2010: Guidelines for Successful Large Scale Outdoor Wi-Fi Networks

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Guidelines for Wireless Broadband Success with Wi-Fi

- Modern wireless broadband networks should deliver a useful service with more than 90% coverage for 802.11n laptops at a performance that exceeds cellular data performance expected in 2012.
- Deploy access network densely - more than 50 nodes per square mile for 2.4 GHz access. Novarum recommends 60 nodes per square mile based on our measurements of over 175 large scale networks.
- Deploy 802.11n technology for infrastructure - both 2.4 GHz access and 5 GHz backhaul.
- Different clients will have different coverage and different performance on the same network infrastructure. Base the network design and expectations on the typical client devices to be used in the next five years.
- Deploy 802.11n technology for clients if at all possible. Avoid 802.11b - these ancient Wi-Fi clients will degrade network performance and every other user's experience.
- Expect very good networks to deliver outdoor 802.11n coverage between 90 and 95%.
- Expect very good (and affordable) 802.11n Wi-Fi networks to deliver outdoor coverage between 50-75% for smartphones.
- Expect legacy 802.11g based wireless broadband networks to deliver largely unacceptable service of 80% for laptops and below 50% for smartphones.

Overview

We are constantly inundated with information about what performance we should expect from our Internet service - particularly from wireless Internet service. Marketing spin from vendors and ISPs, anecdotal reports from friends, colleagues and blogs, claims and counter claims by carriers, overly simplistic tests in the popular media overwhelm us with information; but not necessarily wisdom.

So Novarum decided to test and obtain some real, non-partial information. We went out and independently tested over 175 wireless networks in 36 North American cities from July 2006 through December 2009 and compiled the results as the Novarum Wireless Broadband Review (NWBR). We devised an independent network testing protocol that accurately models the behavior that ordinary users of these services would observe - testing performance delay, upload and download throughput (using industry standard tools) and coverage - the percentage of the claimed service area in which we could actually get Internet access - not just the area in which there were "bars" of service.

We tested in the following cities (some several times to reflect major changes in the networks between tests): Anaheim CA (twice), Baltimore MD (twice), Boston MA (twice), Brookline MA, Chicago IL (twice), Chico CA, Cleveland OH, Cupertino CA, Daytona FL, Denver CO (twice), Eugene OR, Foster City CA, Galt CA, Longmont CO, Madison WI, New York NY (twice), Minneapolis MN, Mountain View CA (twice), New Orleans LO (twice), Orlando FL (twice), Palo Alto CA, Philadelphia PA (twice), Phoenix AZ (twice), Portland OR (four times), Raleigh NC, Riverside CA, Rochelle IL, St. Cloud FL, San Diego CA (twice), San Francisco CA (twice), San Jose CA (twice), Santa Clara CA, Seattle WA (twice), Sunnyvale CA, Tempe AZ, and Toronto ON (twice). Where we could find them, we tested cellular data networks from ATT, Sprint, T-Mobile and Verizon; fixed (802.16d) and mobile (802.16e) WiMAX networks from ClearWire and Wi-Fi networks from a variety of ISPs. In 2009 we collaborated with PC World in this survey and in April 2009 PC World published the first independent benchmarking of 3G cellular networks and we expect an update early in 2010.

This paper summarizes what we've discovered about wireless broadband networks - Wi-Fi and cellular - and concludes with recommendations for the design of modern, high performing Wi-Fi networks that deliver useful service to users.

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Key Findings - What History Tells Us

The results of this substantial amount of real-life experience evaluating wireless broadband networks data really condense down to three essential lessons for new networks:

- Clients matter.
- More infrastructure is better, and too little delivers a unusable grade of service.
- 802.11n technology makes all Wi-Fi networks better.

Clients Matter

A core of the success of cellular wireless networks is strict technical standards for subscriber handsets enforced by the carriers - power, protocol and performance. The completely open nature of Wi-Fi has created wide availability of a variety of clients embedded at low cost in laptops, smartphones, PDAs, cameras, cars, trains, emergency vehicles and many other devices. But each of these Wi-Fi clients performs quite differently, and unlike our experience with cellular data services, expectations of Wi-Fi network performance and network coverage must be tailored to specific types of client devices.

In the process of the NWBR we have tested many client devices to see the effect of different client devices on network performance - testing them in the same networks in the same locations, at the same time - to more accurately assess the performance difference. We tested the following clients:

- Standard, legacy 802.11g laptop client - approximately 30 mW output power.
- A high power 802.11g laptop client - approximately 200 mW output power, similar to the Customer Premises Equipment (CPE) usually specified for large outdoor Wi-Fi networks.
- A first generation 2x2 MIMO 802.11n client - approximately 30 mW output power. Current 802.11n clients, particularly 3x3 MIMO, have even better performance.
- iPhone smartphone Wi-Fi client.

Let's first examine the average outdoor performance of these clients across all the networks in which they were tested.

Client	Delay (msec)	Uplink (kbps)	Downlink (kbps)	Coverage
Average Laptop	157	481	1030	64%
Average High Power	113	767	1286	85%
Average .11n	115	845	1712	82%
Average iPhone	422	231	810	45%

Notice a few items. First, modern 802.11n low power (30 mW) laptops have approximately the same performance and coverage as high power custom CPE. Second, legacy 802.11g laptops using 802.11g networks really do not have very good coverage - the average of all networks tested is 64% and even the best 802.11g Wi-Fi networks topped out at about 80%. Third, smartphones have much more limited coverage and performance due to their lower transmitter power and minimal antennas. The average Wi-Fi network only delivers about 45% outdoor coverage for smartphones. Indoor coverage directly to all of these devices is, of course, substantially lower.

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Let's look at the Wi-Fi networks we examined in the NWBR - which ranged from the some of the early networks deployed during the surge of metro Wi-Fi exuberance - Anaheim and Philadelphia; to some of the more mature networks - such as the successful networks in Toronto and Minneapolis. And for this example, let's look at them focusing on the results from high power 802.11g clients, that use high fixed CPE power levels and antennas that are better than most laptops (and all PDAs) - though still operating with much less than the power used by cellular data or WiMAX modems. (Note also that our measurements indicate that the current generation of 802.11n low power Wi-Fi laptop clients perform very similarly to these numbers as well.)

Wi-Fi Network	Delay (msec)	Uplink (kbps)	Downlink (kbps)	Coverage
Worst	338	106	337	50%
Best	63	2062	2949	100%
Average	113	767	1286	85%

What we learn that it is possible to design a very high performance wireless broadband network with Wi-Fi infrastructure - delivering great coverage for the best clients. The good news is that 3 years of new technology development has dramatically decreased the cost of infrastructure for these networks from the very high levels of Minneapolis and Toronto. 802.11n technology is now commonly available and can be used for clients and infrastructure to deliver these levels of performance and coverage.

Infrastructure Density Matters - 60 is the new 20

With similar client modems, averaged over good and bad networks, Wi-Fi networks deliver almost 3 times better performance than cellular networks and materially better performance than pre-WiMAX networks - with similar levels of availability of service over the promised coverage area for all three network technologies.

Let's look at average measured network performance for these networks. We see that the average network for all three network types offers coverage between 80-90% outdoors and downlink speeds in excess of 1 Mbps. It is important to note that these are historical numbers, and the standard for downlink speed is rapidly increasing to 3 Mbps for cellular networks.

Network	Uplink (kbps)	Downlink (kbps)	Coverage
Average Cellular	195	507	89%
Average Fixed WiMAX	169	1124	83%
Average Wi-Fi	767	1286	85%

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If we look at two of the most successful large scale Wi-Fi networks - Minneapolis and Toronto - we see performance and availability superior to all the cellular data networks (by a factor of 3!) and pre-WiMAX networks we measured - by at least a factor of 2.

Network	Uplink (kbps)	Downlink (kbps)	Coverage
Best Cellular	612	980	100%
Best Fixed WiMAX	164	1129	100%
Best Wi-Fi	2062	2949	100%

The measured performance suggests that Wi-Fi networks materially outperform cellular data networks AND pre-WiMAX networks - and can do it with similar service area coverage.

It is very important to remember that this level of coverage can ONLY be achieved for high performance modern clients - as we shall see outdoor Wi-Fi network coverage between 90-95% is possible for a high density 802.11n network using 802.11n clients. Legacy 802.11g clients will see less coverage on the same networks, as will smartphones.

If we look at what works in these networks - particularly in such networks as Minneapolis that show both high coverage AND high performance - we find a common denominator - high density of access points. Minneapolis averages over 50 access points per square mile and this high density of access points accommodates the low uplink signal levels from Wi-Fi clients. Toronto is deployed with over 100 access nodes per square mile in the dense high rise urban areas.

We found that measured RF signal levels from the infrastructure access points was a poor predictor of performance and coverage. More bars does not necessarily mean better service. Rather it is the density of access nodes that is the best predictor of good performance; since the uplink from client to base station is the limiting factor in performance, capacity and coverage. And based on the type of Wi-Fi clients desired to be used in wireless broadband networks - laptops, smartphones and inexpensive CPE for residential Internet access - a density over 50 access nodes per square mile is required in a typical suburban setting.

There is no magic Wi-Fi infrastructure product that provides a significantly larger coverage area than all others. All of the big outdoor Wi-Fi infrastructure products are operating close to the limits of the FCC regulations already. The limiting factor in terms of range and coverage for outdoor Wi-Fi networks is not how far the access node can transmit. As described above, the limiting factor is the capability of the client device. If a Metro WI-Fi network supports public internet access it must work with a variety of client devices including low power Wi-Fi clients built into notebook PCs and phones. Having to support the least common denominator client device reduces the coverage advantage of one infrastructure product versus another. The real magic in large outdoor Wi-Fi infrastructure is getting the access node as close as possible to the client devices it must support - that means higher node density.

802.11n Matters

Better technology will improve Wi-Fi infrastructure products. The bulk of the historical NWBR research was on Wi-Fi networks using 802.11g for the 2.4 GHz access network infrastructure. Even in these networks, we found that the advanced MIMO techniques used in 802.11n clients dramatically improved performance. Low power 30 mW 2x2 802.11n MIMO clients equalled the performance of high powered 200 mW custom 802.11g clients.

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More recent Novarum research has extended this testing to recently available 802.11n outdoor access points. This data clearly shows that using an 802.11n infrastructure substantially improves performance, capacity, and coverage - even to legacy 802.11g clients. However, the combination of 802.11n infrastructure with 802.11n clients is even more dramatic. The improved coverage of 802.11n does NOT however, replace node density. In combination with high access node density - 802.11n offers the promise of truly useable and high performance wireless networking with robust coverage.

Our field measurements of coverage and performance for deployed public safety networks using 4.9 GHz revealed similar benefits of 802.11n. 4.9 GHz networks deployed using derivative 802.11a technology often have substantial challenges in coverage and performance due to the strong multipath at 5 GHz in urban environments. Novarum measured deep (30 dB) nulls within 30 meters of each other in these networks which were deployed without diversity antennas on base stations and mobile units. Antenna diversity on the 4.9 GHz client would help and 802.11n will be even better. Public safety networks using derivative 802.11n technology for 4.9 GHz access should be materially more resistant to multipath - indeed might use the abundant multipath to improve performance leveraging 802.11n MIMO technology. We look forward to validating this in the field as newer public safety networks based on 802.11n technology are deployed.

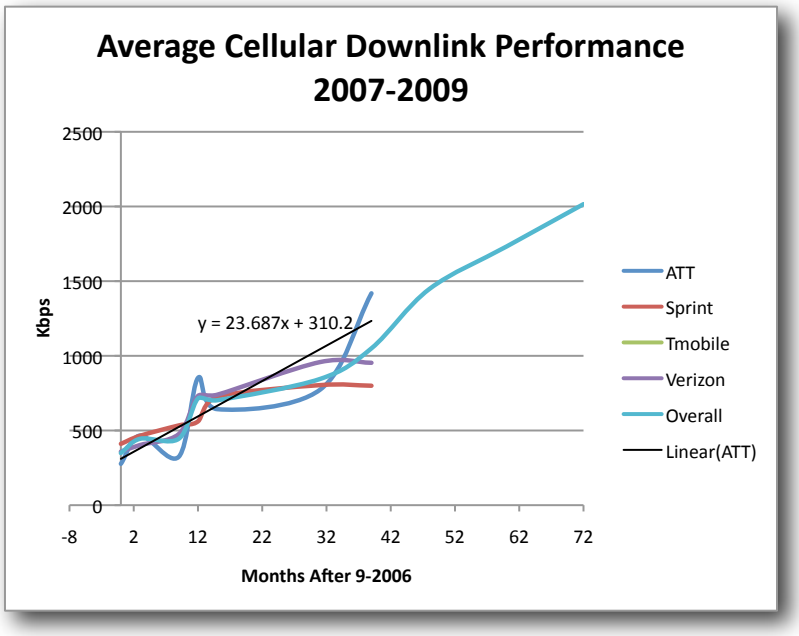
With the industry moving to 802.11n as the standard in new laptops and soon to be available in smartphones, all new Wi-Fi networks should be at least 2x2 MIMO 802.11n for both the access and backhaul tiers. In combination with high density infrastructure deployment, such an architecture will yield high outdoor coverage, reasonable first wall indoor coverage for 802.11n laptop clients and improved service for legacy 802.11g clients.

802.11n technology is moving into high volume production, and is available in a wide array of Wi-Fi infrastructure products. New 802.11n outdoor products from a number of vendors now cost less than 802.11g outdoor infrastructure products from legacy vendors, and that is changing the economics of dense deployments.

What 3G and 4G Cellular Networks Are Delivering

Contemporary 3G and soon to come 4G cellular networks set the performance expectation for wireless data networks. New city wide Wi-Fi networks should at the very least meet the performance of cellular data systems.

Novarum's research, now in partnership with PC World, has been the only independent study of the measured cellular network performance in recent years. We can see that the cellular performance has increased roughly linearly over the last three years reflecting the transition from 2G to 3G data networks.



In December 2009, the standard for cellular data networks is about 1.5 Mbps download speeds - ATT is there today in much of their network, Sprint and Verizon will jump that later in 2010 as they begin lighting up their 4G networks. In three years time, the standard of

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network performance will exceed 3 Mbps - if just the existing trend continues.

New large scale Wi-Fi networks should deliver performance that users expect - and should be designed to provide at least 3 Mbps performance - preferably more.

Guidelines for Wi-Fi Success

- Deliver a useful service with more than 90% coverage for 802.11n laptops at a performance that exceeds cellular in 2012.
- Deploy access network densely - more than 50 access nodes per square mile for 2.4 GHz. Novarum recommends 60 nodes per square mile based on our measurements of over 175 networks.
- Deploy 802.11n for infrastructure - both 2.4 GHz access nodes and 5 GHz backhaul. The use of 2x2 MIMO (or better) dramatically improves the low level rate of packet errors and materially increases network performance, capacity, useful coverage and customer satisfaction.
- Different clients will have different coverage and different performance. Base the network design and expectations on the typical clients to be used in the next five years - which will be dominated by 802.11n MIMO clients.
- Large outdoor Wi-Fi networks are constrained by the Wi-Fi client capabilities. Client uplink performance is the limiting factor for these networks and there is no magic infrastructure product that can overcome this.
- Deploy 802.11n for clients if at all possible. Avoid 802.11b - these ancient clients will degrade the entire network and every other users' experience.
- Expect very good networks to deliver outdoor 802.11n coverage between 90 and 95% and not on the basis of base station RF signal levels.
- Expect very good (and affordable) 802.11n Wi-Fi networks to deliver outdoor coverage between 50-75% for smartphones.
- Expect legacy 802.11g networks to deliver largely unacceptable service of 80% for laptops and below 50% for smartphones.

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