Home and Small Office Wi-Fi® Wireless Network Whitepaper

A Simple Guide to Understanding 802.11 Wireless Networks,
How to Get the Best Performance from Your Network, and
How to Get the Best Bang for Your Buck when Upgrading

From

MTRLC LLC

Wi-Fi® Wireless Network Whitepaper

How can you get the maximum speed from your wireless network? What do you need to look out for to get the biggest bang for your buck when you upgrade or extend your wireless network? Read on!

This whitepaper discusses the wireless technology based on 802.11 standards, which is often referred to as Wi-Fi®. Client devices including laptops, tablets, game stations, smartphones, Internet-connected TVs, and media streaming devices typically connect to routers via some flavor of 802.11 wireless. The wireless features of these devices and routers come with a variety of technical descriptions and a variety of claims about speed and range. This paper attempts to sort out the descriptions and to help interpret the claims.

Overview

It may help to appreciate some of the challenges of wireless networks to consider the power levels involved. 802.11 wireless transmitters typically output power at about 100mW. This is equivalent to approximately half the output of a nightlight[1]. A nightlight provides about 1/10 the light of a standard flashlight.

Now imagine the glow of that nightlight distributed in all directions, through walls and floors, and you have some idea of the extraordinarily low levels of power that Wi-Fi® devices contend with. (Of course the radio waves used in Wi-Fi® devices can penetrate wood and sheetrock, whereas light cannot. But radio waves are attenuated by such barriers, and in any case they must reach the far corners of your home or workplace.)

Don’t you think it’s amazing that such a weak glow could carry for example multiple streams of high resolution video to devices in different corners of your home or workplace? At the same time, can you see how wireless performance can be so sensitive to small changes in your environment? Now let’s try to understand your network, and what you might want to consider to optimize wireless performance.

First, some broad principles:

- A wireless connection always involves two devices, typically a router and a client[2]. Performance is limited by the slower device in the connection. (See the Chart, Wi-Fi® Actual Maximum Speeds.)
- Speed drops dramatically with distance, and across barriers such as walls and floors.
- Wireless performance can degrade when large numbers of users and devices, or even a small number of heavy users, are active on a network.
- Wireless performance can often be improved:
    - By placing your router centrally, so that clients are as close as possible
    - By selecting less heavily utilized wireless channels
    - Where possible, by selecting a different radio band (e.g. 5 GHz instead of 2.4 GHz)
    - By reducing configured bandwidth
    - By placing wireless equipment to avoid interference with other devices that share the same bands, such as cordless phones, Bluetooth headphones, and the like.
    - By deploying equipment that supports one or more of the following features: multiple simultaneous streams, higher power, and radio transmissions that are focused on the device at the other end of the wireless connection.

(See the Wireless Selection Guide below for quick recommendations for your wireless network.)

Wi-Fi® Actual Speed Ranges for Router and Device Combinations

Devices	Routers: **AC3200 – 5300** Tri-band 2.4GHz + 2 x 5GHz	**AC1200 – 2600** Dual-band 2.4GHz + 5GHz	**N600 – 900** Dual-band 2.4GHz + 5GHz	**N150 – 300** Single-band 2.4GHz
AC1600 - 3200 High-spec Dual-band 2.4GHz + 5GHz	**Very High** *50 - 800 Mbps*			
AC1200 Premium Dual-band 2.4GHz + 5GHz		**High** 30 - 500 Mbps		
N600 / AC600 - 900 Dual-band 2.4GHz + 5GHz			**Mid** 30 - 300 Mbps	
N150 - 300 Single-band 2.4GHz				**Low** 20 - 175 Mbps

Note: Speed ranges as observed in a typical 3000 sq. ft. North American home. Speeds will be no faster than the slower of your device or router. Speeds may be further reduced by: distance; wall, floors and other structural elements; bandwidth settings; competition from devices on your network; interference from devices like Bluetooth headsets and cordless phones; and interference from neighboring networks.

Descriptions

We will help you to understand what these principles mean for you and your network. First we'll list Wireless technical descriptions that cover four main areas—version of standard, radio band, number of streams, and power.

I. Version of Standard:

The version of the 802.11 standard defines the modulation used, and capabilities such as multiple simultaneous streams. It may also define the band.

Current standards are	
802.11ac	Applies to 5GHz band and supports multiple streams
802.11n	Applies to both 2.4 & 5 GHz bands, and supports multiple streams

Normally devices described as 802.11ac are dual band devices that also support 802.11n in the 2.4GHz band.

Older standards are	
802.11a	Applies to 5GHz band and supports multiple streams, but at lower rates than 802.11ac
802.11g	Applies to 2.4GHz band at lower rates than 802.11n
802.11b	Applies to 2.4GHz band at lower rates than 802.11g

Variants of particular standards modify something called the symbol rate, which can result in greater throughput. For example, a feature under 802.11n called Turbo QAM offers 33% greater throughput.

II. Radio Band:

802.11 wireless devices operate in one or both of two bands:

2.4 GHz	Less bandwidth available, hence lower throughput. However, lower frequencies typically have longer range and better penetration of walls, so greater range for a given throughput.
5 GHz	More bandwidth available, hence higher throughput. However, higher frequencies typically have shorter range and worse penetration of walls, so shorter range for a given throughput.

Within each band, a frequency bandwidth of from 20 to 160 MHz can be allocated to a particular connection. The higher the allocation, the higher the potential throughput. However, the actual throughput is sometimes highest for 20 MHz, especially if there are many competing wireless networks in your area.

For the 2.4GHz band, either 20 or 40 MHz can be allocated, for nominally 65 or 130 Mbps per stream.
For the 5GHz band, 20, 40, 80 or in some cases 160MHz can be allocated, for nominally 108, 217, 433 or 867 Mbps per stream.
Most statements of nominal throughput assume 40MHz bandwidth for 2.4GHz and 80MHz for 5GHz connections.

III. Number of Streams:

Current 802.11 standards define options for multiple simultaneous data streams. The number of streams is designated by AxB MIMO (Multiple-Input/Multiple-Output), where A and B refer respectively to the number of transmit and receive streams. Typically these are identical, e.g. 2x2 or 3x3, and correspond to the number of internal or external antennas on a device.

1x1	One Transmit and one Receive stream
2x2	Two Transmit and two Receive streams
3x3	Three Transmit and three Receive streams
Etc.	

MIMO technology takes advantage of multipath reflections of signals to reconstitute a more robust image of the transmitted signal.
Each stream contributes the same potential throughput for a given bandwidth. For example, in 802.11n, each stream contributes 150Mbps nominal throughput. Thus, an 802.11n 2x2 MIMO device supports 300Mbps, and a 3x3 device 450Mbps. For 802.11ac, each stream contributes 433Mbps.

IV. Power:

Some devices offer greater power output than standard devices. Increased power will increase range for a given throughput, all other things being equal. In other words, if you were previously experiencing 30Mbps throughput up to 30 ft. from your router, after a power increase you might experience 30Mbps at up to 40 ft. And, by the same token, throughput at 30 ft. might increase to what you had previously experienced at between 20 and 25 ft.

Although increased power will generally increase range at a given throughput, it may not increase the range beyond which you experience no connection at all. In other words, if there is no throughput beyond a certain distance, increasing power may have no effect. This is because all packets in an 802.11 link must be acknowledged. This requires an adequate signal in both directions on the link.

So, if you increase the power of the transmitter in your router, it may blast a stronger signal to your smartphone at a location where you had difficulty connecting before. But unless the smartphone’s signal is strong enough to reach the router in the first place, you still may experience no connection.

Not to worry. Increasing the antenna gain and/or including more powerful Low Noise Amplifiers (LNAs) on the router may improve performance on both legs of the link, and thereby increase range.

To summarize, increasing power on one leg of a link will typically improve throughput over what was already there. When coupled with improved antennas and LNAs, increased power may also improve range.

Typically, where this increased power is offered, power is specified to be just below the legal maximum.

Most devices do not offer this feature because it adds significant manufacturing expense, and for battery powered devices because it represents a significant extra power drain.

Performance Claims

All manufacturers base their performance claims on the maximum theoretical throughput for their device. To achieve these claims, the device must be paired with another endpoint with matching or superior specifications, there must be no interference, and the connection must be over a very short range, possibly as short as a few feet. Needless to say, there must be no physical impediment such as a wall or a floor, or even a large piece of furniture between the two devices.

Because of the ideal testing conditions, the devices may be configured to use the maximum possible bandwidth. This also contributes to impressive throughput claims.

In addition, the claims count transmission overhead as part of the quoted throughput. This overhead is of course not available to the user.

For these reasons, when analyzing your own network, you should keep in mind that claimed data rates will serve at best as rough approximations to the highest conceivable rates you could experience in your environment.

What Does this Mean about Your Network?

The first consideration for your wireless network is whether it serves your needs. If web pages always load quickly, apps run smoothly, and streaming media including music and video run without buffering or stuttering for all users, then your network probably doesn't need improvement.

It may be tempting to run an Internet speed test, and conclude from the results that your wireless connection is sub-par. For example, you may have subscribed to Internet service at 100Mbps, but only see 30Mbps through one or another of your wireless connections.

This may be perfectly acceptable, if your device brings up web pages crisply, and you are able to do what you want on the Internet. This may include streaming videos. Streaming video, even high definition video, typically only requires 5Mbps.

But what if streaming video sessions stall and buffer continuously, or lose the connection completely, at least sometimes or from some parts of your home? Or what if for some other reason a connection is inadequate?

There are several approaches you can take. The first is to follow the suggestions above to optimize the network you have. These include, where possible, moving your router or access point to the most centrally located part of your home or office. Also, you can reconfigure bandwidth, and select different bands and/or channels. You can also move equipment away from potential sources of interference like Bluetooth headsets and cordless phones.

If these don't help, or don't help enough, you can consider upgrading equipment. Knowing what you know now about the constraints on wireless connections, especially that the lowest capability device determines the performance of that connection, you realize that the surest way to improve performance is to upgrade your lowest spec devices.

This is particularly true of devices that use older wireless technology. When these devices transmit or receive, the whole network has to slow down to accommodate them. And, because these devices operate at low rates, this means that they can take a long time to complete transactions.

This can effectively block access of faster devices, and bog down your network. If your network is sluggish, you can temporarily turn off any devices limited to 802.11b or 802.11g to see if this condition improves. If so, the offending devices should be considered obsolete and retired or updated to insure efficient use of your network.

Leaving aside obsolete equipment, many of us nowadays have devices from several different generations of wireless technology that we continue to use. It may be impractical to replace all of them at once. For that reason, it may make sense to consider updates to the core of your network.

Depending on characteristics of your environment, you may want to focus on different types of improvements. For example, if you are in an area like an apartment complex crowded with other wireless networks, you may want to concentrate on moving as much traffic as possible onto the relatively unpopulated 5GHz band. That may require updates to both your router and devices. If you have many users and devices, you may need to increase the capacity of your Internet connection as well as the speed and range of your wireless network to insure adequate performance for all users.

In many cases, it may make sense to start a network upgrade with your router. Even though an upgraded router can't improve the maximum throughput of your devices, a router with high power and beam-forming features can improve the range that you experience with those devices. And, a dual-band router gives you the option of migrating traffic onto the less congested 5GHz band. For these reasons, it may be worth considering an upgrade to your router. See the Wireless Router Selection Guide.

A benefit of taking this approach is that you may see dramatically improved performance with newer devices that are capable of taking advantage of the higher maximum speeds of the new router. Also, as you upgrade devices, you will already have a router to support their greater capabilities.

Finally, you might want to consider a wireless range extender. Alternatively, a pair of PowerLine devices with wireless capability can provide similar functionality. To go back to our original analogy, you could think of either of these as working like added nightlights that extend their glow into each dim hallway in your home.

A wireless range extender relays the signal from your router to remoter corners of your home or office. You may add one or more range extenders to your network, depending on your needs. Unlike a new router, a range extender will do nothing to improve the underlying limits of your network. However, it may do just fine in getting adequate signals to where you need them.

Appendix

Wireless Router Selection Guide

<table>
<tr><th>Select description that best fits your location†</th><th>Concurrent use of your wireless devices*</th><th>Your cable service speed (Mbps)</th><th>Strength of nearby wireless networks**</th><th>Minimum recommended router wireless capability</th></tr>
<tr><td rowspan="5">Less than 1500 sq. ft.</td><td rowspan="2">1 to 5 devices; light usage</td><td rowspan="2">Less than 50</td><td>Weak</td><td>Single-band wireless (“n”)</td></tr>
<tr><td>Moderate</td><td>Single-band wireless (“n”) with Power-Boost</td></tr>
<tr><td rowspan="3">More than 5 devices; and/or heavy usage</td><td>Less than 50</td><td rowspan="2">Weak</td><td>Dual-band wireless (“ac”)</td></tr>
<tr><td>50 or greater</td><td>Dual-band wireless (“ac”) with Power-Boost</td></tr>
<tr><td>Any speed</td><td>Moderate or Strong</td><td>Dual-band wireless (“ac”) with Power-Boost</td></tr>
<tr><td rowspan="2">Greater than 1500 sq. ft.</td><td rowspan="2">Any number of devices and usage type</td><td rowspan="2">Any speed</td><td rowspan="2">Any strength</td><td>Single-band wireless (“n”) with Power-Boost</td></tr>
<tr><td>Dual-band wireless (“ac”) with Power-Boost</td></tr>
</table>

†Regardless of size, if signals have to pass through more than two floors or walls, consider your location equivalent to greater than 1500 sq. ft.

*Computers, smartphones, tablets, game consoles, smart TVs, security cameras, streaming media devices and any other Wi-Fi connected devices.

**Weak: Fewer than three neighboring networks operating at
-70dBm or higher (where higher means a smaller negative number like -60 or -50 dBm)
Moderate: Three or more neighboring networks operating at -70dBm or higher
Strong: Eight or more neighboring networks operating at -70dBm or higher; any operating at
-60dBm or higher
To determine strength of nearby networks, note that some routers offer a utility to scan neighboring wireless devices. Or, you can use a smartphone app such as Wifi Analyzer to do the same thing.
Also note that your results for the 2.4 and 5 GHz bands may be quite different. Often there is very little competition on the 5GHz band even when the 2.4GHz band is quite congested. You will need to measure both to be sure.

[1] Based on luminous flux of 20 for the night light, and converting to watts assuming a luminous efficacy of 90 lm/W for the lamp's LED. Calculator at http://www.rapidtables.com/calc/light/lumen-to-watt-calculator.htm used to determine result.

[2] If you have many clients, for example an assortment of laptops, tablets, smartphones, gameboxes, etc., each client is involved in a pairwise connection to your router.