Achieving Practical MIMO Network Planning Using the Two-Curve MIMO Performance Model

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1 Introduction

To propel MIMO networks into ubiquity, there is a great need for a fast, intuitive network planning model which can predict the performance of a MIMO system that includes site-specific information. Most models of MIMO communication focus on the characterization of measured data and do not emphasize site-specific predictive capability [1]. Further, typical MIMO models simply stop at calculating the ideal Shannon theoretical channel capacity available to a MIMO link. The ideal model would be very similar to existing planning methods which use lookup tables or simple equations [2] to provide a system designer with a clear relationship between bit rate and SNR. The proposed Two-Curve MIMO Performance model (2CMPM) accomplishes this and provides a more than 8 Mbps improvement in the standard deviation of the prediction error over a traditional lookup table for 802.11n system performance in the 5.2 GHz band. Further, the 2CMPM provides a highly intuitive design metric for MIMO network planners, the Line-of-Sight Distance to MIMO Deficiency.

2 The Two-Curve MIMO Performance Model

A proper model of MIMO system performance should include parameters for both SNR and multipath correlation [3] and to accommodate these requirements a Two-Curve MIMO Performance Model (2CMPM) has been suggested. This modeling technique is based upon the assumption that the link will either have rich multipath and MIMO performance will be good, or the link will suffer from strongly correlated multipath and the MIMO performance will degrade. For indoor propagation, rich multipath and good MIMO performance is the much more common scenario and therefore this curve is referred to as the Default performance curve. Subsequently, poor MIMO performance resulting from strongly correlated multipath makes up the Deficient performance curve.

When a link is Line-of-Sight (LOS), the typical assumption that the multipath signals seen by the receiver will be sufficiently uncorrelated can no longer be made. Therefore, when dealing with LOS links, an additional predictor of multipath correlation is necessary. Extensive measurements shown in Section 2.1 and in other published literature [4] demonstrate that for indoor environments one strong predictor of Deficient MIMO performance, and therefore of correlated multipath, is
the separation distance from the transmitter to the receiver when the link is LOS. This effect can be seen when the MIMO link is made via propagation down a long straight hallway where the walls, ceiling, and floor of the hallway tend to act as a waveguide, propagating waves of correlated multipath according to the low-order modes of the waveguide structure [4].

With these two predictors of multipath correlation defined, the linear equation used for predicting MIMO system performance in the 2CMPM is given as:

\[
BR_{Final} = BR_{Default}(SNR) - (BR_{Default}(SNR) - BR_{Deficient}(SNR)) \cdot \left(1 - \exp \left(-d \cdot \ln 2 \frac{1}{DtMD_{LOS}} \right) \right) \tag{1}
\]

where \(BR_{Final}\) is the final bit rate predicted at a given point in the environment, \(BR_{Default}\) and \(BR_{Deficient}\) are the bit rates (in Mbps) predicted for a given SNR by the Default and Deficient performance curves respectively, \(d\) is the transmitter to receiver separation distance in meters when the transmitter to receiver link is LOS, and \(DtMD_{LOS}\) is the LOS Distance to MIMO Deficiency. It should be noted that equation 1 is a general model for predicting the empirically characterized performance of specific hardware. Antenna array element spacing, RF front end sensitivity, dynamic range, and other implementation specific factors will change the Default and Deficient curves used in the model, however, this is no different than the characterization required for current lookup tables [2].

The exponential form of the distance dependent multipath correlation was chosen for two reasons. Firstly, in free-space environments MIMO channel capacity naturally decreases according to an exponential form as the Tx-Rx separation distance increases due to the transition of the signal from near-field to far-field [5]. The second reason for the exponential form of the curve is that it captures the entire correlation-based behavior in an intuitive and useful metric for planning MIMO links, namely the LOS Distance to MIMO Deficiency (\(DtMD_{LOS}\)). The \(DtMD_{LOS}\) represents the distance at which, statistically, MIMO performance transitions to being closer to the Deficient performance curve than it is to the Default performance curve. The simplicity of this metric allows network planners to quickly determine the LOS node spacing required for new MIMO network deployments and also to quickly identify potential problem areas in networks which are migrating from SISO to MIMO technology.

2.1 Model performance

To determine the performance of the suggested model, data on the average bit rate in both the 2.4 GHz and 5.2 GHz bands was collected for an off-the-shelf Draft 2.0 compliant 802.11n AP via a custom measurement driver and a standard, commercially available WLAN adapter based on an Atheros 5008 chipset. The AP used a three-element vertically polarized, dipole array with inter-element spacing of approximately one-half wavelength. The WLAN adapter used a three-element array,
and the polarization and geometry of the array was unknown. After aggregating measurement surveys from a selection of typical indoor propagation environments such as offices and hallways with both NLOS and LOS links, the data was separated into two groups for analysis: LOS links using MIMO coding and everything else. A modified, multi-breakpoint least-squares curve fitting algorithm was used to obtain the Default and Deficient performance curves from these segregated data sets. Figure 1 shows the collected data and the results of these curve-fittings for 802.11n operation in the 5.2 GHz band. Note that all bit rates measured for any packets using a 40 MHz bandwidth or a 400ns guard interval have been scaled down to their base rate values based on the corresponding 802.11n MCS index. Also, the Received Signal Strength Indication (RSSI) has been used to report the signal strength instead of SNR due to increased variation in the noise estimates of the receiver, however additional surveys found the noise floor to be approximately -83 dBm at 2.4 GHz and approximately -93 dBm at 5 GHz and sufficiently flat in both bands.

To obtain a quantitative assessment of the performance of the 2CMPM, the performance curves obtained in the 2.4 GHz and 5.2 GHz bands were used in (1) and the associated $DtMD_{LOS}$ was obtained through a least-squared curve fit. Table 1 shows the accuracy of the bit rate predictions of the 2CMPM for the given data set as well as the accuracy of a standard interpolated, lookup table-based method of prediction obtained using the same curve-fitting algorithms to generate a single curve linking RSSI to bit rate.
Table 1: Bit rate prediction error, $e$, of the 2CMPM compared to a fitted, single-curve, interpolated lookup table.

<table>
<thead>
<tr>
<th></th>
<th>2.4 GHz</th>
<th></th>
<th>5 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$DtMD_{LOS}$ [m]</td>
<td>Mean $e$ [Mbps]</td>
<td>Std Dev [Mbps]</td>
</tr>
<tr>
<td>2CMPM</td>
<td>15.69</td>
<td>-3.81</td>
<td>22.43</td>
</tr>
<tr>
<td>lookup table</td>
<td>—</td>
<td>-9.66</td>
<td>23.84</td>
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3 Conclusion

The Two-Curve MIMO Performance Model provides network planners with an intuitive model for MIMO system performance that not only incorporates the site-specific effects of multipath correlation, but also improves prediction accuracy compared to a single-curve lookup table. Most notably, the 2CMPM improved the standard deviation of the prediction by 8 Mbps in the 5.2 GHz band. Further, analysis of the data shows that in LOS environments 802.11n systems will begin to see significant decreases in MIMO performance as the LOS distance from the transmitter to the receiver increases beyond approximately 15 m at 2.4 GHz and approximately 7 m at 5.2 GHz. These results show that the performance of MIMO systems can be characterized and planned without the need for overly complicated spatio-temporal modeling techniques. The 2CMPM can provide network planners with a prediction of bit rate coverage without having to resort to time-consuming and difficult simulation techniques.

References


