UBC WLAN Group

Recent Developments in Indoor Radiowave Propagation

David G. Michelson

Background and Motivation

- wireless local area networks have been the "next great" technology for over a decade
- the cost and performance of IEEE 802.11b WLAN products marks a watershed for WLAN technology
- now, the focus is switching from system design to enterprise deployment
- design and deployment of wireless communication systems depends critically upon understanding of the propagation environment
- what are the issues for planners and network maintainers?

IEEE 802.11 - An Extensible WLAN Standard

IEEE 802.11 MAC layer is designed to interface with alternative PHY layers

- FHSS at 2.4 GHz with 1 and/or 2 Mbps data rates (original standard)
- DSSS at 2.4 GHz with 1 and/or 2 Mbps data rates (original standard)
- Diffuse IR (not commercially available)
- 802.11b (802.11HR) – DSSS at 2.4 GHz with 1, 2, 5.5, and 11 Mbps data rates
- 802.11g – DSSS at 2.4 GHz with 1, 2, 5.5, 11, and 22 Mbps data rates
- 802.11a – OFDM at 5.2 GHz (U-NII band) with 6, 12, 18, 24, 36, 48, and 54 Mbps data rates

IEEE 802.11b - PHY Specifications

- Transmit power: 35 mW (15 dBm)
- Operating range: 90 m – 550 m
- Current drain: 15 mA (sleep), 250 mA (rx), 300 mA (tx)
- Receiver sensitivity (BER $= 10^5$): between -91 and -94 dBm
- Maximum tolerable delay spread: 400 to 500 ns
- Number of clear channels in NA bandplan: 3

IEEE 802.11a - PHY Specifications

- Mandatory data rates (Mbps): 6, 12, 24
- Optional data rates (Mbps): 18, 36, 48, 54
- Number of subcarriers: 52 (48 for data, 4 for pilots)
- Modulation for subcarrier: BPSK, QPSK, 16-QAM, 64-QAM
- Channel spacing: 20 MHz
- Signal Bandwidth: 16.6 MHz
- Number of clear channels in NA bandplan: 8

Reliable Range - IEEE 802.11b

Data rate	1 Mb/s	2 Mb/s	5.5 Mb/s	11 Mb/s
Receiver sensitivity	-93 dBm	-90 dBm	-87 dBm	-84 dBm
Open Plan Building	490 m	350 m	260 m	190 m
Semi-open Office	100 m	85 m	70 m	55 m
Closed Office	45 m	40 m	35 m	30 m

Reliable Range - IEEE 802.11a

Data rate	6 Mb/s	12 Mb/s	...	48 Mb/s	54 Mb/s
Semi-open Office	70 m	55 m	...	14 m	7 m

Assumptions:

- Tx power $=$ 15 dBm, 99% coverage, 10^{-5} BER

Enterprise *vs.* SOHO Deployment of WLAN's

- *coverage* - cover essential areas but minimize number of access points
- *interference* - develop a suitable channel assignment strategy to minimize interference
- *roaming* - enable "extended service set"
- *network monitoring* - log network statistics for traffic and performance assessment
- *growth* - provide for growth by "cell splitting", new technologies

The University Networking Program at UBC http://www.UNP.ubc.ca

- *Mandate* – to provide each office, lab and classroom at UBC with state-of-the-art Internet connectivity.
- *Original Focus:* 10/100 Mbps wired Ethernet connections with cat 5 cable
- by 2004, 6500 new ports will be installed and another 8500 will be upgraded in 152 buildings and facilities across the campus
- *Extended Focus:* Also provide IEEE 802.11a/b Wireless LAN coverage in classrooms and public spaces
- by 2004, 1500–2000 access points will be installed

Propagation Models for Product Design and Deployment

- Conceptual Design
- **System Design** $\Longleftarrow$ statistical, pathloss and channel
- Implementation
- **System Integration and Test** $\Longleftarrow$ statistical, pathloss and channel
- Manufacture
- **Deployment** $\Longleftarrow$ statistical (planning), site-specific (design to build)
- Operation

Types of Indoor Radiowave Propagation Models

- need to reduce measured data into a compact form: measurement-based modelling
  - empirical narrowband models (pathloss *vs.* range)
  - empirical wideband models (power delay profile)
  - time variation models (Doppler spectrum)
- need to predict pathloss in the absence of measured data
  - deterministic models (site specific prediction using ray tracing, FD-TD, or similar rigorous methods)

Some Indoor Wireless System Planning Tools

- Site Planner (Wireless Valley)
- WiSE (Lucent Technologies)
- Placetool (Worcester Polytechnic Institute, Massachusetts)
- WinProp (AWE Communications)
- CINDOOR (University of Cantebria, Spain)
- Volcano (Siradel)
- SignalPro - Microcell/Indoor Module (EDX)

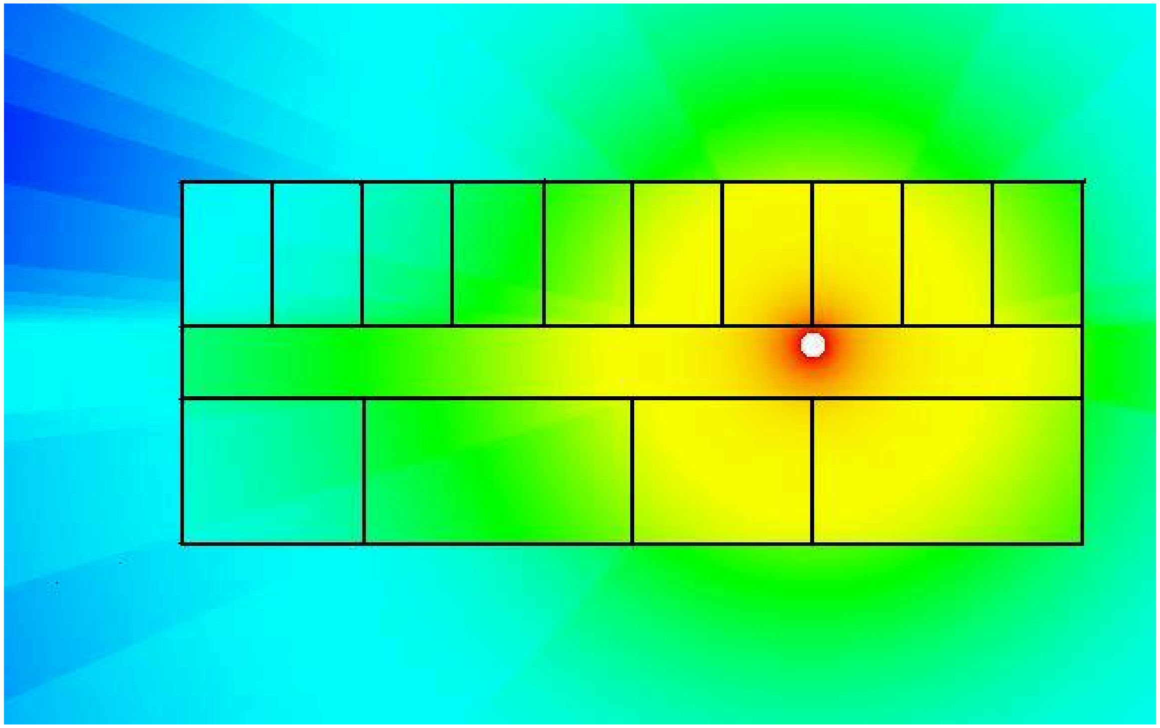
Issues – Indoor Wireless System Planning Tools

- ease of entering building data
  - manual data entry *or* translation of DXF/DWG files
- speed and accuracy of pathloss models
- extensibility of pathloss models
- integration of measured data
- verification of pathloss models
- speed and accuracy of optimization tools (access point locations and channel assignments), if available

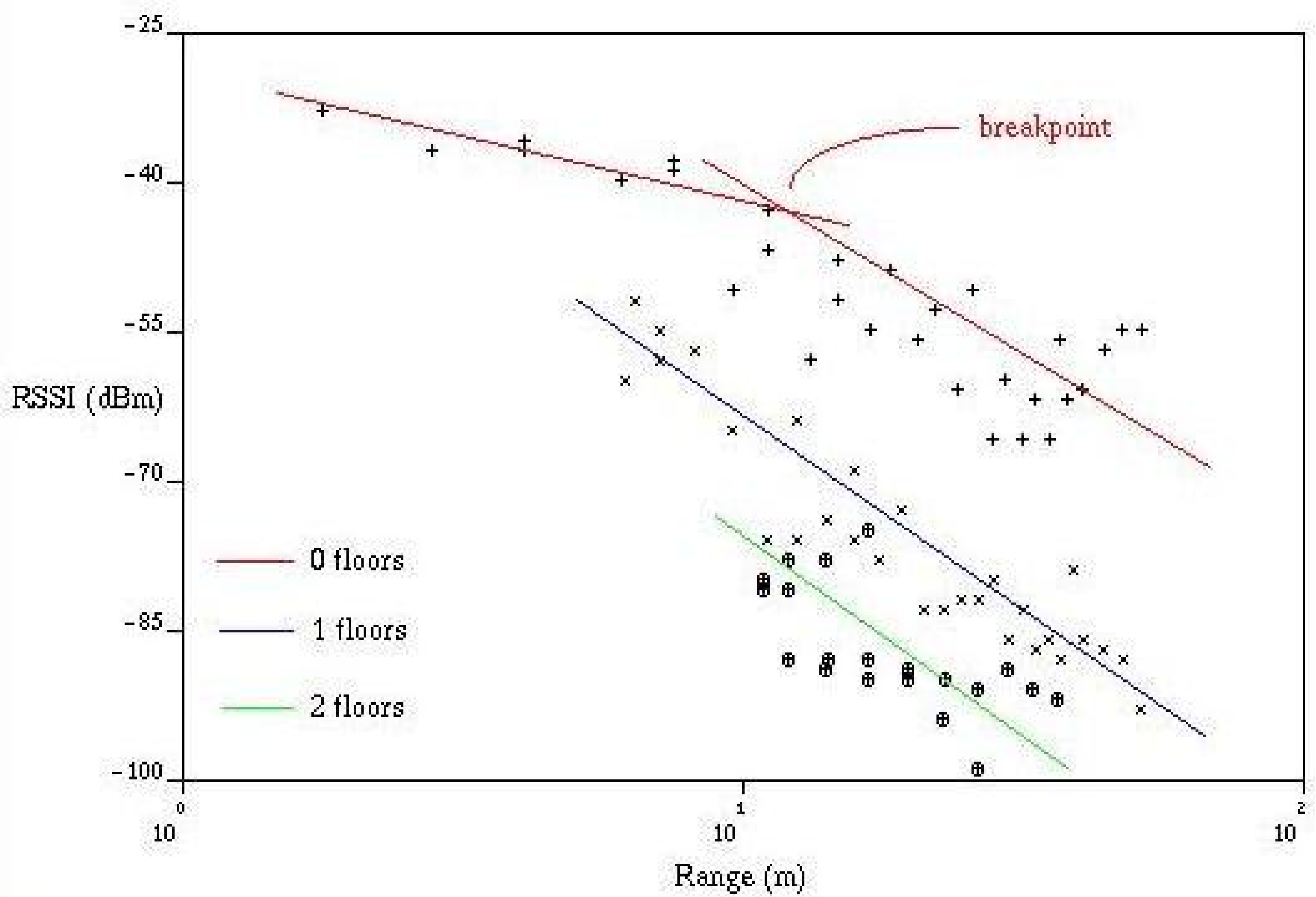
Site Survey for WLAN Deployment

- current practice puts emphasis on site survey rather than use of planning tools
- vendor-supplied site survey tools are convenient but limited
- most emphasize data rate rather than received signal strength
- *cf.* tools offered by Lucent, Symbol, and those derived from the latter
- alternative: CW signal generator and a spectrum analyzer
- alternative: tracking generator and a spectrum analyzer
- alternative: vector network analyzer

Pathloss Prediction using a Measurement-Based Model



Reduction of Measured Pathloss Data



Pathloss in Free Space

If

$$P_r = P_t + G_t - L_T + G_r$$

then

$$L_T = 20\log f_c + 20\log d - 28$$

where

$L_T =$ the total pathloss (in dB)
$f_c =$ frequency (in MHz)
$d =$ distance between the transmitter and receiver (in m)

One-Slope Model

$$L_T = L_0 + 10n \cdot \log(d)$$

where

$L_T =$ the total pathloss (in dB)
$L_0 =$ the pathloss (in dB) at a distance of 1 metre
$n =$ pathloss exponent
$d =$ distance between the transmitter and receiver (in m)

One-Slope Model

$$L = L_0 + 10n \cdot \log(d)$$

- Strengths
  - easy to use, commonly used in mobility applications
  - can be extended using breakpoints, if appropriate
- Limitations
  - dependence of these parameters on the type of environment
  - doesn't account for relatively complex nature of indoor pathloss environment
  - doesn't account for three-dimensional nature of the indoor pathloss environment

Keenan's Model (1990)

$$L_T = L_1 + 20 \log d + n_f a_f + n_w a_w$$

where

$L_T =$ total pathloss (in dB)
$L_1 =$ pathloss (in dB) at $r = 1$ m
$d =$ distance between the transmitter and receiver (in m)
$n_f =$ number of floors between the AP and terminal
$a_f =$ attenuation factor (in dB per floor)
$n_w =$ number of walls between the AP and terminal
$a_w =$ attenuation factor (in dB per wall)

Keenan's Model (continued)

$$L = L_0 + 20\log d + n_f a_f + n_w a_w$$

- Strengths
  - accounts for our understanding of how intervening walls and floors affect the direct path
  - not overly complicated
- Limitations
  - Keenan didn't report any values for these factors
  - only intended as a basis for further work

ITU-R Recommendation P.1238 (1997)

$$L_T = 20 \log f_c + 10n \log d + L_f(n_f) - 28$$

where

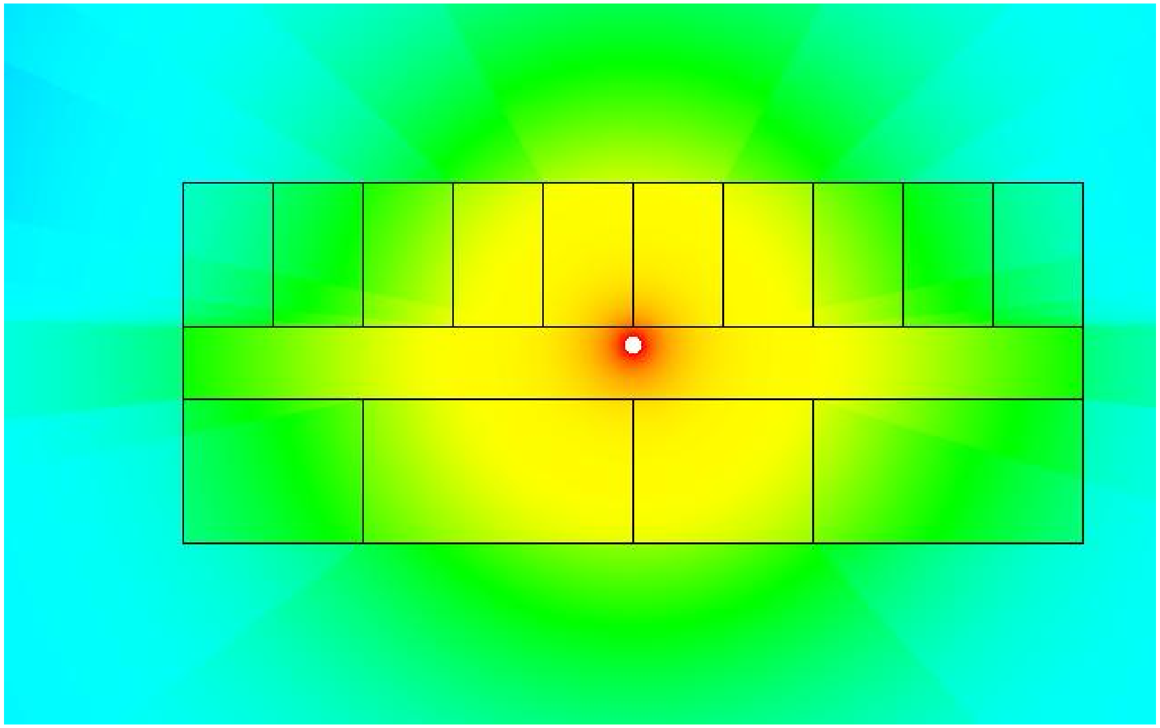
$L_T =$ total pathloss (in dB)
$f_c =$ frequency (in MHz)
$n =$ environment dependent pathloss exponent
$d =$ distance between the transmitter and receiver (in m)
$L_f(n_f) =$ floor penetration loss, which varies with the number of penetrated floors

ITU-R Recommendation P.1238 (continued)

$$L_T = 20 \log f_c + 10n \log d + L_f(n_f) - 28$$

- Strengths
  - doesn't rely on having access to a building database
  - good for quick estimates
- Limitations
  - doesn't take full advantage of a building database (if available)

Pathloss Prediction Using COST-231 Model



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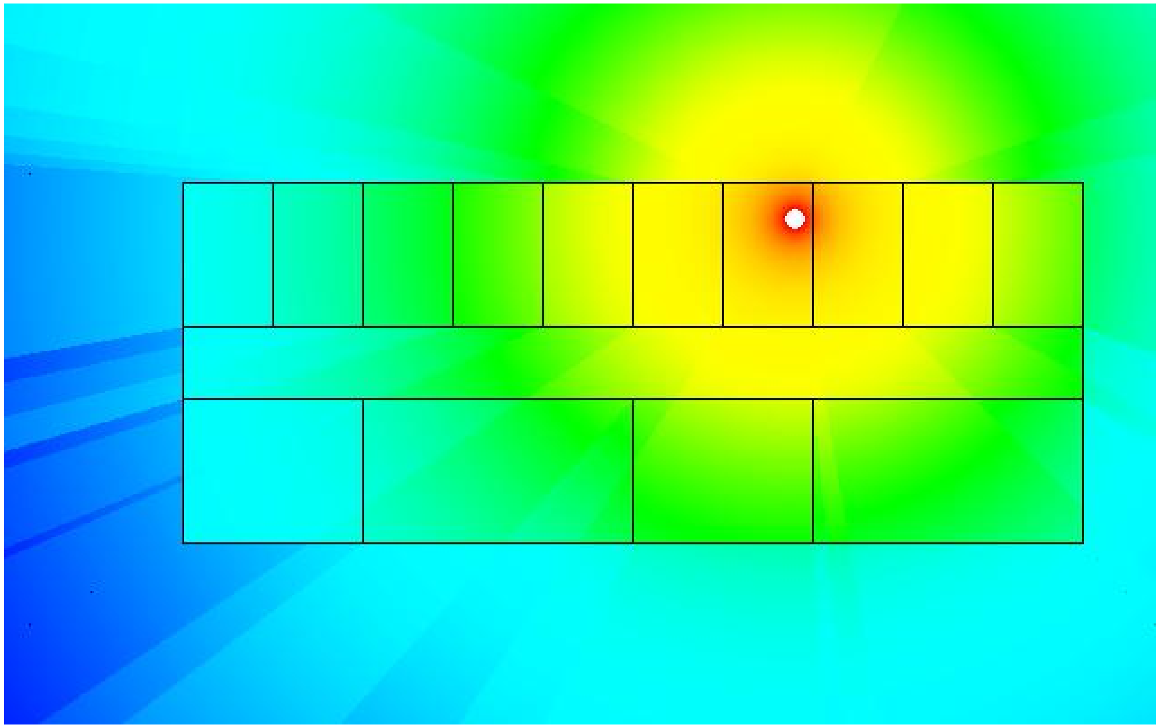

Deterministic Models

- simulate propagation using rigorous electromagnetic methods, *e.g.*,
  - FD-TD (finite difference - time domain)
  - ray tracing (GO (geometric optics), GTD (geometric theory of diffraction), UTD (uniform theory of diffraction))

- two issues:
  - need for very detailed three-dimensional building databases
  - excessive computational complexity

- many practical difficulties, best applied to new designs

UBC WLAN Group – Future Work

- survey selected buildings for WLAN pilot deployment
- compare coverage at 2.4 GHz (802.11b/ISM) and 5.2 GHz (802.11a/NII) in representative buildings
- assess and develop methods for optimizing channel assignments
- assess throughput in the presence of co-channel and offset channel interference
- explore relationship between RSSI and data rate
- develop improved site survey hardware and software
- conduct electromagnetic interference survey

Data Rate *vs.* Signal Strength