White Paper

Evaluating the Wireless Performance of Intel® Centrino™ Mobile Technology

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Introduction

Mobile performance means different things to different people. Some think of it simply in terms of gigahertz. Others, recognizing that processor speed is not as important when your battery runs out of juice at 30,000 feet, are inclined to add battery life to the mix. Intel takes into account the notebook user's total experience, and considers both processor performance and battery life when defining mobile performance. In fact, Intel often cites the MobileMark* 2002 benchmark when comparing mobile processor performance. MobileMark 2002 is a widely recognized and respected industry benchmark that measures processor performance and battery life on popular business-oriented, Microsoft* Windows*-based applications.

For the purposes of investigating the relative merits of Intel® Centrino™ mobile technology, one needs to consider another measure of performance in addition to processing and battery life: wireless. Since there are no industry-standard benchmarks available for this metric, Intel engineers created an in-house wireless LAN (WLAN) testing suite that provides reproducible, objective results, and may contribute to the development of industry-standard wireless performance benchmarks of the future. Intel's WLAN (802.11b) testing and methodology are the focus of this paper.

The Need for WLAN Benchmarks

Through extensive market research, Intel determined that notebook users value four key items: integrated WLAN capability, breakthrough mobile performance, extended battery life and thinner and lighter designs. Thus, Intel® Centrino™ mobile technology was born.

More than just a processor, Intel Centrino mobile technology contains optimized and extensively validated mobile technologies that deliver an outstanding mobile experience. Each of the components (CPU, chipset, wireless) are designed, tested and tuned by Intel to maximize the wireless mobile computing experience. Specifically, Intel Centrino mobile technology comprises:

1. Intel® Pentium® M processor
2. Intel® 855 chipset family
3. Intel® PRO/Wireless 2100 Network Connection

Intel believes that for notebook PCs, industry-standard benchmarks that simultaneously measure battery life and performance are the best indicators of the real end-user mobile experience. And MobileMark 2002 is a good benchmark for that measure. Measuring range and throughput requires that a variety of elements must be included and controlled during testing. These elements include antenna design and orientation, power-management technologies, access point detection systems and form factor limitations. In other words, mobile performance is a complex concept and should be treated as such. Industry-standard benchmarks should be available so that mobile performance can be evaluated in all its forms: processing, battery life and wireless.

For the Intel engineers who developed the Intel PRO/Wireless 2100 Network Connection, there had to be a way to isolate the wireless component from the rest of Intel Centrino mobile technology, and from variables associated with system configuration, to enable an apples-to-apples comparison of wireless technologies. An accurate, industry-standard methodology for evaluating range and throughput was needed but did not exist. For the sake of assessing these aspects of mobile performance and how well Intel Centrino mobile technology compared to other wireless LAN technologies, Intel developed its own.

Wireless Performance Testing Issues

WLANs are highly dependent on the ability to transmit and receive radio waves with minimal interference. The number of people using a WLAN and the computer's distance from access points (AP) affect wireless LAN performance. If the user is next to an AP, he or she is probably getting the optimal connectivity and throughput of the network and network connection, as the signal is very strong. As the user moves further away from the AP and obstacles intrude, the signal may degrade and throughput numbers may decline. By stabilizing key variables, whether inherent to system design and configuration or within the mobile wireless environment, it is possible to generate consistent, reliable range and throughput numbers—thus creating a testing methodology and results that can be replicated.

However, stabilizing variables isn't the same thing as eliminating them. In fact, they are present in any real-world wireless mobile computing environment. Indoors, everything from a building's construction materials to the location of desks, partitions and people may help or hinder the WLAN's range and throughput. Outdoors, terrain and objects of all kinds can impair radio signals and affect test results. Lastly, devices other than the systems being tested can interfere with data transmission and affect range and throughput. Specifically regarding the 802.11b WLAN protocol, microwave ovens, Bluetooth* wireless technology-enabled devices, cordless telephones and other WLANs all share

the 2.4 GHz spectrum and can cause interference. Noise generated by components within the systems being tested can also have an effect.

In the absence of an established industry-standard benchmark, the engineer's challenge is to create a disciplined, standards-based approach and consistent process. This includes creating a stable environment for a testing baseline that closely approximates real-world scenarios (see Figure 1, *Line of Sight (LOS) testing,* page 4, and the Outdoor Testing section, page 5), as well as testing that stabilizes environmental variables but intentionally includes their effects (see Figure 2, *Non-line of Sight (NLOS) testing,* page 5).

Intel Wireless Testing Methodology

Any testing must be done in a controlled environment. In the context of WLAN technology testing, Intel engineers developed a range and throughput testing methodology in a highly controlled environment by adhering to the following principles:

Environmental Parameters. Sources of noise and interference must be identified. The effects of devices other than the systems being tested that operate in the 2.4 GHz frequency band must be quantified, or those devices must be removed from the testing area. The environment should, however, have some real-world dynamics built in, such as the movement of notebooks being tested in reproducible increments in order to simulate user activity. There should also be various degrees of signal scattering and multi-path as well as various signal obstructions, as office and home environments are seldom wide-open and obstruction-free.

System Considerations. There should be no questions as to the type of the notebook PCs being tested, their components, or their configurations. Therefore, with the exception of WLAN connection technologies, all units under test are identically outfitted and configured notebooks running the same Windows operating system.

General Guidelines. Vendor interoperability should never be an issue. The testing environment should contain a single vendor's antennas and access points. Intel engineers also thought it was important to test multiple channels (i.e., 802.11b channels 1, 6, 11, 14), use a consistent set of tools, and automate testing procedures as much as possible in order to minimize human error.

Disciplined, multi-station tests were conducted using identically configured notebook systems with the exception of the wireless

Indoor Performance Test Setup

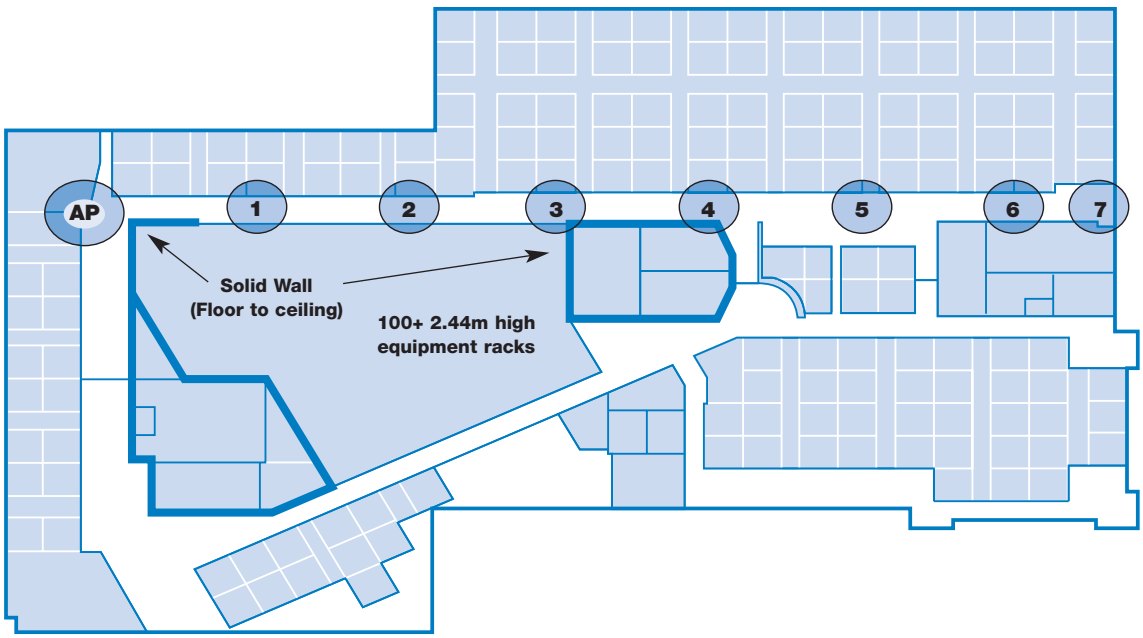

Figure 1. *Line of Sight (LOS) testing.* Units Under Test (UUTs) were placed on a turntable on a cart 3' 6" high. Seven stations were set up at 10, 20, 30, 40, 50, 60 and 65 meters from the access point, and the UUTs were rotated at each station. The access point (AP) was placed eight feet from the floor.

connection. The two notebooks being tested were equipped with the Intel® Pentium® M processor 1.4 GHz and the Intel 855 chipset. The wireless network connections were the Intel® PRO/Wireless 2100 LAN Mini-PCI Adapter Type 3B, which is an integrated component of Intel® Centrino™ mobile technology, and the previous-generation Intel WLAN solution, the Intel® PRO/Wireless 2011b LAN Mini-PCI Adapter.

To measure the full spectrum of antenna placement, systems were placed on a turntable that spins to create movement in a consistent pattern. When a turntable was not practical, measurements were taken at precise angles in relation to the access point, and were used to assure variance in antenna position. Results of these discrete positions were averaged into one position.

It is essential that the testing methodology simulate real-world environments. A key objective of the test was to determine how far away from an AP the user can be in indoor or outdoor environments and still maintain connectivity. This was accomplished by testing within three distinct categories:

Line of Sight Indoors (LOS) (Optimal): This type of testing simulates optimal mobile wireless performance conditions within an enterprise environment. The test took place in a 30,000 square-foot building. The access point and the stations at which the systems were tested were all located in a straight, unobstructed hallway.

Non-line of Sight Indoors (NLOS) (Sub-optimal): This type of testing allows for the evaluation of mobile wireless performance under conditions in which obstacles are present. Again, there are seven test stations in a 30,000 square-foot building. But in this case, each station has its own characteristics in terms of obstacles—solid walls, equipment racks, glass, etc. What is being tested is how wireless solutions respond to reflections, cancellations, and other distortions in the signal.

Outdoor Testing: Wireless solutions were tested outdoors in an unobstructed area 275 meters long—the approximate length of three football fields. Testing was conducted in a similar manner as Indoor LOS testing, using a turntable on a cart, but at 20-meter increments. Care was given to conduct all testing in an environment that was as consistent in terms of temperature, dew point, wind velocity, etc. as possible.

Indoor Performance Test Setup

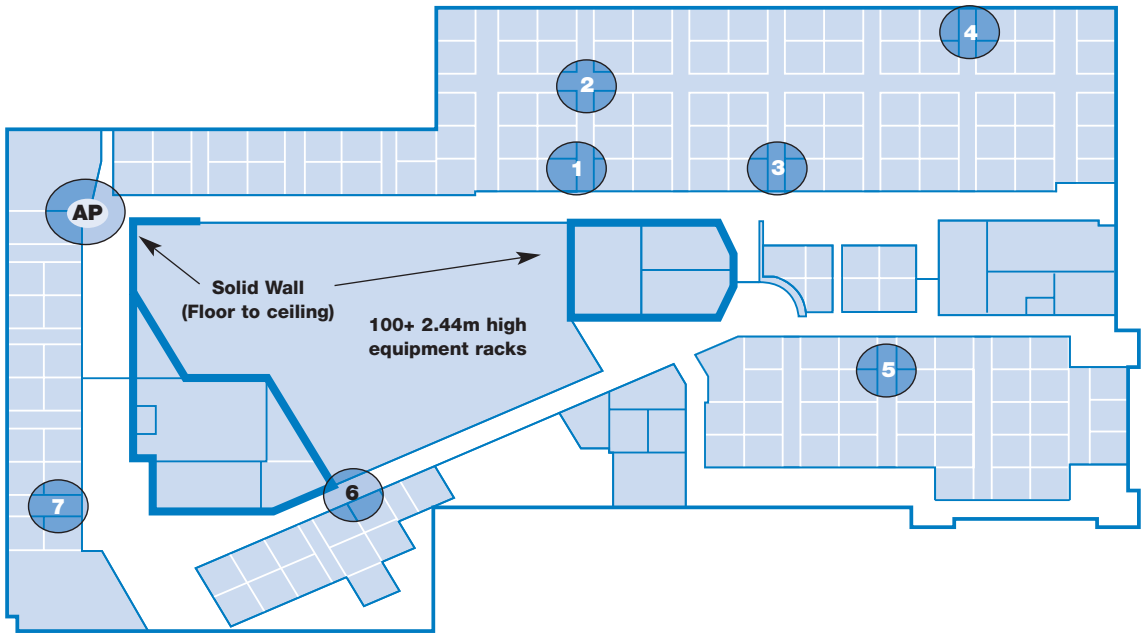

Figure 2: *Non-line of Sight (NLOS) testing.* This type of test provides a realistic simulation of an enterprise environment. Note wall, partition, and equipment rack obstructions. At seven locations throughout the building, Units Under Test (UUTs) were placed on a turntable on a cart 3' 6" high. The access point (AP) was placed in a hall, and was located eight feet from the floor.

Outdoor Performance Test Setup (LOS)

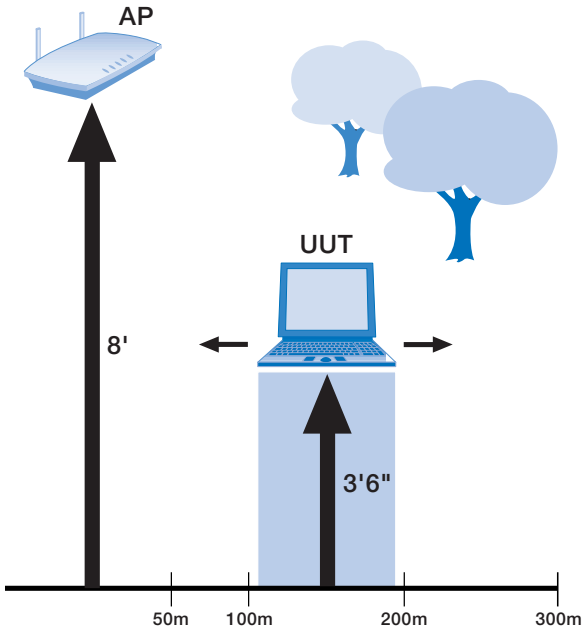

Figure 3: *Outdoor Line of Sight (LOS) testing.* Like the indoor tests, the Units Under Test (UUTs) used in outdoor tests were placed on a turntable on a table at a height of 3' 6" and moved in a straight line away from the access point located eight feet off the ground. Measurements were recorded at 20-meter increments, starting at 10 meters from the AP. No obstructions were present, and weather conditions were stable.

Average Throughput

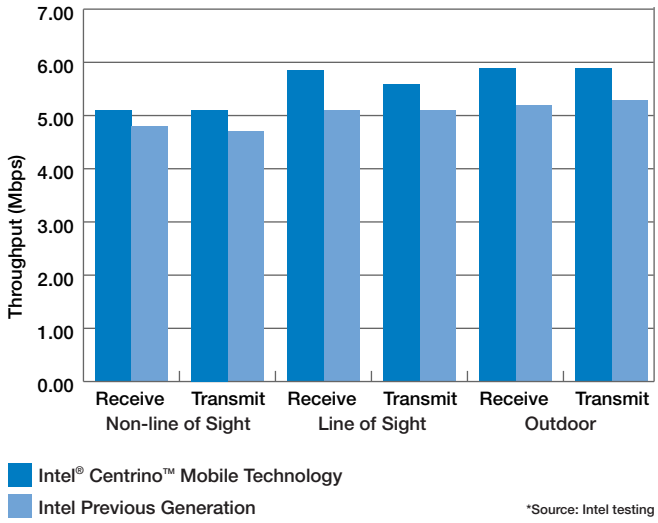

Figure 4. *Integrated WLAN performance (throughput).*[1] In testing conducted by Intel, Intel® Centrino™ mobile technology was consistently superior to Intel's previous-generation integrated wireless LAN technology. Intel Centrino mobile technology's WLAN network connection (Intel® PRO/Wireless 2100 LAN Mini-PCI Adapter throughput was up to 14 percent better than Intel's previous-generation WLAN network connection product, the Intel® PRO/Wireless 80211B.

[1]Configuration: IBM ThinkPad* X31 BIOS v0.22 (1QET22WW); running on power; Windows* 2000 SP3 (IBM Image); Intel® PRO/Wireless 80211B Gold Sample (TIC #56973); Intel® Pentium® M processor 1.4 GHz, Intel® 855 chipset

Cisco 350 AP* (30mW; Default Settings: No WEP; Stealth Mode=OFF; Short Preamble)

Chariot* 4.2 (1026) Console (number_of_timing_records=50; file_size=1,000,000; console Run Options set to "Run until any pair ends"); Chariot Endpoint* SW v4.5.1552

Test Results

Intel designed Intel® Centrino™ mobile technology to bring about a new era of wireless mobile computing in contrast to the occasional plug-to-plug portability that is the norm for many users today. From design inception, Intel Centrino mobile technology was developed specifically to enable integrated wireless LAN capability; breakthrough mobile performance; extended battery life; and thinner, lighter designs—thus delivering on the four key areas of mobility. And although Intel Centrino mobile technology is a compact, lightweight and highly integrated platform, performance was not sacrificed. In fact, using multiple benchmarks, Intel Centrino mobile technology performance, whether defined in terms of processor performance/battery life or range and throughput has demonstrated results that are superior to previous-generation Intel products. In Intel's tests using its own testing methodology, Intel Centrino mobile technology's WLAN network connection throughput was up to 14 percent better than Intel's previous-generation product (see Figure 4).

Throughput, though important, is just one of the key pieces of the mobile experience puzzle. Depending on system design and configuration, in addition to antenna position and access point design among other variables, range and throughput performance can vary significantly from vendor to vendor—often by as much as 10 percent.

There are other WLAN support and software enhancements available for Intel Centrino mobile technology that also have an impact on the mobile experience. These include:

- Advanced Profile Management Support to allow setup of an unlimited number of profiles for easy roaming between different WLAN networks.
- Intel Wireless Coexistence System to reduce interference between Intel PRO/Wireless and certain Bluetooth* devices.

Intel has extensively tested the 3 components of Intel Centrino mobile technology to work together optimally in order to maximize the system's reliability and interoperability. Intel Centrino mobile technology is continuing to undergo extensive security validation with industry-standard security and leading third-party security solutions now and into the future. Intel is continuing to conduct comprehensive infrastructure verification on Intel Centrino mobile technology with the wireless LAN infrastructure ecosystem and public wireless LAN service providers.

So it's important to keep in mind the relative importance of various aspects of mobile performance in the overall mobile experience equation, and to define mobile performance comprehensively. Technologies that enable integrated wireless capabilities, breakthrough mobile performance, extended battery life and the manufacture of thin and light designs enable outstanding mobile experience. Intel Centrino mobile technology does all these things.

Conclusion

There are no industry-standard benchmarks for determining the range and throughput of WLANs. Some would even say that there is no common vocabulary. But Intel engineers wanted tangible evidence to reinforce what they knew intuitively. They wanted proof that Intel® Centrino™ mobile technology provides breakthrough mobile performance—in terms of processor speed, battery life and throughput—and an enhanced user experience overall. So Intel engineers developed a methodology for obtaining controlled, reproducible results. Intel is confident that its test results establish the breakthrough mobile performance of Intel Centrino mobile technology when considering all performance criteria (processing, battery life and wireless), and that the methodology Intel engineers used can serve as a basis for the development of a widely accepted industry-standard benchmark.

WLAN Testing Rules of Thumb

In order to minimize variables when testing WLAN (802.11b) technologies, the following rules should be applied:

Physical Environment

- Controlled and reproducible environment
- Minimize noise and interference (other APs, cordless phones, microwaves, etc.)
- Provide for some dynamics within the test environments – to establish real-world scenarios that include an individual's movement
- Include various degrees of scattering and multi-path – consider obstructions and range

Unit Under Test

- Test using systems from well-known manufacturers
- Notebooks must run same operating system
- Style and position of UUT (i.e., antenna placement) must be consistent

General

- Vendor interoperability can't be an issue (i.e., use Cisco with Cisco)
- Test various channels (i.e., 802.11b channels 1, 6, 11, 14)
- Test under power and battery
- Use a consistent test program
- Chariot*, NetPerf*, Qcheck*, FTP, or homegrown
- Test automation

† Wireless connectivity and some features may require you to purchase additional software, services or external hardware. Availability of public wireless LAN access points limited. System performance, battery life, wireless performance and functionality will vary depending on your specific hardware and software configurations. See http://www.intel.com/products/centrino/more_info for more information.

Performance tests and ratings are measured using specific computer systems and/or components and reflect the approximate performance of Intel products as measured by those tests. Any difference in system hardware or software configuration, as well as system use patterns including wireless connectivity, may affect actual test results and ratings. For more information on performance tests and on the performance of Intel products, visit www.intel.com/performance/resources/limits.htm.

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