmission matrix, is given by:

$$\mathbf{X} = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix}$$

where  $X_1, X_2$  are two consecutive vectors.

- For STBC with 4 Tx antennas, the transmission matrix  $G_4$ , is given by:

$$\begin{bmatrix} X_1 & X_2 & X_3/\sqrt{2} & X_3/\sqrt{2} \\ -X_2^* & X_1^* & X_3/\sqrt{2} & -X_3/\sqrt{2} \\ X_3^*/\sqrt{2} & X_3^*/\sqrt{2} & (-X_1 - X_1^* + X_2 - X_2^*)/2 & (-X_2 - X_1^* + X_1 - X_2^*)/2 \\ X_3^*/\sqrt{2} & -X_3^*/\sqrt{2} & (X_1 - X_1^* + X_2 + X_2^*)/2 & -(X_2 + X_1^* + X_1 - X_2^*)/2 \end{bmatrix}$$

- where in the case of OFDM,  $X_1, X_2, X_3$ , are consecutive vectors before the IDFT operation. This is a  $3/4$  code for complex constellations.
- For Spatial Multiplexing linear processing detection techniques include zero forcing (ZF) and minimum mean squared (MMSE). In this study an MMSE detection algorithm was used.

# Simulation Setup

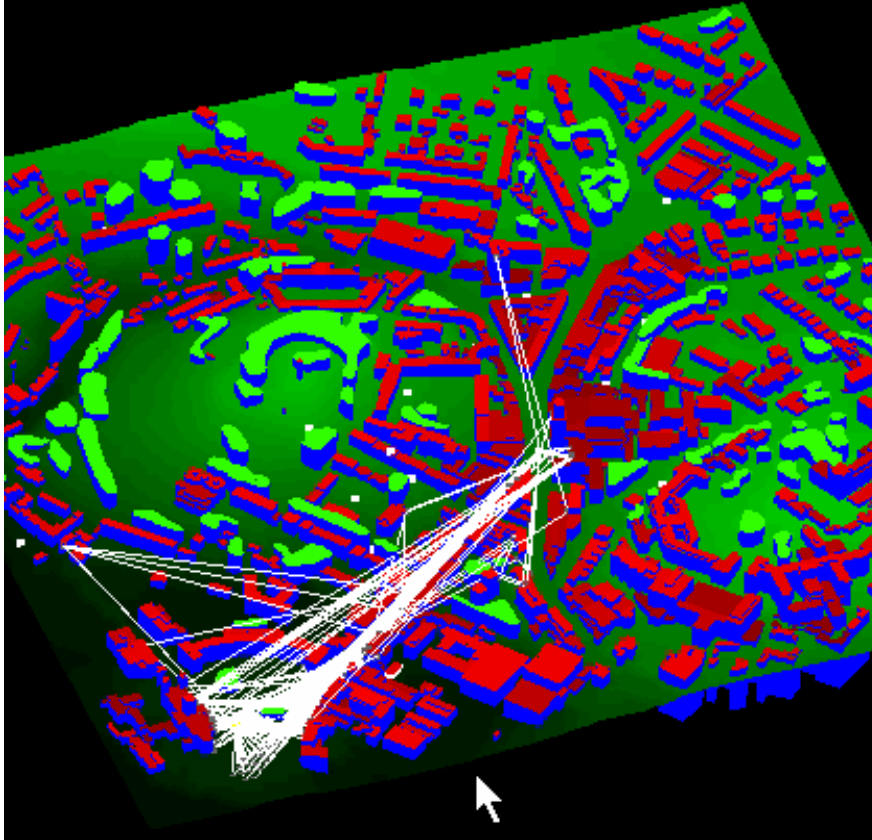
- A number of channel scenarios that represent the most probable environments for WLAN operation in the 5GHz band were defined (see next slide for examples).
- These scenarios correspond to different values of rms delay spread, K-factor and angular spread.
- Link level simulations were performed for all channel scenarios for 2x2 and 4x4 MIMO-OFDM to obtain PER and throughput results.
- Throughput maps for our outdoor 'hot spot' are then produced.

# Channel Scenarios $H_{rmsdelay\_Kfactor\_angularspread}$

Channel Scenario	rms delay spread	K factor	Angular width
H_20_0_60	20 ns	Rayleigh	60°
H_20_0_90	20 ns	Rayleigh	90°
H_20_0_360	20 ns	Rayleigh	360°
H_20_5_60	20 ns	5 dB	60°
H_20_5_90	20 ns	5 dB	90°
H_20_5_360	20 ns	5 dB	360°
H_20_10_60	20 ns	10 dB	60°
H_20_10_90	20 ns	10 dB	90°
H_20_10_360	20 ns	10 dB	360°
H_50_0_60	50 ns	Rayleigh	60°
H_50_0_90	50 ns	Rayleigh	90°
H_50_0_360	50 ns	Rayleigh	360°
H_50_5_60	50 ns	5 dB	60°
H_50_5_90	50 ns	5 dB	90°
H_50_5_360	50 ns	5 dB	360°
H_50_10_60	50 ns	10 dB	60°
H_50_10_90	50 ns	10 dB	90°
H_50_10_360	50 ns	10 dB	360°
H_150_0_60	150 ns	Rayleigh	60°
H_150_0_90	150 ns	Rayleigh	90°
H_150_0_360	150 ns	Rayleigh	360°
H_150_5_60	150 ns	5 dB	60°
H_150_5_90	150 ns	5 dB	90°
H_150_5_360	150 ns	5 dB	360°
H_150_10_60	150 ns	10 dB	60°
H_150_10_90	150 ns	10 dB	90°
H_150_10_360	150 ns	10 dB	360°



# Channel Modelling

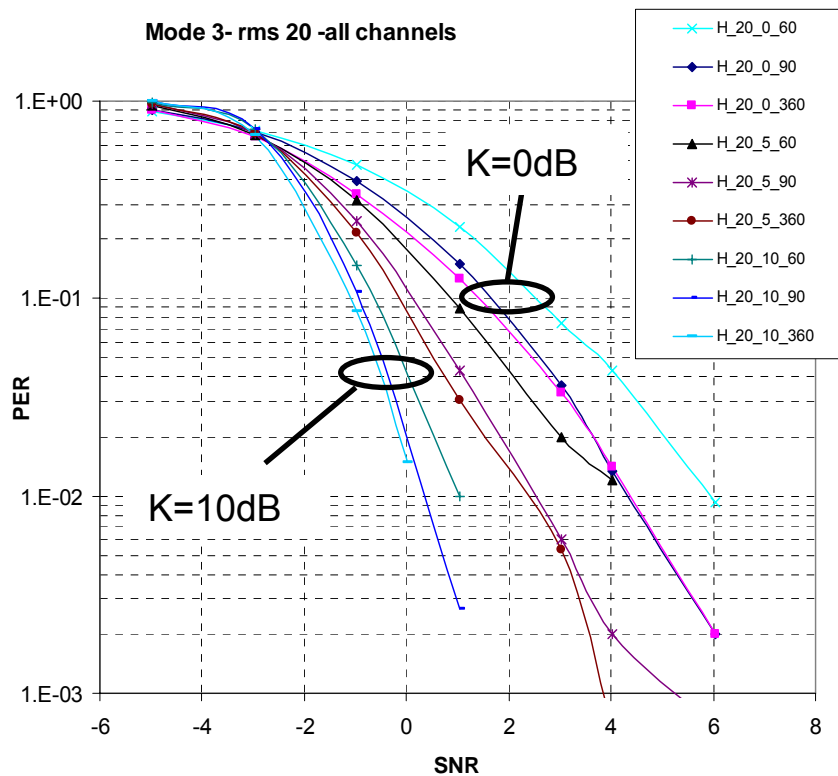


- Characterisation of MIMO channel at 5.2GHz
  - Ray tracing predictions at a hot spot type scenario (AP 5m, MT 1.5m above ground, vertically polarised  $\lambda/2$  dipoles)
  - EIRP 25dBm
- 
- Models 'hot spot' environment and antenna arrays
  - Provides full ray data for each link in the MIMO channel

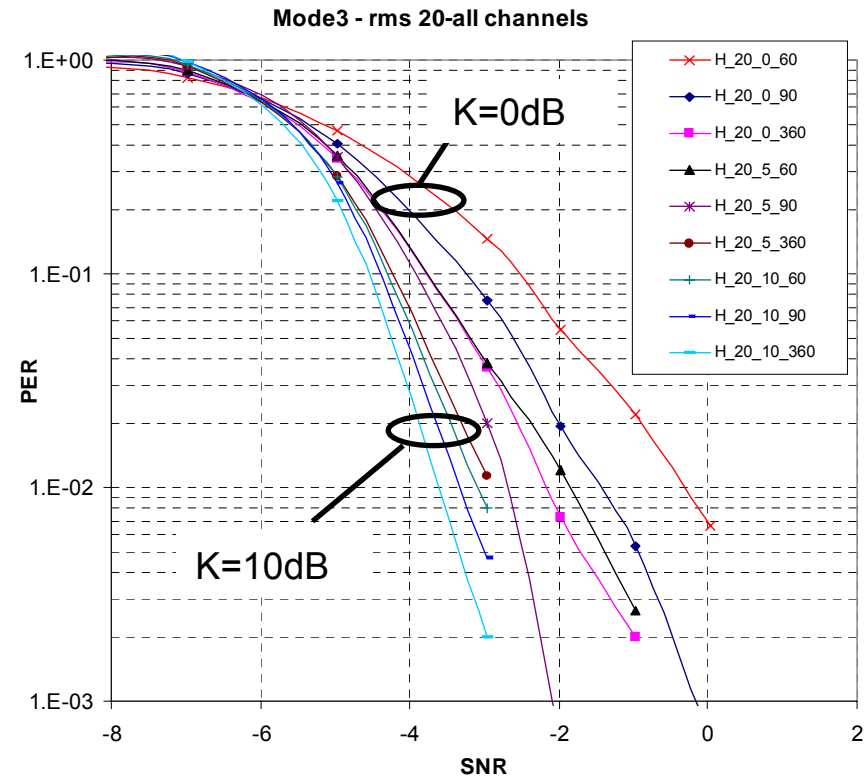
# Classification of the model-based channels

- Using the propagation modelling tool, the MIMO channel response was predicted for every point in the grid.
- Channel information includes SNR values, MIMO channel response ( $\mathbf{H}$ -matrix), K-factor, rms delay spread and angular spread.
- Using the above parameters, the channel at each location was classified based on the closest corresponding pre-defined group.
- Since the PER and throughput performance for each pre-defined group is known as a function of SNR, for each location we are able to map the expected throughput.

# Performance of STBC for different channel scenarios



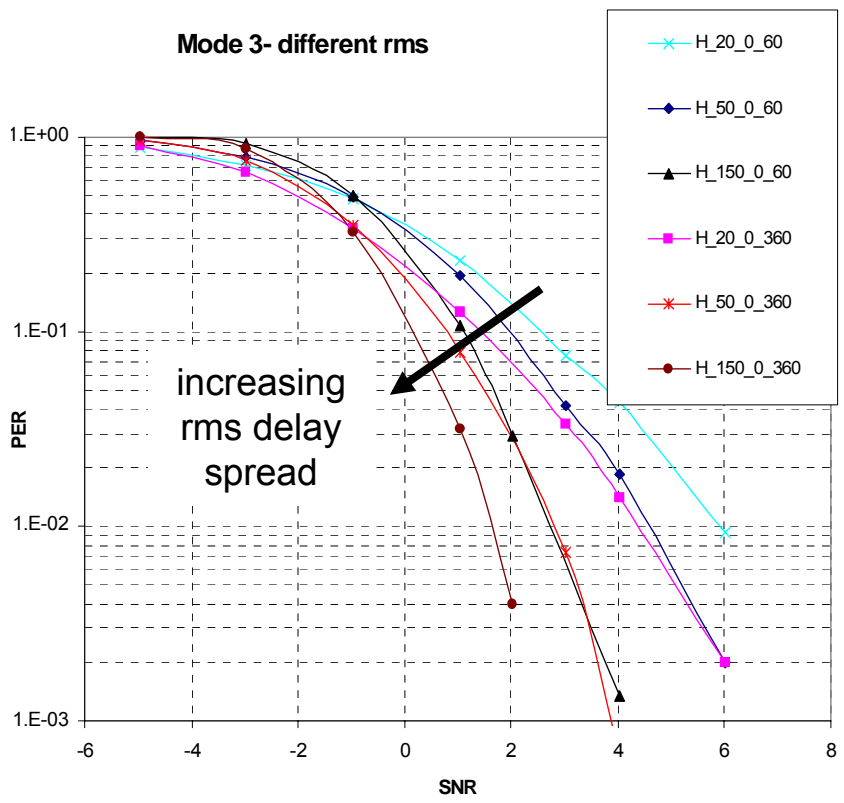
2x2



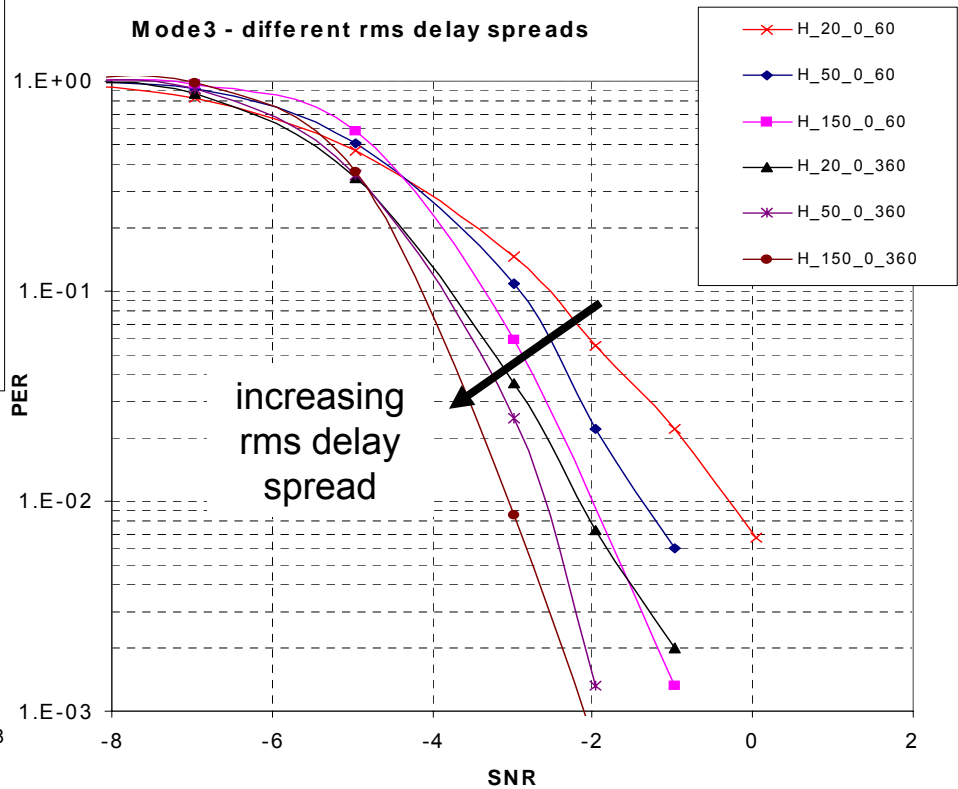
4x4

- As the K-factor increases, the PER lowers.
- Degradation in performance for low angular spread.

# Performance of STBC for different rms delay spread



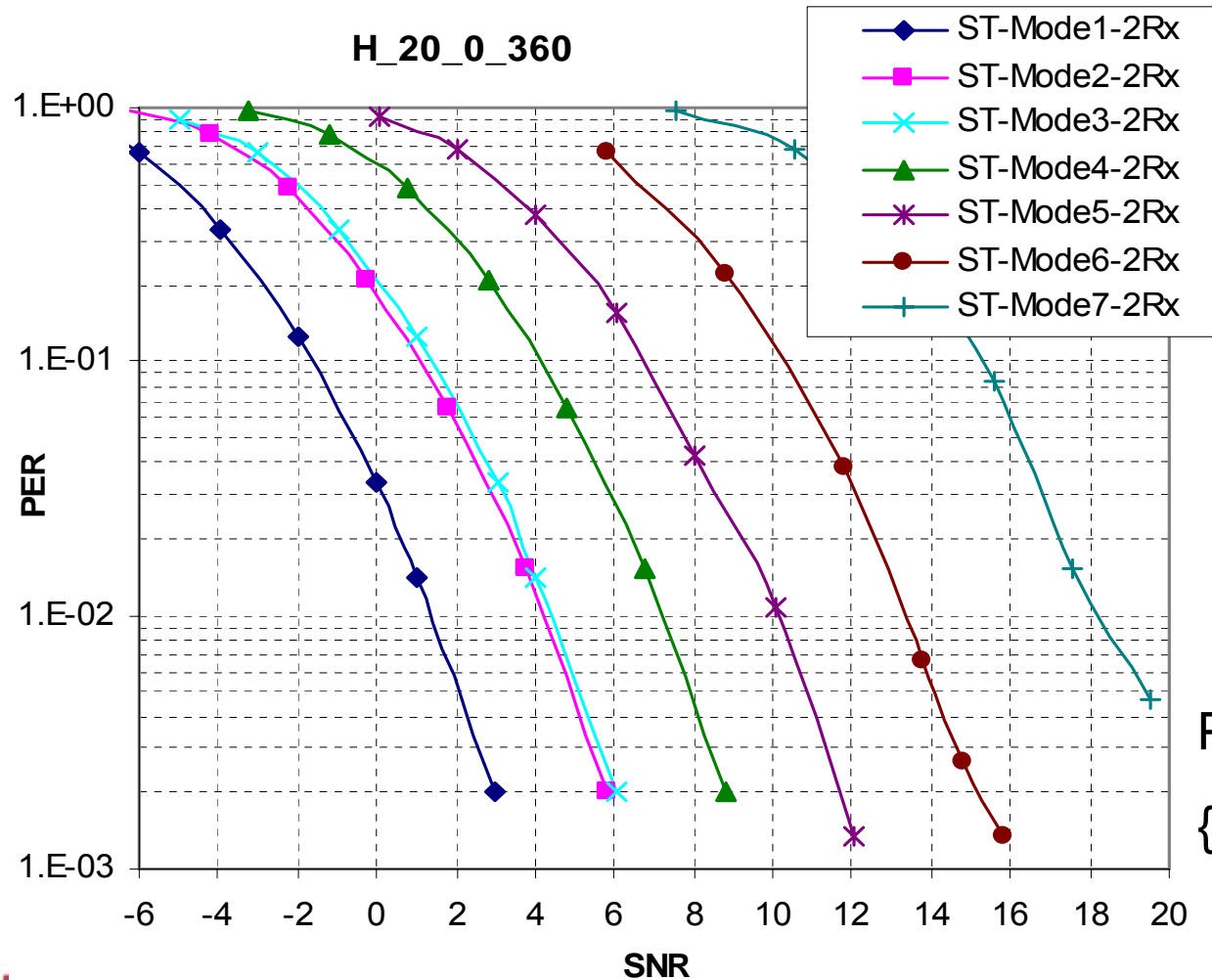
2x2



4x4

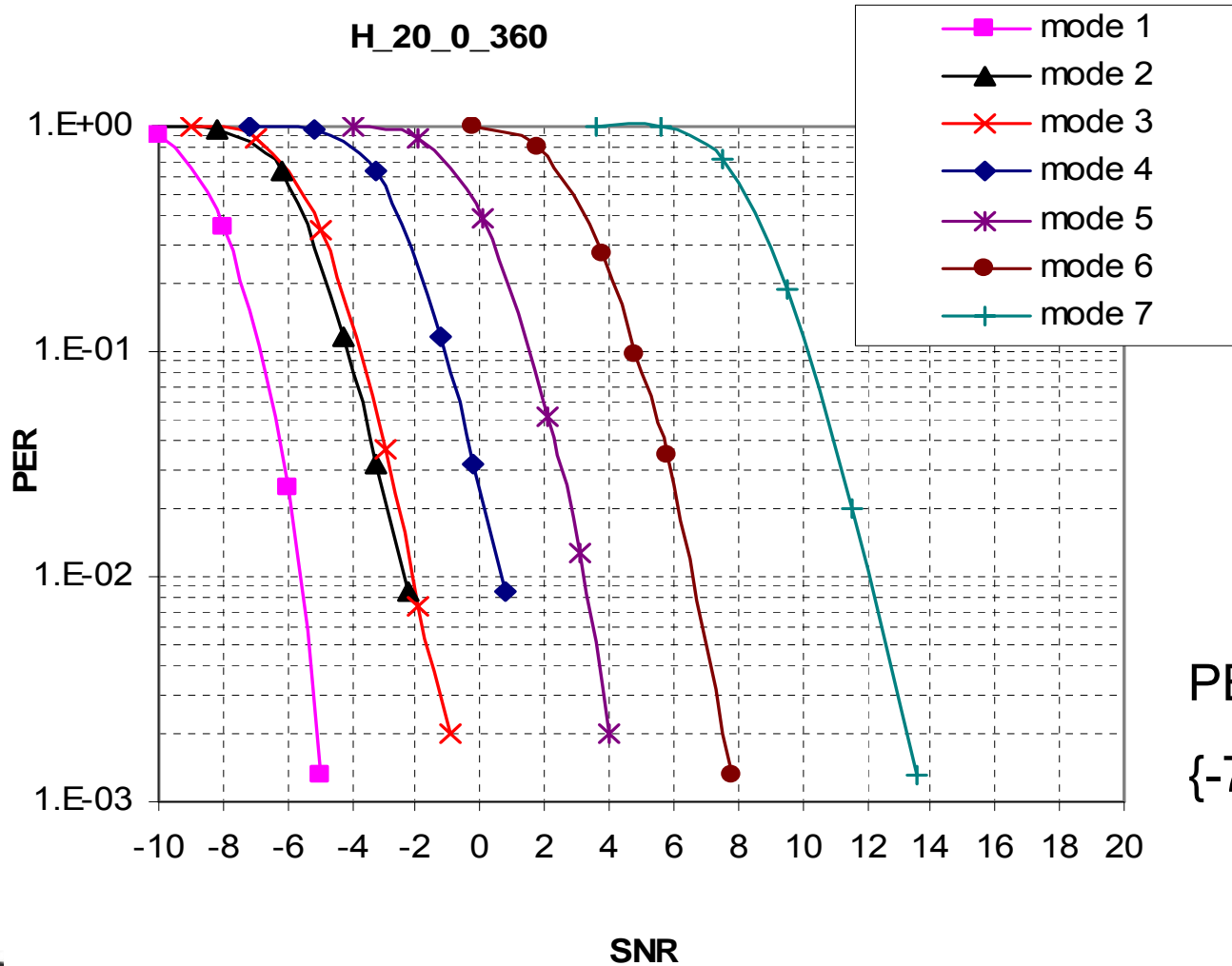
• PER lowers with increased rms delay spread.

# PER vs SNR (2x2) all modes



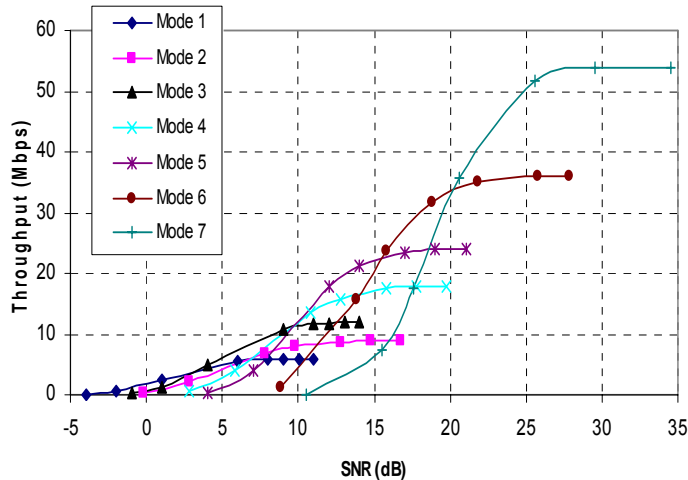
PER = 10%  
{-2 to 15 dB}

# PER vs SNR (4x4) all modes

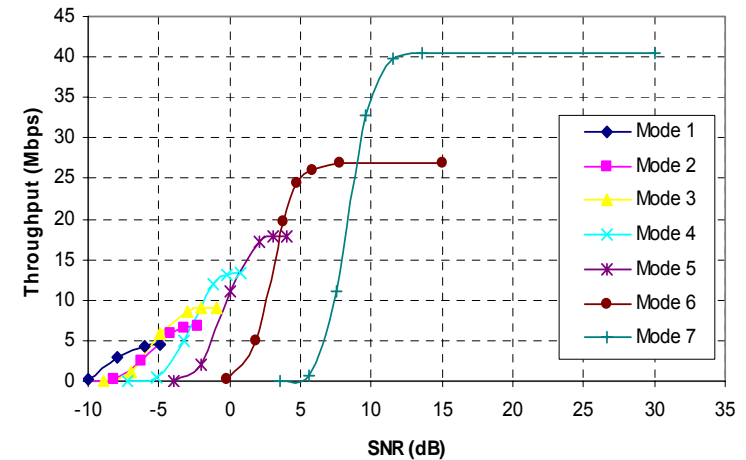


PER = 10%  
{-7 to 10 dB}

# Throughput Performances



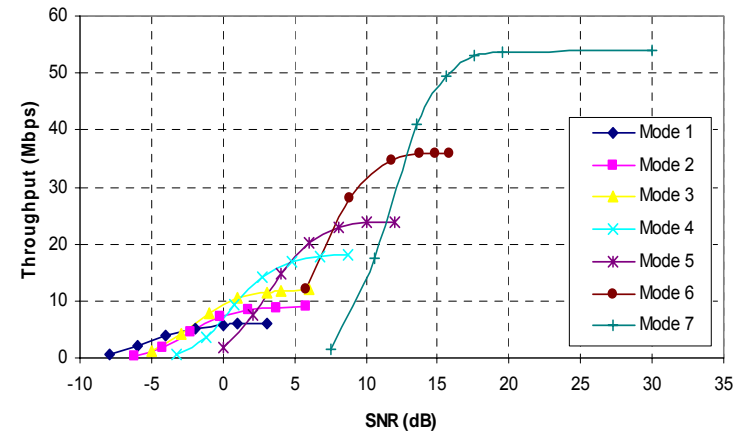
1x1



4x4

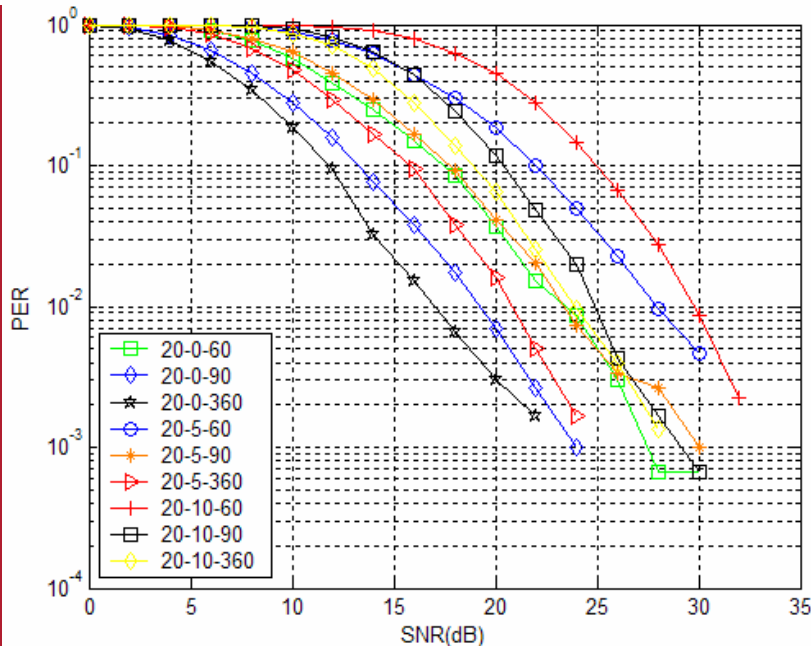
- SNR=5dB, 1x1 7 Mb/s, 2x2 17 Mb/s, 4x4 26 Mb/s
- SNR=20dB, 1x1 34 Mb/s, 2x2 54 Mb/s, 4x4 40 Mb/s
- For higher values of SNR, the 4x4 throughput performance is outperformed by the 2x2 system since the 4x4 STBC is not full rate ( $\frac{3}{4}$  code)

Link Throughput 2Tx-2Rx- H\_20\_0\_360

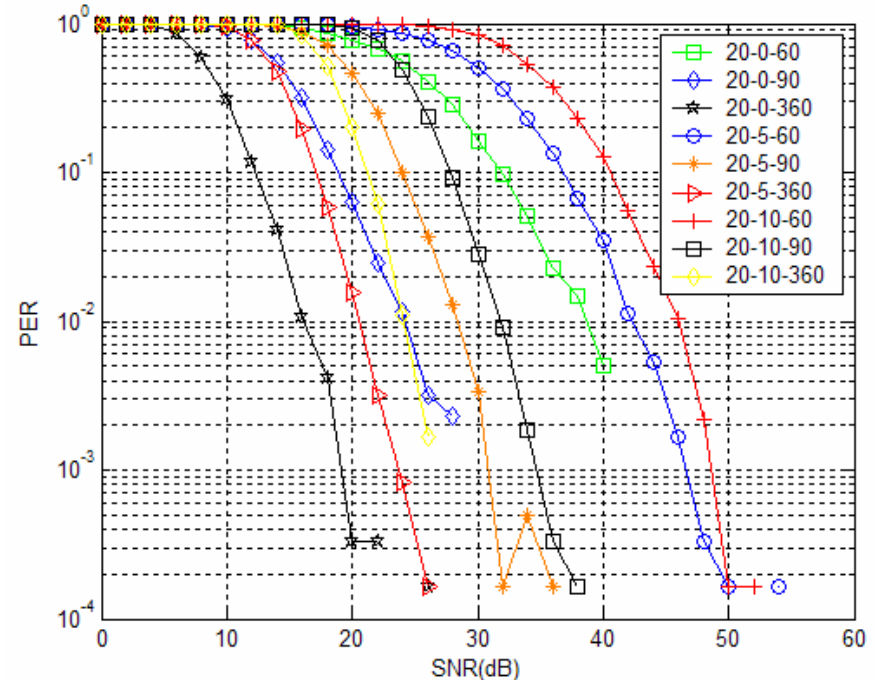


2x2

# Performance of SM mode 3 for different K-factor and angular spread



2x2

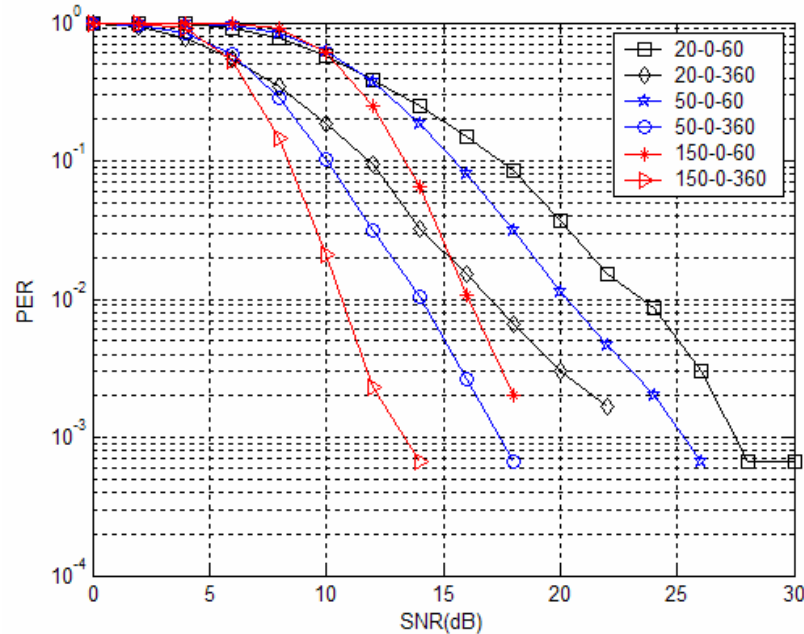


4x4

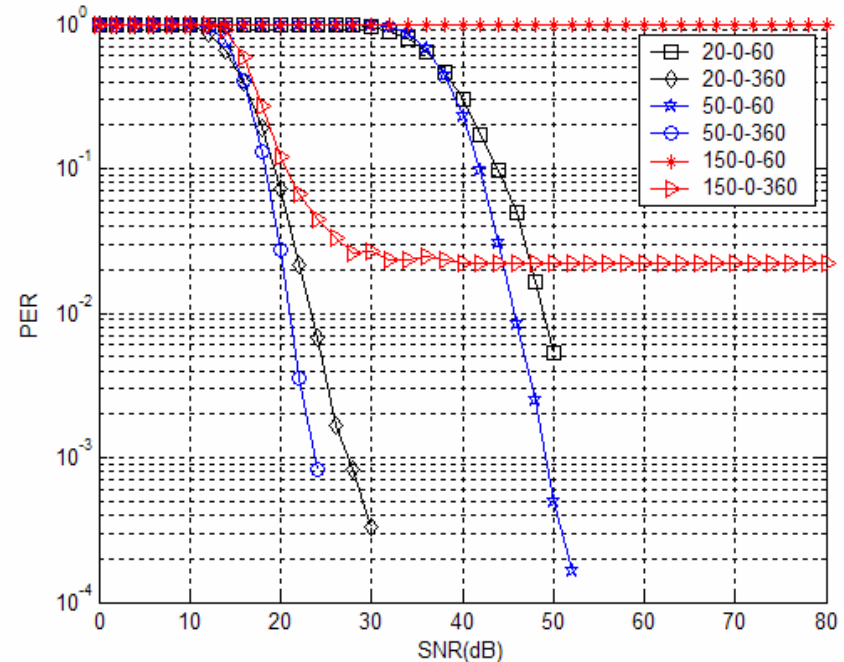
- The K factor introduces more correlation between the channel paths and reduces the capacity of the channel, which results in a degradation in performance
- Degradation in performance for low angular spread.



# Performance of SM for different rms delay spreads



Mode 3

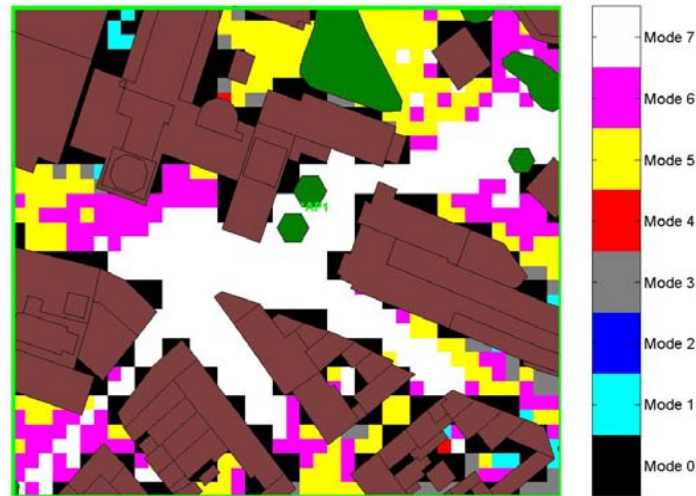


Mode 5

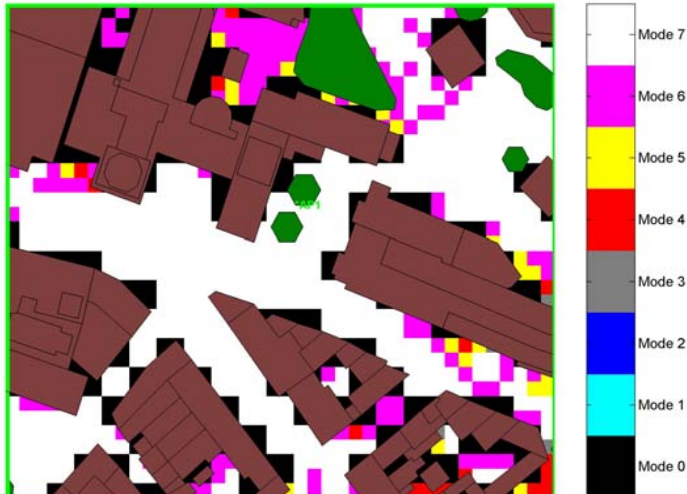
- For channels with high angular spread and RMS delay spread there is performance improvement on the lower transmission modes.
- Higher modes experience an error floor in channels with high RMS delay spread since ISI is introduced (excess delay of the channel is larger than the guard interval).

# Mode Maps

200m x 200m area of downtown Bristol

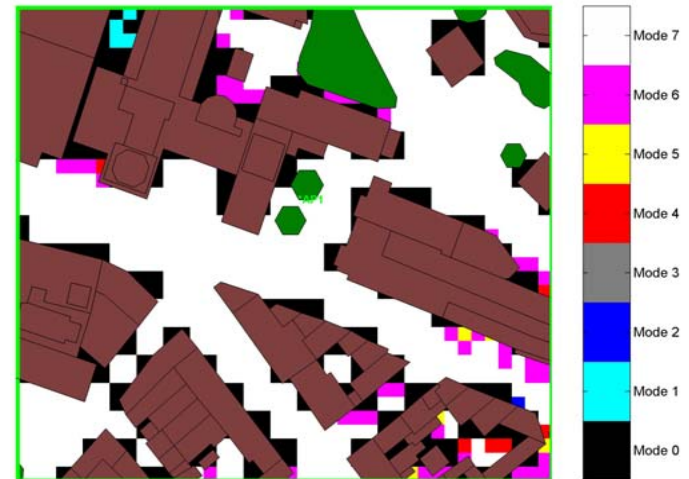


1x1



2x2

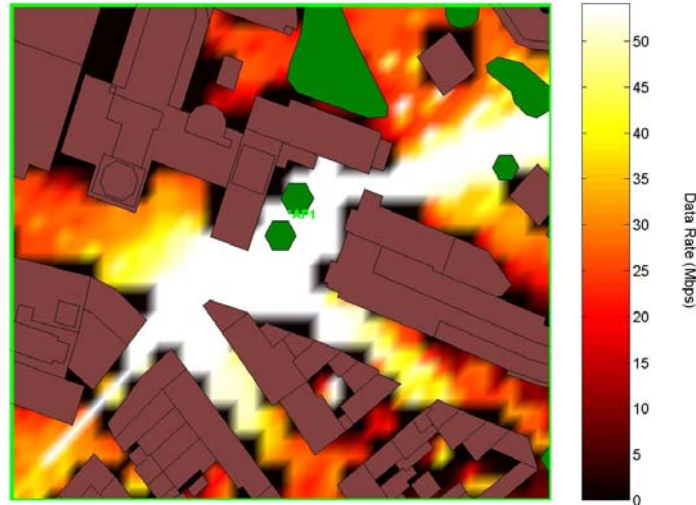
transmit EIRP of 25dBm



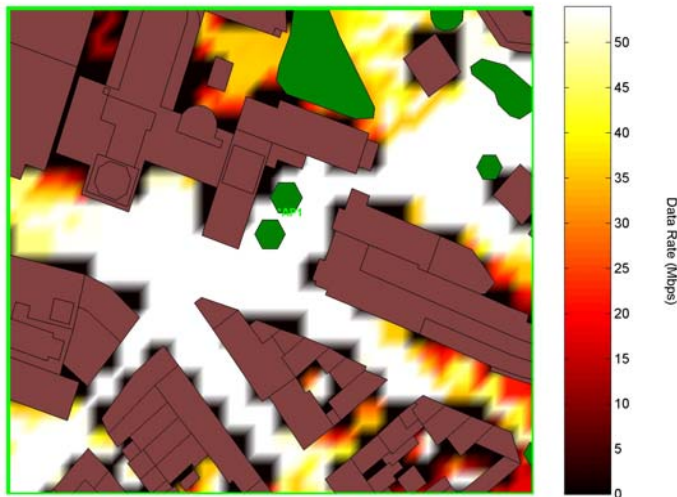
4x4

# Throughput Maps

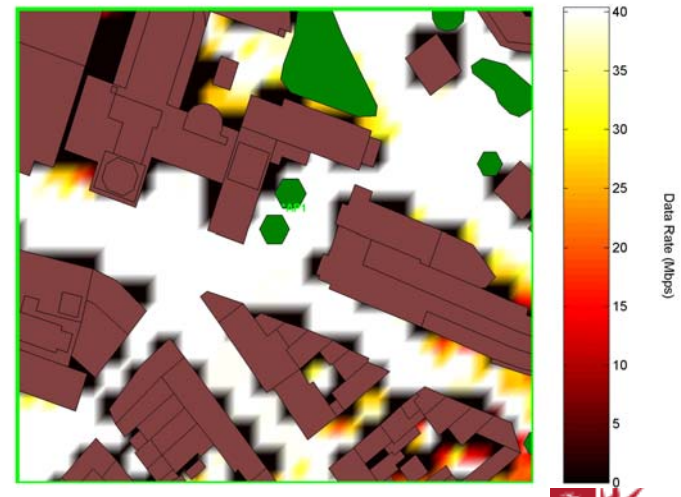
Compared to the SISO case, STBC can provide higher throughputs throughout the coverage area



1x1



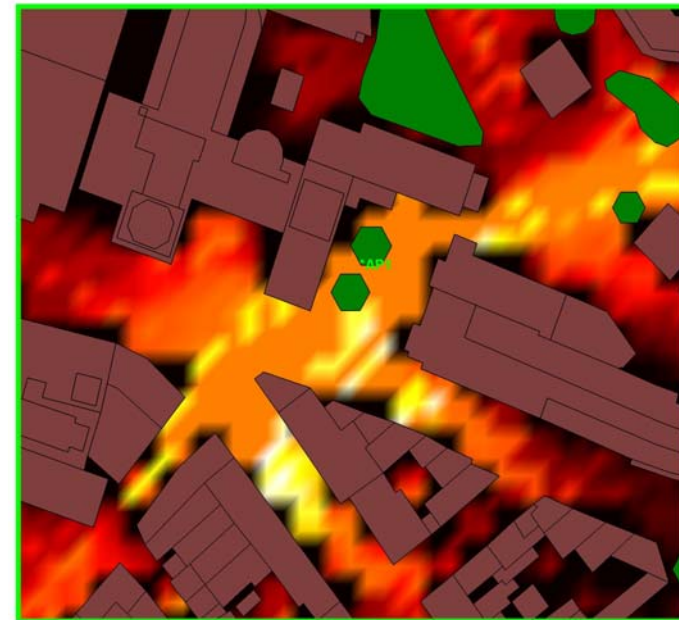
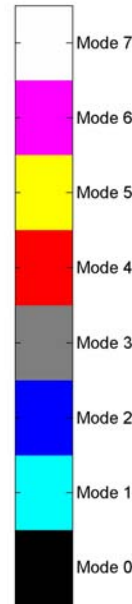
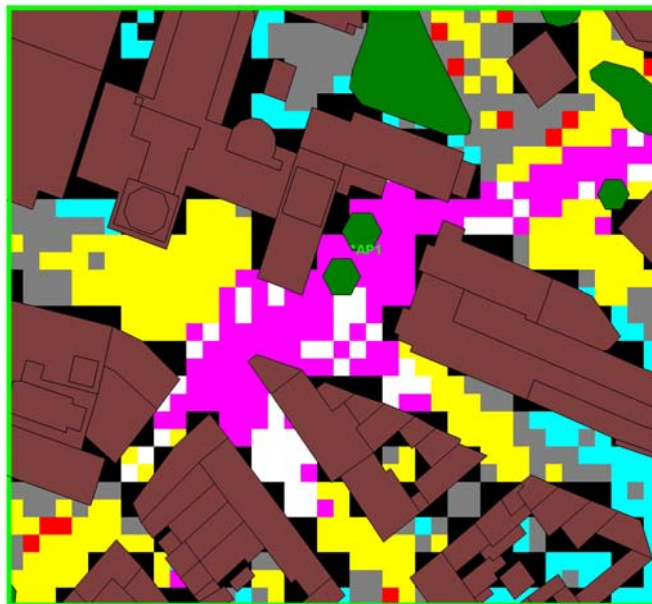
2x2



4x4

# Spatial Multiplexing

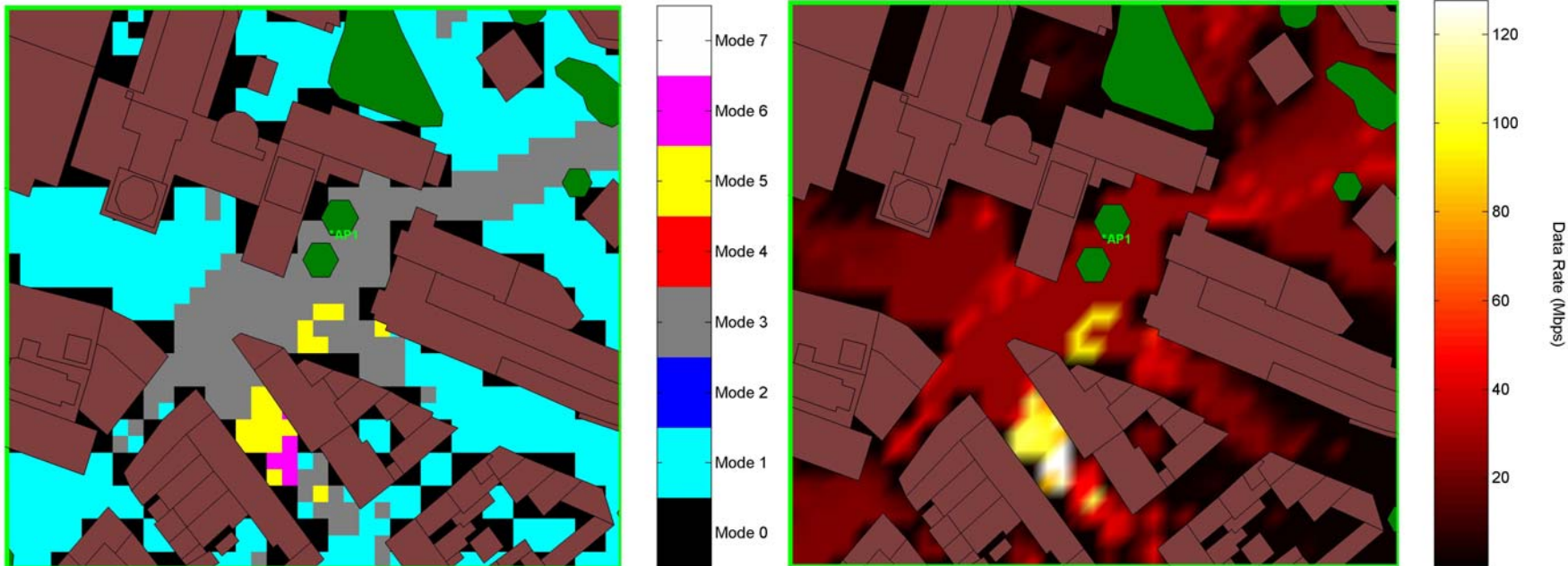
- Modes and Throughput achieved with 2x2 SM



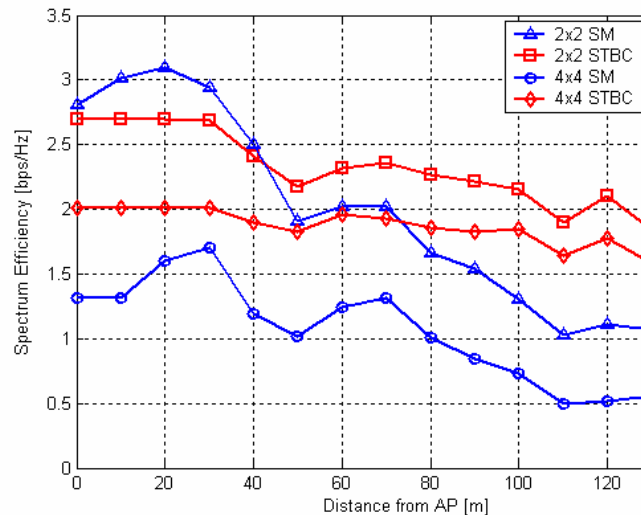
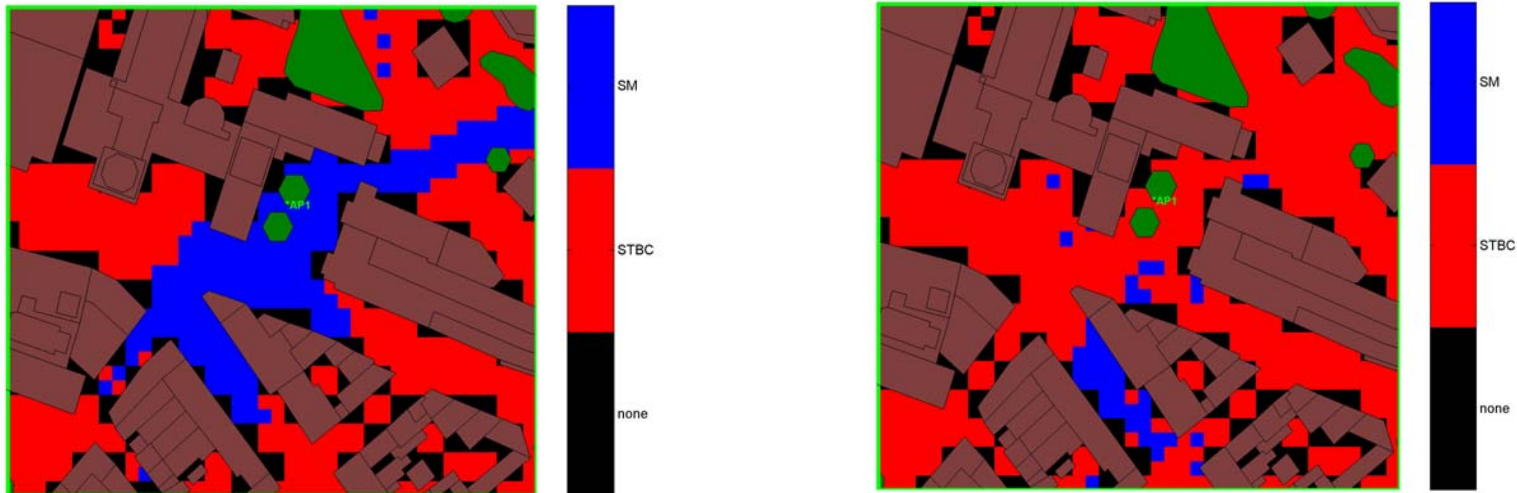
Data Rate (Mbps)

# Spatial Multiplexing

- Modes and Throughput achieved with 4x4 SM



# Best Technique and Average Spectrum Efficiency



# Conclusions

- MIMO PER performance results for the case of 2x2 and 4x4 antennas under different channel conditions were presented.
- Throughput maps were produced showing that significant enhancements can be achieved in both cases. The potential channel capacity is strongly dependent on the channel characteristics.
- STBCs are more able to maintain communication than SM when channels are strongly correlated.
- SNR is a dominant factor in performance, and so system design must not lose sensitivity/gain while trying to minimise channel correlation.
- The capacity gain as a function of the number of antennas has been seen to be less than linear in realistic channels.
- Performance can degrade with larger numbers of antennas if the channel cannot support sufficient spatial modes for the algorithm being used. This degradation is more severe for the SM algorithms studied in this project.