Indoor Network Planning for IEEE 802.11 based WLANs

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Agenda

- **Introduction**
- Review of WLAN technologies
- Indoor Radio Propagation
- WLAN network planning process
- Case study

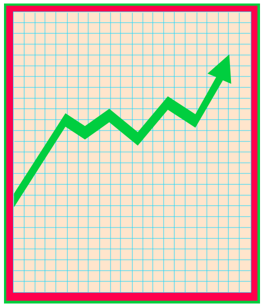
Introduction

- WALN benefits
- WLAN usage status
- WLAN technology problems
- WLAN implementation problems
- Study target

WALN Benefits

- Mobility: Improves working efficiency and productivity, extends the On-line period
- Fast Roll-out: Saves cabling time and convenient to SOHO users and difficult-to-wire case
- Broadband: 11Mbps for 802.11b and 54Mbps for 802.11a/g (GSM:9.6Kbps, HCSCD:~40Kbps, GPRS:~160Kbps, WCDMA:up to 2Mbps)
- Cost saving: Comes from easy maintenance, cabling cost, working efficiency and accuracy. Average Pay back time less than 1 year (WLANA Return-On-Investment survey,2001)

WLAN usage Situation



- 802.11 WLAN market grows rapidly. In 2001, 150% sales increasing over 2000 and reach $1.47 Billion (Synergy Research Group)
- 40% of companies are using WLAN and another 31% plan to deploy in next 18 months (WECA survey to randomly selected 180 US companies with more than 500 computers, autumn, 2001)
- Wide penetration in different organizations (Education: 26%, Healthcare:14%, Government:11% Manufacturing:10%, Others:6%, CISCO Survey to more than 400 companies, Autumn, 2001)

WLAN Technology Problems

- Date Speed IEEE 802.11b support up to 11MBps, lower than 100Mbps fast Ethernet currently deployed
- Interference Work in ISM band, share same frequency with microwave oven, Bluetooth, and others
- Security Current WEP algorithm is weak
- Roaming No industry standard is available and propriety solution are not interoperable
- Inter-operability Only few basic functionality are interoperable, other vendor’s features can’t be used in a mixed network

WLAN Implementation Problems

- Lack of wireless networking experience for most IT engineer
- No well-recognized operation process on network implementation
- Selecting AP position with ‘Best Guess’ method
- Unaware of interference from/to other networks
- Weak security policy
- As a result, your WLAN may have
  - Poor performance (coverage, throughput, capacity, security)
  - Unstable service
  - Customer dissatisfaction

Study target

- The study focus on
  - investigating indoor radio propagation characteristic
  - understanding and planning WALN security
  - analyzing critical issues on WLAN network planning
  - presenting a work process for WLAN implementation
  - improving WLAN coverage in Dept. Of E.E. of HUT

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Review of WLAN technologies

- IEEE 802.11
- IEEE 802.11b
- IEEE 802.11a
- IEEE 802.11g

IEEE 802.11

- First standard was released in 1997, three physical layers are defined
  - Infrared product never show up due the range limitation
  - FHSS frequency hopping spread spectrum
  - DSSS direct sequence spread spectrum
- Use similar LLC and MAC layer frame structure with existing 802.X protocol.
- Designed as a mobile extension to wired LAN

802.11 FHSS

- Support 1 and 2 Mbps data rate and use 2/4-GFSK modulation (Δf = 160 kHz and 216/72 kHz respectively)
- 79 channels from 2.402 to 2.480 GHz (in U.S. and most of EU countries) with 1MHz channel space
- 78 hopping sequences with minimum 6 MHz hopping space, each sequence uses every 79 frequency elements once
- Minimum hopping rate 2.5 hops/second in U.S.
- Tolerance to multi-path, narrow band interference, security
- Low speed, small range due to FCC power regulation (10mW)

802.11 DSSS

- Support 1/2 Mbps data transport, use BPSK and QPSK modulation
- Use 11 chips barker code as spreading code, provide 10.4 dB processing gain
- Define 14 overlapping channels, each has 22MHz channel bandwidth, from 2.401to 2.483 GHz
- Power limit (1000mW in U.S., 100mW in EU, ~200mW in JP)
- Immune to narrow-band interference, cheaper HW

802.11b

- Released in 1999
- A extension to 802.11 DSSS, same channel and bandwidth, similar PLCP frame structure
- Support 5.5 and 11 Mbps data transport
- Use Complementary Code Keying as modulation method
  - M-ray Orthogonal keying

$$C = \{e^{j(j_1+j_2+j_3+j_4)}, e^{j(j_1+j_3+j_4)}, e^{j(j_1+j_2+j_4)}, -e^{j(j_1+j_4)}, e^{j(j_1+j_2+j_3)}, e^{j(j_1+j_3)}, -e^{j(j_1+j_2)}, e^{j(j_1)}\}$$

  - 5.5M 2^2 = 4 complex coding sequences
  - 11M 2^6 = 64 complex coding sequences
- Symbol rate is 1.375 MHz

802.11a

- Operates at U-NII band at 5 GHz (low band: 5180~5240 MHz, middle band: 5260~5320MHz, high band: 5745~5805MHz, 12 channels with 20MHz bandwidth)
- Support multi rate 6Mbps, 9Mbps,… up to 54Mbps
- Use Orthogonal Frequency Division Multiplexing (OFDM), 52 sub-carriers in one frequency channel. 48 for data transmission and 4 for channel estimation
- Use inverse discrete Fourier transform combine multi-carrier signals to single time domain symbol (symbol length 4ms and occupied bandwidth 16.6 MHz)

802.11a cont.

Data Rate (Mbps)	Modulation	Coding Rate	Coded bits per sub-carrier	Code bits per OFDM symbol	Data bits per OFDM symbol
6	BPSK	1 / 2	1	48	24
9	BPSK	3 / 4	1	48	36
12	QPSK	1 / 2	2	96	48
18	QPSK	3 / 4	2	96	72
24	16QAM	1 / 2	4	192	96
36	16QAM	3 / 4	4	192	144
48	64QAM	2 / 3	6	288	192
54	64QAM	3 / 4	6	288	216

Modulation and coding schemas of different data rates

802.11g

- Draft version was released in Nov. 2001, official standard may come in 2003
- Support up to 54Mbps data rate at 2.4 GHz, backward compatible to 802.11b
- Three proposals are competed
  - Pure OFDM (basic requirement)
  - CCK + OFDM (optional, supported by *Intersil*)
  - CCK + PBCC (Packet Binary Convolution Code) (optional, supported by *Texas Instruments*)

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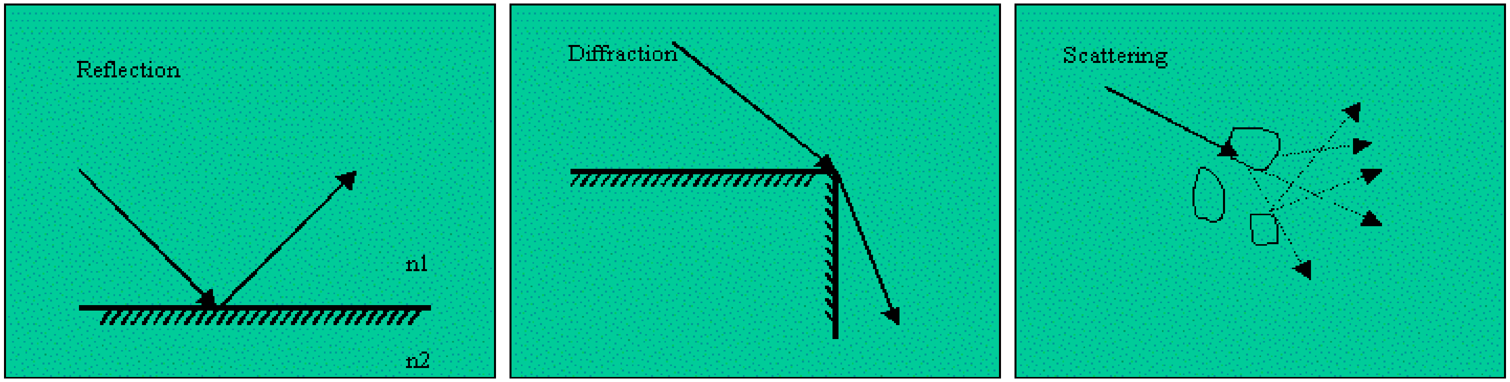
Indoor Radio Propagation

- General radio propagation
- Indoor radio propagation model
- Diversity and combining
- WLAN Antennas

General Radio Propagation(1)

Three basic radio propagation mechanisms

– Reflection
– Diffraction
– Scattering



General Radio Propagation(2)

- Path loss
  - determines power budget, coverage, interference
  - log-distance model

$$PL(d) = PL(d_0) + 10n\log(d/d_0) + X_s$$

- Delay Spread
  - describes the multipath property of radio channel
  - three power delay profiles
    - Mean excess delay
    - RMS excess delay
    - Maximum excess delay

$$m_t = \frac{\sum_i P(t_i)\, t_i}{\sum_i P(t_i)} \qquad s_t = \sqrt{\frac{\sum_i (t_i - m_t)^2 P(t_i)}{\sum_i P(t_i)}}$$

Empirical narrow band models (COST231)

- Single slop model $L \quad L_0 \quad 10n \; \log(d)$

Environment	Dense/1 Floor	Dense/2 Floor	Dense/Multi Floor	Open	Large	Corridor
L_0 (dB)	33.3	21.9	44.9	42.7	37.5	39.2
n	4.0	5.2	5.4	1.9	2.0	1.4

- Multi-wall model $L = L_{FS} + L_c + \sum_{i=1}^{l} K_{wi} L_{wi} + K_f^{\frac{K_f+2}{K_f+1} - b} L_f$

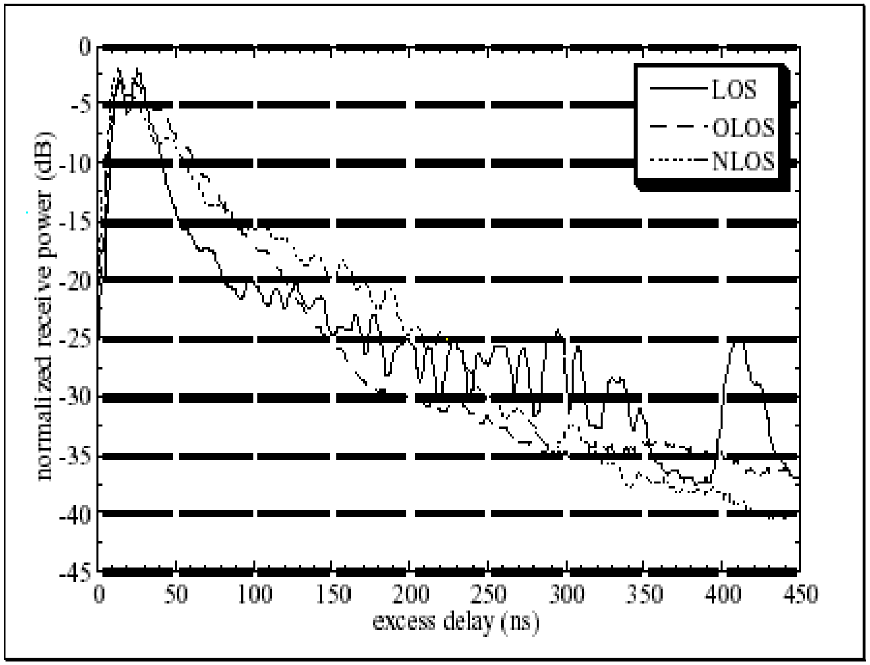
Parameter(s)	Light Wall Loss (dB)	Heavy Wall Loss (dB)	Floor Loss (dB)	Multi-floor Non-linear factor b
Value	3.4	6.9	18.3	0.46

Empirical wide band models

- Delay spread in typical indoor environments

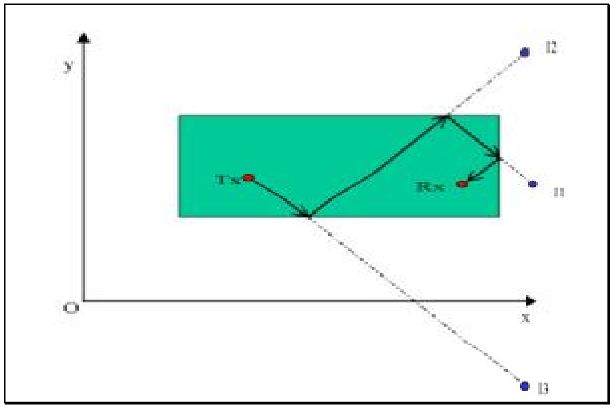
Environment	Typical r.m.s. Delay (ns)	Worst case r.m.s. Delay (ns)	30 dB Excess Delay (ns)
Residential House	150	420	1100
Office Building in Suburban	25~125	40~320	200~600
Office Building in Urban	25~50	100	NA
Factory Building with heavy machinery	19~105	40~300	800
Other factory, stadium, exhibition	15~20	40~146	NA

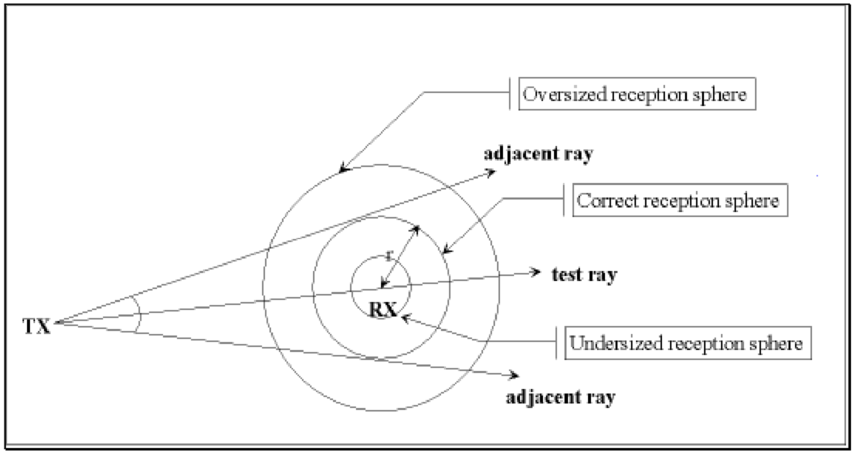
- Delay spread of LOS, OLOS, and NLOS channel



Deterministic model

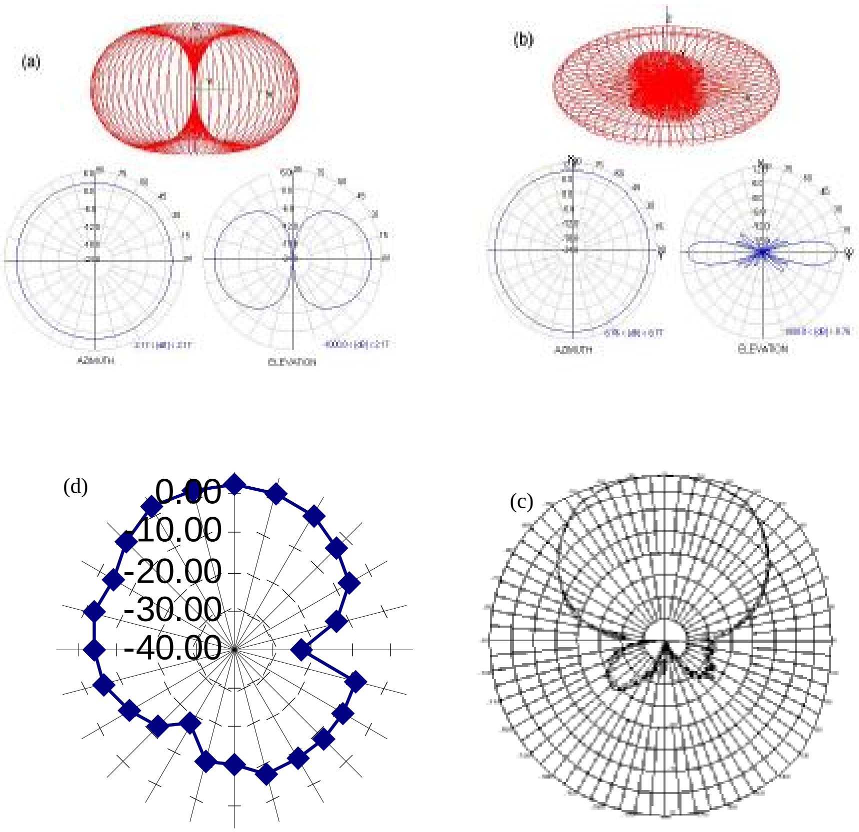
- Simulate propagation of radio wave physically using either uniform theory of Diffraction (UTD) or Geometric Optics (GO). GO is simpler than solving Maxwell's equation.
- Two GO methods
  - Image method
  - Brutal Force Ray tracing





WLAN Antenna

- Omni directional Antenna
  - 1/2 λ Dipole Antenna (a)
  - Multi dipole Antenna (b)
- Directional Antenna
  - Yagi Antenna
  - Patch Antenna (c)
  - Parabolic Antenna
- PCMCIA integrated Antenna
  - with space or polarity diversity
  - poor gain
  - directivity (d)



Radiation Patterns of antennas

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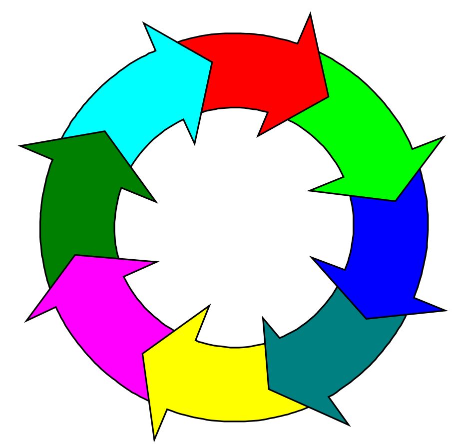
WLAN Network Planning

- Network planning target
  - Maximize system performance with limited resource
  - Including coverage, throughput, capacity, interference, roaming, security, etc.
- Planning process
  - Requirement management
  - Site investigation
  - Computer-aided planning practice
  - Verifying planning

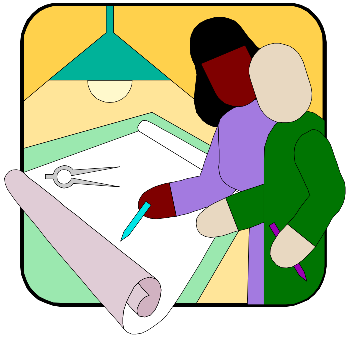


Requirement Analysis

- Starting point of a project, include:
  - Business requirement
  - Functional requirement
  - Performance requirement
  - Management requirement
- Processing requirement
  - Verification & Validation
  - Prioritizing requirement
- Document requirement

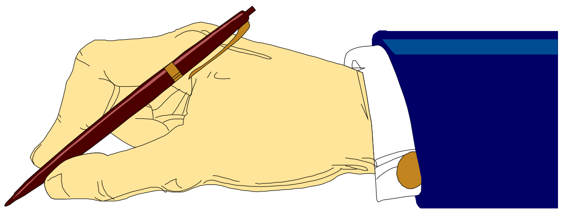
Site Survey

- Understand existing network infrastructure
  - Check Ethernet and electricity socket distribution
  - Check high level profile, such as IP address, VPN, Network service, Security policy
  - Make interference survey and identify interference sources
  - Study building blueprint and check the consistency with practical
- Site survey report including
  - Site information
  - Primary coverage plan (number, position of AP)
  - Primary frequency plan (Interference avoidance)



Coverage planning

- Base on primary selected locations
  - Select best AP location
  - Select suitable antenna pattern
  - Optimized by planning software



- Set coverage target
  - -70 dBm for 802.11b 11Mbps
  - ~ 10 dB fading margin to receiver sensitivity level (-84 dBm)
- Link budget
  - TX power
  - Antenna gain, cable loss
  - Path loss (most difficult part !!!)

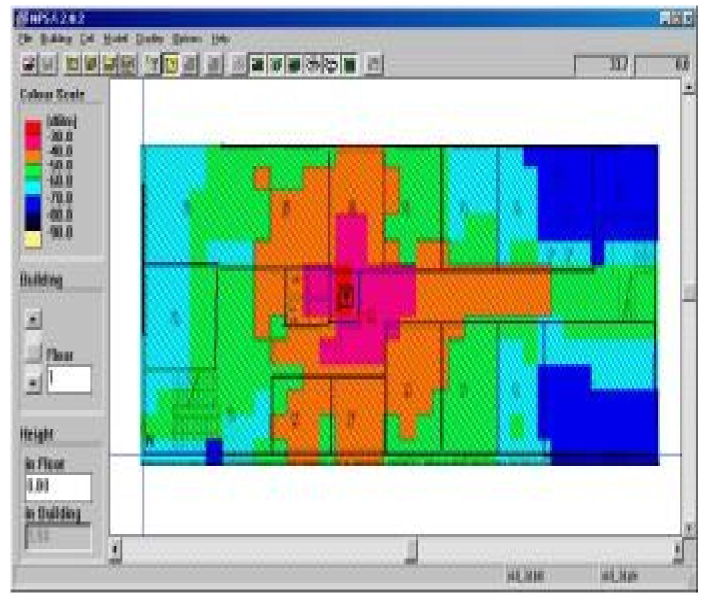
$$P_{MS\_RX} = P_{AP\_TX} + G_{MS\_Ant} - L_{MS} - L_{path} - L_{AP} + G_{AP\_Ant}$$

Planning tools (1)

NPS/indoor (Nokia Network, Finland)

- Indoor radio planning designed for GSM/DCS
- Support three models
  - One slop model
  - Multi-wall model
  - Enhanced Multi-wall model
- System parameters can be adjusted and optimized by field measurement
- Graphical planning interface and coverage view

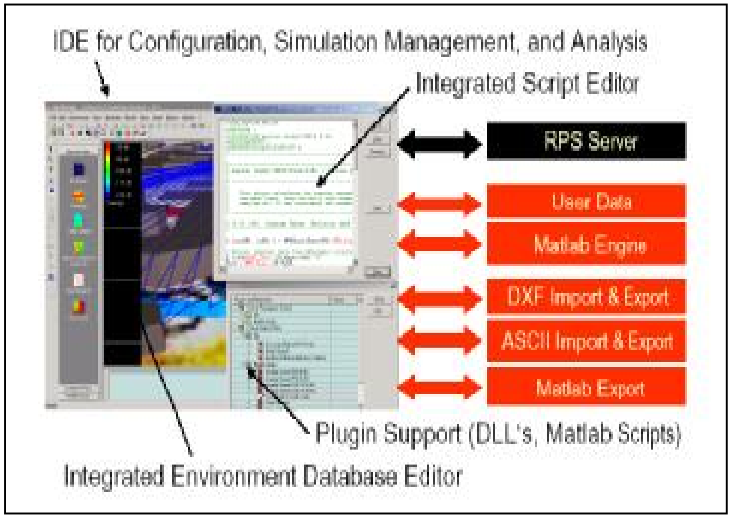
NOKIA



Planning tools (2)

Radio Propagation Simulation
(RadioPlan GmbH, Germany)

- 3D Ray tracing tool
- Construction material database
- Graphic interface for
  - Building modeling
  - TX and RX placement
  - Signal level and coverage present
- Support classical propagation models
- Data import and export



Field Measurement

- Basic tools
  - Laptop or PDA
  - Utility come with radio card HW (i.e. Lucent client manager)
  - Support channel scan, station search
  - Indicate signal level, SNR, transport rate

- Advanced tools
  - Special designed for field measurement
  - Support PHY and MAC protocol analysis
  - Integrated with network planning tools
  - Examples
    - Procycle™ from Softbit, Oulu, Finland
    - SitePlaner™ from WirelessValley, U.S.

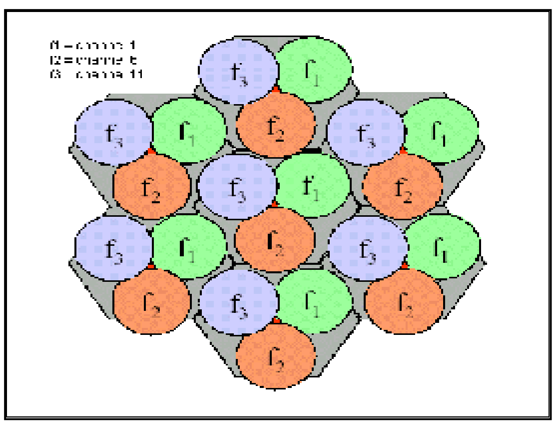
Capacity Planning

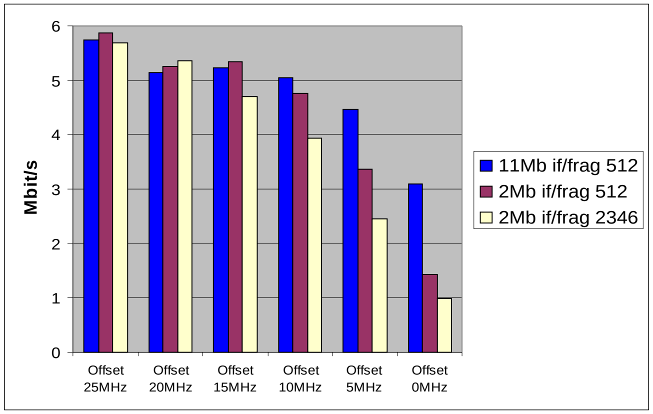
- 802.11b can have 6.5 Mbps rate throughput due to
  - CSMA/CA MAC protocol
  - PHY and MAC management overhead
- More user connected, less capacity offered
- Supported users in different application cases

Environment	Traffic content	Traffic Load	Number of simultaneous users		
			11Mbps	5.5Mbps	2Mbps
Corporation Wireless LAN	Web, Email, File transfer	150 kbits/user	40	20	9
Branch Office Network	All application via WLAN	300 kbits/user	20	10	4
Public Access	Web, Email, VPN tunneling	100 kbits/user	60	30	12

Frequency Planning(1)

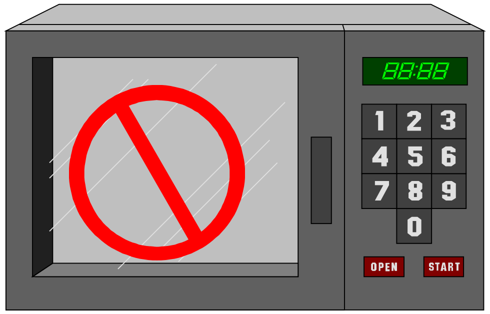
- Interference from other WLAN systems or cells
  - IEEE 802.11 operates at uncontrolled ISM band
  - 14 channels of 802.11 are overlapping, only 3 channels are disjointed. For example Ch1, 6, 11
  - Throughput decreases with less channel spacing
- A example of flat allocation in multi-cell network

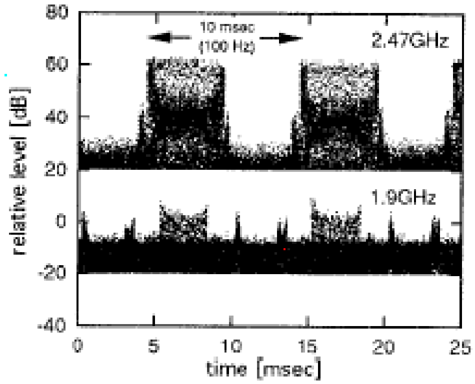




Frequency Planning(2)

- Interference from microwave oven
  - Microwave oven magnetrons have central frequency at 2450~2458 MHz
  - Burst structure of radiated radio signal, one burst will affect several 802.11 symbols
  - 18 dBm level measured from 3 meter away from oven, hide all WLAN signal
- Solutions
  - Use unaffected channels
  - Keep certain distance between them
  - Use RF absorber near microwave oven

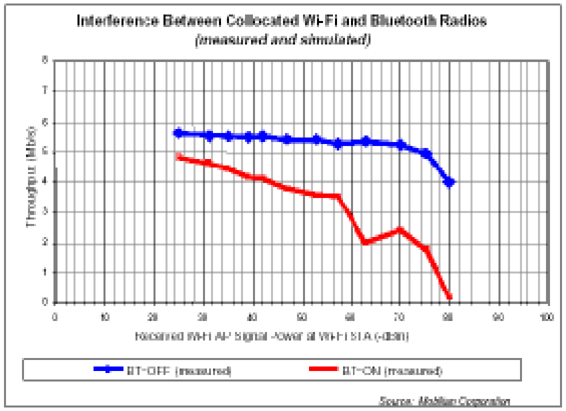




(a) Overview within 25 msec

Frequency Planning(3)

- Interference form Bluetooth
  - The received signal level from two systems are comparable at mobile side
  - In co-existing environment, the probability of frequency collision for one 802.11 frame vary from 48% ~62%
  - Deterioration level is relevant to many factors
    - relative signal levels
    - 802.11 frame length
    - activity of Bluetooth channel
- Solution
  - Co-existing protocol IEEE 802.15 (not ready)
  - Limit the usage of BT in 802.11 network



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Case study

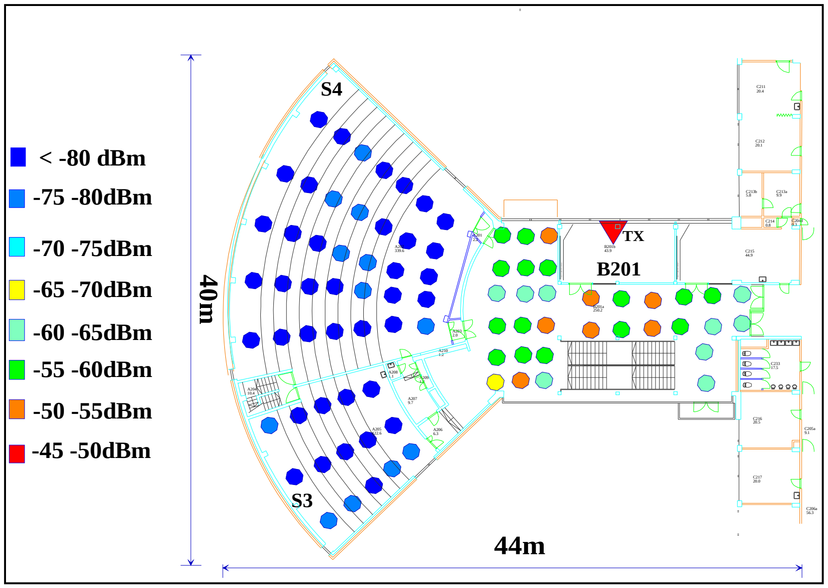
- Background
  - 802.11b Wireless MediaPoli network in Otaniemi
  - Ad Hoc mode (0B89), free access, support DHCP or Mobile IP
  - 9 APs allocated in Otakaari 5 and Otakaari 8
- Filed measurement setup
  - Compaq Pocket PC with Lucent 802.11b PC card
  - IBM ThinkPad 600E laptop with Lucent Gold and Nokia C111 PC card
  - Utility software provided by radio card vendors
- Targets
  - Improve WLAN coverage performance in selected areas
  - Follow planning process and use planning software

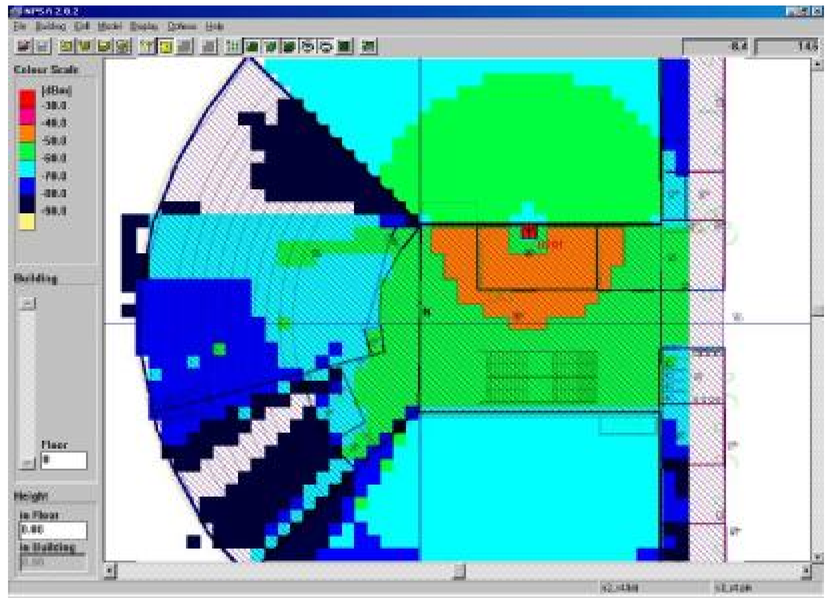
Method

- Understand coverage target and priority
- Check current coverage performance
- Model case by planning tools
- Optimize location of AP and antenna pattern
- Verify result of system optimization

Case 1 Lecture Hall S3/S4(1)

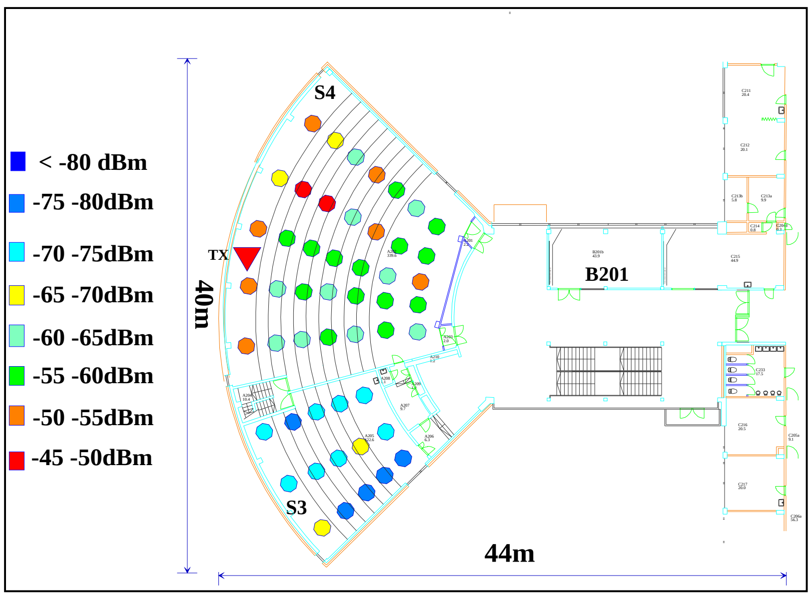
- Old coverage status (measured)
- Old coverage status (NPS simulated)

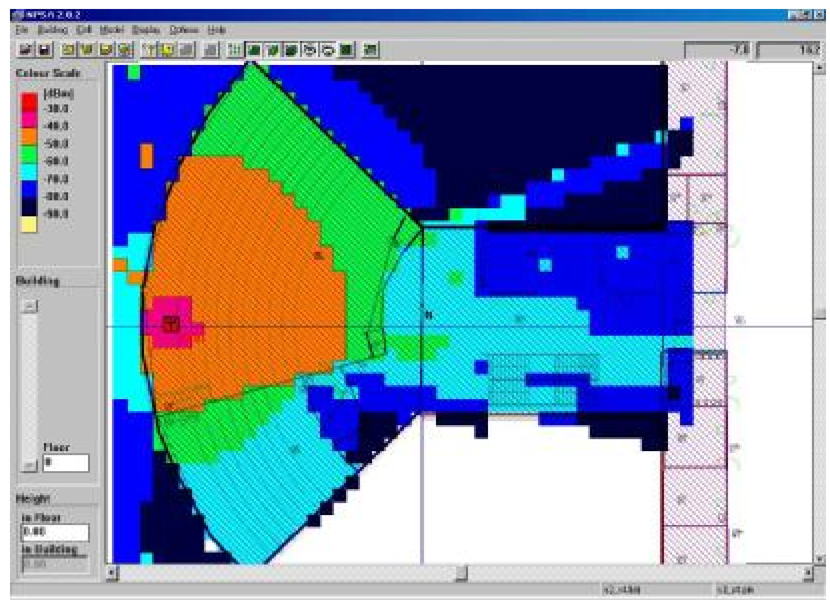




Case 1 Lecture Hall S3/S4(2)

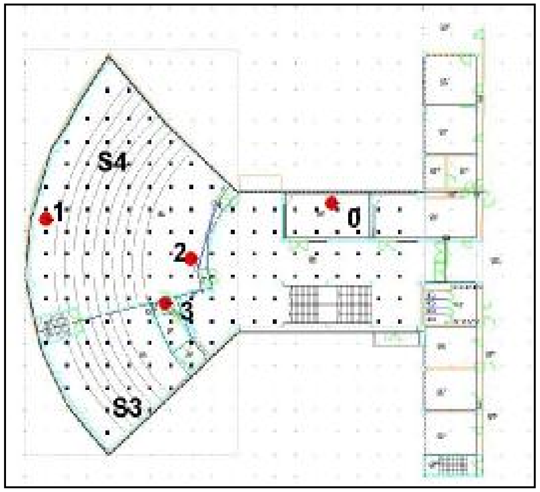
- New coverage status (measured)
- New coverage status (NPS simulated)



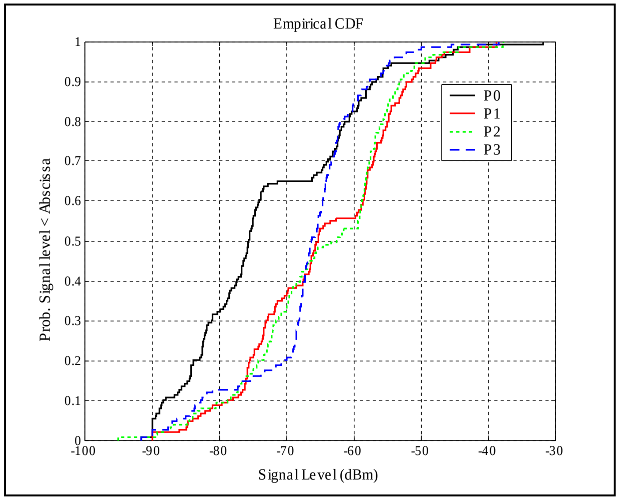


Case 1 Lecture Hall S3/S4(3)

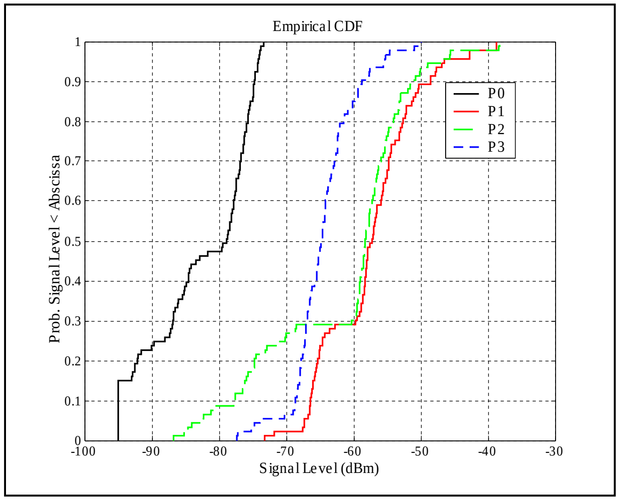
- AP location optimization (RPS simulation)
- Conclusion: Position 1 is the best place



Position candidates



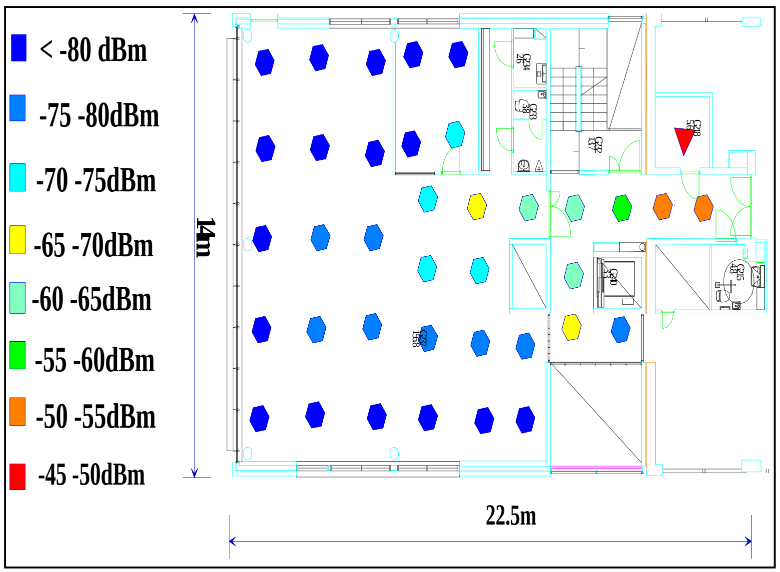
Coverage CDF (all areas)



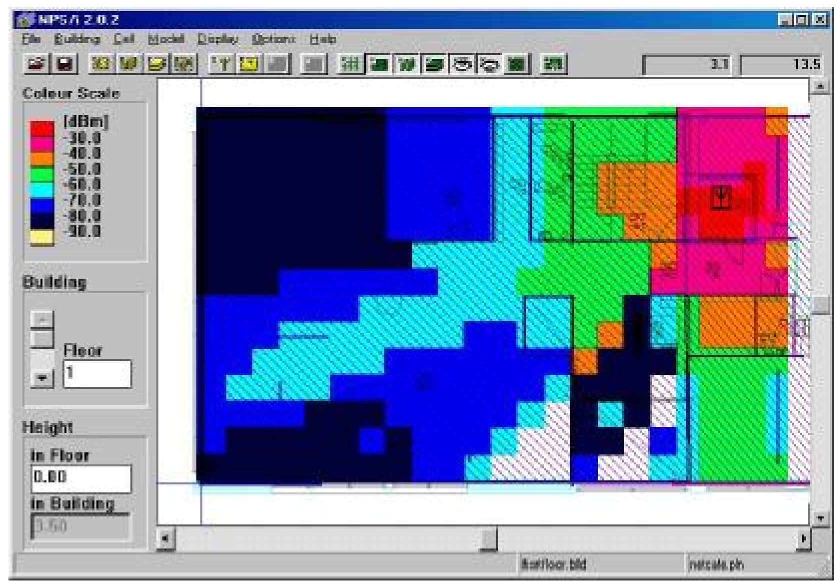
Coverage CDF (S3/S4 only)

Case 2 Dept. Library (Reading area) (1)

- Old coverage status (measured)

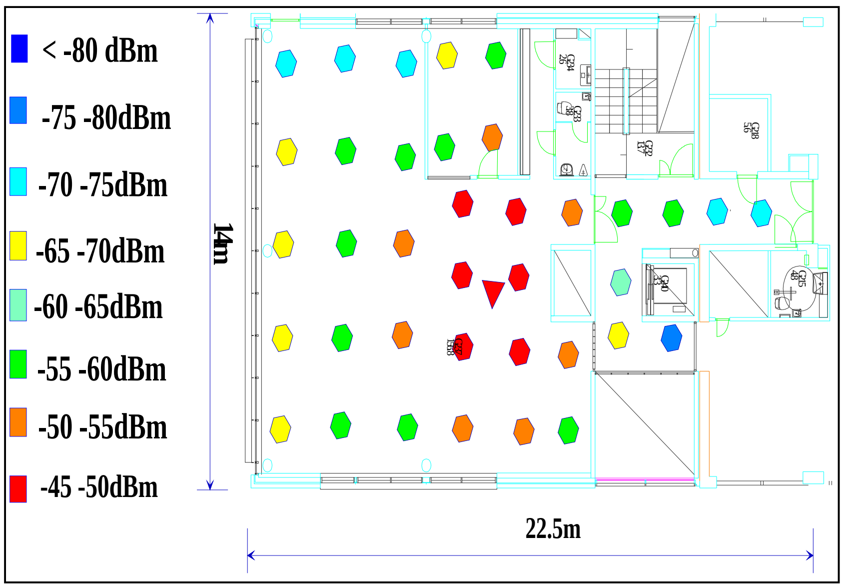


- Old coverage status (NPS simulated)

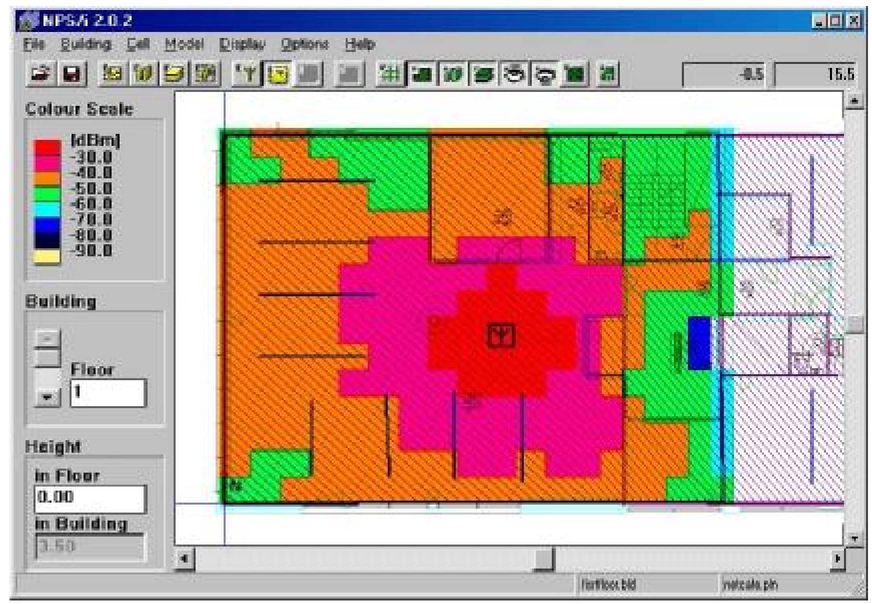


Case 2 Dept. Library (Reading area) (2)

- New coverage status (measured)



- New coverage status (NPS simulated)



Case 2 Dept. Library (Reading area) (3)

- RPS simulation result
- Position 1 has much better coverage