Uplink Pattern Optimisation and Power Control for Smart Antennas in an Indoor Infrastructure WLAN

Karim M. Nasr, Fumie Costen and Stephen K. Barton

Department of Computer Science, University of Manchester, UK

Abstract: This paper investigates uplink pattern optimisation algorithms with and without power control for a smart antenna system operating in an infrastructure Wireless Local Area Network (WLAN) following IEEE802.11a or HIPERLAN/2 standards. An indoor infrastructure WLAN scenario with multiple users communicating with an access point is modelled using a deterministic ray-tracing tool. The WLAN access point is serving multiple users simultaneously through Space Division Multiple Access (SDMA). The aim of the pattern optimisation and power control algorithm is to minimise the total power and interference to other systems while achieving target Signal to Interference plus Noise Ratio (SINR) values for each user. The target SINR is a minimum required to achieve a certain Error Rate (BER). It is shown that for high target SINR value, a null steering pattern is expected while for a low SINR target a beamsteering pattern is expected. For mixed targets, the best compromise between null steering and beamsteering is achieved.

1. Introduction

Infrastructure Wireless Local Area Networks (WLANs) for high data rate applications following the IEEE 802.11a or the HIPERLAN/2 standards [1,2], are becoming increasingly popular due to the flexibility they can offer. The main problem with WLANs is the lower capacity compared to wired LANs mainly due to the restrictions on the transmit power and bandwidth usage and the distortion introduced by the wireless channel. Smart antennas for infrastructure WLANs have the potential to multiply the capacity by serving multiple users simultaneously through Space Division Multiple Access (SDMA)[3,4]. This paper continues the work presented in [5-6] and studies the performance of a smart antenna uplink pattern optimisation and power control algorithm. In this paper, a deterministic channel model based on ray tracing and capable of estimating the Power Delay Angle Profile (PDAP) [5] is used to study an arbitrary indoor environment. Using this model, an optimum combiner based on the Minimum Mean Square Error (MMSE) criterion is developed in the case where the number of users is equal to the number of antenna elements. The uplink pattern optimisation and power control algorithm is then introduced to minimise the total power and interference to other systems while achieving a target SINR for each user. The target SINR is defined as the minimum value required to achieve a certain Bit Error Rate (BER). This paper is organised as follows: Section II presents the studied arbitrary indoor environment and develops the optimum combiner. Section III investigates the behaviour of the uplink pattern optimisation algorithm when power control is introduced for cases when all the users have same high or low targets and then when mixed targets are considered. Finally, Section IV concludes the paper.

2. An MMSE Optimum Combiner

Four users are communicating with an access point (AP) in an indoor environment (30m x 30m) with several partitions. Ray tracing results of the studied scenario and the Power Delay Angle Profile of the four users are shown in Fig.1. The statistical channel parameters of User 1 (at approx. 50 degrees) are summarised in Table 1.

A Uniform Linear antenna Array (ULA) of four elements is used at the access point with an inter-element spacing "d" of approximately 2.75cms ($\lambda/2$ at 5.44GHz). This value ensures no grating lobes [7] for the operation in the lower frequency band. Four users are transmitting simultaneously in a SDMA scheme. The field strength is in the complex form ($A\ e^{j\phi}$) and the angle of arrival is denoted by θ .The received signals r_n at each antenna element and the transmitted signals s_i are related as follows taking into account the LOS received field as well as L multipath rays, with element 1 taken as the reference element and ($k = 2\pi/\lambda$):

$$r_n = \sum_{i=1}^{u} [A_{ilos}\, e^{j\phi_{ilos}}\, e^{-jkd\,(n-1)\sin\,\theta_{ilos}} + \sum_{m=1}^{L} A_{im}\, e^{j\phi_{im}}\, e^{-jkd\,(n-1)\sin\,\theta_{im}}]s_i\,, \qquad \underline{r} = [\,\Gamma\,]\,.\,\underline{s} \tag{1}$$

The correlation matrix "R" can be formed according to the following equation with "σ_n^2" being the variance of the random thermal noise at the antenna element and "I" the identity matrix:

$$R=\Gamma*\Gamma^H + \sigma_n^2 *I \tag{2}$$

An optimal combiner is an array processor aiming at the maximisation of the SINR of the four users. The antenna weight vectors " $\underline{w}$" achieving this target are given by [4]:

$$\underline{w} = (R^{-1}\underline{s}) / (\underline{s}^{H} R^{-1} \underline{s}) \qquad (3)$$

After obtaining the optimal weights, the $SINR_i$ for user "i" can be calculated as:

$$SINR_i = \underline{w}_i^{H}.R_i.\underline{w}_i \,/\, \underline{w}_i^{H}.R_j.\underline{w}_i \qquad (4)$$

"R_i" being the spatial covariance matrix of the desired user and "R_j" being the spatial covariance matrix of the interferers and noise.

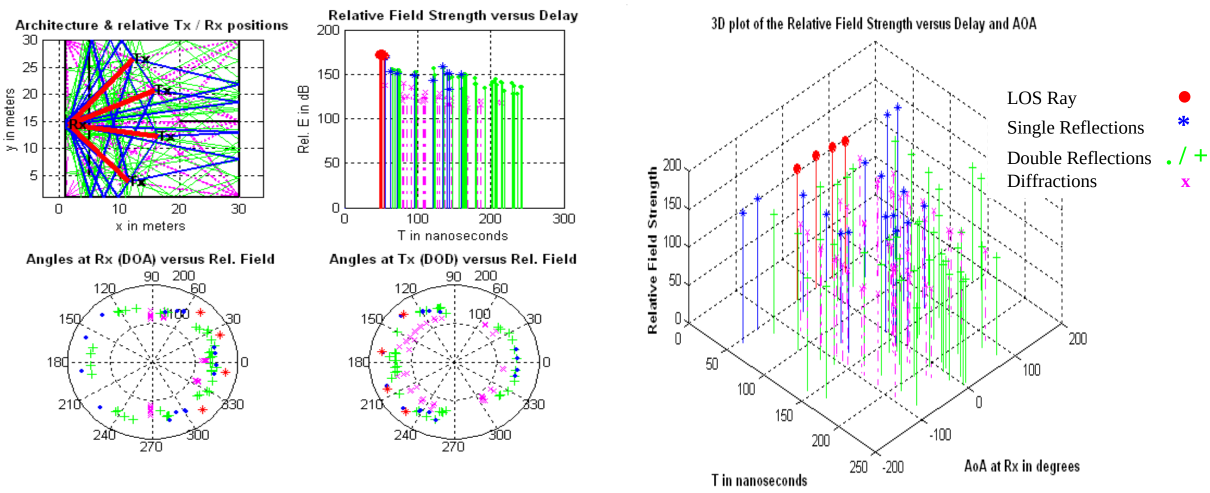
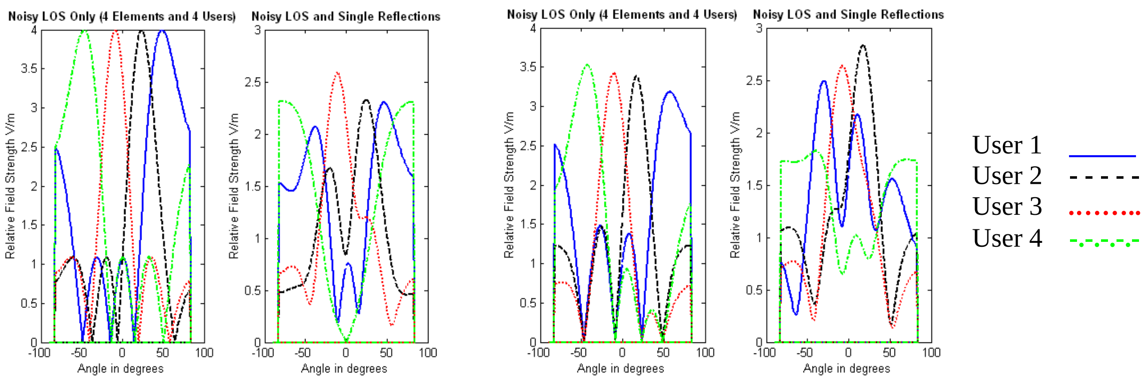


Fig.1 Channel Impulse Response (PDAP) of the indoor environment with four users communicating with the AP

The performance of the optimal combiner in the uplink case with the variation of the thermal noise level per antenna element (SNR) at the AP was studied in detail in [6]. An example of the typical performance is shown in Fig.2 showing the patterns of the four users of Fig. 1 for the low noise (SNR = 60dB) and the high noise case (SNR = -60 dB) in the LOS and multipath cases. The LOS case helps interpreting the behaviour of the multipath patterns. For the "low noise" case (SNR > 20dB) as shown in Fig.2 (b) curves, the optimum combiner acts as a null steerer (zero forcer) to eliminate the interference of all the users with respect to the user of interest. With N antenna elements, N-1 interfering users are eliminated (this is contrasted to the traditional approach of eliminating specific angular directions). In the multipath case, the array adjusts the weights to produce a pattern taking into account the phasor sum of the multipath rays of each user to achieve interference mitigation (suppression) in a way similar to a zero forcing time domain equaliser. For the "high noise" (SNR < 10dB) as shown in Fig.2 (a) curves, the array sacrifices a part of its nulling capability by shifting the nulls from the exact positions of other users, hence allowing some interference in exchange for focusing the beam towards the intended user in order to mitigate the effect of noise which is more important in this case. The maximum gain that can be achieved depends on the number of antenna elements (in this case four elements can achieve ~ 6dB). A smooth transition region exists between the two cases.

Table 1 Channel Parameters of the Studied Indoor Environments (User 1 at (12,27)m from origin)

Parameter	Value
Mean Excess Delay (ns)	57.62
Delay Spread (ns)	14.74
Coherence Bandwidth (approx.) (MHz)	13.56
Ricean K Factor	0.93
Angular Spread at Rx (Degrees)	42.38



(a) Low SNR : Beamsteering (b) High SNR : Null Steering

Fig.2 Uplink Normalised Patterns of the four Users in the high noise (left) and low noise (right) cases for (LOS) (noting the shifting of nulls and the change in the gain) and multipath

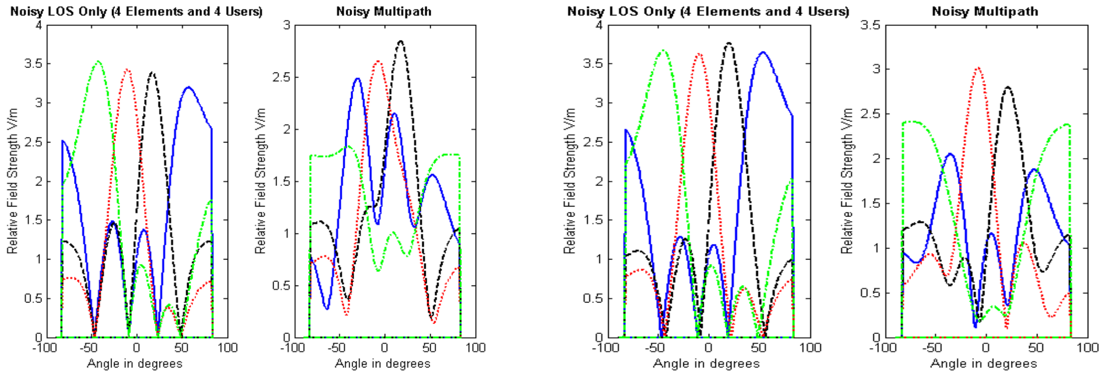
3. Uplink Pattern Optimisation with Power Control

The aim of power control is to minimise the total power and interference to other systems while achieving a target SINR for each user. The region of operation of the array processor (i.e. whether it is beam steering or null steering) depends on the target SINR value. The considered cases are when all the users have equal target values and when each user has a different target value. The expected behaviour is as follows: Low SINR targets suggest a beamsteering behaviour while high targets suggest a zero forcing (null steering) behaviour. For different targets, the best compromise between zero forcing and beam steering is reached. Assuming that noise is low enough to allow targets to be met, interference from other users towards high target users is more important than noise when considering the SINR value. Low target users are expected to steer a null as much as possible in the direction of high target users to help reduce the interference and achieve the high target value.

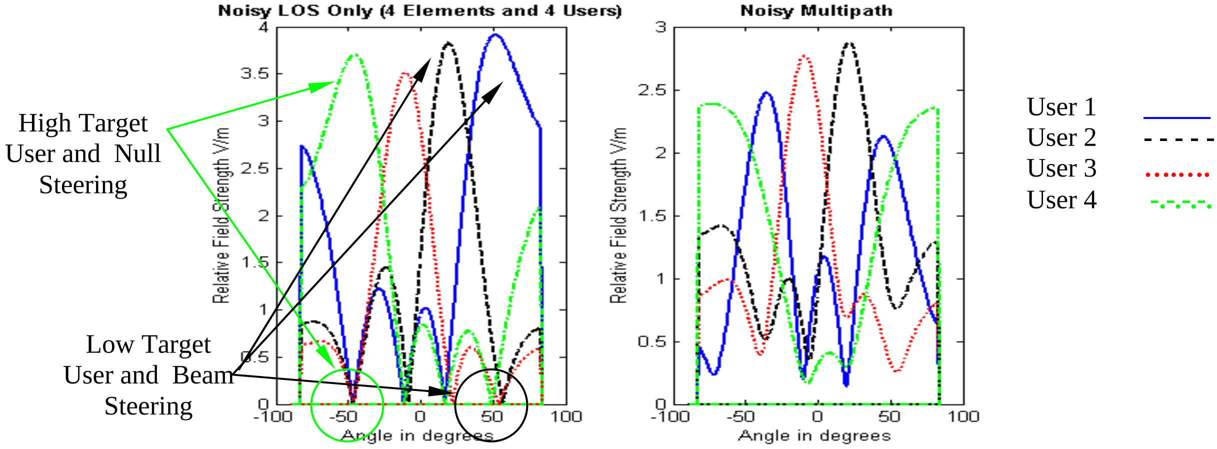
The uplink power control algorithm calculates first the uplink weights with no power control using equation (3) based on the channel transfer matrix (Γ). The initial SINR value for each user is then calculated and compared to the target SINR (T). If the SINR value is not equal to the target, a power scale is applied to the user in question to achieve the target. An effective power scale matrix is obtained and multiplied by the original channel transfer matrix and the new weights are calculated following (3). The process is repeated until all the targets are achieved. Several cases are simulated for same and different targets SINR. These cases are summarised in Table 3 showing the amount of power reduction achieved a) when all the target SINR values are high (20dB each), b) when all the target values are low (5dB each) and c) a mixture of high and low target SINR values (5, 0, 5, 20) dB for Users 1, 2, 3 and 4 respectively. The corresponding normalised antenna patterns are shown in Fig.3. The starting uplink weights are those of the low noise case of Table 2 and Fig.2 (b). The targets are normally achieved in a maximum of four iterations for all cases. The simulation results of Fig.3 and Table 2 confirm the expected behaviour. High SINR targets result in a null steering (zero forcing) behaviour since interference is the dominant effect when noise is low enough to allow targets to be met (Fig 3a). When targets start to decrease, noise becomes more important and this results in patterns towards a beam steering behaviour as shown in Fig. 3b where the null positions are shifted for the LOS case and more gain is achieved. For mixed targets, the patterns will depend on the exact threshold point. The best compromise between beamsteering and null steering is reached to achieve all the targets simultaneously as shown in Fig 3c. For the high target SINR value user (20dB) (User 4 at –48 degrees), all other users have a null in his direction in the LOS case of Fig3c (left) to reduce interference, which is more important than noise. For the low target Users 1, 2 and 3 (5, 0and 5dB SINR targets), noise is more important than interference and a beamsteering behaviour is obtained. Fig3c shows the spreading of the null positions and that gain is achieved (i.e. a beamsteering behaviour) for low target users.

Table 2 Summary of Uplink Pattern Optimisation and Power Control Cases (SINR Value in dB)

	Original Uplink SINR (SNR= 60dB)		High Targets Power Reduction (SINR=20dB)		Low Tagets Power Reduction (SINR=5dB)		Mixed Targets Reduction (SINR=5,0,5,20dB)	
	LOS	Multipath	LOS	Multipath	LOS	Multipath	LOS	Multipath
User 1	65.23	58.09	45.23	38.09	60.41	54.56	60.59	54.70
User 2	65.15	56.66	45.15	36.66	60.34	53.17	65.31	58.37
User 3	65.83	58.04	45.83	38.04	60.87	54.39	60.85	55.47
User 4	65.78	59.46	45.78	39.46	60.83	55.18	45.87	40.25



(a)High Targets (20 dB): (Null Steering Behaviour)   (b) Low Targets (5dB) (Towards Beamsteering)



(c) Mixed Targets (5, 0, 5, 20)dB (Beam steering for low targets and null steering for high targets)

Fig.3 Uplink Pattern Optimisation and Power Control Cases

4. Conclusion

This paper studied uplink pattern optimisation and power control algorithms in an arbitrary indoor WLAN. An infrastructure WLAN scenario was studied using a deterministic ray tracing tool capable of producing the Power Delay Angle Profile (PDAP). An uplink optimum combiner was then developed for the LOS and multipath cases. It was shown that a null steering (zero forcing) behaviour occurs in low noise (high SNR) case while a beamsteering behaviour occurs in a high noise (low SNR) case. The uplink case with power control was also investigated and it was shown that low SINR targets suggest a beamsteering behaviour while high targets suggest a null steering (zero forcing) behaviour. For mixed targets, the best compromise between zero forcing and beam steering is reached. Assuming that noise is low enough to allow targets to be met, interference from other users towards high target users is more important than noise when considering the SINR value. Low target users are expected to steer a null as much as possible in the direction of high target users to help reduce the interference and achieve the high target value. On the other hand, noise is more important for low target users and a beamsteering behaviour is expected.

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