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The Correlation of Data Throughput with Link Loss for Commercial WLAN Devices

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This article provides practical data on the relative performance of WLAN systems operating at 2.4 or 5 GHz, but points out that performance is not consistent among various brands and models of equipment

This article reports on measured propagation characteristics of CW signals at 2.5 and 5.2 GHz in the WJ Communications facility (a typical Silicon Valley office and manufacturing facility), including a comparison of the CW link loss/signal strength to the throughput of 802.11b and 802.11a links, respectively.

Interestingly, we found that the propagation characteristics of the building do not differ much between 2.5 and 5.2 GHz. Data throughput was well-correlated with link loss measured for a CW signal, within the limitations imposed by the complex nature of the fading CW signal. We observed significant differences in path loss tolerance among the various models of commercial equipment. One of our conclusions is that recently developed 802.11a hardware achieves equivalent sensitivity to 802.11b equipment, providing the same indoor range at significantly higher data rates.

WLAN Hardware

Indoor use of wireless local area network (WLAN) connections based on the IEEE 802.11b and 802.11a standards (WiFi and WiFi5, respectively) is becoming increasingly popular. Numerous manufacturers provide equipment which has been validated for interoperability by WECA, although not necessarily for equivalent performance. WiFi5 equipment has just recently become available and the relative utility of the two standards remains to be clarified. In this work we examined the correlation of WLAN link performance with path loss of a CW signal at a similar frequency, and we used the measured path loss as a reference for comparison of the indoor performance of equipment from different vendors using different communications standards.

Measurement Procedures

The path loss was measured using a CW source driving a quarter-wave dipole antenna in a fixed location, and a second quarter-wave dipole in various locations through the facility connected to a spectrum analyzer; details of the measurement are provided in [1]. The locations of the first set of measurements are shown in Figure 1. Measurements were made at 2.5 and 5.2 GHz in the same nominal locations—to within 1 meter in each case—and compared with data rate measurements made in the same nominal locations as the link loss measurements, with the relevant access point hardware placed in the same location as the CW signal source, again to within 1 meter.

A second set of measurements at 5.2 GHz only, with corresponding WiFi5 data rates, was performed to confirm that the intial data rate measurements were not affected by any unusual artifact particular to the initial access point position. The locations of these measurements are shown in Figure 2.

The data rate measurements on the commercially-available equipment were made using NetIQ's Qcheck software, with a 1000 byte packet sent under TCP using numerical addresses for both endpoints. Data rate was tested in both directions (laptop to desktop and vice versa), and location and orientation were varied randomly within a 50 cm range of the nominal location; at least 5 datapoints

Figure 1 · Floor plan showing measurement locations; River Oak facility, access point site #1.

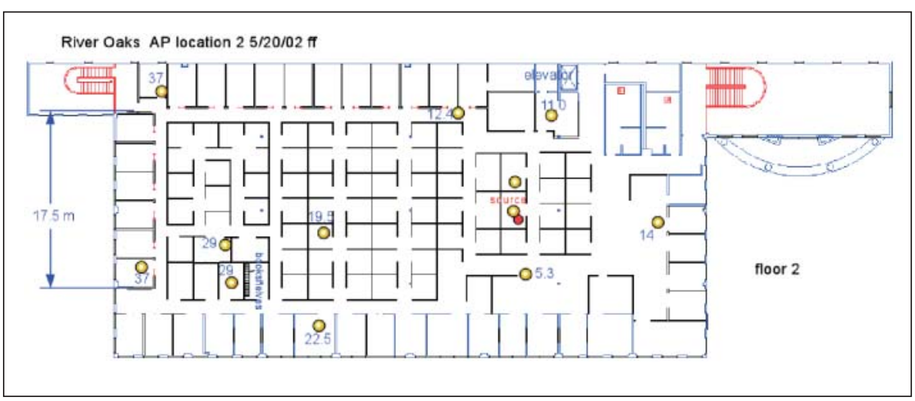

Figure 2 · Floor plan showing the measurement locations of additional 5.2 GHz points; access point site #2.

were taken in each location and each direction, except where no link could be achieved.

For the 802.11b measurements, the relevant access point was connected via a Cisco 100baseT switch to a 100baseT Ethernet card on a desktop computer with a 200 MHz Pentium II. Various PC (PCMCIA, Cardbus) cards were compared on a Sony Vaio PCG-N505VX laptop. The pairs examined were:

PC card	Access point
Orinoco Gold	Orinoco Gold
D-Link DWL650	Orinoco Gold
Cisco Aironet 350	Cisco Aironet 350

In all cases encryption (WEP) was turned off and when applicable the card was set in the "always on" condition for maximum data rate. The Cisco pair was configured for maximum transmit power.

For 802.11a commercial measurements, the corresponding pairs were:

PC card	Access point
Intel Pro 5000	Intel Pro 5000
Proxim Harmony 8450	(PC card in infrastructure mode)

Example configurations for the WiFi and WiFi5 measurements are shown schematically in Figure 3.

Finally, the Atheros Generation II reference design access point and Cardbus card were connected to laptop computers, and characterized using the Netperf utility, which is functionally similar to Qcheck.

Results

First, let us briefly summarize the propagation results of [1]:

- Losses varied widely with nominal location, exact location, and orientation, as one would expect for an indoor environment; we modeled an approximate propagation exponent of 3.0.

- No statistically significant difference was found between link losses at 2.5 and 5.2 GHz. The results from the first set of locations are summarized in Figure 4.

The average throughput in Mbps is shown in Figure 5 as a function of CW signal strength at the corresponding points, for all data sets, and in Figure 6 versus propagation distance (results for the Proxim 8450 were essentially identical to those obtained with the Intel Pro 5000 and are omitted for clarity). Note that the Cisco data includes only the "forward" direction (access point to PC card); data rate in the reverse direction was consistently measured to be 10× lower, but since the "reverse" rate was robust and consistent throughout all the measurement points it is believed that the low apparent rate is due to a software problem or erroneous setting of the system parameters that we were unable to correct.

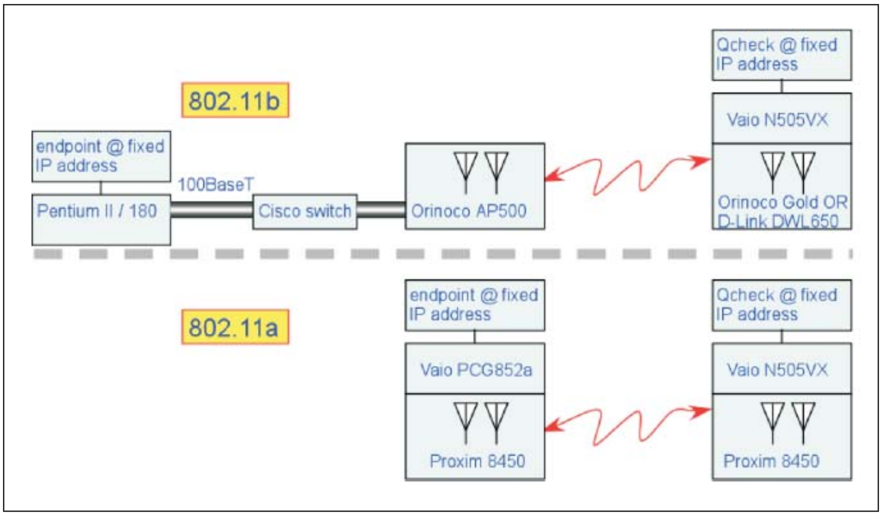

Figure 3 · Data throughput measurement setup examples.

ing performance of the Proxim cards or the Atheros Generation II hardware, some other performance-limiting factor (e.g. delays in the CardBus interface) may also be present.

The Cisco card/AP pair shows an additional 10 dB of link budget (about 70 dB vs. link loss at 1 meter); roughly 5 dB of this difference may simply be due to the higher rated transmit power of 100 mW, compared to the typical power of 20-30 mW for the other cards. Both 802.11a (Proxim and Intel) use the Atheros chipset; and both produced similar results, with an effective link budget of about 40 dB (with respect to link loss at 1 meter),which is much less than the 802.11b systems. No distinguishable difference is apparent in the data rate vs. link loss with the access point at site 1 vs. site 2. The Atheros Generation II reference design achieves significantly improved loss tolerance, equivalent to the commercial 802.11b cards, with much higher average data throughput.

The average throughputs shown above do not correspond to the raw bit rates claimed for the various standards, but to the actual TCP-to-TCP protocol throughput. The 802.11b results reflect reported best-case throughput performance for that protocol [2]. The 802.11a results are slightly lower than that expected for the best-case throughput of this protocol, expected to be slightly more than 30 Mbps [3]. We measured the TCP-to-TCP throughput of the "backhaul" link (the pair of FastEthernet cards and switch shown in Figure 3) with the WLAN link removed, and found a peak throughput of about 60 Mbps. The additional delay due to this wired link may account for the reduction in performance from that expected for the Intel AP, but since this link was not used in measur-

Discussion and Conclusions

For the same directivity antennas one would expect approximately 6 dB additional link loss between 2.5 GHz and 5.2 GHz; however, we were unable to extract this relatively small difference from the large variations in link loss that are observed from one location to another within our facility; RF propagation is discussed in more detail in [1]. The data rates observed for card-access point pairs

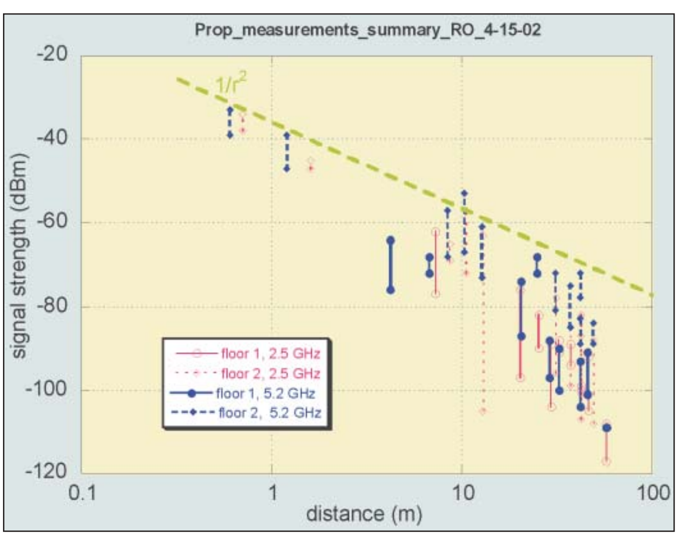

Figure 4 · Signal strength at various positions on both floors at both frequencies, AP position 1; the bars show the total range (maximum to minimum signal) detected in the vicinity of the measurement location.

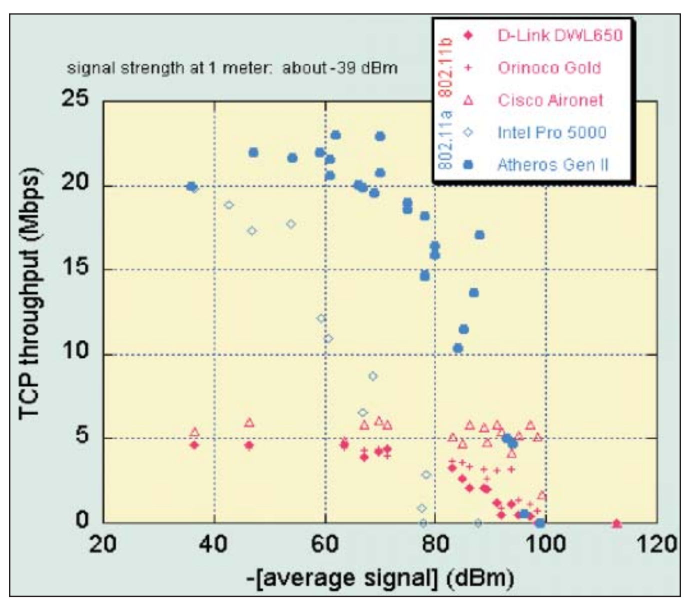

Figure 5 · Summary of data rate vs. CW signal strength (802.11b in red, 802.11a in blue).

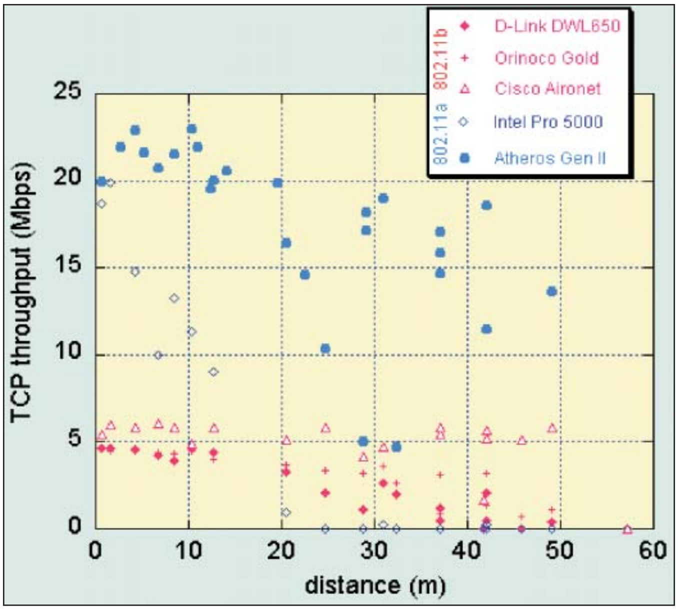

Figure 6 · Summary of data rate vs. link distance (802.11b in red, 802.11a in blue).

were found to be well-correlated with CW measurements of link loss at the corresponding locations, suggesting that CW link loss is a useful measurement for predicting WLAN behavior.

The effective sensitivity of recent 802.11a hardware is equivalent to that of commonly available 802.11b cards. In our tests, propagation loss did not differ between the two bands, therefore, we would expect that 802.11a hardware should be capable of achieving similar indoor ranges (about 50 meters on a single floor or 40 meters between floors in our facility).

We conclude that currently available 802.11 WLAN systems can offer coverage of large indoor areas with a small number of access points, though significant differences in performance exist between different vendor hardware. Recently-developed 802.11a hardware displays equivalent range to commercial 802.11b devices, at much higher data rates. Coverage in indoor areas is reasonably well predicted from simple CW propagation mapping.

Conclusions

- Indoor coverage of IEEE 802.11b (WiFi) or 802.11a (WiFi5) can reach 50 meters on a single floor; 40 meters between floors.
- Coverage is the same for either the 2.4 GHz or 5 GHz systems, with the 5 GHz IEEE 802.11a systems providing much higher data rate.
- Indoor coverage can be reasonably well predicted by CW measurements.
- Significant variations in data throughput were found among various manufacturers' hardware.

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