Architecture and Predicted Performance of an IEEE 802.11b-like Wireless Metropolitan Area Network Transceiver at 5.8 GHz

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Outline

- Anntron Inc.’s WMAN System Architecture
  - Network Topology
  - Components:
    - UNII-Link Transceiver, Multibeam Antenna Assembly, Intelligent Hub Access System
  - Predicted Performance Analysis
  - Benefit of Adaptive Rate-Switching

- Narrowband Channel Sounding at 5.8 GHz
  - RSS Data Reduction Methodology
  - RSS Data Histogram and CDF
  - Minimum Fade Margin Analysis
  - Minimum Chi-Square ($X^2$) Analysis
  - Level Crossing Rate and Average Fade Duration
WMAN Architecture

Remote Stations

Station Gateway Ethernet Switch

10/100Base-T

Remote Network

Web Browser Interface to Hub Controller

Multi-beam Antenna Assembly (MAA)

Controller Software

1000Base-T or ATM to backbone

Intelligent Hub Access System (IHAS) - Hub Side

Switch

Transceiver

Encryption

Ethernet Switch

Transceiver

Fixed Beam Antennas

Database Server

Application Server

Web Server

VideoCon Server
Anntron’s WMAN Components

- **Wireless Metropolitan Area Network (WMAN)**
  - **UNII-Link** - point-to-point wireless LAN bridge
    - Based on IEEE 802.11b WLAN standard
    - Intersil’s PRISM II chipset
    - Custom Medium Access Controller (MAC) optimized for outdoor, point-to-point LAN bridging
  
- **MAA - Multibeam Antenna Assembly**
  - 6 main lobes over 90 degrees
  - Angular and antenna polarization diversity

- **IHAS - Intelligent Hub Access System**
  - Contention-free medium access through switched Ethernet LAN microsegmentation
  - Pause packets provide full-duplex flow control
UNII-Link WMAN Transceiver

- Modem: Intersil’s Prism II Chipset
  - Baseband Processor (HFA3863)
    - DSSS Modulation: 1, 2, 5.5, and 11 Mbps rates
    - Rake Receiver and Decision Feedback Equalizer
  - I/Q Mod/Demodulator (HFA3783)
    - Baseband to IF conversion with 70 dB of AGC
- MAC optimized for outdoor, point-to-point LANs
  - Rate-Switching algorithm reduces probability of packet errors (adaptive modulation)
  - Removed inherent latency of IEEE 802.11b’s Distributed Coordination Functions (DCF)
  - Prevent buffer overflow through MAC layer flow control
Convert PRISM II BER vs. $E_b/N_0$ curves to BER vs. SNR
**BER vs. Rx Power (dBm) Performance Curves**

**Benefit of Adaptive Rate-Switching**

- BER vs. Rx power curves – apply adaptive rate-switching
- Define minimum performance, select modulation level that can provide BER
- Required Rx power to maintain BER of $10^{-6}$ drops 15 dB going from 11 to 1 Mbps

![BER vs Received Power (dBm)](image)
IHAS - Intelligent Hub Access System

- Switched Ethernet Hub – LAN Microsegmentation
- Pause packets quench Ethernet source when transmit buffers reach capacity
Multi-beam Antenna Assembly

- Provides angular and antenna polarization diversity
- Segments coverage area into point-to-point subsectors

Input from Radio Transceivers -> Planar Butler Matrix Beamforming Network -> Planar Microstrip Antenna Array
Narrowband Channel Sounding at 5.8 GHz

Narrowband channel sounding for Near-Line-of-Sight (NLOS) Link: Measure Received Signal Strength (RSS) of a transmitted CW signal
Capture Fading Intervals:

- RSS sampling rate = 2000 S/sec
- Segment long-term measurement into 2-second intervals
- Calculate running-average of previous 2000 interval averages
- Record interval RSS samples if 15 samples are 5 dB below running-average of interval averages
Data analysis procedure:
- Normalize RSS samples to fading interval average
- Calculate histogram, CDF, level crossing rate, and average fade duration

Find lowest received power:
- Minimum of temporal variations relative to interval mean: -8 dBm
- Temporal minimum occurred during 2\textsuperscript{nd} lowest RSS interval mean: -64 dBm
- Lowest received power: -72 dBm
Calculating Minimum Fade Margin

- Consider the lowest received signal power: -72 dBm
- Take measurement during worst-case channel conditions
- Use maximum accepted BER to establish the fade margin

![BER vs Received Power (dBm)](image-url)

Fade Margin: Less than 1 dB
Experimental RSS Data Histogram and CDF

Histogram of RSS
- Outlier intervals due to mobile scattering (moving foliage in path)

CDF of RSS
- Probability of a 6 dB fade
  - Outlier interval: 10%
  - Mean: 0.7%
Minimum Chi-Square ($X^2$) Analysis - Fitting Rayleigh and Rician PDFs to Experimental PMF (1/2)

- **Minimum Chi-Squared ($X^2$) Analysis**

  \[ X^2 = \sum_i \frac{N(\hat{p}(X_i) - p(X_i))^2}{p(X_i)} \]

- **Rayleigh Channel Fading Model – expressed in dB**

  \[ p(y) = \frac{1}{M\sigma^2} \exp \left[ \frac{2y}{M} - \frac{1}{2\sigma^2} \exp \left( \frac{2y}{M} \right) \right] \quad M = \frac{20}{\ln 10} \]

- **Rician Channel Fading Model – expressed in dB**

  \[ p(y) = \frac{1}{M\sigma^2} \exp \left\{ \frac{2y}{M} - \frac{1}{2\sigma^2} \left[ r_s^2 + \exp \left( \frac{2y}{M} \right) \right] \right\} \cdot I_0 \left[ \frac{r_s}{\sigma^2} \exp \left( \frac{y}{M} \right) \right] \]

  - Vary LOS component of K-Factor: \[ r_s = 2\sigma^2 10^{\frac{K}{10}} \]
Minimum Chi-Square ($X^2$) Analysis - Fitting Rayleigh and Rician PDFs to Experimental PMF (2/2)

<table>
<thead>
<tr>
<th>PDF Type</th>
<th>$\sigma^2$</th>
<th>K-Factor (dB)</th>
<th>$X^2$ Goodness-of-fit test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rayleigh</td>
<td>0.51</td>
<td>-</td>
<td>7.1%</td>
</tr>
<tr>
<td>Rician</td>
<td>0.027</td>
<td>12.6</td>
<td>99.99%</td>
</tr>
</tbody>
</table>
Level Crossing Rate (LCR)

LCR of RSS

- LCR is mostly symmetrical around 0 dBm
  (Fading Interval mean)

- LCR at −6 dBm
  - 90th Percentile: $70 \frac{\text{crossings}}{\text{second}}$
  - Mean: $< 5 \frac{\text{crossings}}{\text{second}}$
AFC of RSS

- AFC at –6 dBm
  - 90th percentile: 1 ms
  - Mean: < 100 μsecs
Conclusion

- **WMAN architecture benefits from an optimized bridge**
  - Stripped down MAC – remove IEEE 802.11b’s inherent latency
  - Data Link Layer flow control through Pause packets
  - Adaptive rate-switching algorithm mitigates poor channel conditions due to RSS fading
  - Eliminate co-channel interference through frequency, angular, and antenna polarization diversity

- **Narrowband channel sounding of NLOS link at 5.8 GHz**
  - RSS measurement test hardware & software is reusable
  - Rician Channel model fit the experimental RSS data (99.99%) with K-Factor = 12.6 dB and variance = 0.027
  - A posteriori required fade margin: < 1 dB