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Throughput Sensitivity to Antenna Pattern and Orientation in 802.11n Networks

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Background

- 802.11n offers a range of new high throughput modes by exploiting MIMO signal processing.

- High throughput and low packet loss rate opens up the possibility of high quality video streaming around the home.

- Many multiple service operators (MSOs) are exploring the viability of streaming high-definition video around the home from a set top box.

- This application requires robust high throughput links to most rooms in the home.

- 802.11n antenna solutions are often ignored even though they represent one of the biggest areas for product differentiation.

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Introduction

- To achieve the headline rates in 802.11n a very high SNR is required, and this is only possible in near-ideal conditions.

- Modulation and Coding Scheme (MCS) adaptation is vital to match the data rate to the quality of the link.

- For MIMO systems we also need to dynamically adapt the number of concurrent spatial streams.

- The antenna configuration and element orientations must be carefully considered at the AP and client.

- We will show that different antenna configurations and orientations have a *very* significant impact on 802.11n performance.

🔥 Test Environment
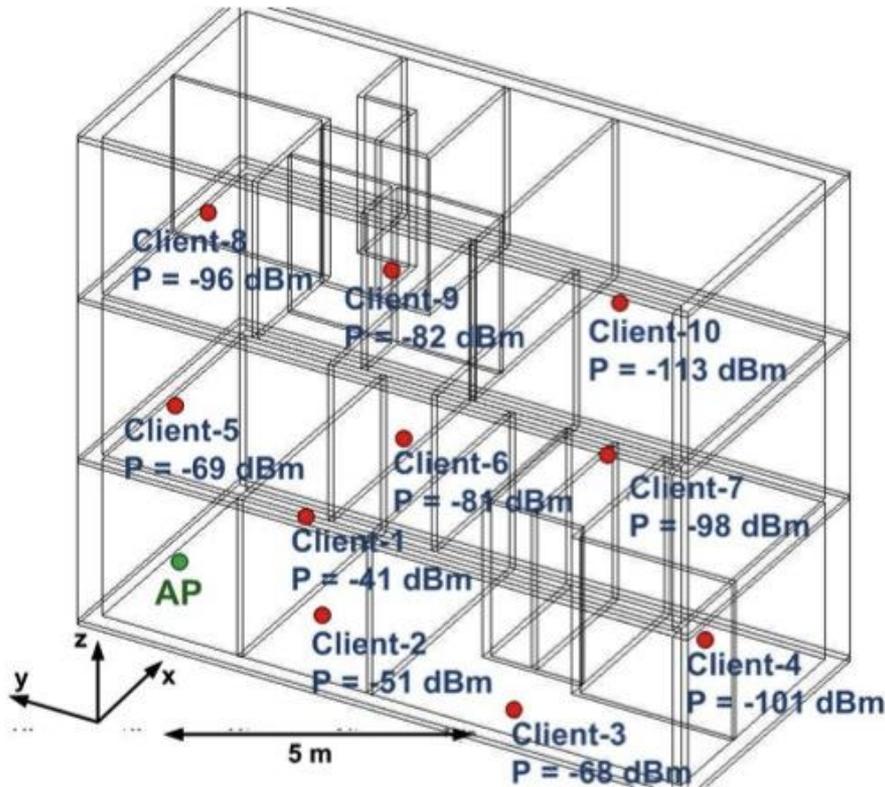
Note: the power levels are shown for a SISO system

- We consider a typical three-storey home with the AP located on the ground floor.

- 10 client locations are distributed around the property – one in each room.

- Spatial and temporal multipath components are modelled using a 3D indoor ray-tracer.

- Analysis is performed at 5GHz with 12dBm transmit power per radio chain.
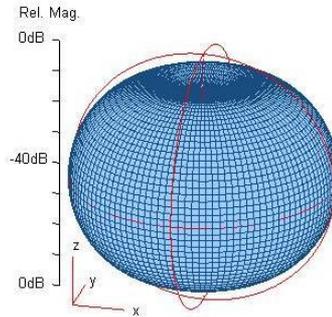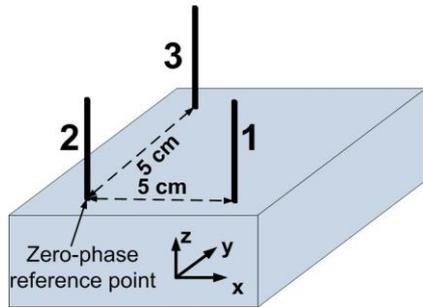
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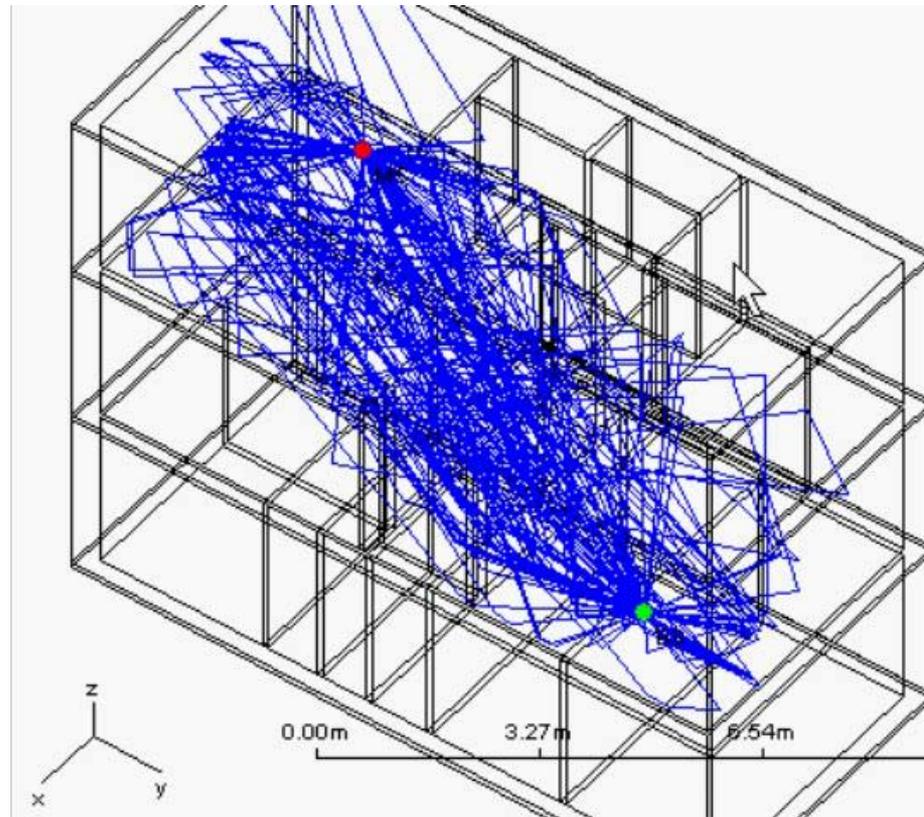
🔥 Antenna Configuration

Configuration A
(Omni-directional elements with 80% efficiency)

Element	Power in Polarisation (%)		Maximum Directivity (dBi)	
	Vertical	**Horizontal**	**Vertical**	**Horizontal**
Omni	100	0	1.8	-
Directional 1	0	100	-	7.9
Directional 2	84	16	7.9	0.4
Directional 3	57	43	7.9	-8.8

Table 1: RADIATION PATTERNS STATISTICS

Configuration B
(Orthogonally oriented and polarised directional elements with 50% efficiency*)
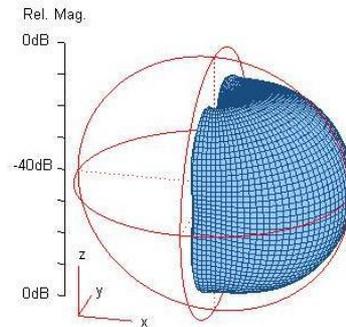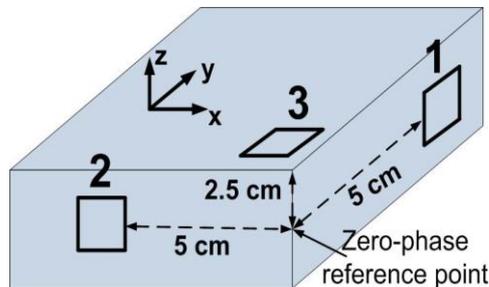
- AP and client use the same array configuration.

- AP orientation fixed; Client rotated in azimuth in steps of 10º.

* We have recently developed dual-resonant patch antennas for the 5GHz band with 90% efficiency

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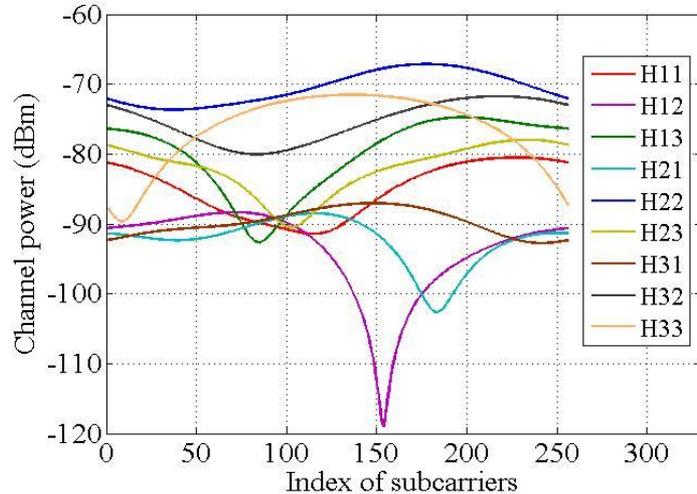CCr centre for communications research

Channel/Antenna Response

Fig. 1: Instantaneous 3x3 frequency response

- The double-directional time-invariant channel impulse response for the mth transmitting and n^{th} receiving antenna link is given by:

$$h_{mn}(\tau,\Omega_{AoD},\Omega_{AoA}) = \sum_{l=1}^{L} h_{m,n,l}(\tau,\Omega_{AoD},\Omega_{AoA}) =$$

$$= \sum_{l=1}^{L} \mathbf{E}_l \delta(\tau - \tau_l)\delta(\Omega_{AoD} - \Omega_{AoD,l})\delta(\Omega_{AoA} - \Omega_{AoA,l})$$

where

$$\mathbf{E}_l = \begin{bmatrix} E_{Tx,m}^V \\ E_{Tx,m}^H \end{bmatrix}^T \begin{bmatrix} a_l^{VV} e^{j\Phi_l^{VV}} & a_l^{VH} e^{j\Phi_l^{VH}} \\ a_l^{HV} e^{j\Phi_l^{HV}} & a_l^{HH} e^{j\Phi_l^{HH}} \end{bmatrix} \begin{bmatrix} E_{Rx,n}^V \\ E_{Rx,n}^H \end{bmatrix}$$

- The MIMO-OFDM channel matrix between the AP and each client is modelled as the spatial convolution of the detailed polarmetric element patterns with the spatial and temporal multipath components.

Link-level Abstraction

- Link-level analysis for large numbers of locations, MCS modes, antenna configurations and element orientations is computationally prohibitive with bit-accurate PHY simulation.

- A novel Received Bit mutual Information Rate (RBIR) abstraction technique is used to efficiently compute PHY layer throughput.

- 5 hours of computing time with a bit-accurate simulator corresponds to just 20 seconds of computing time using the RBIR abstraction technique.

- The RBIR technique allows us to analyse problems that were previously too computationally demanding.
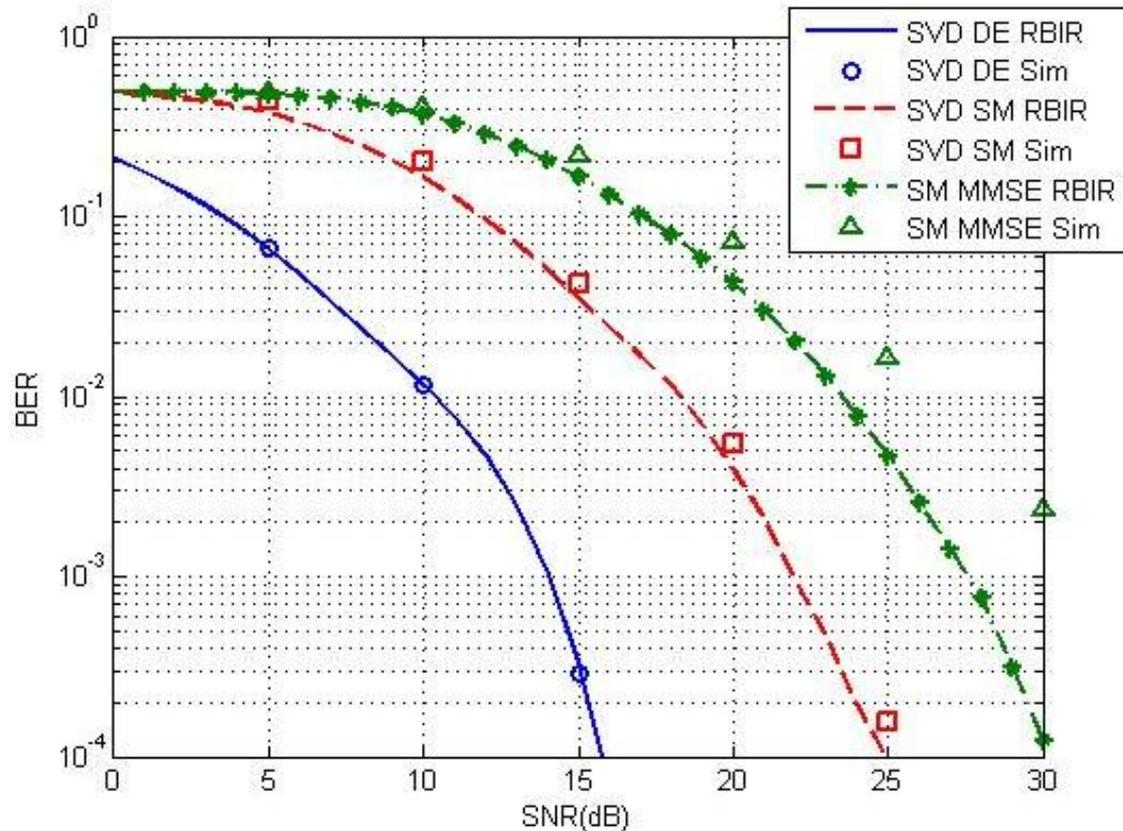
Link-level Abstraction: Verification

Fig. 2: Validation for wideband 2x2 MIMO

Simulation Parameters

- 1000 channel matrix snapshots are used to obtain statistically relevant results for each client location and orientation.

- MIMO Modes: 1, 2 and 3 stream closed-loop eigen-beamforming (EBF) and 3 stream open-loop spatial multiplexing (SM-MMSE) are considered, giving a total of 32 MCS modes.

- Peak Throughputs: 450, 300 and 150 Mbps are achieved for 3, 2 and 1 spatial streams respectively.

- Results are presented for channel-bonded 40MHz transmission using 128 subcarriers in the 5GHz band.

Optimum Selection Algorithm

PHY Layer Throughput

$$T_{j,r} = (1 - PER_{j,r})R_j$$

Optimum Throughput

$$T_r = \max_{j=1:j_{\max},\, PER<0.1} (T_{j,r})$$

j = 1..32 (MCS mode); r = 1..36 (azimuth orientation of client)

For each Location

$$T_{mean} = \frac{1}{36}\sum_{r=1}^{36} T_r$$

$$T_{peak} = \max_{r=1:36}\{T_r\}$$

$$\text{mode} = \operatorname*{argmax}_{j,\, PER<0.1}\{T_{j,r}\}$$

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🔥 Optimum Throughput Results

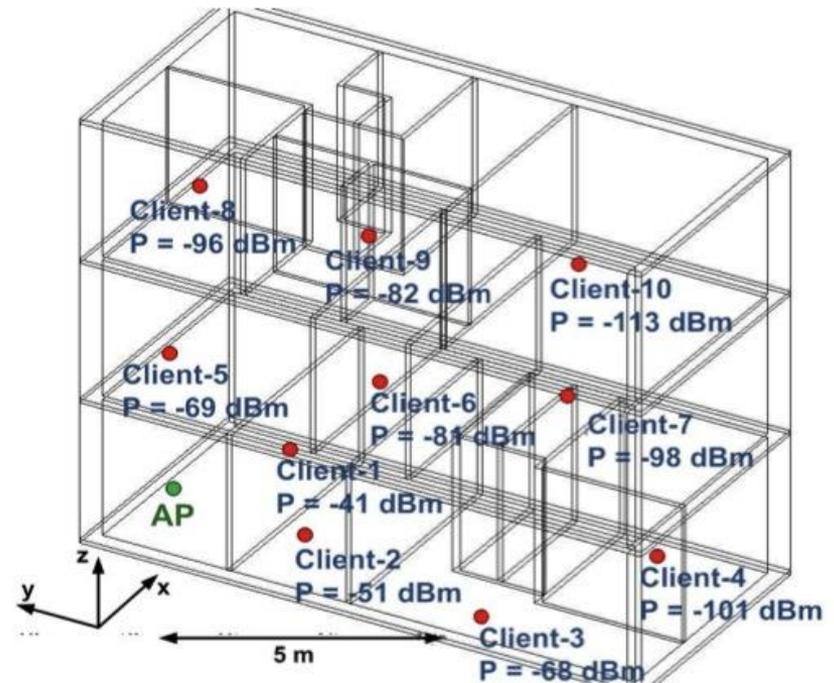| Loc	Mean (dB)		Mean Throughput (Mbps)	
	Dir	Omni	Dir	Omni
1	56.4	52.0	449.6	447.2
2	47.5	42.4	414.4	382.9
3	30.0	24.5	213.3	169.7
4	-6.5	-8.3	None	None
5	39.3	23.9	363.7	287.4
6	18.3	12.0	154.2	86.8
7	-1.1	-5.2	21.0	15.0
8	23.4	-3.1	184.0	15.3
9	16.8	10.6	143.4	118.2
10	-4.5	-20.6	None	None

Table 2: DIRECTIONAL/OMNI PERFORMANCE AT ALL LOCATIONS

- Results compare the performance of our embedded directional elements against large external monopoles (directional vs omni).
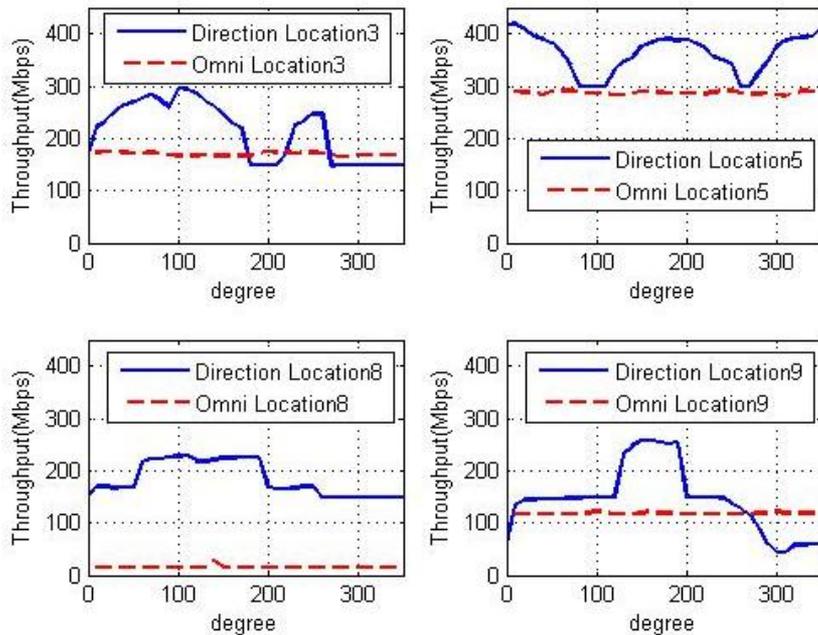
Impact of Antenna Orientation

Fig. 3: Average Directional and Omni Throughputs (1000 realisations) as clients rotate through 360 degrees at locations 3, 5, 8 and 9
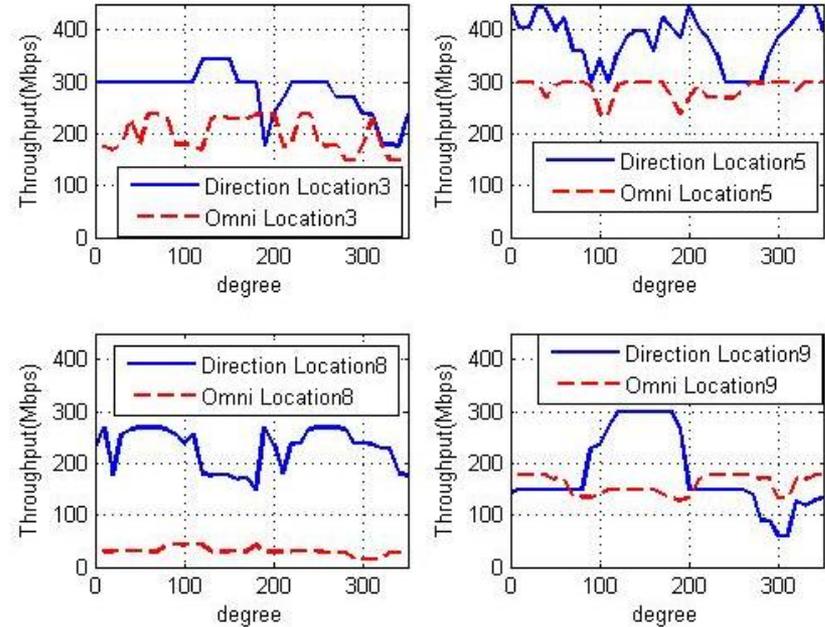
Fig. 4: Instantaneous Directional and Omni Throughputs as clients rotate through 360 degrees at locations 3, 5, 8, 9

Impact of Antenna Orientation

- Average throughput (over 1000 channel snapshots) for omni antennas insensitive to client orientation; however for instantaneous channels omni throughput varies with rotation angle.

- Directional antennas exhibit larger angular variations and these are seen for both average and instantaneous channels.

- For 83% of locations and orientations the throughput observed with our directional elements exceeds that of our omni elements.

Results Discussion

- Directional Antennas
  - low spatial correlation is almost guaranteed
  - spread the mean power per element can differ significantly

- Omni Antennas
  - Similar power level per element is almost guaranteed
  - The spatial fading can become correlated

Conclusions

- The average throughput with directional antennas in 10 test locations and 36 different client orientations was 243 Mbps with random rotation, increasing to 296 Mbps when the client was optimally aligned to the multipath scatter.

- This compared to just 190 Mbps and 195 Mbps respectively for our ideal omni antennas.

- Directional antennas were found to deliver 33% more throughput for random client orientations, increasing to 52% with optimum alignment.

Conclusions

- On average, omni-directional antennas were insensitive to client orientation, although this was not the case for instantaneous throughput.

- Directional antennas had increased sensitivity to rotation, however for 83% of locations and orientations they resulted in enhanced exploitation of the available MIMO resources.

- Directional antennas are easier to embed into the casing of a router or set top box.

Any Questions?

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