Measurement and Analysis of the Error Characteristics of an In-Building Wireless Network

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Motivation

- Move wireless beyond best-effort connections
  - Wireless error characteristics not as well understood
  - Error patterns imply particular strategies

- Distributed Filesystem (ex. Coda)
  - Bulk data transport
    - Packet loss: congestion or a radio error?
    - Link-level retransmission?
    - Forward error correction?
  - Network adaptation
    - Is service reduction temporary or long-term?
      - long-term $\Rightarrow$ relax consistency, prioritize

Goal

Study a high-speed wireless LAN error environment

- **What causes errors?**
- **Beyond BER (bit error rate)**
    - **best, worst BER**
    - **distribution (implies strategy)**
    - **burst characteristics**
    - **timescale of error rate variation?**

Approach

- **Choose a representative wireless LAN (WaveLAN)**
- **Subject it to stress**
    - **attenuation, front end overload, interference**
- **Observe frequency, type of errors**

Outline

- WaveLAN
- Methodology
- Related Work
- Results
  - Error rate often comparable to wired networks
  - Observed static and dynamic sources
    - walls, people, interference
  - Error distribution is roughly tri-modal
- Conclusions

Lucent/AT&T/NCR WaveLAN

Overview

- 900 MHz ISM band (we did not test 2 GHz version)
- Ethernet chip, custom modem, radio
- MAC - “Wireless Ethernet” CSMA/CA

Modulation

- 2 Mb/s user data, DQPSK modulated
- Direct Sequence Spread Spectrum
  - 1 fixed sequence, 11 chips/bit
  - resists narrowband sources, multipath fading

Receive threshold

- ignore packets below a given signal strength

Methodology

Instrument data traffic between two laptop computers

- **promiscuous mode**
- **record even damaged packets**
- **record multiple packet bursts, each at maximum rate**
  - **10^7 bits - 10^{10} bits, depending on subtlety**

Post-process

- **determine lost, truncated packets**
- **generate error syndromes for each whole packet**
- **summarize signal information**
  - **signal level, silence level, signal quality, antenna**

Scope

Huge parameter space

- **laptop operation (CPU clock, peripheral activity, ...)**
- **precise radio placement, orientation**
- **location and composition of furniture**

No clean room

- **proximity of unknown interference sources**
  - **cellular phones, WaveLAN in other buildings**

Examples presented

- **specific - one human, two buildings, four phones**
- **interesting - clearly significant change in behavior**
- **representative?**

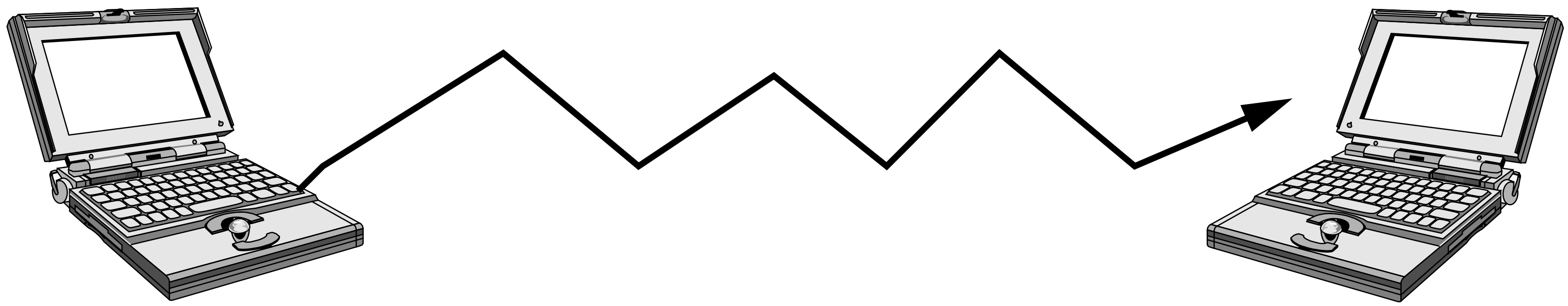
Outline of Experiments

Base Case (in-room, unstressed)
- **best-case BER**
- **effect of distance**
- **receive threshold - artificial distance**

Obstacles
- **wall(s), person**

Interference
- **narrowband FM**
- **spread spectrum**
- **competing WaveLAN units**

Base Case



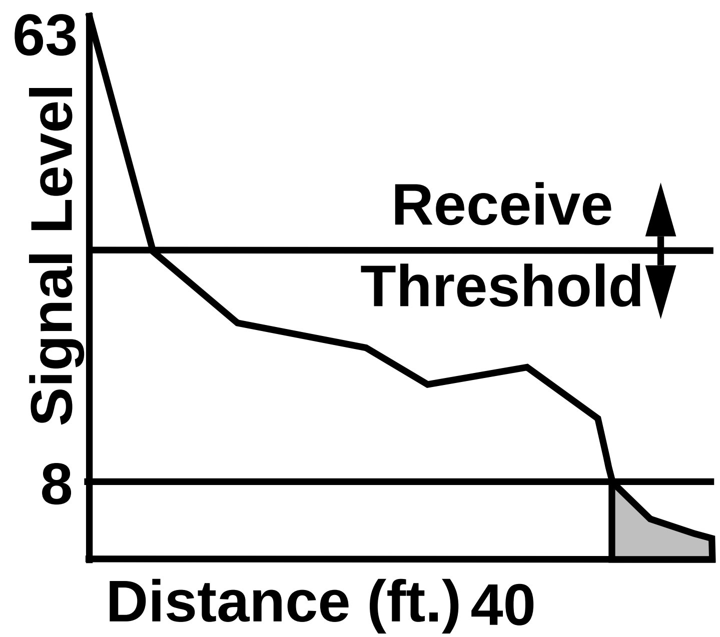
Questions

- long-term BER
- long-term loss rate
- effects of distance
- effects of receive threshold

Base Case Results

Results

- long-term BER: roughly 10^{-10}
- long-term loss rate: less than 10^{-3} packets
- distance: large rooms (lecture halls) gave no trouble



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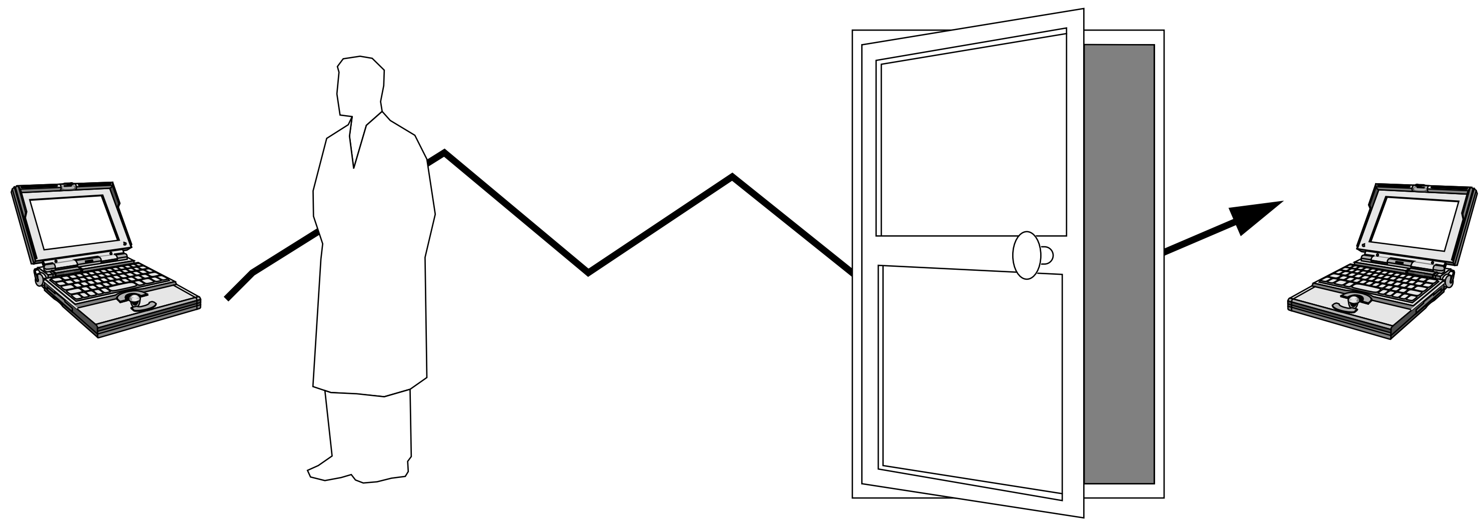
Obstacles



Questions

- packet loss, bit errors
- signal degradation

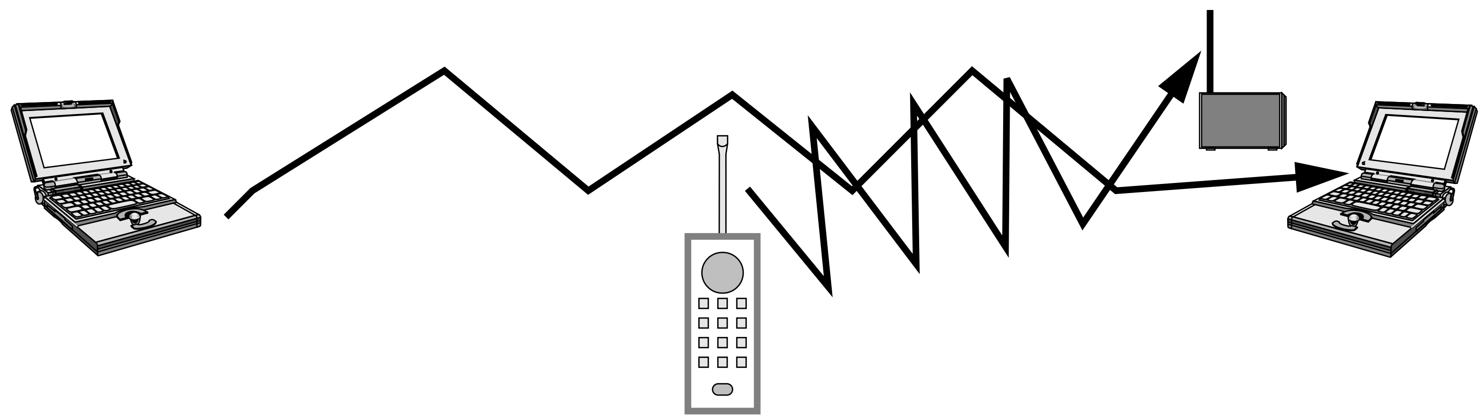
Obstacle Results

Obstacle	Loss	Damaged Packets	Bits per Packet	Signal Level
Plaster/mesh	none	none	none	-5
Concrete block	none	none	none	-2
Multiple walls	minor	5%	7 bits	-20
Person	minor	15%	27 bits	-6

Implications

- 900 MHz WaveLAN penetrates obstacles well
  - Construction materials differ
- Human placement is a dynamic error source

Cordless Phone Interference



Sources

- 900 MHz narrowband FM (ex. AT&T 9100)
- 900 MHz digital spread spectrum (ex. AT&T 9300)

Questions

- Packet loss, bit errors, signal degradation
- Are base and handset different?
- What are the effects of multiple interference sources?

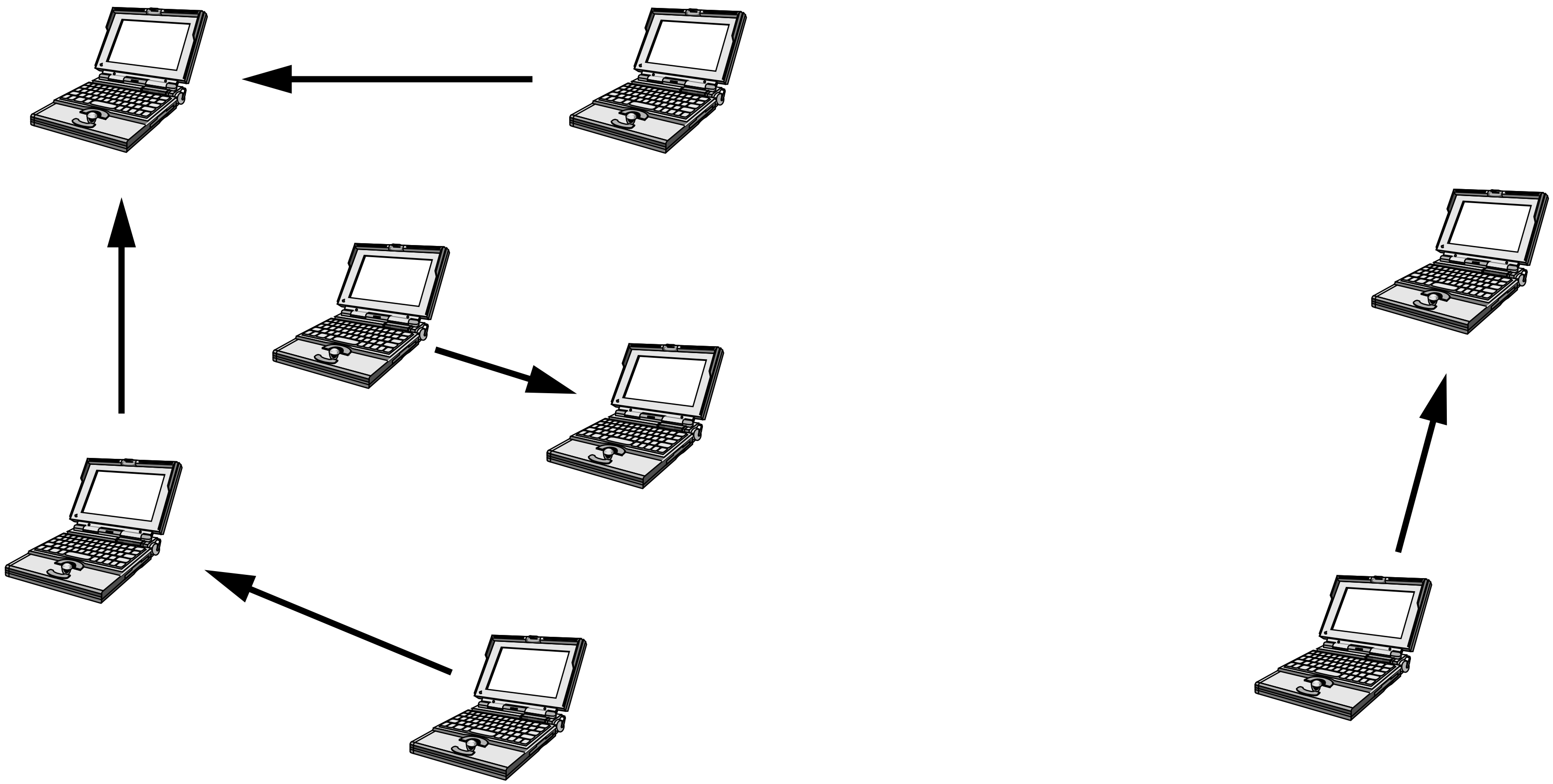
Cordless Phone Results

Phone	Narrowband	Spread Spectrum
Loss	none	up to 50%
Truncation	none	up to 100%
Error	none	up to 60% @ 5% of bits
Signal	some noise	much noise
Comments	base = handset	sensitive to distance
Phone audio	white noise	occasional clicks

Implications

- DSSS modulation resists narrowband interference
- challenging but recoverable packet corruptions exist
- multi-radio mobile computing may be a challenge

Competing WaveLAN units



Competing WaveLAN units

- CSMA/CD vs. CSMA/CA
  - Ethernet
    - CD allows backoff from “tailgating” collisions
  - Wireless
    - CS is easy, CD is expensive
  - WaveLAN reduces post-packet collision storms
    - “medium busy” on transmit $\Rightarrow$ random backoff
- Questions
  - How much interference is possible in the worst case?
    - What if carrier sense fails?
  - Is it possible to screen out nearby WaveLAN units?
  - Are “border zones” troublesome?

Competing WaveLAN units

Carrier Sense

- Informal experiments: very good
- Disable carrier sense: unusable link
  - no reasonable packet for many seconds

Receive Threshold

- Receive threshold can partition “clusters” very well
  - ex., two clusters per table-top
- “Border zone” machines troublesome
  - will receive garbled packets
  - may reduce throughput in both clusters
- Thresholding alone not enough for per-office cells
  - frequency or code diversity

Related Work

- Measuring commercial wireless LANs
  - Duchamp & Reynolds - ISA WaveLAN
    - distance, scattering
  - Lewis & Guy - Arlan 610
- Analytical models
  - indoor delay spread; fading models; ray tracing
- Wireless ATM development
  - many groups (ex. Olivetti Research Labs/Cambridge)
  - often assume an analytical error environment
- Extensive satellite work
  - high-speed multiple-access error-corrected channels

Conclusions

- Low-error cases
  - significant cases: very low BER
    - probably low enough for predictable services
- High-error cases
  - rare cases: unusable link
- Reasonable middle ground
  - plausible cases: significant but correctable errors
- Adaptable timescale
  - error bursts seem due to human-timescale events
    - which software could probably react to
- High-speed, low-error wireless links seem plausible