CS294-1 Mobile Computing and Wireless Networking **Fall 2000**

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5.1 Papers

5.1.1 Examples of wireless LAN / WAN networks

- N. Reynolds and D. Duchamp. Measured Performance of a Wireless LAN. In Proc. 17th Conf. on Local Computer Networks, IEEE, Minneapolis, Sep. 1992, p. 494-499.
- Hollemans, W., Verschoor, A. (Edited by: Weber, J.H., Arnbak, J.C., Prasad, R.) Performance study of WaveLAN and Altair radio-LANs. Proceedings of Wireless Networks - Catching the Mobile Future, 5th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'94), and ICCC Regional Meeting on Wireless Computer Networks (WCN), The Hague, Netherlands, 18-23 Sept. 1994.) Amsterdam, Netherlands: IOS Press, 1994. p. 831-837 vol. 3.
- Cheshire, S. and Baker, M. A wireless network in MosquitoNet. IEEE Micro, vol. 16, no. 1, Feb. 1996, p. 44-52.

5.1.2 The future of wireless

- V. Bose, M. Ismert, M. Welborn, J. Guttag, Virtual Radios, to appear in JSAC issue on software radios, 4th Qtr., 98

5.1.3 Background

- Claessen, A., Monteban, L., Moelard, H. (Edited by: Weber, J.H., Arnbak, J.C., Prasad, R.) The AT&T GIS WaveLAN air interface and protocol stack. Proceedings of Wireless Networks - Catching the Mobile Future, 5th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'94), and ICCC Regional Meeting on Wireless Computer Networks (WCN), The Hague, Netherlands, 18-23 Sept. 1994.) Amsterdam, Netherlands: IOS Press, 1994. p. 1442-1446 vol. 4.
- V. G. Bose and A. B. Shah, Software Radios for Wireless Networking, accepted to Infocomm '98, San Fransisco, April, 1997.

5.2 Columbia WaveLAN Tests (Duchamp et. al.)

This paper presents measurements of a CSMA/CA commercial high speed wireless LAN. It shows that the access protocol is fairly successful in allocating bandwidth within the recommended range, but performance deteriorates sharply outside the operating range.

5.2.1 Background (Claessen et. al.)

WaveLAN is a CSMA/CA (Carrier Sense Multiple Access, Collision Avoidance) mechanism. It is not possible to do CD (Collision Detection) as in ethernet. In wireless media, it is not possible to both listen to remote transmissions and transmit messages at the same time, since the local transmission will drown out any remote transmissions locally.

There is one WaveLAN specification, but three main entities back it, who are all related to each other. NCR Amsterdam was acquired by AT&T which split into various companies, Lucent being one of them.

The main commercial wireless LAN products that are available today are Lucent's WaveLAN, Motorola's Altair, Proxim's RangeLAN, Spectrix and Photonics. Proxim's products are typically used in the industrial community, in factories and warehouses for inventory control. The Photonics product is IR based.

5.2.2 Motivation

The paper performs an application study of wireless LAN behavior. Past signal propagation studies are inadequate because they focused on signal propagation, fading characteristics, range and modulation techniques. They did not study the end-to-end performance of a wireless LAN. This is difficult to predict because LAN traffic is bursty. The results of such a study can help us place basestations optimally to achieve good end-to-end performance. Outdoor wireless telephony by contrast is very different. In building LANs are constructed by computing the optimal placement of basestations given signal strength maps of the building. The AT&T WaveLAN website has a page that gives help on planning the installation of basestations. When installing the new Lucent WaveLAN system in Soda Hall, IDSG had to walk around the building with a laptop, measuring signal strength at various locations. Calculations of signal strength degradation rather than measurements are possible using a floor-plan, but it is hard to characterize delay from these calculations, especially due to multipath effects.

5.2.3 AT&T / Lucent / NCR WaveLAN

WaveLAN uses DSSS (Direct Sequence Spread Spectrum) at 900MHz and 2.4 GHz (ISM band) and is CSMA/CA (RangeLAN uses frequency hopping). The old specification was proprietary, but the new one is IEEE 802.11b and is publicly available for a fee. The RF signal is polarized horizontally and vertically. WaveLAN devices have two antennas in a cross and this is used to pick the strongest signal (this reduces multipath fading effects). It does not use different spreading codes for different cells. Instead, one spreading code is used throughout an installation and different logical IDs are used by each cell. As a result, nodes in regions of overlapping cell ranges will experience excessive interference. The rated throughput is 2 megabits per second, but due to overheads such as packet headers, the maximum realizable throughput is 1.6 Mbps. The end stations can either run in a peer-to-peer mode or in a hub topology. Multiple end stations can be grouped into cells which are controlled by access points. The access points will have wired connectivity. Clients can roam between cells, but all basestations must be on the same physical wired subnet. The roaming client simply informs the new basestation about its new location and the basestation will inform the previous basestation about this change. Basestations will periodically beacon their logical IDs. Clients will switch to a new basestation when the signal strength from the current basestation drops below a certain level and the ID of a new basestation is heard. The pcmcia WaveLAN radio draws power from the laptop. It supports power management and its rated powers are 250mW for receiving and 600mW for transmitting.

5.2.4 Columbia WaveLAN experiment

This experiment was conducted in a well known environment (a hallway). The authors did a packet level analysis of the network. The rated range of WaveLAN is 29 meters. The study shows that signal strength degrades starting at 20 meters. Around 10 meters, reasonably good signal strength and capture rates are experienced (the loss rate is around 1%).

Multipath fading becomes important when the line-of-sight signal is weak. The rated LOS range of WaveLAN is 800 feet. In the study, when they placed the receiver near a wall facing the transmitter, local scattering from the wall caused sharp increases in the error rates. It was found that about 75% of the multipath components of the signal are smaller than 50ns. These reflected signals generally have lower power, but are phase shifted from the original transmitted signal. When they are fully out of phase, they will cancel some or all of the transmitted signal. Thus for weak signals, the original and reflected or refracted signals can be indistinguishable. Systems with slower chipping rates are less susceptible to these effects. That is why Metricom modems are less susceptible to multipath fading than WaveLAN devices. The Bluetooth chipping rate is 1600, but its cells are much smaller.

In the throughput experiments, a high percentage of the advertised bandwidth was seen. They experienced around 1.5 Mbs with one sender receiver pair. However, with more users, medium contention (CSMA/CA) became a problem. The study recommends smaller packets to avoid card overflows at transmitters. 99% of the traffic experienced no errors.

The authors also analyzed packet errors. The most common errors were 1 byte errors (which motivates the use of CRC or FEC), but certain run lengths were more common. A sawtooth nature of run length frequencies was noted. These errors may have been hardware dependent. One might be able to mask some of these errors.

5.2.5 Paper flaws

The paper did not explore how WaveLAN behaves with multiple users. The density of users can be very high in classrooms. It would be interesting to model the underlying error process that causes correlated error patterns. This can lead to better encodings.

5.3 WaveLAN vs. Altair Study (Hollemans et. al.)

5.3.1 Altair

The Altair system runs on a 18 GHz (microwave frequency) carrier and has a lower range than WaveLAN (about 10-15 meters indoors, 40 meters outdoors, very line of sight limited). Because of this high frequency, standard silicon cannot be used. Germanium chips have to be made, and this is one of the main reasons why Altair systems are expensive. A pair of units can cost many thousands of dollars. The frequency band is split into smaller bands and TDMA / Packet Reservation is used within each band. Half of the slots are allocated for the uplink and the other half for the downlink (Bluetooth is asymmetric in this regard). The radio consumes 25 mW of power and can support a throughput of 15 Mbps. The 18 GHz frequency is not in the ISM band, but rather in the pioneer band. This requires a pioneer license, which the FCC allocates for special uses. No other devices operate in this range. The license is free, but the user must seek permission from the FCC, which can be a slow process.

5.3.2 Results

The study showed that WaveLAN and Altair offer the same throughput even though Altair boasts a 7.5X transmission rate. This discrepancy might be due to Altair's packet reservation protocol. However, Altair's throughput did not degrade as the number of users was increased because TDMA is better at scaling users than a random access scheme such as WaveLAN.

The study also found that the Altair system is better at handling multipath fading because of its 6 sectored antenna, versus the omni-directional antenna of WaveLAN. The WaveLAN antenna can only distinguish polarity. They found that WaveLAN degrades with a delay spread greater than 84ns. The sectored antenna of Altair allows it to distinguish reflections from the original transmission and thus has better multipath resilience. Also, the Altair system uses different physical frequencies rather than logical IDs between cells, thus making it easier to implement multiple cells.

5.4 MosquitoNet using Metricom (Chesire et. al.)

5.4.1 Metricom

The Metricom network is unique in that it uses a wireless backbone. Cellular telephony networks use a wired backbone to connect their basestations. Laying cable between basestations is usually very costly and time consuming. In Metricom, only a few basestations have wired access. The network runs at 900 MHz (ISM band) with FHSS (Frequency Hopping Spread Spectrum). The frequency hopping is slow (50 hops per second). The hopping is done on pseudo-random sequences. 1 watt of power consumed in the radio provides a 1 mile line of sight range. The experience latency is high, and variable. The transmission rate is 100kbps, but now it may be much higher. The system supports both a modem emulation mode (point-to-point) and a star mode (packet based).

This wide-area wireless network is deployed in the San Francisco Bay Area, Washington D.C. and Seattle. It is also deployed in Los Angeles, New York City, Atlanta, Boston and Chicago. It had only 30,000 customers last year. The network topology consists of radios mounted on street lamp posts which act as repeaters. These radios have a plug that plugs into the photocell on a street lamp. Street lamps can be owned by many entities - the city, town, state or electric company. Obtaining the license to attach a radio can be a long and expensive process. This is why there is no coverage in Emeryville. One in every 20-25 poletops is a wired access point (WAP) that is connected to the wired Internet. The WAP is actually several radios with different hop codes. Because of the multihop route to get to a wired network through the poletops, latency is high and variable.

Small Ricochet wireless modems (6" X 4" X 1") connect to the serial or USB port on a computer. These units cost a few hundred dollars and monthly service rate is a flat fee of $25. The price for the new 128 Kbps service is higher. The unit contains a separate battery that lasts 8 to 12 hours. The Stanford paper provides a good overview of the Ricochet network technology.

The radios operate in two modes - modem emulation mode which uses PPP and the common AT command set, and the star mode which is a connection-less datagram service that allows peer-to-peer communication between radios in range, even when not connected to the Ricochet backbone. There is no power management. Thus single cells cannot be shrunk by reducing the transmit power to accommodate more cells in the same area. The radios are half-duplex. The sender and receiver go through an initial handshake protocol that does RTS-CTS (request-to-send and clear-to-send). This phase increases latency because of the high radio turnaround time.

The system uses geographical routing, based on lattitude and longitude. Each poletop is configured (using

GPS) with its own lattitude and longitude at the time of installation. Mobile radios communicate with the basestation with the strongest received signal. Then geographical routing is employed. However, in congestion, mis-routing is purposely employed. Metricom addresses are 8 decimal digits. The radio can report the signal strength and GPS locations of nearby basestations.

Utilinet is a network also by Metricom. It is used for meter reading and other monitoring access for public utility companies. This network is commercially more successful than Ricochet. This network is public, and semi-nationwide. The advertised raw bandwidth is 100 Kbps, but in reality it is often 30 Kbps. The next generation network will use 128 Kbps capable modems. It uses a combination of multiple radios - 2.4 GHz for radio-to-radio communication (not sure), 900 MHz for radio-to-poletop and a special band for WAP-to-poletop.

5.4.2 Results

The study shows a high variance in latency in the modem emulation mode. The outlier points a from retransmitted packets. Starmode does not do retransmissions. The serial line delay can be masked with pipelining. However, the pipelining benefit is limited since the RTS/CTS exchange must be performed on every packet.

5.5 Virtual Radios (Bose et. al.)

5.5.1 Goals

The goal is to implement software radios in user space on off-the-shelf PCs rather than a host of diverse communication devices. The advantages include portability (the system can run on a variety of platforms), compatibility with other devices (applications can now interoperate with other hardware and software systems) and flexibility (using general purpose processors instead of special purpose DSP processors allows it to ride Moore's Law). Software radios can be reused across hardware platforms. This simplifies the process of developing new applications by constructing a modular environment. Also, dynamic allocation of channel capacity between analog and digital services can be performed (cellular telephony systems do this manually on a coarse grained basis).

For example, Winmodems offload signal processing tasks to the CPU. However, only $2 in parts are saved at the expense of CPU time. Police radios use different radio frequencies and standards in different regions. Thus police patrol cars that cross state lines cannot communicate with other patrol cars.

5.5.2 System Description

The system replaces all of the link and many of the physical layer functions typically implemented in dedicated hardware on a network card. The multiband front-end is currently the missing link in the system. It converts an RF band to the IF (intermediate frequency). A project at Wisconsin showed that it is possible to build antennas for a variety of ranges (200 MHz to 4 GHz). The amplification and baseband conversion must be done in hardware. Baseband conversion is the process of shifting the received signal down to 0 MHz. Reading digital samples in the A/D conversion is a problem since memory bandwidth is limited. Transmitters are easy to build in hardware - fast D/A converters and wideband amplifiers are easier in hardware.

The system consists of a multiband front end and the GuPPI card. This card is a high performance general purpose PCI I/O card. It connects analog front ends to a workstation's I/O bus and appears as a UNIX device. It solves the problems of jitter, lack of a high throughput port on workstations and the inefficiency of the path between the device driver and the application. It uses scatter gather techniques and ring buffers.

The spectrumware programming environment is used with some OS additions. The link layer and much of the physical layer are replaced with software modules. The SPECTRA environment allows the construction of portable DSP systems with real time constraints. The modules work on blocks of data rather than on individual samples, thus amortizing the constant overheads.

5.5.3 Current status

The two applications that they have are a software cellular receiver and a software radio for wireless networking. Processing is the bottleneck. They chose commodity processors instead of specialized DSP processors because DSP architectures change from generation to generation and offer a poor programming interface. As processors get faster and cheaper, and caches get larger, faster and cheaper, software radios will become more practical. They still have a long way to go.