White Paper

XIRRUS®

802.11n:
Lessons Learned from the First 1,000 Installations

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Introduction

Since early 2008, Xirrus has deployed over 1,000 802.11n Wi-Fi networks for universities, K-12 school districts, enterprises, hospitals, conventions centers and other customers. During the design and implementation of these networks, Xirrus has gained a wealth of experience and knowledge in 802.11n technology and what it takes to successfully install and operate high performance, resilient 802.11n networks.

This White Paper outlines key lessons Xirrus has learned from our 802.11n deployment experience. Every network is different, but as our experience has shown, following several key guidelines will help optimize new 802.11n networks to achieve maximum performance and robustness towards the ultimate goal of using wireless to replace wired networks.

Network Design

Proper planning is crucial prior to deploying 802.11n networks. Appropriate planning is a good idea with any 802.11 network, but it is especially important with new 802.11n networks because:

1. 802.11n will be used more often as the primary network connection compared with 802.11abg
2. 802.11n has more flexibility and configuration options than legacy Wi-Fi, so network designs must take into account end-user needs in order to optimize performance and robustness.

There are five key parameters to look at for a proper 802.11n network design, as reviewed in the sections below.

Site Survey

Executing an active site survey prior to deploying Wi-Fi equipment (whether a Xirrus Array or other AP) is important because it lets the network administrator know exactly where equipment needs to be placed prior to deploying. With an active site survey, real equipment is taken on site and used to determine the best placement prior to pulling cables and drilling walls for the actual installation. Rather than doing an active site survey some Wi-Fi vendors and network designers merely guess at the location of APs by looking at floor plans and assuming that the RF propagation of all buildings is the same. Active site surveys are always important with Wi-Fi, but they are especially important with 802.11n networks for the following reasons.

MIMO

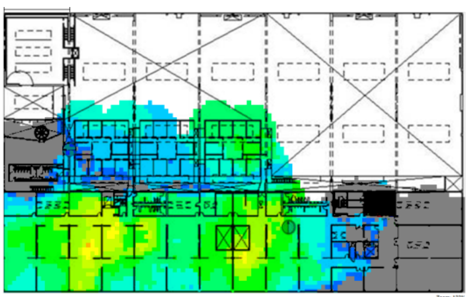
To improve throughput, 802.11n networks use Multiple Input Multiple Output (MIMO). MIMO increases overall throughput by using multiple antennas and signals to send the traffic. With MIMO, rather than having a single high-powered stream carrying the data traffic, there are two or three lower powered streams carrying the data traffic. In general, MIMO increases network and station performance, however because of MIMO 802.11n penetration, characteristics are more dependent on the environment; MIMO can be affected by wall and other objects differently than standard transmission techniques. Before deploying an 802.11n network, it is imperative to see how 802.11n radios will behave in the current environment and not assume that the RF propagation will be the same as existing 802.11abg networks.

Lesson Learned: Because of MIMO, 802.11n RF propagation can be significantly different than with traditional 802.11abg networks. An active site survey should always be done to test the RF characteristics of the environment prior to deployment.

Dual-band Coverage

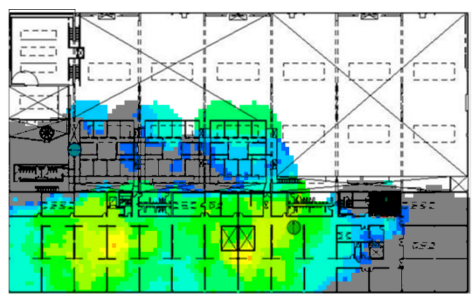
A discussed in the *RF Design* section later in this White Paper, operating 802.11n in the 5GHz band is a key requirement to fully realizing the benefits of 802.11n. When doing a site survey, it is imperative that readings be taken for both 2.4GHz and 5GHz. In most environments, 2.4GHz will propagate further than 5GHz. If 5GHz is to be used in 802.11n networks (as is highly recommended), the survey should take readings in both bands and both should be seen from all areas to be covered.

The diagrams below show the results of a standard survey for 802.11n. As can be seen, the coverage characteristics of 2.4GHz and 5GHz are different, with 2.4GHz providing coverage where 5GHz does not. Adjusting equipment location or adding additional equipment may be necessary to provide full 5GHz band coverage, and hence realize the benefits of 802.11n's high performance.



2.4GHz Coverage

VS.



5GHz Coverage

Lesson Learned: When doing site surveys, look at both 5GHz and 2.4GHz bands. 802.11n can operate in both bands and to fully realize its benefits, both bands should be supported throughout the entire network.

Multiple Radios

Another consideration when doing a site survey is ensuring that multiple radios are available at a sufficient RSSI level (Xirrus recommends -72dBm or greater for most applications) from every area to be covered by the Wi-Fi network. For a resilient, dynamic connection there should be multiple radios from which a station can choose in case one of the radios is heavily utilized or if one of the radios goes down. The following table shows the signal readings from a sight survey of an actual Xirrus customer survey. As one can see, multiple 2GHz and 5GHz channels can be seen with strong signal coverage (-72dBm or higher).

Channel/AP Name	Signal	Noise	S/N	PHY Data Rate Predictive Down	Interf.
Channel 6	-75	-95	20	0.0	0
Xirrus:06:D4:F1	-75	-95	20	0.0	0
Channel 157	-53	-85	32	0.0	0
Xirrus:06:CC:81	-53	-85	32	0.0	0
Channel 149	-52	-88	36	0.0	0
Xirrus:06:CC:E1	-52	-88	36	0.0	0
Channel 11	-70	-94	24	0.0	0
Xirrus:06:D4:D1	-70	-94	24	0.0	0
Channel 44	-55	-88	33	0.0	0
Xirrus:06:CC:C1	-55	-88	33	0.0	0
Channel 36	-49	-89	40	0.0	0
Xirrus:06:CC:A1	-49	-89	40	0.0	0
Channel 1	-72	-92	20	0.0	0
Xirrus:06:D4:91	-72	-92	20	0.0	0

Sample Signal Strength

In a properly designed network, readings like this should be seen anywhere in the designed area of coverage.

ⓘ ***Lesson Learned: Survey for at least two radios at all locations. Be sure at least one 2.4GHz and one 5GHz radio are visible from anywhere, and preferably two 5GHz radios.***

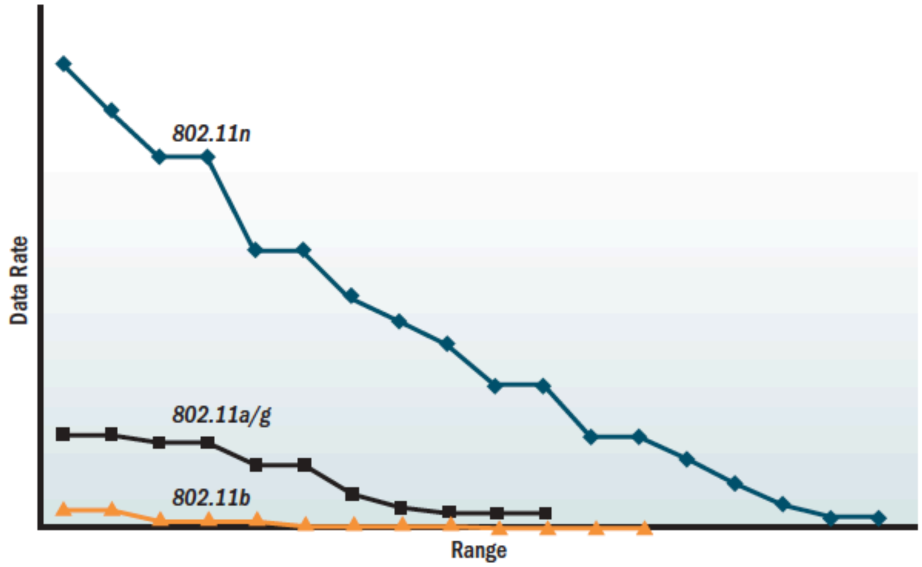
Device Placement

Setting the appropriate cell size is important when planning a wireless network. The natural inclination is to set the cell size as large as possible because this seems to be the best way to maximize equipment utilization. However, larger cell sizes may not always be the best way to achieve maximum performance. If a single radio is used to cover too large of an area, the overall performance will drop. This occurs because too many users are forced to use a single radio. Performance will also degrade because the stations at the edge of the cell will have slower connection speeds. In general, one or two slow stations will adversely affect the overall throughput of the network. If the goal is to do wire-switch replacement, which is often the case with 802.11n Wi-Fi, care should be given to set the cell size for optimum performance.

ⓘ ***Lesson Learned: Use multi-radio Arrays/APs so that large numbers of users do not have to share a single radio. Set the cell size so that a minimal number of users are at the fringe of the cell.***

ⓘ ***Lesson Learned: Do not create large cell size for an 802.11n design if you want to achieve the full performance 11n has to offer.***

There are many articles that review the range of 802.11n APs compared with legacy APs. When using 802.11n APs and 802.11n stations, the range should be greater than when using 802.11abg APs and 802.11n stations.



802.11 Relative Rate and Range Comparison

Because of the increased range of 802.11n many network administrators assume they can use fewer APs than with 802.11abg APs. However for a large majority of networks, there will still be a large number 802.11abg stations in the environment (very few networks will be 100% 802.11n). Because of the existing 11abg stations, the new 802.11 APs will need to be placed in positions that will give adequate coverage for 802.11n and 802.11abg stations. If the existing 802.11abg network was providing adequate coverage, it is reasonable to assume that the new 802.11n APs can be placed in the same locations and all stations types should be covered. This assumption should of course be validated with an active site survey prior to deployment.

ⓘ ***Lesson Learned: Don't assume a lower network device count when designing 802.11n networks. Design for high performance and plan support for legacy stations.***

Security

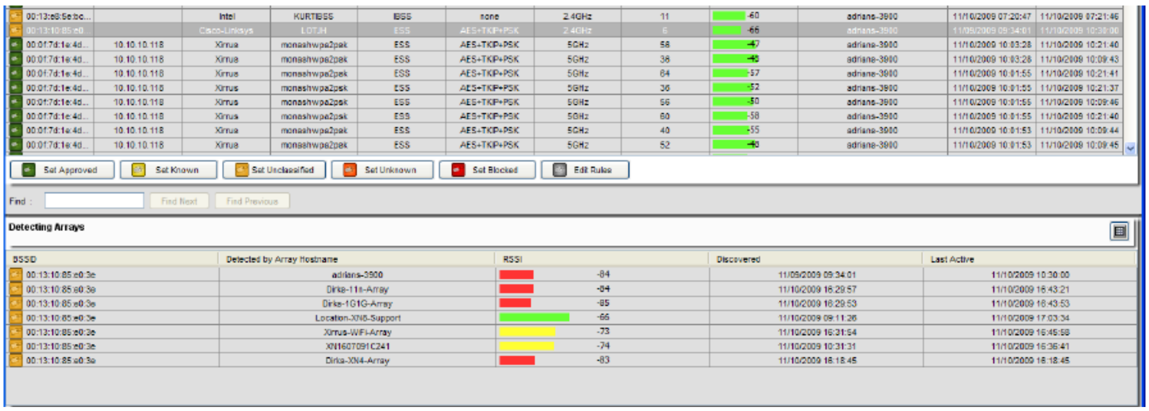
A key concern with any wireless network is security. With 802.11n, the recommended security configuration is to use 802.1x for authentication and AES for encryption. This setup will provide the highest performing, most secure network possible. When using 802.11n, the other authentication options are none, WEP, and TKIP. Using no encryption is not a realistic option for today's networks. WEP and TKIP provide some security, but are not nearly as robust as AES. Besides inferior security, WEP and TKIP have inferior performance. When using WEP and TKIP, the data rate is limited to 54Mbps per the 802.11n standards. When using inferior security algorithms, 802.11n restricts the stations from using 802.11n specific high throughput rates so the increased speed of 802.11n cannot be realized.

ⓘ ***Lesson Learned: Use WPA2/AES encryption for 802.11n deployments; anything else is a compromise on security and performance.***

While AES creates a more secure network, it does create an increase in required encryption power on the core network (i.e. controllers). As AES is deployed, care should be given to make sure that the controllers have enough encryption power to process all of the data. Since 802.11n supports approximately six times the data throughput of 802.11ag, there will be a need to encrypt around six times as much traffic. Many back-end controllers cannot handle this increase in encryption. In fact, some vendors state an 80% drop in throughput capability when using encryption.

ⓘ ***Lesson Learned: Check the encryption performance of your wireless controllers and/or APs; many cannot handle the load and will become oversubscribed.***

Best practices indicate that a wireless network should have a 24/7 dedicated network threat sensor. If the network is migrated to 802.11n, the monitoring tool needs to be migrated as well.



802.11n Rogue AP Monitoring

ⓘ ***Lesson Learned: Legacy 802.11abg monitoring tools may not catch all of the threats for an 802.11n network. If the network is being migrated to 802.11n, the monitoring tools needs to be migrated as well.***

Wired Switch Network

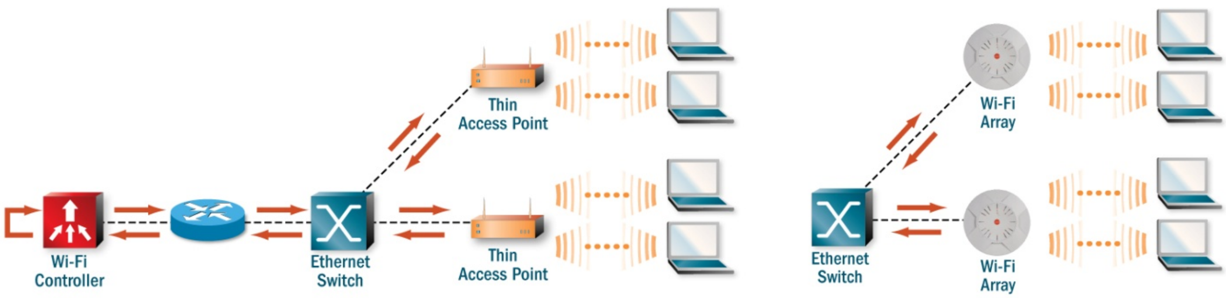
In many networks, legacy APs and Arrays are plugged into 10/100 Ethernet ports. When using 802.11abg devices this makes sense, however with the increase in throughput expected with 802.11n this creates an inefficient network design. With 802.11ag, each radio can achieve only about 27Mbs of actual throughput for a combined throughput of 54Mbs coming from a two-radio AP. With the move to 802.11n and multi-radio access points, 100Mbps switch ports are no longer a viable option. Two-radio 802.11n APs can put up to 250Mbps of data traffic onto the wire, easily oversubscribing a 10/100 Ethernet uplink. As more network administrators move to 4- and 8-radio Arrays, the traffic back to the switch port goes up even more. Gigabit Ethernet switch ports are required to support the data traffic coming from 11n APs and Arrays.

ⓘ ***Lesson Learned: 802.11n Arrays/AP must be plugged into Gigabit Ethernet switch ports to take full advantage of the throughput improvement of 802.11n.***

In addition to increased traffic on edge switches, core switches will see a large spike in traffic as well. Two issues cause the increase:

1. The increased traffic throughput of 802.11n over 802.11abg stations
2. The uptick of users using Wi-Fi as their primary network once the transition has been made to 802.11n.

The increase on core traffic can be especially severe when using controller-based wireless networks. With a controller, all of the wireless traffic must go from the APs to the controller for processing and then back to the APs (an effect know as tromboning). To minimize the impact on the core, as much traffic as possible should be processed at the edge.



Wi-Fi Architecture Comparison

ⓘ ***Lesson Learned: Minimize traffic load from 802.11n networks on the core by processing as much traffic as possible at the edge.***

ⓘ ***Lesson Learned: Be sure the core is capable of seeing an increase in data traffic from an 802.11n network.***

Power

Most wireless networking devices are powered through their Ethernet cables using some type of power over Ethernet (PoE). With 802.11abg, most of the access points were powered through standards based 802.3af PoE (15.4W). However 802.11n equipment typically requires too much power to be powered with just 15.4W so most 802.11n equipment requires special power injectors that can provide more power. Some vendors have a low power mode that allows their devices to be run with standard 802.3af PoE ports; however in this mode many of the features of 802.11n must be turned off and/or performance reduced. If an 802.11n network is going to be deployed, the benefits of 802.11n should be fully available. In general, it is better to go ahead and plan for full power and all of the functionality by using higher-powered injectors. This will allow for immediate improvements with the new 802.11n network and allows the network to handle any new features that are introduced in the future.

ⓘ ***Lesson Learned: Plan to use power injectors that take full advantage of 802.11n performance and functionality as well as being prepared for future 802.11n technology advances.***

RF Design

One of the key drivers for moving to 802.11n is the increase in network performance. An 802.11n network will always perform higher than an 802.11abg network, however there are a few design decisions that can be made to increase the performance even more.

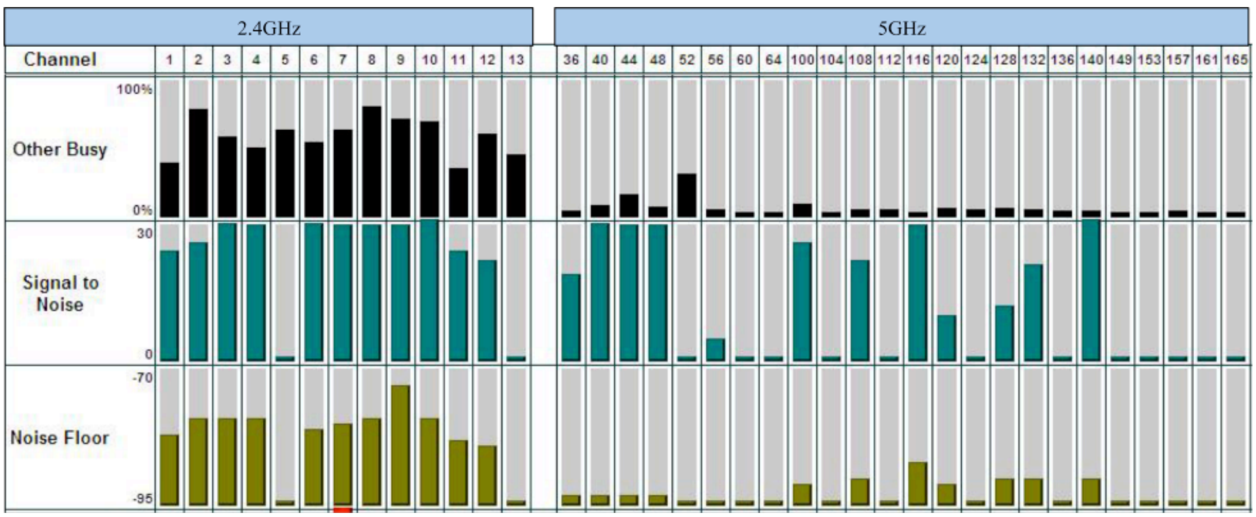
5GHz vs. 2.4GHz

802.11n is the first Wi-Fi standard that can operate in both the 2.4GHz and the 5GHz bands. 5GHz has many advantages over 2.4GHz and every possible effort should be made to move the network to primarily 5GHz. Most enterprise class laptops can support 5GHz today so making

5GHz the primary networking type should not be a problem. The key will be setting up the network equipment to properly support the traffic. There are a large number of handheld devices (e.g. Blackberry and iPhones) that are primarily 2.4GHz so while moving to 5GHz makes a lot of sense, leaving some 2.4GHz in place is prudent to support the proliferation of handheld Wi-Fi devices.

Several of the key advantages 5GHz has over 2.4GHz are listed below:

1. **Less Congestion**
   A lot of non-Wi-Fi devices today operate in the 2.4GHz range such as microwaves, Bluetooth, and cordless telephones. If other devices are operating in the 2.4GHz frequency, there is less useable bandwidth for Wi-Fi devices. When other non-802.11 devices operate in the same frequency spectrum there will be frame loss and retransmissions for any Wi-Fi device operating in this frequency. The diagram below shows typical interference for 2.4GHz and 5GHz.

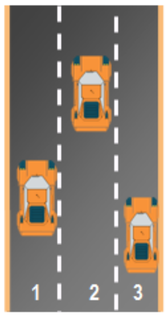


Spectrum Analysis of 2.4GHz and 5GHz

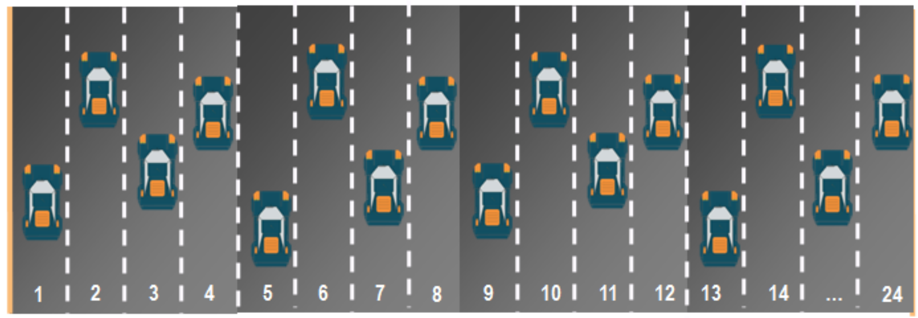
   The 5GHz range contains the least amount of noise. With less interference, any device operating in 5GHz will have a much cleaner signal and a more enjoyable user experience than one operating in the congested 2.4GHz range.

2. **More Available Channels**
   In the 2.4GHz frequency, there are three non-overlapping channels: channel 1 (2.418GHz), channel 6 (2.426GHz), and channel 11 (2.4319GHz). Technically there are 11 channels, but the other channels cannot be used without interfering with each other, so there are actually only three channels that can be used simultaneously. Each channel has a fixed amount of bandwidth, so by limiting the network to three channels the overall network bandwidth is essentially limited.

   In the 5GHz band, there are 24 non-overlapping channels. By moving to 5GHz you have 8x the bandwidth of a 2.4GHz bandwidth.

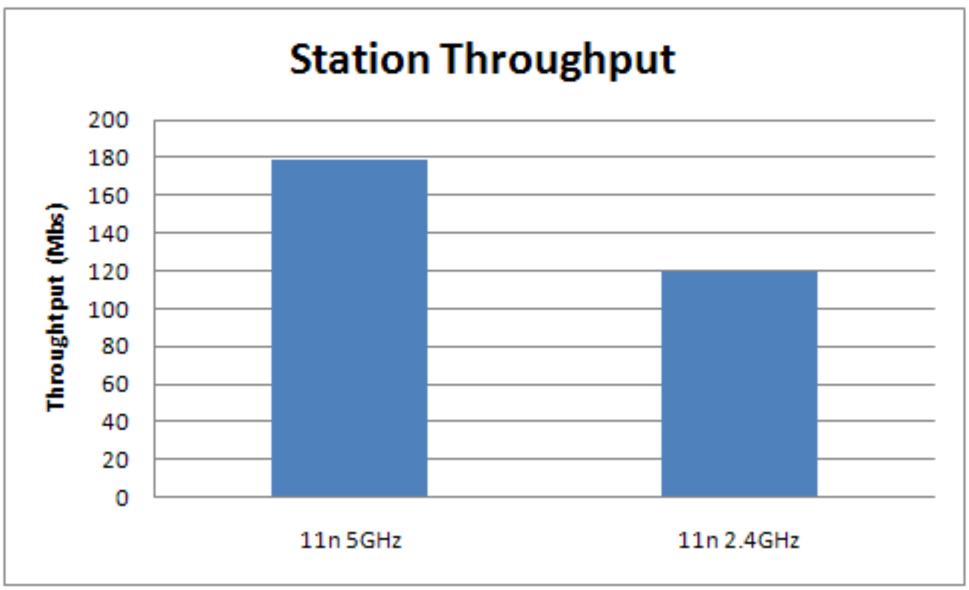


2.4GHz – 3 Lanes



5GHz – 24 Lanes

3. **Higher Throughput**
   5GHz stations typically perform better than 2.4GHz stations. Theoretically 802.11g stations and 802.11a stations should have the same throughput, however 802.11a stations almost always show higher performance based on the typical level of interference and noise in the 2.4GHz spectrum from other non-Wi-Fi devices. Based on Xirrus' experience, 5GHz stations will typically have a 3:2 performance advantage over 2.4GHz stations in both legacy Wi-Fi (802.11a vs. 802.11g) and in 802.11n.



802.11n Station Throughput

ⓘ ***Lesson Learned: A 5GHz Wi-Fi network will be more resilient and higher performing than a 2.4GHz Wi-Fi network will be. Every effort should be made to transition to 5GHz when deploying 802.11n***.

Most enterprise-class equipment can support both 5GHz and 2.4GHz so rolling out a dual frequency network with any equipment type should not be a problem. However, some APs are fixed with one radio operating at 5GHz and one radio at 2.4GHz. With this type of equipment as the wireless network transitions to predominately 5GHz, the 2.4GHz radios will go largely unused or underutilized. Better alternatives are Access Points and Arrays that have software selectable frequencies. With these types of device the equipment can be deployed with 5GHz and 2.4GHz, but then the 2.4GHz radios can be converted to 5GHz as a majority of the stations become 5GHz capable.

ⓘ ***Lesson Learned: Buy networking equipment that allows the radios frequency to be selected in software rather than fixed at a certain frequency.***

There are also choices when selecting Wi-Fi stations. Most enterprise-class laptops will support both 2.4GHz and 5GHz 802.11n, however, many netbooks will only support 2.4GHz. When buying netbooks, care should be given to select devices that support both 2.4GHz and 5GHz. Just because a devices says it is 802.11n capable, that does not mean that it supports 5GHz. With 802.11n there are two classifications:

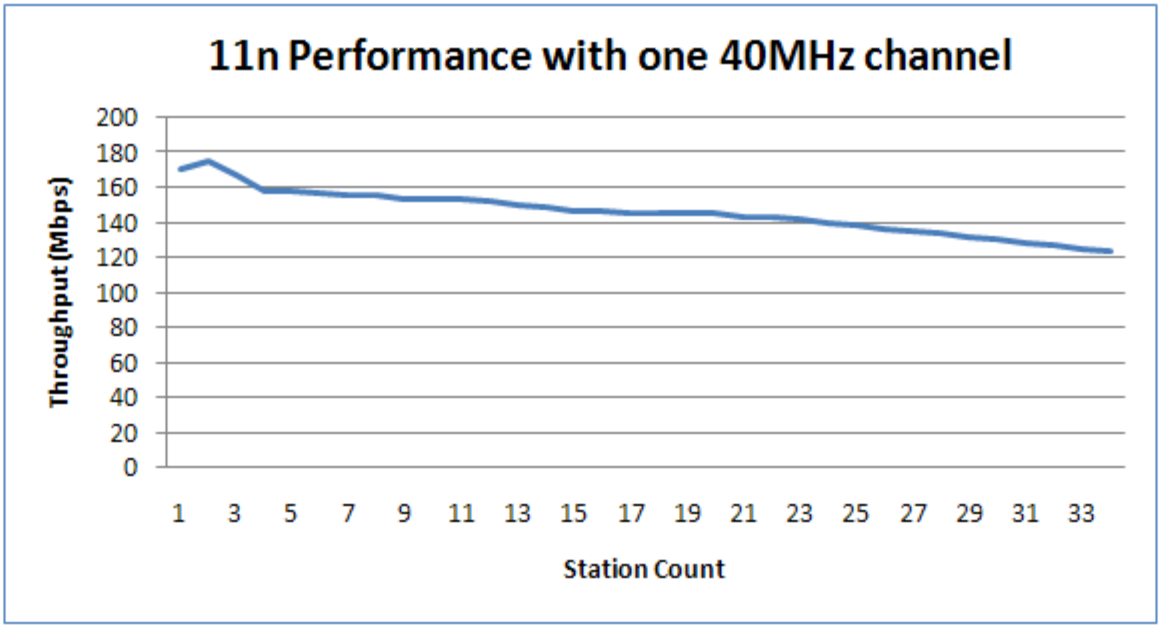
1. 802.11bgn, which appears on the product box
2. 802.11abgn, which appears on the devices (has an "a" in front)

Devices in the latter category that support both frequencies should be purchased. This will allow the devices to be higher performing and be used for several years.

ⓘ ***Lesson Learned: Only buy 5GHz capable stations. There is no point in moving to 802.11n if the equipment is going to be restricted to 2.4GHz***.

Users Per Radio

When network administrators see the higher throughput of 802.11n, they often assume they can put more users per 802.11n radio than they could with 802.11abg. While there is more bandwidth available with 802.11n, one of the key concerns with Wi-Fi network design is how much of the bandwidth is taken up with network overhead and congestion. There is a fixed amount of bandwidth that must be shared, but there is more to available bandwidth when deciding the number of users per radio. There is also a certain amount of overhead per user that must be taken into account. As more users are added to the network more of the bandwidth is taken up by network overhead and less by actual user data traffic. In general, there is a negative correlation between the number of users and the overall throughput per radio. The following charts show the total throughput for a single radio as more users are added. As the number of users per radio increases, the total throughput starts to decrease.



Single Radio Performance With Different Station Counts

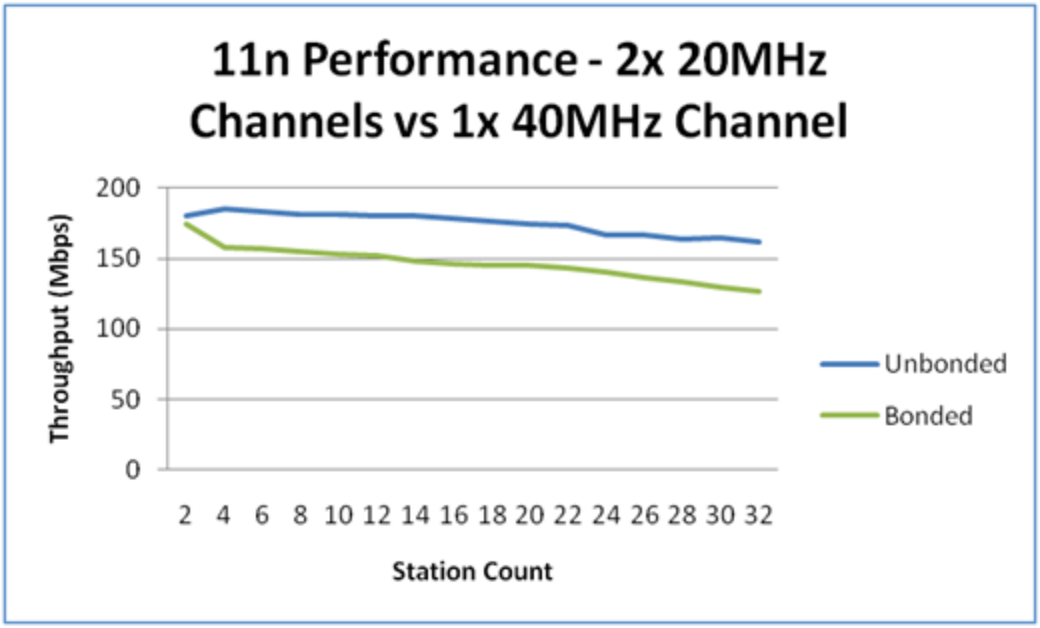
Lesson Learned: When moving to 802.11n, don't expect to support more users per radio. The goal of deploying 11n should be to get more bandwidth per user. Because wireless is a shared medium, total performance of a radio will drop as more users are added.

Channel Bonding

One of the most significant new features of 802.11n is channel bonding. Channel bonding takes two 20MHz channels and combines them together to form a single 40Mhz channel, effectively doubling the bandwidth of the channel. Use of bonding effectively cuts the number of available channels to use in half and so is most practically implemented in the 5GHz band where many more channels are available. In the 2.4GHz band, with only three non-overlapping channels available, bonding is only possible on one pair of channels. Due to this channel limitation and the interaction with legacy Wi-Fi clients, bonding is not recommended in the 2.4GHz band.

The doubling of capacity on a given radio with bonding is readily evident with low numbers of stations. However as the number of stations operating in the overall network increases, the benefit of a bonding is affected. If bonding is used and two 20MHz channels are allocated for every radio, there are fewer channels available overall for the design of the wireless network. Depending on the physical environment and other factors, this can impact the overall bandwidth available in the network. With channel bonding turned off, the bandwidth can be more easily distributed. In the design of an 802.11n network, there are situations where it will be more efficient to run without bonding enabled.

The following chart compares the performance between one radio with bonding enabled vs. two radios without bonding. As can be seen, the aggregate throughput is higher with the two non-bonded radios, even with a small number of stations on the radio. If the user density is high on the network and/or 5GHz channel availability is an issue (due to radar detection issues or country-specific limitations), using non-bonded channels should be considered.



Single Bonded Radio vs. Two Non-bonded Radios

ⓘ ***Lesson Learned: In high density, high performance environments, using non-bonded 20MHz channels may improve overall performance.***

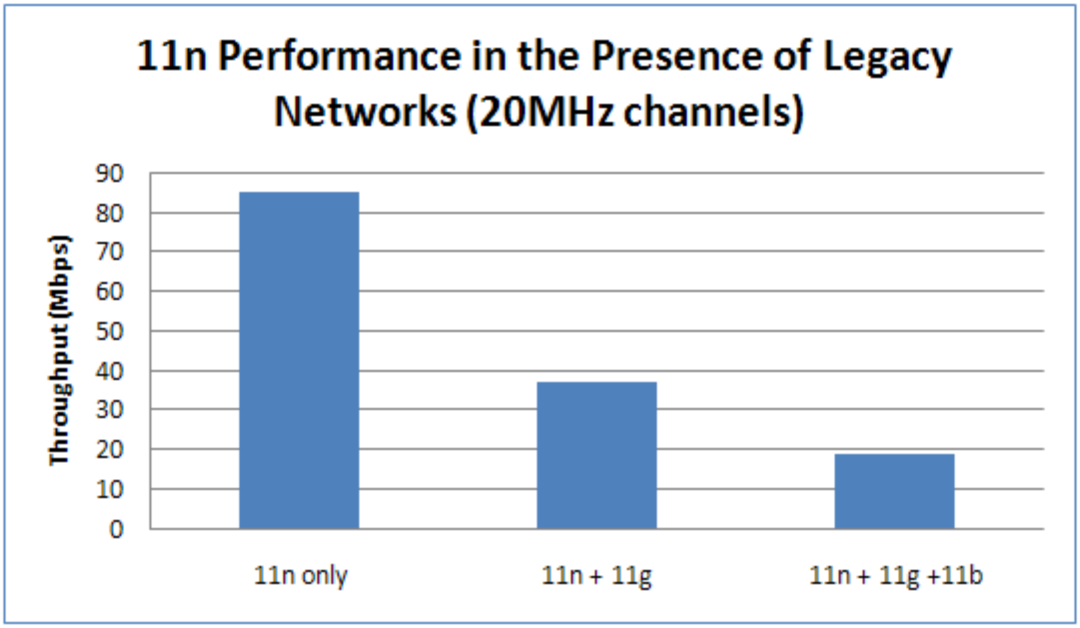
Another consideration when deciding if channel bonding should be used is how well the stations support bonding. Some stations do not handle channel bonding very well and will either not connect or will revert to 2.4GHz. If the stations used in the network cannot properly support bonding, it should be kept off.

ⓘ ***Lesson Learned: Some clients may not operate properly with bonded channels. The network should be designed to handle these clients by turning bonding off on certain radios or entirely.***

Coexistence with Legacy 802.11abg Networks

The main reason most network administrators are moving to 802.11n is to increase the overall performance of their networks. However, the slowest connected station will always limit a wireless network. Even an 802.11n network may operate more slowly than expected if slower, legacy stations are still in use on the network. Legacy stations slow down network performance because management traffic must be sent at slower rates so that the slower stations can process the management frames. Slow stations also reduce overall network performance because while such a station is transmitting, no other stations can transmit. The slower the connection rate, the slower the station can send its traffic and the longer it takes for the wireless network to become available for any other stations to send traffic. The most problematic station type to the performance of an 802.11n network is 802.11b. Both 802.11g and 802.11n networks are compatible with 802.11b stations. Supporting 802.11b stations on an 802.11n network can greatly slow it down.

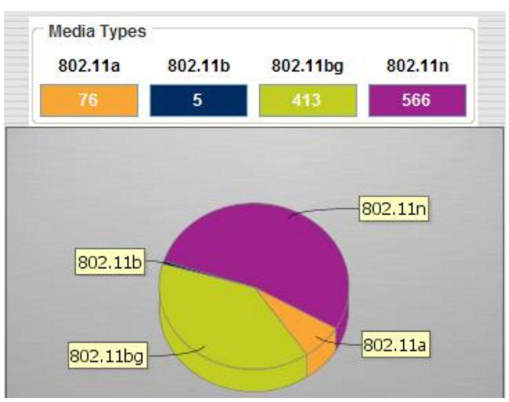
The diagram below shows the performance of an 802.11n station in a pure 802.11n network, compared to a network with an 802.11g station associated, and to one with an 802.11g and an 802.11b station associated. As can be seen, the performance drops by almost 50% if an 802.11g station is causing congestion in the network. The performance is cut by almost 75% if there is an 802.11b station causing congestion.



Effects of Legacy Stations on 802.11n Performance

ⓘ ***Lesson Learned: 802.11b stations will greatly reduce the overall throughput of 802.11n networks.***

Rather than taking a significant performance hit by supporting 802.11b, 802.11n networks may be designed to disallow 802.11b stations from connecting. In most Wi-Fi networks today, there are very few 802.11b stations. The diagram below shows the station type distribution from one of Xirrus' customers, which is representative of a common network.



Station Type Distribution

As can be seen, out of only five out of 1060 stations are 802.11b-only, or in other words less than 0.5%. The network performance would be greatly enhanced by buying relatively inexpensive 802.11n (or at least 802.11a or 802.11g) NIC cards and upgrading these users. With all of the users upgraded, 802.11b support could be turned off.

ⓘ ***Lesson Learned: 802.11b support should be turned off to improve 802.11n network performance if at all possible. Small numbers of 802.11b-only stations can be inexpensively upgraded to 802.11agn.***

Stations Considerations

In order to support 802.11n, 802.11n capable NICs will be needed on any station hoping to leverage its performance advantages. Fortunately many laptops today already ship with 802.11n NICs, and for upgrading older laptops there are a large number of 802.11n adapters available. Before buying new 802.11n capable equipment, it is worthwhile testing to see which stations or network adapters give the best performance. If 802.11n stations already exist, taking the time to qualify their behavior will help optimize station and network settings for the best 802.11n network possible.

Performance

Performance can vary greatly between network adapters. The chart below shows the test results for throughput of three different laptop configurations performed in Xirrus labs. As can be seen, the total throughput can vary greatly between devices.

Laptop 802.11n Throughput

Manufacturer	Auth/Encrypt	Down Stream	Up Stream	Total
Laptop 1	OPEN	124.87	133.25	258.12
Laptop 1	WPA2-PSK/AES	125.9	127.14	253.04
Laptop 2	OPEN	74	85.5	159.5
Laptop 2	WPA2-PSK/AES	74	85.5	159.5
Laptop 3	OPEN	36.28	30.28	66.56
Laptop 3	WPA2-PSK/AES	22.7	20.5	43.2

Comparison of Laptop Performance

In general, integrated adapters typically perform better than external adapters but it is always best to confirm what works best for a specific network. Encryption can also affect performance. Most network adapters do encryption at the chip level so performance is not affected, but with some adapters the encryption is done in software and can be much slower than when using open networks.

ⓘ ***Lesson Learned: Test network adapters before making a purchasing decision. Throughput can vary greatly depending on the adapter and laptop configuration.***

Channel Preference

Xirrus has observed that some stations will not associate to particular channels in the 5GHz band. If a Wi-Fi network is using these particular channels, the station may not associate at all or will associate to another Array using different channels, even if that Array is further away. Support for the mid-band channels in 5GHz (channels 100-140) is inconsistent between different NIC brands, but some more commonly used channels can cause issues as well with certain NICs.

ⓘ ***Lesson Learned: Check that wireless stations can connect to the specific channels being designed for use in the 802.11n network.***

Frequency Preference

Many network adapters have a tendency to favor the 2.4GHz band over 5GHz. These stations will associate to 2.4GHz radios even if 5GHz radios are available with the same or stronger signal strength. This was especially an issue with early network adapters developed before 5GHz was widely deployed. With many adapters, upgrading to the latest drivers will change this preference.

ⓘ ***Lesson Learned: Be sure all network adapters are running the latest drivers for optimal frequency and radio selection.***

If the latest drivers do not fix this tendency, it may be possible to set stations to only use 5GHz. By setting the stations to 5GHz-only, those stations should associate to the 5GHz radios and have better performance. Also, by moving some stations to 5GHz-only, additional bandwidth can be freed for stations that are not capable of running at 5GHz.

Another option to maximize 5GHz utilization is to turn down the power on some 2.4GHz radios. Assuming sufficient 5GHz coverage (which a well-planned 11n network will have), it may be possible to turn off (or turn down) some 2.4GHz radios. By lowering the power of the 2.4GHz radios, the stations will be more likely to associate to the higher-powered 5GHz radios.

ⓘ ***Lesson Learned: If stations prefer 2.4GHz, it may be possible to coax them to 5GHz by doing some RF planning.***

Roaming Aggressiveness

Many stations have a tendency to stick to a particular Array even if there is an Array nearby with a stronger signal. The tendency to stick to a particular Array can lower station performance as they get father away from the Array. To encourage a station to roam more readily, the Roaming Aggressiveness setting in the station's driver can often be changed. By setting stations to have a higher tendency to roam, the stations will more readily change to an Array with a stronger signal. Care should be given to not make the station too aggressive or else the station will spend too much time associating and re-associating to new Arrays and not enough time sending traffic.

ⓘ ***Lesson Learned: If stations stick to an Array/AP for too long, performance may drop. Tweak the Roaming Aggressiveness to optimize roaming behavior***.

Homogeneous Networks

In general, the more similar the wireless NIC cards being deployed, the better network performance will be. If all stations support 802.11n, performance will be significantly improved. By the same token, if all the adapters support AES encryption so that high throughput rates can be achieved, network performance will be much better. As discussed in previous sections, a single slow station can lower the performance for all stations. Increasing the performance of as many stations as possible will have a tremendous affect on network performance.

ⓘ ***Lesson Learned: If possible, use the same NIC cards on all stations. At a minimum, use NICs with the same 802.11n feature set.***

Conclusion

To achieve a high performance network capable of replacing wired switches, a multi-radio, 5GHz 802.11n Wi-Fi network will provide the best results. The overall network must be appropriately designed, from the supporting wired network, to wireless device placement, to the RF design. Stations should be capable of operating at 5GHz to take full advantage of 802.11n functionality and achieve maximum performance.

With a properly designed 802.11n Wi-Fi network, IT managers now have the ability to deploy wireless networks that can replace their wired networks. Existing wired network budgets can be reallocated to wireless equipment that, with proper design, will deliver similar end-user experience but with all the flexibility and mobility benefits wireless brings.