Empirical Path Loss Model for Outdoor 802.11b Wireless Links
WHY SPREAD SPECTRUM?

The main factors limiting the usability of radio communications systems are:

- thermal noise,
- multipath, and
- interference

Spread spectrum systems overcome the multipath and interference problems.
<table>
<thead>
<tr>
<th>Data rate Mbp</th>
<th>Symbol rate Msp</th>
<th>Chip rate Mcps</th>
<th>Coding scheme</th>
<th>Modulation</th>
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<tbody>
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<td>1</td>
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<td>11</td>
<td>11 chip Barker code</td>
<td>DBPSK</td>
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<tr>
<td>2</td>
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<td>11 chip Barker code</td>
<td>DQPSK</td>
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<td>5.5</td>
<td>1.375</td>
<td>11</td>
<td>8 chip CCK</td>
<td>DQPSK</td>
</tr>
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<td>1.375</td>
<td>11</td>
<td>8 chip CCK</td>
<td>DQPSK</td>
</tr>
<tr>
<td>5.5</td>
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<td>Does not apply</td>
<td>PBCC</td>
<td>BPSK</td>
</tr>
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<td>11</td>
<td>Does not apply</td>
<td>Does not apply</td>
<td>PBCC</td>
<td>QPSK</td>
</tr>
</tbody>
</table>
Figure 2. PPDU frame with long preamble
Figure 3. PPDU frame with short preamble
Motivation

- 802.11b is a promising technology for Wireless Connectivity. It is designed for indoor use. However it can be used for deployment for campus-wide Wireless network & also for long distance Point-to-Point links; which has been verified with various experimental links already set up & running.

- 802.11b is an economic technology as it works in “Licence Free” ISM band of 2.4 GHz & gives a very good data rate of 11 Mbps. This data rate meets most of the demands of Audio, Video & Data. Moreover, the cost of the Hardware & Software is coming down drastically with lot of competition which is based on a huge potential in the demand of wireless internet connectivity. Already many hotspots have been setup world wide & their number is increasing exponentially. Even 802.11g standard is also envisaging use of OFDM in 2.4 GHz range which can give data-rates up to 54 Mbps.
Motivation--Continued

• Since there is going to be so much usage of this bandwidth, it will be appropriate to study the Path-Loss model for this band.

• At present there are various models available for Pathloss in MW range. However they don’t cater specifically to 2.4 GHz range of 802.11b. They are either for frequency range below 2 GHz or they cater to long distances like > 1 Km.

• The purpose of this thesis will therefore be to provide empirically
  – pathloss model in following scenarios-
    • Campus wide networks
    • Along the roads in straight line
    • Long distance Point to Point links. (Distance form 1 to 40 Kms)
  – SNR Vs Throughput Curves & a comparison of these with standard SNR Vs BER curves available for the modulation techniques used.
Path Loss Models Available

- **Okumura Model**: It is one of the most widely used models for signal prediction in urban areas. It is an empirical model in the frequency range of 150 MHz to 1920 MHz & distances from 1 to 100 Km. It can be extrapolated up to 3 GHz.

- **Hata Model**: It is an empirical formulation of the path loss data provided by Okumura, & is valid from 150 Mhz to 1500 MHz for urban area.

- **PCS Extension to Hata Model**: This is an extension of Hata model up to 2 GHz for Personal Communication Systems which have cells of the order of 1 Km to 20 Km radius.
Okumura Model

Path Loss = FPL + A(f,d) - G(hre) - G(hte) - G(Area)

Where:

FPL = Free Space Path Loss = 20 log \( \frac{4\pi d f}{c} \)

c = Speed of Light

d = distance

f = Frequency

G(hte) = 20 log \( \frac{hte}{200} \) \( 1000m > hte > 30m \)

G(hre) = \begin{cases} 
20 \log \left( \frac{hre}{3} \right) & \text{if } 10m > hre > 3m \\
10 \log \left( \frac{hre}{3} \right) & \text{if } hre < 3m 
\end{cases}

G(Area) @ 2.4 GHz from the Curves

= 33 (Open Area)

= 27 (Quasi Open Area)

= 13 (Suburban Area)

A(f,d) = Median Attenuation: function of frequency & distance

= 13 dB from curve @ 2.4 GHz & distance up to 1 Km.
**Hata Model**

**Path Loss in Urban areas is given by**

Path Loss = 69.55 + 26.16*\(\log(f)\) - 13.82*\(\log(h_{te})\) -a\(h_{re}\) +(44.9-6.55*\(\log(h_{te})\)\)*\(\log(d)\)

Where:

- \(f\) = Frequency (in MHz) from 150 MHz to 1500 MHz
- \(h_{te}\) = Effective Transmitter Height, from 30 to 200 meters
- \(h_{re}\) = Effective Receiver Height, from 1m to 10 meters.
- \(d\) = Transmitter - Receiver separation (in Km)
- \(a(h_{re})\) = Correction factor for effective mobile antenna height, which is a function of the size of the coverage area.

\[
(1.1*\log f - .7)h_{re} -(1.56*\log f - .8)\ dB \quad \text{For medium sized city}
\]

\[
=8.29(\log 1.54h_{re})^2 - 1.1 \ dB \quad f \leq 300 \ MHz \quad \text{For large city}
\]

\[
=3.2(\log 11.75h_{re})^2 - 4.97 \ dB \quad f \geq 300 \ MHz \quad \text{For large city}
\]

**Path Loss in Suburban Areas**

Path Loss (Suburban) = Path Loss (Urban) - 2*\([\log(f/28)]^2\) - 5.4

**Path Loss for Open Rural Areas**

Path Loss(Open Suburban) = Path Loss (Urban) - 4.78*(\log f)^2 +18.33*(\log f) - 40.94
PCS Extension to Hata Model

Path Loss = 46.3 + 33.9*(log f) - 13.82*(log th_e) - a(h_re) + 

\[44.9 - 6.55*(\log h_{te})]\times(\log d) + C_M

C_M = 0 \quad \text{For medium sized city & suburban areas}

= 3 \quad \text{For metropolitan centers}

The model is restricted to following range of parameters:

f: 1500 MHz to 2000 MHz

h_{te}: 30 m to 200 m

h_{re}: 1 m to 10 m

d: 1 Km to 20 Km
Propagation Models

- Large Scale Propagation Models:
  - Propagation models that predict the mean signal strength for an arbitrary T-R separation. The distances involved are hundreds or thousands of meters.

- Small-Scale or fading models:
  - Models that characterize rapid fluctuations of recd sig. Strength over very short travel distances (a few wavelengths) or short time durations (of the order of seconds).
  - As a mobile moves over very small distances, the instantaneous recd sig. Strength may fluctuate rapidly giving rise to small-scale fading. The reasons for this is that the recd sig is a sum of many contributions coming from different directions.
  - The recd signal may vary as much as 30 or 40 dB when the receiver moved by only a fraction of wavelength.
Indoor Path Loss

As a first cut approximation to estimating indoor path losses, if we assume that propagation follows an approximate $1/(\text{range}^{3.5})$ power rule, rather than $1/(\text{range}^{2})$, we can predict propagation losses with the following relationship (at 2.4 GHz):

$$\text{Path Loss (in dB)} = 40 + 35 \times [\log (\text{D in meters})]$$
Tools Used

• To measure the signal strength, a suitable receiver is required which is calibrated correctly. We have used the standard WLAN cards themselves, along with commercially available software “Airopeek” & calibrated them with the help of “Network Analyzer”.

• Various Attenuators have been used for calibration, which again have been calibrated using “Network Analyzer”.

• For measuring distance between two points, GPS receiver is used which can give accuracy of about 5 meters in absolute position of any point & < 1 m for distance between two points.
Setup for Calibration

- Variable Attenuator
- 50° Co-axial Cable
- Access Point
- Pig-tail
- WLAN Card

Diagram: Flowchart showing the setup process with labeled components.
Loss of 50 feet Co-axial cable (1/2” dia)
As measured by Network Analyzer
Path Loss Measurements (Along Campus Roads)

Path Loss Vs Distance (Campus Roads)

SBRA-Nursery
SBI_Board-Airstrip
Spool-Hall1
Path Loss Measurements in Academic Area

Path Loss Vs Distance (Academic Area)
Deviation of Path Loss as compared to FPL
(Academic Area)
Deviation in Path Loss From FPL (Campus Roads)

![Graph showing deviation in path loss from FPL vs distance for different locations on campus roads.]
Path Loss Vs Distance (FBTop upto GH)

Path Loss Vs Distance

Distance (Meters)

Path Loss (dBm)

Series1
Deviation of Path Loss from FPL
(From FBTop upto GH)
SNR Vs Throughput (FBTop upto GH)
SNR Vs Throughput Curves.  
(Under Controlled Environment in Lab)
Path Loss Vs Distance: Tx at 15 Meter Height

Path Loss Vs Distance (LOS)
Path Loss Vs Distance: Tx at 15 Meter Height

Path Loss Vs Distance (Non LOS)
Distance Vs Path Loss : Yagi Antenna (LOS): Tx at 25 Meters

Distance (Meters)

Path Loss (dB) / Difference in PL (dB)

-40 -20 0 20 40 60 80 100 120 140 160

0 100 200 300 400 500 600 700

-40 -20 0 20 40 60 80 100 120 140

PCSE_Hata PL

APL - PCSE_Hata PL

APL - FPL

APL

FPL

Distance Vs Path Loss : Yagi Antenna (LOS): Tx at 25 Meters

Distance (Meters)
Distance Vs Path Loss (Non LOS): Tx at 25 Meters Height

-40
-20
0
20
40
60
80
100
120
140
160

0 100 200 300 400 500

Distance (Meters)

Path Loss / Difference in PL (dB)

-40
-20
0
20
40
60
80
100
120
140
160

APL (Omni)
APL (Yagi)
FPL
APL - FPL (Omni)
APL - FPL (Yagi)
PCSE_Hata PL
APL - PCSE_Hata PL: Omni
APL - PCSE_Hata PL: Yagi
Long Distance Point to Point Links
Measured Path Loss Vs Distance

Excess Path Loss over FPL Vs Distance (Point to Point Long Distance Links)
FIGURE 3. PATH DELAY PROFILE OF A 2-RAY CHANNEL MODEL
$P(t) = \frac{1}{T_d} \exp \left( \frac{-t}{T_d} \right)$

$T_M = T_d$

**Figure 6. Path Delay Profile for an Exponential Channel Model**
PCS JTC CHANNELS

- Channel models have been recommended for
  - indoor and
  - outdoor applications
- Areas in indoor applications
  - office
  - residential
  - commercial
- In each area three channel profiles denoted by A, B, and C have been defined by using tapped delay line model
TAPPED DELAY LINE MODEL OF A MULTIPATH CHANNEL

- Excess delay = $T_i - T_1$
- Relative attenuation = $20 \log_{10} \left( \frac{h_i}{h_1} \right)$
FIGURE 7. CHANNEL PROFILES FOR THE 3 DIFFERENT CHANNELS THAT COMPOSE THE “RESIDENTIAL” JTC MODEL
JTC MODEL ASSUMES THAT CHANNEL PROFILE AND CHANNEL ATTENUATION ARE CORRELATED

Probabilities of selecting channel profiles A, B and C

Values for $PL_1$ and $PL_2$

<table>
<thead>
<tr>
<th>Area</th>
<th>$P(A)$ (%)</th>
<th>$P(B)$ (%)</th>
<th>$P(C)$ (%)</th>
<th>$PL_1$ (dB)</th>
<th>$PL_2$ (dB)</th>
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<tbody>
<tr>
<td>Office</td>
<td>60</td>
<td>35</td>
<td>5</td>
<td>50</td>
<td>75</td>
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<td>Residential</td>
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<td>45</td>
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<tr>
<td>Commercial</td>
<td>50</td>
<td>45</td>
<td>5</td>
<td>60</td>
<td>100</td>
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</tbody>
</table>
Simulation using MATLAB

• Generation of BPSK, QPSK & CCK Modulated Waveforms
• Adding Channel Model to it
• Doing BER Analysis & Comparison of different schemes.
Results
Path Loss for Long Distance Point to Point Links

\[
\text{Path Loss} = \text{FPL} + 3 + 0.15 \times \text{D(Km)}
\]
## Path Loss for Long Distance Point to Point Links

<table>
<thead>
<tr>
<th>Link</th>
<th>Date</th>
<th>Set up</th>
<th>Rx Sig. Strength</th>
<th>Distance (Km)</th>
<th>dBM</th>
<th>%</th>
<th>Free Space Path Loss (dB)</th>
<th>Measured Path Loss</th>
<th>Difference</th>
<th>Trend Line</th>
<th>APL-TrendLine</th>
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</thead>
<tbody>
<tr>
<td>IITK-MBSNL</td>
<td>23-Jan-03</td>
<td>Parabolic both sides; Cisco RB 100 mw-70m Low Loss Cable--100mw Power AMP at top @ MBSNL, 50' Lucent cable @ IITK end--Cisco WLAN card</td>
<td>-55</td>
<td>5.1</td>
<td>76</td>
<td></td>
<td>114.33</td>
<td>118</td>
<td>3.67</td>
<td>118.10</td>
<td>-0.10</td>
</tr>
<tr>
<td>Safipur-Saroha</td>
<td>13-Dec</td>
<td>Parabolic both sides, 50 m Low Loss cable on Safipur side &amp; 60 m Low Loss cable on Saroha Side, Cisco RB 100 mw--Cisco WLAN card @ Safipur</td>
<td>-76</td>
<td>17.7</td>
<td>30</td>
<td></td>
<td>125.14</td>
<td>131</td>
<td>5.86</td>
<td>130.80</td>
<td>0.20</td>
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<tr>
<td>MBSNL-Safipur</td>
<td></td>
<td>Parabolic both sides, 70 m Low Loss cable on MBSNL side &amp; 50 m Low Loss cable on Safipur Side, Cisco RB 100 mw, 1 W Amp below @ Mandhana--Cisco WLAN card without AMP @ Safipur</td>
<td>-70</td>
<td>22.7</td>
<td>50</td>
<td></td>
<td>127.30</td>
<td>134</td>
<td>6.70</td>
<td>133.71</td>
<td>0.29</td>
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<td>IITK-Saroha</td>
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<td>Parabolic both sides, 15 m Lucent Cable at IITK, Cisco WLAN card-- 60 m Low Loss cable at Saroha, 500 mw AMP at Top @ saroha, Cisco RB 100 mw</td>
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<td>37.02</td>
<td>50</td>
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<td>131.55</td>
<td>140</td>
<td>8.45</td>
<td>140.10</td>
<td>-0.10</td>
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</table>

Free Space Path Loss (dB) = 20log(4*pi*distance / lambda) = 20log10(40*distance^2 / wavelength^3)
distance in Km, wavelength in MHz

Tx Power = (Tx Gain + Rx Gain) - (Tx Cable Loss + Rx Cable Loss) - (Rx Sig. Str.) dB

FPL = 3 + 1.5x

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Path Loss for Long Distance Point to Point Links

<table>
<thead>
<tr>
<th>Link</th>
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<th>APL-TrendLine</th>
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<td>118</td>
<td>3.67</td>
<td>118.10</td>
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<td>50</td>
<td></td>
<td>127.30</td>
<td>134</td>
<td>6.70</td>
<td>133.71</td>
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<tr>
<td>IITK-Saroha</td>
<td>18-Dec</td>
<td>Parabolic both sides, 15 m Lucent Cable at IITK, Cisco WLAN card-- 60 m Low Loss cable at Saroha, 500 mw AMP at Top @ saroha, Cisco RB 100 mw</td>
<td>-70</td>
<td>37.02</td>
<td>50</td>
<td></td>
<td>131.55</td>
<td>140</td>
<td>8.45</td>
<td>140.10</td>
<td>-0.10</td>
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Path Loss along the Roads

Distance Vs Path Loss

Trend Line
Path Loss = FPL + 15 + 0.02*D(Meters)
# Path Loss along the Roads

<table>
<thead>
<tr>
<th>Name</th>
<th>Distance Meters</th>
<th>Sig Strength dBm</th>
<th>Input Signal (250 mw) 24 dB</th>
<th>Actual Path Loss in dB (APL)</th>
<th>Free Space Path Loss in dB (FPL)</th>
<th>Difference in Path Loss</th>
<th>Fixed Loss (FL)</th>
<th>Slope</th>
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<td>VH1</td>
<td>253.16</td>
<td>-48.00</td>
<td>24.00</td>
<td>108.00</td>
<td>88.25</td>
<td>19.75</td>
<td>108.31</td>
<td>-0.31</td>
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<td>VH2</td>
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<td>101.47</td>
<td>31.53</td>
<td>139.67</td>
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From SBRA to Nursery

<table>
<thead>
<tr>
<th>Name</th>
<th>Distance Meters</th>
<th>Sig Strength dBm</th>
<th>Input Signal (250 mw) 24 dB</th>
<th>Actual Path Loss in dB (APL)</th>
<th>Free Space Path Loss in dB (FPL)</th>
<th>Difference in Path Loss</th>
<th>Fixed Loss (FL)</th>
<th>Slope</th>
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<td>Pole-317</td>
<td>194.16</td>
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<td>106.00</td>
<td>85.95</td>
<td>20.05</td>
<td>104.83</td>
<td>1.17</td>
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<td>374.26</td>
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<td>91.65</td>
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<td>Pole-309</td>
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<td>24.00</td>
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<td>93.99</td>
<td>26.01</td>
<td>118.79</td>
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<td>Pole-305</td>
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<td>Pole-302</td>
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<td>98.26</td>
<td>44.74</td>
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From SBI Board to Air-Strip

<table>
<thead>
<tr>
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<th>Sig Strength dBm</th>
<th>Input Signal (250 mw) 24 dB</th>
<th>Actual Path Loss in dB (APL)</th>
<th>Free Space Path Loss in dB (FPL)</th>
<th>Difference in Path Loss</th>
<th>Fixed Loss (FL)</th>
<th>Slope</th>
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<td>Spool</td>
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<td>24.00</td>
<td>109.00</td>
<td>85.34</td>
<td>23.66</td>
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<td>5.04</td>
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<td>Hall-4</td>
<td>330.01</td>
<td>-54.00</td>
<td>24.00</td>
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<td>90.55</td>
<td>23.45</td>
<td>112.15</td>
<td>1.85</td>
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<tr>
<td>Hall-3</td>
<td>497.10</td>
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<td>24.00</td>
<td>130.00</td>
<td>94.11</td>
<td>35.89</td>
<td>119.05</td>
<td>10.95</td>
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<td>24.00</td>
<td>130.00</td>
<td>96.21</td>
<td>33.79</td>
<td>123.87</td>
<td>6.13</td>
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<td>140.00</td>
<td>97.87</td>
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<td>128.19</td>
<td>11.81</td>
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From Barasirohi Gate (Near Swimming Pool) to Hall 1

<table>
<thead>
<tr>
<th>Name</th>
<th>Distance Meters</th>
<th>Sig Strength dBm</th>
<th>Input Signal (250 mw) 24 dB</th>
<th>Actual Path Loss in dB (APL)</th>
<th>Free Space Path Loss in dB (FPL)</th>
<th>Difference in Path Loss</th>
<th>Fixed Loss (FL)</th>
<th>Slope</th>
</tr>
</thead>
</table>
| Conclusion    | Path Loss = FPL + 15 + 0.02 * Distance (Meters)
Path Loss Vs Distance:
Academic Area with Transmitter at 25 Meters

Trend Lines
Path Loss (Yagi) = FPL + 4 + 0.005*D(Meters)
Path Loss (Omni) = FPL + 7 + 0.005*D(Meters)
Path Loss for Academic Area: Transmitter at 25 Meters

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance</th>
<th>Omni High Gain Antenna (12 dBi Gain)</th>
<th>Yagi Antenna (14 dBi Gain)</th>
<th>Path Loss in dB (Actual)</th>
<th>Path Loss in dB (Free Space)</th>
<th>Difference in Path Loss with FPL</th>
<th>Yagi Trend</th>
<th>Actual - Yagi Trend</th>
<th>Omni Trend</th>
<th>Actual - Omni Trend</th>
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<td>Base-FBTop</td>
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Path Loss = FPL + 4 + .005*Distance (Meters) For Yagi
Path Loss = FPL + 7 + .005*Distance (Meters) For Omni
Path Loss vs Distance in Academic Area:
Transmitter at 4 Meters Height

Path Loss = FPL + 5 + 0.03*D(Meters)
Path Loss for Academic Area : Transmitter at 4 Meters

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Distance</th>
<th>Signal Strength</th>
<th>Input Signal</th>
<th>Actual Path Loss (dB) (APL)</th>
<th>Path Loss in dB (Free Space)</th>
<th>Difference in Path Loss with FPL</th>
<th>Trend-Line = FPL + FL +slope *x</th>
<th>Actual - Trend Line</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Base-AcadArea (Stage Near Faculty Lounge)</td>
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<td>20</td>
<td>79</td>
<td>72</td>
<td>77.97</td>
<td>1.03</td>
</tr>
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</table>

Path Loss = FPL + 5 + 0.03 * Distance (Meters)

With inbuilt antenna of Cisco Card