RYSAVY RESEARCH

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Wireless Network Assessment

EV-DO and Wi-Fi Hotspots

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1 Overview

Mobile professionals have an increasing number of wireless networks from which to choose. These networks provide effective access to organizational information and allow workers to be more productive than ever before. However, there is significant variation in how different wireless networks perform and which applications make the most sense in what usage scenario. Although some may argue that one type of wireless network is better than another for all cases, our analysis shows that each wireless network best supports specific types of applications, or specific usages of such applications, and that mobile professionals are best served by having access to a combination of wireless technologies.

Under sponsorship from T-Mobile, Rysavy Research and Quality in Motion conducted a series of tests to quantify network performance for different application scenarios. T-Mobile's HotSpot network and Verizon's EV-DO network were examined in detail. Testing also encompassed, though to a lesser extent, T-Mobile's EDGE network. The tests showed significantly better and more consistent application performance using T-Mobile's HotSpot when compared to EV-DO. This paper discusses the general capabilities of wireless networks, the communications needs of mobile professionals in different scenarios, the tests performed, and the test results.

2 Capabilities of Wireless Networks

In an ideal world, we would have broadband networking access from any location. However, the reality is that a fundamental tradeoff exists between the amount of bandwidth and the degree of mobility. Fixed fiber-optical-based networks provide the greatest network performance in the 100 megabit per second (Mbps) to 1 gigabit per second (Gbps) range, but they have no mobility. Cellular-data networks provide the greatest degree of mobility, but average downlink throughputs are limited to about half a megabit per second and uplink throughputs today are even slower, at around 100 kilobits per second (kbps). Another wireless networking approach is the deployment of wireless hotspots, where service providers offer broadband wireless data service at specific public locations such as coffee shops, airports and hotels. T-Mobile is the leading hotspot provider in the United States.

A fundamental concept in understanding wireless network performance is to consider how many people are using a particular amount of spectrum. Because a cellular-network base station services a larger geographic area, it must support a higher number of simultaneous users than a wireless local-area network. The result is greater radio bandwidth per user in a local-area network such as a Wi-Fi network. Other factors further improve the performance of local-area networks. One is that more spectrum is available for Wi-Fi networks than for cellular networks. Another is that the radio protocols are simpler, as the network does not have to address challenges like greatly varying power levels and supporting users moving at high speeds. The net result is that Wi-Fi networks operate at very high throughput rates, up to 25 Mbps (54 Mbps raw throughput rate), with existing Wi-Fi standards such as IEEE 802.11a and IEEE 802.11g. IEEE 802.11n will provide even higher throughputs, exceeding 100 Mbps.

Meanwhile, peak data rates for cellular networks today are around 1 Mbps. Not only do wide-area networks such as cellular exhibit lower throughput, they have much higher latencies than local-area networks. As our testing results show, latency can impact application performance as much, if not more, than throughput.

A final consideration is the backhaul capability between the wireless base station or access point and external networks such as the Internet. This backhaul, commonly supported by T1 lines at 1.544 Mbps, is a bottleneck for both local- and wide-area networks. However, this limitation constrains cellular performance more than Wi-Fi hotspot performance because of the larger number of voice and data users that the cell site must support. For most cellular-data systems, a high level of voice loading can affect data capacity. Even with EV-DO, which has a dedicated radio channel for data, a high level of voice activity can diminish data capacity because the limited backhaul must support both services.

3 Wireless Networking Needs

Two important questions are what performance do different applications require and what type of connectivity is optimal for each application. A good starting point is to look at some general throughput and latency requirements for different types of applications, as shown in the following table.

Table 1: Bandwidth Requirements for Different Types of Applications[1]

Type of Application	Throughput and Latency Requirements
Text-oriented	8 to 32 kbps
Mobile phone microbrowser	8 to 32 kbps
Audio streaming	32 to 64 kbps
Multimedia messaging	8 to 100 kbps
General purpose Web browsing	32 kbps to 1 Mbps, depending on richness of content. Lower latency improves performance.
Enterprise applications such as e-mail, database access, and virtual private networking	100 kbps to 1 Mbps for applications transferring large amounts of content. Lower latency improves performance.
Large document transfer	1+ Mbps
Video streaming	100 to 500 kbps

The table indicates that networks in the 100 kbps to 1 Mbps range should serve many of today’s applications. However, supporting an application and supporting an application *well* are two very different things. For example, in our testing, downloading a typical news Web page over a T-Mobile HotSpot connection took an average of 6 seconds, but with a “broadband” cellular-data connection it took an average of 40 seconds because of Wi-Fi’s higher average throughput and significantly lower latency.

[1] Rysavy Research analysis

Most mobile professionals actually have a mix of networking needs that typically consist of sending and receiving small amounts of data more frequently and larger amounts of data less frequently. For example, although a professional with a smartphone may want to receive e-mail, which does not consume much data, in real time, that same person may not want to send a large Microsoft PowerPoint presentation until he or she is working in the comfort and convenience of a stationary location such as a coffee shop or airport lounge.

Wi-Fi hotspots only provide coverage in select areas, whereas cellular data is available across wider areas. So why wouldn't users always prefer a cellular-data connection? The answer is multifold. First, Wi-Fi hotspots support virtually any networking application, but the number of networking applications suitable for cellular data is more restricted. When in a Wi-Fi hotspot's coverage area, network dependability is excellent. With cellular data, on the other hand, the likelihood of networking anomalies is much greater because of a more challenging RF environment, a greater variation in network loading, and variations in signal strength. In our testing, we had a 94 percent success rate in downloading a 3-megabyte file over T-Mobile HotSpot connections but only a 75 percent success rate with EV-DO.

Because of the variability of network performance and the possibility of losing connections mid-transaction, especially when mobile, most cellular-data applications benefit from wireless middleware, which is designed to accommodate these wireless networking challenges. Although such an approach stabilizes applications, it can increase the complexity of deploying networking applications. Since a Wi-Fi hotspot connection better replicates an Ethernet connection, such middleware is not generally needed.

As supported by our test results, the following table explains the fundamental differences between a Wi-Fi hotspot connection and a cellular-data connection.

Table 2: Fundamental Differences Between Wi-Fi Hotspots and Cellular Data

	Wi-Fi Hotspot	**Cellular Data**
Coverage	Select areas	Wide areas
Application support	Virtually any networking application	More restricted networking applications
Network dependability	Excellent	Good
Need for optimization or wireless middleware	None	Preferred
Consistency of application experience	Excellent	Variable
Ability to do concentrated work for an extended time period	Excellent	Poor to good depending on the amount of network communications

An informative example of the effects of cellular-data variability is e-mail. Wireless e-mail can be extremely reliable when using an optimized system like a RIM BlackBerry, which was designed from the ground up for wireless connectivity. In contrast, using an Internet e-mail protocol such as POP3 results in fairly regular failures.

One reason that wide-area wireless poses a challenge for networking applications is that most applications use the Internet Transmission Control Protocol (TCP). TCP employs timers and other methods to carefully control how quickly the protocol injects packets into the network. This is essential for Internet communications spanning multiple networks. However, TCP can misinterpret a high over-the-air error rate in a wireless network as congestion, and it responds by slowing down its transmission rate through a mechanism called slow start. Between the errors and TCP effects, the transmission rate at the application layer can slow down considerably, possibly causing application timeouts. This is why many wireless middleware solutions do not use TCP and instead employ their own transport-layer protocols, which are more finely tuned for wireless effects.

Our testing showed extremely consistent application performance (throughput and execution times) for Wi-Fi, but variable application performance for cellular. Since cellular-data connections are sensitive to signal strength, a challenge for cellular data is that signal strength can be particularly poor, or even non-existent, in conference rooms and other areas deep inside buildings.

Another aspect of cellular-data performance today is that current radio links favor higher speed downlinks rather than uplinks. For example, EV-DO downlink throughputs were over three times as high as uplink throughputs. This is fine for Web browsing, but it is not optimal for applications that upload large amounts of data.

The bottom line is that cellular data is well suited to providing mobile users select data access across large areas. However, for concentrated work sessions that involve extensive networking usage, a Wi-Fi hotspot provides a much more satisfying and productive experience. In the words of one of our test engineers, "We always looked forward to doing the Wi-Fi portion of the tests because we knew that the tests would complete quickly and reliably."

Wi-Fi hotspots provide a significantly superior networking experience. Nevertheless, there are significant benefits to also having mobile connectivity. The best of all worlds, then, is having a combination of Wi-Fi hotspot service and wide-area connectivity, thereby allowing workers to choose their connectivity method based on their needs and location.

4 Test Summary T-Mobile HotSpot and EV-DO

To determine how well different applications work with different wireless networks, we methodically conducted a series of performance tests on T-Mobile's EDGE network, T-Mobile's HotSpot network and Verizon's EV-DO network. Tests included FTP download and upload, Web page download, and Outlook Exchange operations over VPN connections. We did our tests in multiple locations in the Seattle metropolitan area. We chose this location based on the location of our test engineers and because we believe Seattle is representative of major metropolitan areas.

We also performed a network loading test on both the EV-DO and Wi-Fi networks in several locations using four network clients simultaneously. A summary of test methodology used includes the following:

- **Multiple locations.** Cellular data tested in eight locations to accommodate variability in geography and time.
- **Variable signal strength.** Cellular data tested with poor, good, and excellent signal strength.
- **Automated scripts.** All tests done using automated scripts to load test data, initiate applications, and record start and stop times.

- **Controlled test environments.** All tests used a dedicated test server located on a high-speed Internet backbone node with consistent static test data.

Subsequent sections describe the test parameters, test results, testing framework details, and testing methods.

4.1 Test Parameters

We chose the test parameters that offer a representative view of network performance.

Table 3: Test Parameters and Values

Parameter	Value
City tested	Seattle, Wash., metropolitan area
Number of EV-DO locations tested	8
Number of EV-DO locations with good or excellent signal	5
Number of Wi-Fi locations tested	6
Times tested	Morning, afternoon, evening
Dates tested	Dec. 18, 2005, to Dec. 30, 2005
Applications tested	FTP download, FTP upload, Web page download, Outlook over VPN download, Outlook over VPN upload
Test repetitions	3 per application per location
FTP download size	3 megabytes
FTP upload size	1 megabyte
Web page	Mirror of www.ccn.com on Dec. 16, 2005
Download mailbox size	50 messages, 19 attachments, 3.95 megabytes
Upload mailbox size	50 messages, 10 attachments, 777 kilobytes

4.2 FTP Tests

The following table summarizes FTP test results. Observations are as follows:

- T-Mobile HotSpot service provided significantly higher download and upload throughput.
- T-Mobile HotSpot download speed was much more consistent.
- Even a light level of loading (four simultaneous downloads) was sufficient to bring down average data rates for both T-Mobile HotSpot and EV-DO service.
- EV-DO throughput with a good or excellent signal strength was higher.
- EV-DO throughput at the Sea-Tac Airport was low (232 kbps) despite excellent signal strength, possibly because of network loading.

- EV-DO upload speed was significantly lower than download speed.
- Although not shown in the table, EDGE throughput rate averaged 148 kbps across all locations.

Table 4: Summary of FTP Test Results

Test	T-Mobile HotSpot	Verizon EV-DO
FTP download throughput, average of all locations	1,274 kbps	310 kbps
FTP download throughput, good or excellent cellular signal strength, five locations	N/A	390 kbps
FTP download throughput, good or excellent cellular signal strength, excluding airport, four locations	N/A	429 kbps
Highest FTP download speed	1,396 kbps	528 kbps
Lowest FTP download speed	548 kbps	51 kbps
FTP download failures	1 in 18 tests (6% failure rate)	6 in 24 tests (25% failure rate)
FTP download standard deviation across all eight locations	348 kbps	162 kbps
FTP download standard deviation as a percentage of average throughput	27%	52%
Throughput test, loaded network (4 simultaneous clients)	367 kbps	248 kbps
FTP upload throughput, average of all locations	1,329 kbps	100 kbps
FTP upload, good or excellent cellular signal strength	N/A	108 kbps

4.3 Web Tests

The following table summarizes Web download test results. The test procedure involved clearing browser caches before each download. Observations are as follows:

- T-Mobile HotSpot service provided significantly better results. The reason is a combination of higher throughput and lower latency. Prolonged Web interaction is feasible with T-Mobile HotSpot service but less so with EV-DO.
- With good or excellent coverage, and removing the busy airport location, the best EV-DO download time was 25 seconds.

Table 5: Summary of Web Test Results

Test	T-Mobile HotSpot	Verizon EV-DO
Test Web page (www.cnn.com snapshot) download time, average of all locations	6 sec	55 sec
Test Web page (www.cnn.com snapshot) download time, good or excellent cellular signal strength	N/A	42 sec
Test Web page (www.cnn.com snapshot) download time, good or excellent cellular signal strength, excluding airport	N/A	25 sec

4.4 Microsoft Outlook Tests

The following table summarizes Microsoft Outlook test results. Observations are as follows:

- T-Mobile HotSpot service provided significantly better download and upload times.

Table 6: Summary of Outlook Test Results

Test	T-Mobile HotSpot	Verizon EV-DO
Microsoft Outlook download time (3 megabytes), all locations	23 sec	122 sec
Microsoft Outlook download time (3 megabytes), good or excellent cellular signal strength	N/A	111 sec
Microsoft Outlook over VPN upload time (.8 megabytes), all locations	16 sec	214 sec
Microsoft Outlook over VPN upload time (.8 megabytes), good or excellent signal strength	N/A	172 sec

4.5 Ping Tests

The following table summarizes Ping test results. Observations are as follows:

- T-Mobile HotSpot service had significantly lower ping times.
- T-Mobile HotSpot service had extremely consistent ping response time. EV-DO service ping time varied considerably, as shown by the standard deviation between ping times.

Table 7: Summary of Ping Test Results for T-Mobile HotSpot and Verizon EV-DO

Test	T-Mobile HotSpot	Verizon EV-DO
Ping test to test server	12 msec	288 msec
Ping test standard deviation	2.4 msec	285 msec
Ping test standard deviation as a percentage of average ping time	19.7%	99.2%

5 Analysis of Test Results

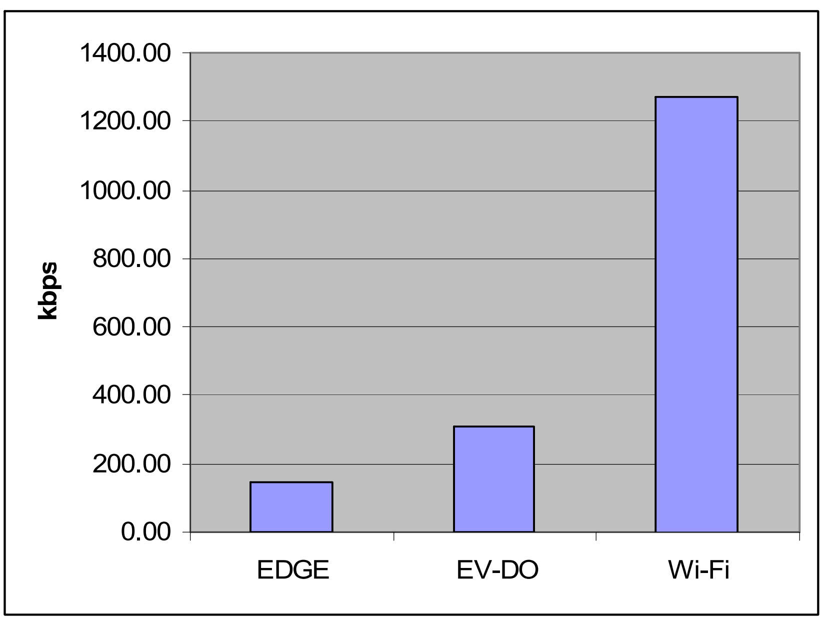
Based on the test results, Wi-Fi clearly had the highest throughput and the lowest variation. Wi-Fi also had the best performance for downloading the test Web page and performing Outlook operations. This is because these applications, particularly Web access, require opening multiple TCP connections, which is affected by higher latency. In contrast, higher latency is not as notable for applications such as FTP or when performing a single HTTP GET.

Testing showed that performance does not drop linearly for EV-DO as the signal strength drops. In other words, the throughput was nearly the same for test runs whether the signal strength was good or excellent. However, when the signal strength was poor, there was a significant drop in performance.

Although all the Wi-Fi connections were IEEE 802.11b at a raw rate of 11 Mbps, none was able to achieve this throughput rate to the Internet because the T-Mobile HotSpots are limited by T1 backhaul connections operating at 1.5 Mbps. This can be clearly seen in the test results, where many of the operations occur at nearly 1.5 Mbps.

The figure below illustrates the average throughput of FTP downloads over the various wireless networks.

Figure 1: Comparison of Throughput Across All Locations



The capabilities of EV-DO can be better understood by looking at how EV-DO achieves different data rates. This is shown below in Table 8. The commonly quoted theoretical rate of 2.4 Mbps occurs with 16 Quadrature Amplitude Modulation (QAM) and the full power of the cell sector directed at one user. This peak theoretical rate is not achievable in currently deployed networks, particularly as this throughput rate would require commensurate capacity in the backhaul connection between the cell site and the operator infrastructure network.

Table 8: EV-DO Data Rates

Data Rates (Kbps)	38.4	76.8	153.6	307.2	307.2	614.4	614.4	921.6	1229	1229	1843	2458
Modulation Type	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	8PSK	QPSK	16 QAM	8PSK	16 QAM
Code Rate	1/5	1/5	1/5	1/5	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3
Number of Slots	16	8	4	2	4	1	2	2	1	2	1	1

The slots in the fourth row of the table above show the number of instantaneous users that can be supported at each data rate. Taking the rate of 400 to 700 kbps quoted by Verizon, only two users would achieve that rate if both were doing a continuous download. This suggests that even a light level of loading begins to impact network performance. Our testing demonstrated this effect, where average data rates with four simultaneous downloads resulted in an average throughput rate of 248 kbps. One constraint of the time slot structure is that it limits the total number of simultaneous users on an EV-DO cell sector to 16.

Another important consideration is that average user throughput is dictated by interference and signal quality across the entire cell site. Analysis by Rysavy Research[2] shows EV-DO to have a spectral efficiency of .4 bps/Hz sector. This means that the overall sector capacity across all users is only 500 kbps. For a three sector site, this translates to 1.5 Mbps. Although this allows for reasonable throughput per user when the number of active data users is relatively low, it means that average throughputs will go down quickly as the number of users increases. For example, 10 simultaneous active users in a cell sector would each see about 50 kbps of throughput.

This capacity analysis raises the question of how many broadband users the network can actually support. Although operators can add EV-DO channels, this takes away from voice capacity, and spectrum may not always be available. In contrast, Wi-Fi hotspots can scale to almost any level of user activity by adding access points and T1 circuits. Compared to cellular networks, there are few spectrum constraints. This capacity question is one of the driving forces behind developments such as municipal Wi-Fi networks, WiMAX, and evolved 3G systems.

Although it is true that a very large number of users at a hotspot can also degrade service significantly, this is generally only an issue at extremely busy locations such as conferences and it is not a problem for the types of locations where T-Mobile has implemented its hotspot service. Normally, the spectral resources of a hotspot are divided among a much smaller number of users than a cell site.

With regard to network delays, ping times over Wi-Fi always yielded very quick response times with very little deviation between individual ping responses. The maximum ping

[2] Data Capabilities GPRS to HSDPA and Beyond, September 2, 2005, white paper for 3G Americas.

time for Wi-Fi at any of the sites was 22 milliseconds, with a minimum ping time of 10 milliseconds. This is in sharp contrast to EV-DO, where ping responses were significantly higher and showed much higher deviation.

To determine the hop count difference for each of the networks, we traced the route from the client connection to the test server. Surprisingly, the hop count for each of the networks was nearly the same. Wi-Fi had 12 nodes to traverse, while EV-DO had 14 nodes. Thus, it is highly unlikely that the increased latency for EV-DO was a result of the Internet route.

6 Test Configuration Details

To ensure consistent and comparable results, we designed a test framework to minimize potential tester error as well as eliminate the possibility of performance results being affected by the server-side network. This section describes the steps we took and the components we created to achieve this goal.

6.1 Test Server

Since many of the wireless networks being tested can achieve relatively high throughput, it was extremely important that the server and its network connection were not potential bottlenecks. This would have artificially lowered the performance numbers for a high throughput wireless network. To eliminate these potential bottlenecks, we placed the server on a 100 Mbps Internet backbone hosted at the Internap co-location site at 140 4th Avenue North, Seattle, Wash. In addition, we gathered baseline performance numbers by executing the test plan over cable Ethernet. The cable Ethernet connection used to gather the performance numbers was rated at 4 Mbps download and 768 kbps upload. The test results achieved show that the test server's network connection was not the bottleneck when compared to all the wireless networks tested.

The test server configuration was as follows:

Windows Enterprise Server 2003 for Small Business Server (5.2.3790)

All available hot-fixes and security updates as of Dec. 18, 2005

Microsoft © IIS 6.0 for HTTP and FTP

Microsoft © Exchange Server 2003

Microsoft © VPN Server

6.2 Test Applications

To help achieve consistent test results and eliminate potential operator error, we created test applications to automate many portions of the test plan. We created and used the following applications to gather performance data:

ASP.NET MailPost Web application

Windows Form SendMail application

Windows Form BaseTest application

Windows Form MultiClient application

6.2.1 ASP.NET MailPost

The purpose of this test application was to automate the posting of messages to a Microsoft Exchange mailbox to assess performance in receiving an inbox using Microsoft Outlook. This application allowed the test operator to browse to a Web site hosted on the test server and post all the test messages to an Exchange mailbox. This eliminated potential errors that could have been caused by the operator manually posting the set of test messages. It also increased testing efficiency by allowing the operator to perform a single function to post the set of test messages. In addition, the size of the Exchange mailbox was ensured to be identical in each test cycle.

6.2.2 Windows Form SendMail

This application was the opposite of the MailPost application above. Instead of posting messages to the Exchange inbox for a user, it posted messages to the Microsoft Outlook outbox on the client computer. This application greatly increased the efficiency with which the operator could gather performance data for sending Microsoft Outlook messages.

6.2.3 Windows Form BaseTest

This application was used to automate the gathering of performance results for FTP download, FTP upload, and Web page browsing. The application performed the following functions when the operator clicked the 'Run' button:

Opened an FTP connection to the test server, set the FTP mode to binary, and then initiated an FTP GET operation. The timing results displayed were based only on the FTP GET operation.

Opened an FTP connection to the test server, set the FTP mode to binary, and then initiated an FTP PUT operation. The timing results displayed were based only on the FTP PUT operation.

Using Internet Explorer as an embedded ActiveX control, retrieved a Web page hosted on the test server that was a mirror of CNN.com on Dec. 16, 2005. The timing results displayed were calculated from the moment the first HTTP request was sent to the moment the final HTTP GET operation concluded.

6.2.4 Windows Form MultiClient

This application automated the network load testing. It sent an HTTP GET request to the test server and then outputted the time required to download a large file. We designed it to be easy for an operator to simultaneously initiate requests from multiple client computers. The original version of this test application used FTP instead of HTTP. This proved problematic because of the high latency of EV-DO, which caused problems when attempting to have four client computers try to open the FTP data port at the same time. The summary performance information includes one test run done with FTP. However, the FTP results attained are not statistically different from the HTTP results.

6.2.5 Ping Testing

We did ping testing with blocks of 11 ping tests and discarded the first result to eliminate the increased delay of acquiring a traffic channel after a traffic channel had timed out.

6.3 Test Plan

This section describes the test plan used to gather all the performance results. We designed the test plan to eliminate operator error and increase the efficiency of test operations performance. The following list outlines the instructions provided to the tester to complete a test round for a single network.

Record the address of test location and the time of day.

Establish a connection to the desired network. Ensure that the adapters for the other networks are disabled to prevent any possible interference.

Record the network strength as indicated by the associated network connection tool.

Clear the IE cache (Tools – Options – Delete Files)

Launch the BaseTest application and click the 'Run' button.

When the BaseTest application is completed, record the results printed by the application.

Repeat the steps to run the BaseTest application three times.

Establish a VPN connection to the test server.

Open Outlook on the client computer, ensure the Outlook junk mail filter is turned off and all folders are empty, and then set the mode to offline.

Populate the Exchange inbox using the MailPost application.

Set the Outlook mode to online and begin timing the synchronization operation.

When synchronization is complete, record the elapsed time.

Empty all Outlook folders and resynchronize.

Repeat the steps to record the receive e-mail three times.

Set the Outlook mode to offline.

Run the SendMail application to populate the Outlook outbox.

Set the Outlook mode to online and begin timing the synchronization operation.

When synchronization is complete, record the elapsed time.

Repeat the steps to record the send e-mail three times.

Close the VPN connection.

Perform a ping operation to the test server from the command line issuing 11 pings.

Record all but the first ping time.

Perform a trace route operation from the command line and record the results.

In addition to the previous test, we performed a network loading test at three of the eight locations for the EV-DO and Wi-Fi networks. This test was meant to determine the throughput profile when multiple clients simultaneously access the network. The following list outlines the steps required to perform the network loading test.

Establish a connection to the desired network (either EV-DO or Wi-Fi) on all four client computers.

Launch the MultiTest application on all four client computers.

Ensure that each MultiTest application is set to download a different file. The test server contains four identical files for downloading by each of the clients.

Set focus to each of the MultiTest applications.

Each of the two test operators presses 'Enter' on each of their two client computers at the same time. This initiates all four downloads at the same time.

When all four clients have finished downloading, record the results.

6.4 Test Files

In addition to the processes and applications developed, we gave considerable thought to the files, site, and messages used to gather the performance data.

6.4.1 FTP Files

We designed the files used for the FTP portion of the testing with size and data content in mind. Size is an important factor because the files should represent a real-world example of data upload and download but be large enough to provide meaningful results. For these reasons, files of the following sizes were chosen:

FTP Download – 3 MB

FTP Upload – 1 MB

Then we chose the FTP download file size to be approximately the size of an average MP3 file. We chose the FTP upload file size to be the size of a reasonably complicated PowerPoint file.

In addition to file size, content was important to prevent skewed results because of file compression during data transmission. Thus we created the files using the strong random number generation functions in the Windows Cryptography API. To verify that the files could not be compressed, we tried to compress the files using WinZip and confirmed that the compressed file was larger than the original file.

6.4.2 Web Site

The Web site criterion was that it be a reasonably complicated site with approximately 100 objects. For this reason, we mirrored the CNN.com site as of Dec. 16, 2005, onto the test server.

6.4.3 E-mail Messages

We chose the e-mail messages so that they represented a typical office worker's inbox and outbox. In addition, the sample message set contained a representative set of attachments of various sizes and types, including JPEG, Word, PowerPoint, PDF, and Windows Media files. We set the sample message sets as follows:

Inbox – 50 messages, 19 attachments, 3.95 MB

Outbox – 50 messages, 10 attachments, 777 KB

6.5 Test Locations, Times, and Signal Strength

In addition to the quantitative testing aspects, we included three more qualitative aspects: location, time of day, and signal strength. We chose the locations to provide a representative sample of wireless access in the greater Seattle area. We chose the following eight locations to run the tests:

Ballard Starbucks, 9999 Holman Road NW, Seattle, WA

SeaTac Airport/Red Roof Inn, 16838 International Blvd, Seattle, WA

University Village Starbucks, 4634 26th Avenue NE, Seattle, WA

Southcenter Starbucks, 17501 Southcenter Parkway, Tukwilla, WA

Lynnwood Starbucks, 19720 44th Avenue West, Lynnwood, WA

Downtown Bank of America Building, 700 4th Avenue, Seattle, WA

Bellevue Barnes & Noble Starbucks, 626 106th Avenue NE, Bellevue, WA

Redmond Town Center Starbucks, 16500 NE 74th Street, Redmond, WA

To provide results that would be representative of variable signal strength and different user loads, we created the following test matrix to ensure that the desired variables would be included in the test results. This matrix was only applied to EV-DO and EDGE, because under normal user conditions, most Wi-Fi users will see a good or excellent connection by being in close proximity to the Wi-Fi access point.

Morning with a poor to good signal.

Morning with an excellent signal.

Afternoon with a poor connection.

Afternoon with a good connection.

Afternoon with an excellent connection.

Evening with a poor connection.

Evening with a good connection.

Evening with an excellent connection.

Test start times do not indicate end times (e.g., morning test ended in afternoon, etc.)

For EV-DO, we used the following matrix to determine what constituted poor, good, and excellent connections. We used the Verizon Connection Manager to determine the connection strength.

Poor – 0 to 2 bars, averaging 1 bar

Good – 2 to 3 bars

Excellent – 3 to 4 bars

For EDGE, we used the following matrix to determine what constituted poor, good, and excellent connections. We used the T-Mobile Connection Manager to determine the signal strength.

Poor – 1 to 2 bars

Good – 2 to 4 bars, averaging 3 bars

Excellent – 4 to 5 bars

For Wi-Fi, we used the following matrix to determine what constituted poor, good, and excellent connections. We used the Windows Wireless Connection Manager to determine the signal strength.

Poor – 1 to 2 bars

Good – 2 to 4 bars, averaging 3 bars

Excellent – 4 to 5 bars

7 Summary

This paper has discussed the varying networking requirements of mobile professionals and presented the key differences between Wi-Fi hotspot and cellular-data networks. Although cellular-data networks provide an advantage in mobility, they significantly underperform Wi-Fi hotspot networks for many common applications.

Using interactive networking applications across longer working periods, most users are likely to prefer the higher throughput, lower latency, and more stable connections of a Wi-Fi hotspot, as these translate to a true broadband experience. In a series of methodical tests, Rysavy Research quantified the performance of a number different applications operating over both EV-DO and T-Mobile HotSpots. These applications included FTP, Web access, and e-mail over a VPN. Across all tests, the T-Mobile HotSpot connections provided greater application performance by at least a factor of four. Not only did applications perform significantly faster, they were more reliable. And compared to cellular-data connections, their response times were much more consistent. All these factors make for a more productive and satisfying work experience.

However, a hotspot is not always available. Hence, for many professionals, a blend of services – hotspots at some locations and a cellular-data service such as EDGE at other locations – provides the optimum solution.

8 Appendix: Test Measurements

This section tabulates some of the raw test results for EV-DO and Wi-Fi.

8.1 T-Mobile HotSpot

Location	Test	Size (MB)	Elapsed (sec)	Rate (kbps)
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP DL	3.00	18.00	1365.33
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP DL	3.00	18.20	1350.33
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP DL	3.00	23.60	1041.36
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP UL	1.00	6.20	1321.29
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP UL	1.00	6.20	1321.29
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP UL	1.00	6.10	1342.95
BN-Starbucks, 606 NE 106th St., Bellevue, WA	WEB	0.33	6.28	430.50
BN-Starbucks, 606 NE 106th St., Bellevue, WA	WEB	0.33	6.05	447.16
BN-Starbucks, 606 NE 106th St., Bellevue, WA	WEB	0.33	6.83	396.02
Starbucks, Redmond Town Center, Redmond	FTP DL	3.00	17.78	1382.23
Starbucks, Redmond Town Center, Redmond	FTP DL	3.00	17.92	1371.43
Starbucks, Redmond Town Center, Redmond	FTP DL	3.00	23.60	1041.36
Starbucks, Redmond Town Center, Redmond	FTP UL	1.00	6.14	1334.20
Starbucks, Redmond Town Center, Redmond	FTP UL	1.00	6.14	1334.20
Starbucks, Redmond Town Center, Redmond	FTP UL	1.00	6.08	1347.37
Starbucks, Redmond Town Center, Redmond	WEB	0.33	5.10	530.20
Starbucks, Redmond Town Center, Redmond	WEB	0.33	5.17	523.02

Starbucks, Redmond Town Center, Redmond	WEB	0.33	6.00	450.67
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-DL	3.95	21.38	1514.69
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-DL	3.95	22.69	1427.24
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-DL	3.95	22.82	1419.11
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-UL	0.77	14.62	429.00
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-UL	0.77	15.18	413.18
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-UL	0.77	14.81	423.50
Starbucks, Ballard	FTP DL	3.00	18.09	1358.26
Starbucks, Ballard	FTP DL	3.00	17.97	1367.71
Starbucks, Ballard	FTP DL	3.00	17.98	1366.52
Starbucks, Ballard	FTP UL	1.00	6.17	1327.31
Starbucks, Ballard	FTP UL	1.00	6.13	1337.47
Starbucks, Ballard	FTP UL	1.00	6.16	1330.68
Starbucks, Ballard	WEB	0.33	6.69	404.37
Starbucks, Ballard	WEB	0.33	5.69	475.39
Starbucks, Ballard	WEB	0.33	5.39	501.58
Starbucks, Ballard	Outlook-ExchVPN-DL	3.95	23.35	1386.90
Starbucks, Ballard	Outlook-ExchVPN-DL	3.95	23.00	1408.00
Starbucks, Ballard	Outlook-ExchVPN-DL	3.95	23.50	1378.04
Starbucks, Ballard	Outlook-ExchVPN-UL	0.77	15.12	414.81
Starbucks, Ballard	Outlook-ExchVPN-UL	0.77	14.47	433.45
Starbucks, Ballard	Outlook-ExchVPN-UL	0.77	14.48	433.15
Airport, Alaska Air Check-in	FTP DL	3.00	18.55	1325.07
Airport, Alaska Air Check-in	FTP DL	3.00	20.64	1190.66
Airport, Alaska Air Check-in	FTP DL	3.00	18.23	1347.78
Airport, Alaska Air Check-in	FTP UL	1.00	6.47	1266.40
Airport, Alaska Air Check-in	FTP UL	1.00	6.22	1317.31
Airport, Alaska Air Check-in	FTP UL	1.00	6.36	1288.18
Airport, Alaska Air Check-in	WEB	0.33	5.62	480.71
Airport, Alaska Air Check-in	WEB	0.33	8.77	308.46
Airport, Alaska Air Check-in	WEB	0.33	5.48	493.07
Airport, Alaska Air Check-in	Outlook-ExchVPN-DL	3.95	23.84	1358.39
Airport, Alaska Air Check-in	Outlook-ExchVPN-DL	3.95	23.18	1397.07
Airport, Alaska Air Check-in	Outlook-ExchVPN-DL	3.95	23.00	1408.00
Airport, Alaska Air Check-in	Outlook-ExchVPN-UL	0.77	15.03	417.30
Airport, Alaska Air Check-in	Outlook-ExchVPN-UL	0.77	15.50	404.65
Airport, Alaska Air Check-in	Outlook-ExchVPN-UL	0.77	17.06	367.64
Starbucks, U-Village	FTP DL	3.00	18.03	1362.97
Starbucks, U-Village	FTP DL	3.00	17.84	1377.29
Starbucks, U-Village	FTP DL	3.00	17.61	1395.62
Starbucks, U-Village	FTP UL	1.00	6.23	1314.01
Starbucks, U-Village	FTP UL	1.00	6.19	1323.96
Starbucks, U-Village	FTP UL	1.00	5.97	1372.48
Starbucks, U-Village	WEB	0.33	5.55	487.47
Starbucks, U-Village	WEB	0.33	6.00	450.67
Starbucks, U-Village	WEB	0.33	6.30	429.41
Starbucks, U-Village	Outlook-ExchVPN-DL	3.95	23.19	1396.46

Starbucks, U-Village	Outlook-ExchVPN-DL	3.95	24.87	1302.13
Starbucks, U-Village	Outlook-ExchVPN-DL	3.95	23.13	1400.09
Starbucks, U-Village	Outlook-ExchVPN-UL	0.77	38.78	161.73
Starbucks, U-Village	Outlook-ExchVPN-UL	0.77	19.63	319.51
Starbucks, U-Village	Outlook-ExchVPN-UL	0.77	16.56	378.74
Starbucks, Southcenter	FTP DL	3.00	44.88	547.65
Starbucks, Southcenter	FTP DL	3.00	17.91	1372.48
Starbucks, Southcenter	FTP DL	3.00	17.91	1372.48
Starbucks, Southcenter	FTP UL	1.00	6.16	1330.68
Starbucks, Southcenter	FTP UL	1.00	6.13	1337.47
Starbucks, Southcenter	FTP UL	1.00	5.98	1368.90
Starbucks, Southcenter	WEB	0.33	5.84	462.78
Starbucks, Southcenter	WEB	0.33	4.86	556.38
Starbucks, Southcenter	WEB	0.33	5.30	510.48
Starbucks, Southcenter	Outlook-ExchVPN-DL	3.95	23.31	1389.27
Starbucks, Southcenter	Outlook-ExchVPN-DL	3.95	22.43	1443.78
Starbucks, Southcenter	Outlook-ExchVPN-DL	3.95	23.22	1394.66
Starbucks, Southcenter	Outlook-ExchVPN-UL	0.77	16.81	373.11
Starbucks, Southcenter	Outlook-ExchVPN-UL	0.77	16.50	380.12
Starbucks, Southcenter	Outlook-ExchVPN-UL	0.77	16.09	389.81

8.2 EV-DO

Location	Test	Size (MB)	Elapsed (sec)	Rate (kbps)
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP DL	3.00	54.40	451.76
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP DL	3.00	50.20	489.56
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP DL	3.00	58.10	422.99
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP UL	1.00	71.90	113.94
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP UL	1.00	70.40	116.36
BN-Starbucks, 606 NE 106th St., Bellevue, WA	FTP UL	1.00	70.00	117.03
BN-Starbucks, 606 NE 106th St., Bellevue, WA	WEB	0.33	22.70	119.12
BN-Starbucks, 606 NE 106th St., Bellevue, WA	WEB	0.33	24.10	112.20
BN-Starbucks, 606 NE 106th St., Bellevue, WA	WEB	0.33	25.20	107.30
BN-Starbucks, 606 NE 106th St., Bellevue, WA	Outlook-ExchVPN-DL	3.95	91.43	353.91
BN-Starbucks, 606 NE 106th St., Bellevue, WA	Outlook-ExchVPN-DL	3.95	112.27	288.22
BN-Starbucks, 606 NE 106th St., Bellevue, WA	Outlook-ExchVPN-DL	3.95	104.78	308.82
BN-Starbucks, 606 NE 106th St., Bellevue, WA	Outlook-ExchVPN-UL	0.77	246.91	25.55
BN-Starbucks, 606 NE 106th St., Bellevue, WA	Outlook-ExchVPN-UL	0.77	227.53	27.72
BN-Starbucks, 606 NE 106th St., Bellevue, WA	Outlook-ExchVPN-UL	0.77	198.34	31.80
Starbucks, Redmond Town Center, Redmond	FTP DL	3.00	201.13	122.19
Starbucks, Redmond Town Center, Redmond	FTP DL	3.00	112.06	219.31
Starbucks, Redmond Town Center, Redmond	FTP DL	3.00	116.13	211.62
Starbucks, Redmond Town Center, Redmond	FTP UL	1.00	74.53	109.92
Starbucks, Redmond Town Center, Redmond	FTP UL	1.00	336.69	24.33
Starbucks, Redmond Town Center, Redmond	FTP UL	1.00	149.81	54.68

Starbucks, Redmond Town Center, Redmond	WEB	0.33	80.28	33.68
Starbucks, Redmond Town Center, Redmond	WEB	0.33	46.48	58.18
Starbucks, Redmond Town Center, Redmond	WEB	0.33	56.64	47.74
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-DL	3.95	143.03	226.41
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-DL	3.95	117.35	275.96
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-DL	3.95	111.97	289.22
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-UL	0.77	303.94	20.64
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-UL	0.77	346.19	18.12
Starbucks, Redmond Town Center, Redmond	Outlook-ExchVPN-UL	0.77	295.53	21.22
Starbucks, Ballard	FTP DL	3.00	86.95	282.64
Starbucks, Ballard	FTP DL	3.00	91.52	268.54
Starbucks, Ballard	FTP DL	3.00	76.03	323.24
Starbucks, Ballard	FTP UL	1.00	127.75	64.13
Starbucks, Ballard	FTP UL	1.00	170.02	48.18
Starbucks, Ballard	FTP UL	1.00	85.97	95.29
Starbucks, Ballard	WEB	0.33	18.28	147.91
Starbucks, Ballard	WEB	0.33	70.33	38.45
Starbucks, Ballard	WEB	0.33	22.19	121.87
Starbucks, Ballard	Outlook-ExchVPN-DL	3.95	140.12	231.12
Starbucks, Ballard	Outlook-ExchVPN-DL	3.95	124.97	259.13
Starbucks, Ballard	Outlook-ExchVPN-DL	3.95	135.03	239.83
Starbucks, Ballard	Outlook-ExchVPN-UL	0.77	345.29	18.16
Starbucks, Ballard	Outlook-ExchVPN-UL	0.77	170.88	36.70
Starbucks, Ballard	Outlook-ExchVPN-UL	0.77	202.15	31.03
Airport, Alaska Air Check-in	FTP DL	3.00	204.67	120.08
Airport, Alaska Air Check-in	FTP DL	3.00	202.73	121.22
Airport, Alaska Air Check-in	FTP DL	3.00	54.20	453.41
Airport, Alaska Air Check-in	FTP UL	1.00	72.38	113.19
Airport, Alaska Air Check-in	FTP UL	1.00	72.53	112.94
Airport, Alaska Air Check-in	FTP UL	1.00	85.91	95.36
Airport, Alaska Air Check-in	WEB	0.33	58.38	46.32
Airport, Alaska Air Check-in	WEB	0.33	21.63	125.04
Airport, Alaska Air Check-in	WEB	0.33	250.99	10.77
Airport, Alaska Air Check-in	Outlook-ExchVPN-DL	3.95	96.75	334.72
Airport, Alaska Air Check-in	Outlook-ExchVPN-DL	3.95	106.29	304.68
Airport, Alaska Air Check-in	Outlook-ExchVPN-DL	3.95	109.81	294.91
Airport, Alaska Air Check-in	Outlook-ExchVPN-UL	0.77	160.59	39.06
Airport, Alaska Air Check-in	Outlook-ExchVPN-UL	0.77	155.88	40.24
Airport, Alaska Air Check-in	Outlook-ExchVPN-UL	0.77	167.87	37.36
Starbucks, U-Village	FTP DL	3.00	47.88	513.34
Starbucks, U-Village	FTP DL	3.00	58.30	421.57
Starbucks, U-Village	FTP DL	3.00	50.03	491.21
Starbucks, U-Village	FTP UL	1.00	80.20	102.14
Starbucks, U-Village	FTP UL	1.00	70.30	116.53
Starbucks, U-Village	FTP UL	1.00	73.42	111.57
Starbucks, U-Village	WEB	0.33	22.81	118.53
Starbucks, U-Village	WEB	0.33	22.95	117.81

Starbucks, U-Village	WEB	0.33	20.75	130.31
Starbucks, U-Village	Outlook-ExchVPN-DL	3.95	101.91	317.77
Starbucks, U-Village	Outlook-ExchVPN-DL	3.95	115.15	281.23
Starbucks, U-Village	Outlook-ExchVPN-DL	3.95	119.84	270.23
Starbucks, U-Village	Outlook-ExchVPN-UL	0.77	155.85	40.24
Starbucks, U-Village	Outlook-ExchVPN-UL	0.77	161.09	38.93
Starbucks, U-Village	Outlook-ExchVPN-UL	0.77	151.54	41.39
Starbucks, Southcenter	FTP DL	3.00	72.48	339.05
Starbucks, Southcenter	FTP DL	3.00	46.53	528.18
Starbucks, Southcenter	FTP DL	3.00	54.78	448.63
Starbucks, Southcenter	FTP UL	1.00	76.92	106.50
Starbucks, Southcenter	FTP UL	1.00	75.08	109.11
Starbucks, Southcenter	FTP UL	1.00	73.86	110.91
Starbucks, Southcenter	WEB	0.33	21.09	128.19
Starbucks, Southcenter	WEB	0.33	19.84	136.26
Starbucks, Southcenter	WEB	0.33	43.06	62.79
Starbucks, Southcenter	Outlook-ExchVPN-DL	3.95	113.78	284.62
Starbucks, Southcenter	Outlook-ExchVPN-DL	3.95	118.18	274.02
Starbucks, Southcenter	Outlook-ExchVPN-DL	3.95	112.78	287.14
Starbucks, Southcenter	Outlook-ExchVPN-UL	0.77	144.81	43.31
Starbucks, Southcenter	Outlook-ExchVPN-UL	0.77	152.22	41.20
Starbucks, Southcenter	Outlook-ExchVPN-UL	0.77	166.25	37.73
Starbucks, Lynnwood	FTP DL	3.00	66.34	370.43
Starbucks, Lynnwood	FTP DL	3.00	70.47	348.75
Starbucks, Lynnwood	FTP DL	3.00	76.23	322.37
Starbucks, Lynnwood	FTP UL	1.00	86.42	94.79
Starbucks, Lynnwood	FTP UL	1.00	85.75	95.53
Starbucks, Lynnwood	FTP UL	1.00	83.34	98.29
Starbucks, Lynnwood	WEB	0.33	26.69	101.32
Starbucks, Lynnwood	WEB	0.33	23.37	115.68
Starbucks, Lynnwood	WEB	0.33	23.77	113.78
Starbucks, Lynnwood	Outlook-ExchVPN-DL	3.95	124.47	260.18
Starbucks, Lynnwood	Outlook-ExchVPN-DL	3.95	123.16	262.94
Starbucks, Lynnwood	Outlook-ExchVPN-DL	3.95	108.44	298.64
Starbucks, Lynnwood	Outlook-ExchVPN-UL	0.77	164.91	38.03
Starbucks, Lynnwood	Outlook-ExchVPN-UL	0.77	161.65	38.80
Starbucks, Lynnwood	Outlook-ExchVPN-UL	0.77	159.05	39.43
Bank of America, Downtown	FTP DL	3.00	435.92	56.38
Bank of America, Downtown	FTP DL	3.00	481.67	51.02
Bank of America, Downtown	FTP DL	3.00	392.15	62.67
Bank of America, Downtown	FTP UL	1.00	63.83	128.34
Bank of America, Downtown	FTP UL	1.00	65.50	125.07
Bank of America, Downtown	FTP UL	1.00	65.23	125.59
Bank of America, Downtown	WEB	0.33	133.38	20.27
Bank of America, Downtown	WEB	0.33	121.25	22.30
Bank of America, Downtown	WEB	0.33	141.93	19.05
Bank of America, Downtown	Outlook-ExchVPN-DL	3.95	147.94	218.90

Bank of America, Downtown	Outlook-ExchVPN-DL	3.95	118.06	274.30
Bank of America, Downtown	Outlook-ExchVPN-DL	3.95	240.54	134.63
Bank of America, Downtown	Outlook-ExchVPN-UL	0.77	427.29	14.68
Bank of America, Downtown	Outlook-ExchVPN-UL	0.77	202.34	31.00
Bank of America, Downtown	Outlook-ExchVPN-UL	0.77	264.77	23.69