Wireless RF Systems

Anthony D. Joseph
CS 294-1

Lecture 5
September 27, 2000

Outline

- Scribe?
- Projects
  - One week to proposal deadline
  - Anthony's office hours M 10-11
- Papers: Examples of wireless LAN/WAN networks
  - Duchamp, D. Reynolds, N. Measured Performance of a Wireless LAN. In Proc. 17th Conf. on Local Computer Networks, IEEE'92
  - Hollemans, W., Verschoor, A. Performance study of WaveLAN and Altair radio-LANs. PIMRC'94
  - Cheshire, S. and Baker, M. A wireless network in MosquitoNet. IEEE Micro, Feb. 1996
- Paper: The future of wireless
  - V. Bose, et. al., Virtual Radios, JSAC: software radios, Fall'98
- Project topics and partners

Columbia WaveLAN Tests

- Duchamp, D. Reynolds, N. Measured Performance of a Wireless LAN. In Proc. 17th Conf. on Local Computer Networks, IEEE'92
- Measurement experiments
  - Characterize packet level network performance

Background

- Claessen, A., Monteban, L., Moelard, H. The AT&T GIS WaveLAN air interface and protocol stack
- Summary:
  - Measurements of a CSMA/CA commercial high-speed wireless LAN
  - Access protocol is fairly successful in allocating bandwidth within the recommended range, but performance deteriorates sharply outside of the operating range
  - Commercial wireless LAN products: Lucent WaveLAN, Motorola's Altair, Proxim's RangeLAN, Spectrix, Photinics, etc.

Motivation

- Application study of wireless LAN behavior
- Signal propagation studies inadequate
  - Most past work focused on signal propagation, fading characteristics, range, modulation technique

More Motivation

- What is the end-to-end measured performance of a wireless LAN?
  - Significantly different from what we can predict, because LAN traffic is bursty
- Outdoor wireless telephony studies inadequate
  - In-building LANs are constructed by computing the optimal placement of base stations given signal strength degradation and interference from walls
  - Performance studies are key to modeling in-building networks

AT&T/Lucent/NCR WaveLAN

- DSSS at 900 MHz and 2.4 GHz ISM
  - Old version was proprietary, new one is IEEE 802.11b
- Antenna diversity used to pick strongest signal
- Pico-cellular infrastructure through logical channels (shared media!)
  - 2.4 Ghz also has physical channels
- CSMA/CA transmission
- Max bandwidth is 2 Mbit/s

AT&T WaveLAN Radio

- ES (end stations) peer-to-peer or hub topology
- Multiple ES grouped into cells w/ AP (access point)
  - Multiple cells connected by wired backbone network
  - Roaming assisted by AP
- Power Management through Enhanced Power Management
  - Radio draws power from computer
  - Rated power ~250 mW transmitting ~ 600 mW, receiving

Columbia WaveLAN Experiment

- Well known environment
- "Packet level" analysis of network
  - Packet size
  - Coverage range

Results

- Range
  - Signal strength degrades starting at 20m
  - For ~ 10m, reasonably good signal strengths and capture rates (small loss rate ~1-2%)
- Multipath fading important when LOS signal is weak
  - WaveLAN advertised LOS is 800 ft
  - Local scattering from wall caused sharp increase in the error rates
  - About 75% of the multipath components are smaller than 50 ns

Multipath Effects

- Reflected signal generally has lower power
  - Also is phase-shifted with respect to the transmitted signal
- For weak signals, the original and reflected/refracted signals are indistinguishable
- Systems with slower chipping rate, are less susceptible to multipath
  - Ex. Metricom modems are less susceptible than WaveLAN

Throughput

- High percent of bandwidth realized
  - ~ 1.5 Mb/s with 1 sender-receiver pair
  - With more users, harder to gain access to channel (common CSMA/CA problem)
  - Recommend smaller packets to avoid card overflow at senders
- 99% w/o errors

Packet Errors

- Long bad-byte runs are not uncommon
  - Most common runs are 1B in length
  - Certain run lengths are more common
    - Sawtooth nature of run length frequencies
  - May be hardware dependent
- Might be able to mask some errors

Flaws in the Paper?

- Not clear how WaveLAN behaves with multiple users
  - Think about classrooms!
  - Very high density
- Would be interesting to model the underlying error process that causes correlated error patterns
  - Could lead to better encodings

WaveLAN vs. Altair Study

- Hollemans, W., Verschoor, A. Performance study of WaveLAN and Altair radio-LANs. PIMRC'94
- Altair System Characterization
  - 18 GHz, microwave frequency carrier, lower range (10-15 indoors / >40 outdoors)
  - Frequency band is split into smaller bands and TDMA/Packet Reservation is used within each band
  - 25 mW
  - 15 Mbit/s

Altair System

- 18 GHz is not in ISM
- $\Rightarrow$ Need a pioneer license that the FCC allots for special uses

  ++ No other devices operate in this range, operation is free, although user must seek permission from FCC (slow!).

  -- Hardware is expensive

Results

- WaveLAN and Altair about same throughput though Altair has 7.5 times the transmission rate!
  - Due to Altair's packet reservation protocol?
  - Altair didn't degrade as the number of users was increased
    - TDMA better for scaling

More Results

- Multipath: Altair better due to sectored antenna
  - 6-sectored versus omni-directional antenna
- WaveLAN degrades with delay spread >84ns
  - Sectored antenna enables better multipath resilience (possible to distinguish reflections from original transmission)
- Multiple cells easier to implement with Altair
  - Separate physical frequencies versus logical channels

5-minute Break

MosquitoNet using Metricom

- Cheshire, S. and Baker, M. A wireless network in MosquitoNet. IEEE Micro, Feb. 1996
- Metricom network

  wireless backbone
  - 900MHz ISM band with FHSS (1 watt = 1 mile LOS)
  - Variable, high latency
  - Transmission rate of 100 Kbps (now much higher)
  - Modem emulation mode (point-to-point) vs. star mode (packet-based)

Metricom

- Wide-area wireless network
  - Deployed in SF bay area, D.C., and Seattle
  - Now deployed in L.A., NYC, Atlanta, …
- Network topology consists of poletop radios serving as repeaters
  - One in every 20-25 poletops is a wired access point (WAP) connected to the wired internet
  - Small Ricochet wireless modems (6in x 4in x 1in), connect to the host computer via the serial port (now USB)

Metricom (cont'd)

- Pricing
  - Modems cost a few hundred $
  - Monthly flat service rates ($25)
    - Price is higher for new 128 Kb/s service
- Power Management
  - Separate battery lasts 8-12 hours
- Paper provides good overview of Ricochet network technology

Metricom Radios

- Radios operate in two modes:
  - Modem Emulation Mode
    - Uses PPP and the AT command set (common)
  - Star Mode
    - Connectionless datagram service that allows peer-to-peer communication between radios in range, even when completely disconnected from the Ricochet backbone (rare)
- No power management
  - Cannot shrink single cell by reducing power to accommodate more cells in the same area
  - Radios are half-duplex
    - Sender and receiver go through an initial handshake protocol with Request To Send / Clear To Send
    - This phase increases latency because of the high radio turnaround time

Metricom Routing

- Geographical routing
  - Based on (latitude, longitude)
  - Each poletop is configured (using GPS) with its own latitude and longitude at the time of installation
- Mobile radios communicate with the base station with the strongest signal
- Metricom addresses are 8 decimal digits

Metricom Networks

- Utilinet
  - Meter reading and other monitoring access for public utility companies
- Public semi-nationwide network
- Raw bandwidth is 100 Kb/s
  - Reality ~ 30 Kb/s)
- Next generation is 128Kb/s per modem
- Combination of multiple radios
  - 2.4 GHz for radio-to-radio communication?
  - 900 MHz for radio-to-poletop
  - Special band for WAP-to-poletop

Results

- High variance in latency with modem emulation mode
  - Outliers from retransmitted packets
  - No retransmissions in Starmode
- Serial line delay can be masked with pipelining
  - Pipelining benefits are limited since the RTS/CTS operation must be performed on each packet

Virtual Radios

- V. Bose, et. al., Virtual Radios, JSAC: software radios, Fall'98
- Goals:
  - Software radios implemented in user space on off-the-shelf PCs instead of a host of diverse communication devices
    - Advantages include portability, compatibility with other devices, and flexibility (and ride Moore's Law!)
  - Potential reuse of software radios across hardware platforms
  - Dynamic allocation of channel capacity between analog and digital services
    - Cellular systems due this manually on a coarse basis

Motivation

- Dynamic Flexibility
  - Use general purpose processors instead of special purpose DSP processors
  - Moore's law!!
- Portability
  - System can run on variety of platforms
- Compatibility
  - Applications interoperate with other hardware and software systems

Motivation (cont'd)

- Software reuse
  - Simplify the process of developing new applications by constructing a modular environment
- Envision systems that can dynamically modify their functionality to interact with different systems and /or adapt to changing conditions

Description

- Replace all of the link and many of the physical layer functions typically implemented in dedicated hardware on a network interface card (NIC)

Multiband Front end

- Currently the missing link in system
- Converts RF band to IF frequency
- Project at Wisconsin showed that it's possible to build antennas for a variety of ranges (200 MHz to 4 GHz)
- Amplification and baseband conversion must be done in hardware
  - Baseband conversion refers to the process of shifting the received signal down to 0 Mhz

Description (cont'd)

- A/D conversion
  - Reading digital samples is a problem since memory bandwidth is limited
- Transmitters are easy in hardware
  - Fast D/A converters and wideband amplifiers are easier to build

System Description

- Multiband front-end
- High performance General Purpose PCI I/O (GuPPI) Card
  - Connects analog front-end to workstation's I/O bus and appears as UNIX device
  - Solves problem of jitter, lack of a high throughput port on workstations, and inefficiency of path between device driver and application
- Spectrumware programming environment
  - Operating system additions

Programming Environment

- Replace link layer and much of physical layer with software modules
  - SPECTRA environment supports construction of portable DSP systems with real time constraints
- Modules work on blocks of data, instead of operating on sample by sample basis
  - Amortizes constant overheads

Current Status

- Applications
  - Software Cellular Receiver
  - Software Radios for Wireless Networking
- Processing is the bottleneck
  - Processor is the bottleneck
    - Their choice of commodity processor instead of specialized DSP processors was because DSP architectures change from generation to generation!
    - Also, DSP architectures offer a poor programming env.
    - As processors get faster and cheaper and caches get larger, faster, and cheaper, software radios will be become more practical
- Happy with work, but still long way to go

Project Topics

- ICEBERG
  - Wide-area performance analysis with testbed at TU Berlin (signaling, call quality, available bandwidth, loss rates, failure latencies)
  - Security protocols for authenticating callers (also, more work on secure billing protocols)
  - QoS for applications over GPRS (many inputs/outputs)
- OceanStore
  - Analysis, simulation, design of OS protocols for low-bandwidth/high-latency environments (or satellite)
  - Disconnected operation and reconciliation in OS

More Topics: Avideh Zakhor

- Video compression techniques and link/transport protocols for RT unicast/multicast delivery of video over lossy wireless
- Adaptive link layer protocols that distinguish between reliable/non-RT and RT/delay sensitive flows combined with video apps that separate their flows
- Sending delay sensitive video over time varying and low bandwidth wireless channels
  - Implementing error resiliency into our matching pursuit codec and trying it on a real cellular phone connection
  - Investigating streaming issues in wireless scenarios
  - How diffserv can be used to facilitate streaming over QoS enabled wireless networks
  - Wireless multicast of video and other delay sensitive multimedia

More Topics

- Telegraph, Data Recharging, Ninja, Smart Dust
  - Dealing with data from intermittently connected sensor networks