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# Closed-loop Antenna Selection for Wireless LANs with Directional & Omni-Directional Elements

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## Abstract


- The system-level performance of a 3x3 Eigen-Beam-Formnig (EBF) 802.11n WLAN solution is compared with a reduced cost 2x2 EBF approach with ideal antenna selection in a home environment. A comparison of directional and omni-directional antennas is considered.
- The in-home propagation channels are modelled using 3D ray tracing and combined with appropriately oriented complex polarmetric antenna radiation patterns.
- PHY layer throughput is calculated for all MCS and (for the 2x2 case) all possible antenna combinations using a novel RBIR abstraction technique [1][2].
- Results show that with ideal antenna selection the performance of 2x2 EBF is competitive, especially when directional antennas are used at low SNR values (3x3 EBF only 15% better).


## Introduction

- WLANs are commonly deployed in the home and office and are used as a wireless extension for the internet. Modern consumer applications like HD video streaming require a cost-effective and reliable high throughput wireless link.
- The recent 802.11n standard for WLANs offers enhanced throughput modes and supports higher quality video streaming applications via the use of MIMO technology.
- To achieve the headline rates in 802.11n a very high SNR is required, and this is only possible in near-ideal channel conditions. MCS adaptation is used to match the data rate to the quality of the link. The antennas used at the AP and client significantly influence the perceived channel quality.
- In order to fully exploit the diversity, spatial multiplexing and array gains available to MIMO systems, the antenna configuration and orientation must be carefully considered, as different antenna configurations and orientations have a significant impact on performance.

## Test Environment & Antenna Configuration

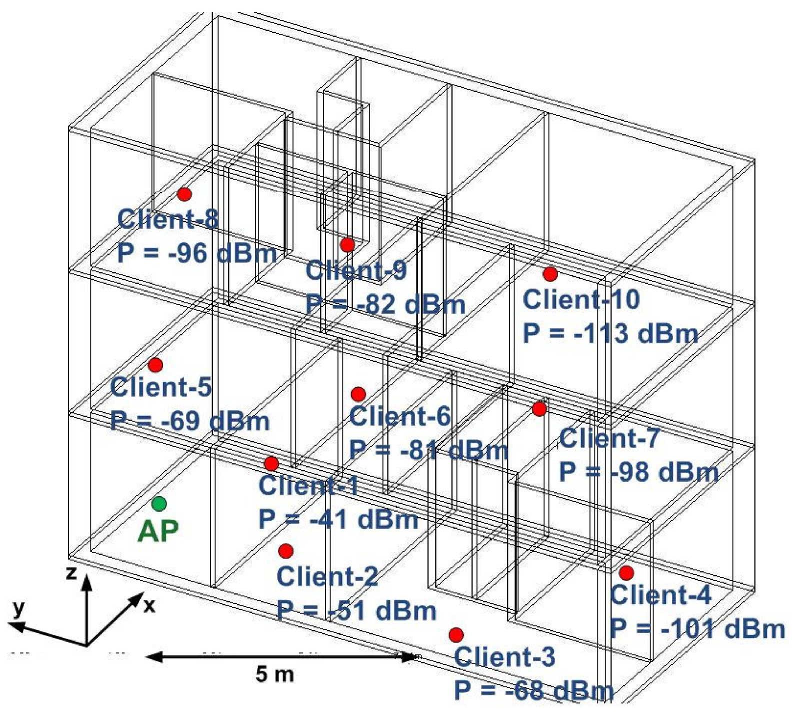
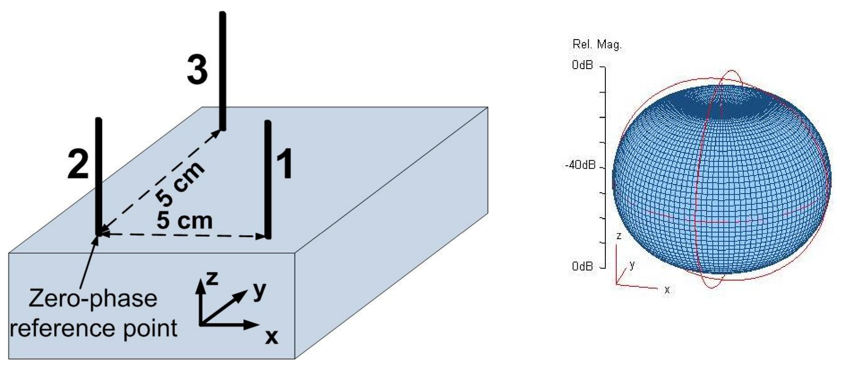
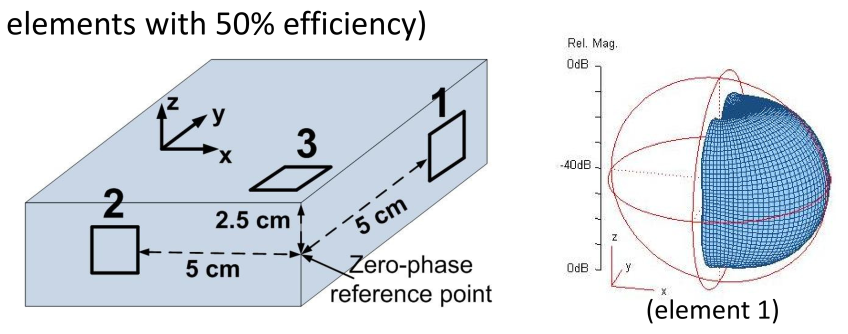



**Fig. 1: Indoor environment with AP and client locations (power levels for SISO system with omni-directional elements)**

Configuration A
(Ideal omni-directional elements with 80% efficiency)




Configuration B
(Ideal orthogonally oriented and polarised directional elements with 50% efficiency)



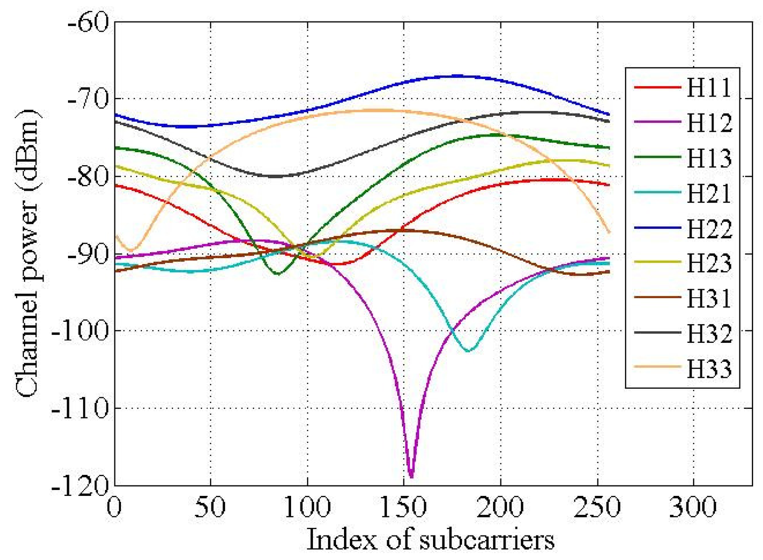




**Fig. 2: Instantaneous frequency 3x3 channel power profile example**

| 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**

- Spatial and temporal multipath components modelled with a 3D indoor ray-tracer (analysis performed at 5GHz with 12dBm transmit power per radio chain).
- Typical three-floor home with AP location fixed on ground floor and ten client locations distributed around the property
- AP and client use the same array configuration.
- AP orientation fixed; Client rotated in azimuth in steps of 10°.
- MIMO-OFDM channel matrix between the AP and each client location and orientation modelled as the spatial convolution of the detailed polarmetric element patterns with the spatial and temporal multipath components (see instantaneous frequency 3x3 channel power profile example in Fig. 2).

## Link-level Abstraction and Validation

- Link-level analysis for large numbers of locations, MCS modes, antenna configurations and orientations is computationally prohibitive with bit-accurate PHY simulation.
- A novel Received Bit mutual Information Rate (RBIR) abstraction technique is used to compute PHY layer throughput.
- Fig. 3 confirms the accuracy of the RBIR abstraction technique when computing BER vs. SNR.
- 5 hours of computing time with a bit-accurate simulator correspond to 20 seconds with the RBIR abstraction technique.

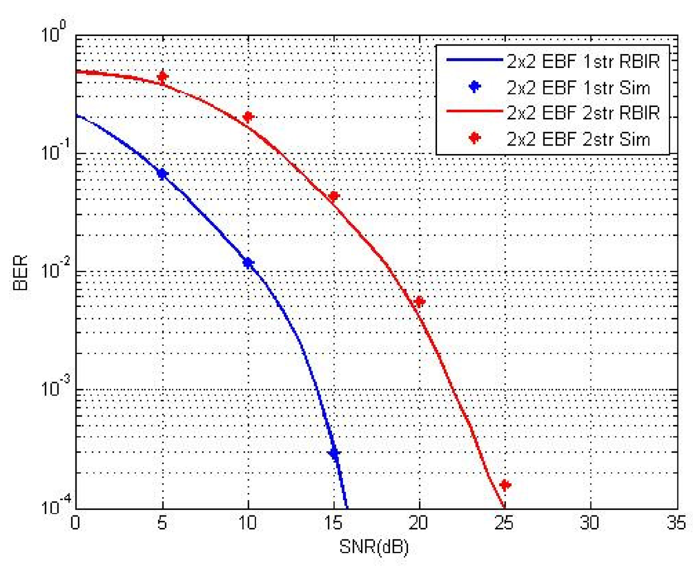



**Fig. 3: Validation for wideband channel 2x2 EBF (1 and 2 streams)**

## Results

Simulation Parameters:

- 1000 channel matrix snapshots for each client location and orientation.
- 3x3 EBF: 8 MCS modes for 1, 2 and 3 spatial streams.
- 2x2 EBF: 9 antenna selection combinations, 8 MCS modes for 1 and 2 spatial streams.
- Channel bonded 40MHz transmission using 128 subcarriers (5GHz carrier).
- The ideal MCS is chosen using the RBIR abstraction technique (the mode that maximizes throughput for PER<10%).

| Average SNR 3x3 (dB) | | | | | 41.6/24.0 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Average Throughput 3x3 (Mbps) | | | | | 375.4/289.5 | | | | |
| Best SNR 2x2 (dB) | | | | | 44.3/23.9 | | | | |
| Best Throughput 2x2 (Mbps) | | | | | 299.9/169.0 | | | | |
| SNR 2x2 (dB) | 33.0/ 20.3 | 40.0/ 20.4 | 39.3/ 20.3 | 33.2/ 20.3 | 40.8/ 20.3 | 40.2/ 23.9 | 25.9/ 20.4 | 37.7/ 20.4 | 47.7/ 20.5 |
| Throughput 2x2 (Mbps) | 296.1/ 163.0 | 298.1/ 165.2 | 279.9./ 164.5 | 295.7/ 150.0 | 299.9/ 150.0 | 279.2/ 162.5 | 283.4/ 165.5 | 292.8/ 165.0 | 260.7/ 169 |

**Table 2: Directional/Omni performance of 3x3 EBF and all nine of the 2x2 EBF combinations at location 5 (see Fig. 1), client rotation 150°**

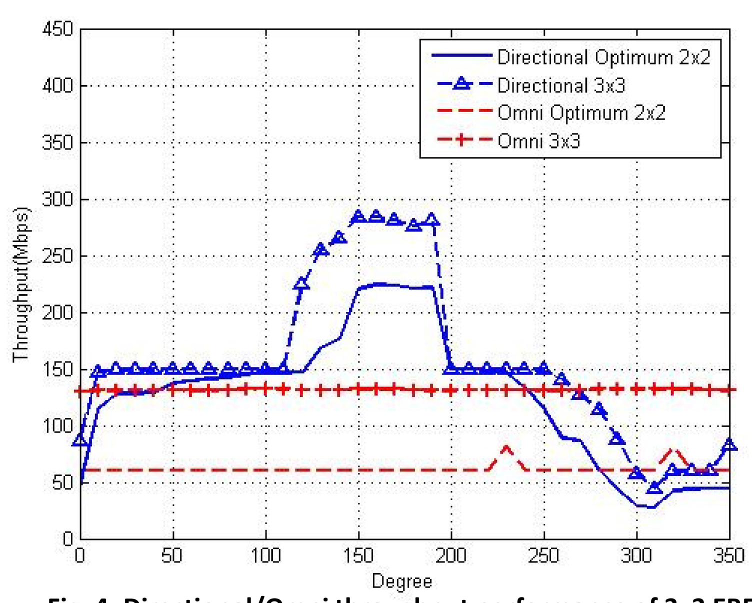



**Fig. 4: Directional/Omni throughput performance of 3x3 EBF and optimum 2x2 EBF through 360° client azimuth rotation at location 9 (see Fig. 1)**

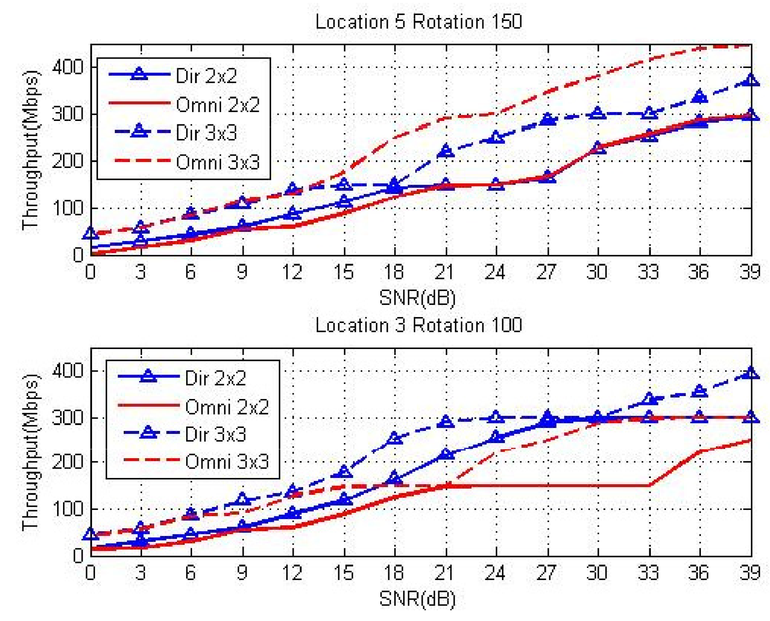



**Fig. 5: Throughput vs. SNR performance for selected 2x2 and 3x3 solutions at locations 5 and 3 (see Fig. 1)**

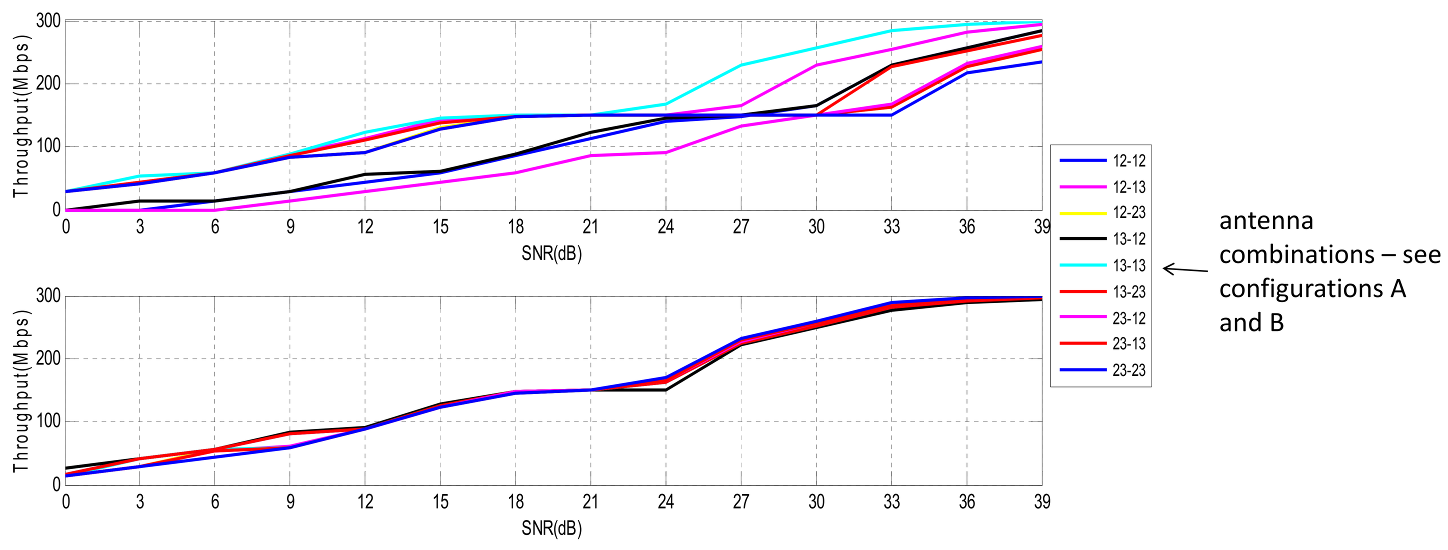



**Fig. 6: Throughput vs. SNR performance of all nine 2x2 antenna combinations at location 5 (see Fig. 1; Top: Directional, bottom: Omni)**

| | | SNR (dB) | Selected antennas (CL, AP) | Eigenvalues of 2x2 | Eigenvalues of 3x3 |
|---|---|---|---|---|---|
| Location 5 | Directional | 18,21 | 12, 13 | 3.38, 2.94 | 7.75, 0.62, 0.61 |
| | | others | 13, 13 | 4.49, 3.03 | |
| | Omni | 0-21 | 13, 12 | 2.35, 1.60 | 6.24, 1.63, 1.11 |
| | | 24-36 | 23, 23 | 2.40, 1.73 | |
| | | 39 | 12, 13 | 2.37, 1.63 | |
| Location 3 | Directional | 0-12 | 23, 23 | 2.33, 2.25 | 4.71, 2.21, 2.07 |
| | | 15-39 | 13, 13 | 2.91, 2.84 | |
| | Omni | 27 | 12, 13 | 2.51, 1.49 | 8.67, 0.28, 0.05 |
| | | others | 13, 13 | 2.52, 1.49 | |

**Table 3: Selected antennas and Eigen-structure of the 3x3 and optimum 2x2 channel matrix for locations 5 and 3 (see Fig. 1)**

Discussion of Results:

- In more distant rooms (e.g. location 9), dynamic 2x2 EBF using directional antennas provides 70-99% (depending on client orientation) of the throughput achieved by the more expensive 3x3 system. For omni antennas the relative throughput dropped to 45-62%.
- Results vary significantly according to the chosen antenna pair when directional antennas are applied. With omni antennas performance was largely independent of antenna choice.
- For directional antennas, dynamic antenna selection ensures good Eigen-structure in the 2x2 channel matrix for most client orientations, reducing the sensitivity to orientation observed with a fixed 2x2 directional system.
- Overall, the performance of optimum 2x2 EBF is particularly strong at low SNR values for directional antennas.

## Conclusions

- The performance of 2x2 EBF with optimum antenna selection is competitive to 3x3 EBF, especially when directional antennas are used at low SNR values. For distant rooms, 3x3 EBF is only 15% better (in terms of throughput) than 2x2 EBF when directional antennas and dynamic antenna selection are applied. 2x2 EBF with omni-directional antennas results in a 45% reduction in throughput (compared to 3x3 EBF).
- Multiple directional antennas can enhance 802.11n performance in a home environment. The combined effect of the antennas should provide near isotropic radiation and reduce the impact of client polarisation and orientation.
- We conclude that EBF with ideal 2x2 antenna selection (taken from a larger set of 3x3 directional antennas) is an attractive and cost effective solution for wireless applications in the home.
- Future work will incorporate real antenna pattern data into the model.

**References:**

[1] L. Wan, S. Tsai, and M. Almgren, 'A fading-insensitive performance metric for a unified link quality model,' IEEE WCNC 2006.

[2] D. Halls, A.R. Nix, and M.A. Beach, 'System Level Evaluation of UL and DL Interference in OFDMA,' IEEE WCNC 2011.

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