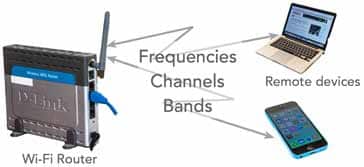
**802.11 WIFI Family**

Wi-Fi IEEE 802.11 is used by very many devices from smartphones to laptops and tablets to remote sensors, actuators televisions and many more.

There are several frequency bands within the radio spectrum that are used for the Wi-Fi and within these there are many channels that have been designated with numbers so they can be identified.

Although many channels are selected automatically, it sometimes helps to have an understanding of the Wi-Fi spectrum, bands, frequencies and the channels with their channel numbers to enable the best performance to be gained.



**ISM bands**

Wi-Fi is aimed at use within unlicensed spectrum - the ISM or Industrial, Scientific and Medical bands. These bands have been internationally agreed and unlike most other bands, they can be used without the need for a transmitting licence. This gives access to everyone to use them freely.

The ISM bands are not only used by Wi-Fi, but everything from microwave ovens to many other forms of wireless connectivity and many industrial, scientific and medical uses.

Whilst the ISM bands are available globally, there are some differences and restrictions that can occur in some countries.

The main bands used for carrying Wi-Fi are those in the table below:

| **Summary of Major ISM Bands** | | |
| --- | --- | --- |
| **Lower Frequency MHz** | **Upper Frequency MHz** | **Comments** |
|  |  |  |
| 2400 | 2500 | Often referred to as the 2.4 GHz band, this spectrum is the most widely used of the bands available for Wi-Fi. Used by 802.11b, g, & n. It can carry a maximum of three non-overlapping channels. |
| 5725 | 5875 | This 5 GHz band or 5.8 GHz band provides additional bandwidth, and being at a higher frequency, equipment costs are slightly higher, although usage, and hence interference is less.It can be used by 802.11a & n. It can carry up to 23 non-overlapping channels, but gives a shorter range than 2.4 GHz. |

**802.11 systems & frequency bands**

There are several different 802.11 variants in use. Different 802.11 variants use different bands. A summary of the bands used by the 802.11 systems is given below:

| **802.11 Types & Frequency Bands** | | |
| --- | --- | --- |
| **IEEE 802.11 variant** | **Frequency bands used** | **Comments** |
|  |  |  |
| 802.11a | 5GHz |  |
| 802.11b | 2.4GHz |  |
| 802.11g | 2.4GHz |  |
| 802.11n | 2.4 & 5 GHz |  |
| 802.11ac | Below 6GHz |  |
| 802.11ad | Up to 60 GHz |  |

In 1997, the Institute of Electrical and Electronics Engineers (IEEE) created the first WLAN standard. They called it *802.11* after the name of the group formed to oversee its development. Unfortunately, 802.11 only supported a maximum [network bandwidth](https://www.lifewire.com/what-is-bandwidth-2625809) of 2 Mbps – too slow for most applications. For this reason, ordinary 802.11 wireless products are no longer manufactured.

**802.11b**

IEEE expanded on the original 802.11 standard in July 1999, creating the *802.11b* specification. 802.11b supports bandwidth up to 11 Mbps, comparable to traditional [Ethernet](https://www.lifewire.com/what-is-ethernet-3426740).

802.11b uses the same *unregulated* radio signaling frequency (2.4 [GHz](https://www.lifewire.com/story-of-hertz-megahertz-and-gigahertz-818308)) as the original 802.11 standard. Vendors often prefer using these frequencies to lower their production costs. Being unregulated, 802.11b gear can incur interference from microwave ovens, cordless phones, and other appliances using the same 2.4 GHz range. However, by installing 802.11b gear a reasonable distance from other appliances, interference can easily be avoided.

* **Pros of 802.11b** - Lowest cost; signal range is good and not easily obstructed
* **Cons of 802.11b** - Slowest maximum speed; home appliances may interfere on the unregulated frequency band

**802.11a**

While 802.11b was in development, IEEE created a second extension to the original 802.11 standard called *802.11a*.

Because 802.11b gained in popularity much faster than did 802.11a, some folks believe that 802.11a was created after 802.11b. In fact, 802.11a was created at the same time. Due to its higher cost, 802.11a is usually found on business networks whereas 802.11b better serves the home market.

802.11a supports bandwidth up to 54 Mbps and signals in a regulated frequency spectrum around 5 GHz. This higher frequency compared to 802.11b shortens the range of 802.11a networks. The higher frequency also means 802.11a signals have more difficulty penetrating walls and other obstructions.

Because 802.11a and 802.11b utilize different frequencies, the two technologies are incompatible with each other. Some vendors offer hybrid *802.11a/b* network gear, but these products merely implement the two standards side by side (each connected devices must use one or the other).

* **Pros of 802.11a** - Fast maximum speed; regulated frequencies prevent signal interference from other devices.
* **Cons of 802.11a** - Highest cost; shorter range signal that is more easily obstructed.

**802.11g**

In 2002 and 2003, WLAN products supporting a newer standard called *802.11g* emerged on the market. 802.11g attempts to combine the best of both 802.11a and 802.11b.

802.11g supports bandwidth up to 54 Mbps, and it uses the 2.4 GHz frequency for greater range. 802.11g is backward compatible with 802.11b, meaning that 802.11g [access points](https://www.lifewire.com/wireless-access-point-816545) will work with 802.11b wireless [network adapters](https://www.lifewire.com/definition-of-adapter-817585) and vice versa.

* **Pros of 802.11g** - Fast maximum speed; signal range is good and not easily obstructed.
* **Cons of 802.11g** - Costs more than 802.11b; appliances may interfere on the unregulated signal frequency.

**802.11n**

*802.11n* (also sometimes known as "[Wireless N](https://www.lifewire.com/what-is-wireless-n-818280)") was designed to improve on 802.11g in the amount of bandwidth supported by utilizing multiple wireless signals and antennas (called *MIMO* technology) instead of one.

Industry standards groups ratified 802.11n in 2009 with specifications providing for up to [300 Mbps](https://www.lifewire.com/get-300-mbps-speed-on-802-11n-network-818267) of network bandwidth. 802.11n also offers somewhat better range over earlier Wi-Fi standards due to its increased signal intensity, and it is backward-compatible with 802.11b/g gear.

* **Pros of 802.11n** - Fastest maximum speed and best signal range; more resistant to signal interference from outside sources.
* **Cons of 802.11n** - Standard is not yet finalized; costs more than 802.11g; the use of multiple signals may greatly interfere with nearby 802.11b/g based networks.

**802.11ac**

The newest generation of Wi-Fi signaling in popular use, [802.11ac](https://www.lifewire.com/802-11ac-in-wireless-networking-818284) utilizes [dual-band wireless](https://www.lifewire.com/dual-band-wireless-networking-explained-818279) technology, supporting simultaneous connections on both the 2.4 GHz and 5 GHz Wi-Fi bands. 802.11ac offers backward compatibility to 802.11b/g/n and bandwidth rated up to 1300 Mbps on the 5 GHz band plus up to 450 Mbps on 2.4 GHz.

**Bluetooth**

Aside from these five general-purpose Wi-Fi standards, several other related wireless network technologies exist.

* IEEE 802.11 working group standards like 802.11h and 802.11j are extensions or offshoots of Wi-Fi technology that each serve a very specific purpose.
* Bluetooth is an alternative wireless network technology that followed a different development path than the 802.11 family. Bluetooth supports a very short range (approximately 10 meters) and relatively low bandwidth (1-3 Mbps in practice) designed for low-power network devices like handhelds. The low manufacturing cost of Bluetooth hardware also appeals to industry vendors. You can readily find Bluetooth in the networking of PDAs or cell phones with PCs, but it is rarely used for general-purpose WLAN networking due to the range and speed considerations.
* [WiMax](https://www.lifewire.com/wimax-wireless-networking-818321) also was developed separately from Wi-Fi. WiMax is designed for long-range networking (spanning miles or kilometers) as opposed to local area wireless networking.

The following IEEE 802.11 standards exist or are in development to support the creation of technologies for wireless [local area networking](https://www.lifewire.com/local-area-network-816382):

* [802.11a](https://www.lifewire.com/history-of-wireless-standard-802-11a-816554) - 54 Mbps standard, 5 GHz signaling (ratified 1999)
* [802.11b](https://www.lifewire.com/history-of-wireless-standard-802-11b-816555) - 11 Mbps standard, 2.4 GHz signaling (1999)
* 802.11c - operation of bridge connections (moved to 802.1D)
* 802.11d - worldwide compliance with regulations for use of wireless signal spectrum (2001)
* 802.11e - [Quality of Service](https://www.lifewire.com/quality-of-service-qos-3426725) (QoS) support (not yet ratified)
* 802.11F - Inter-Access Point Protocol recommendation for communication between access points to support roaming clients (2003)
* [802.11g](https://www.lifewire.com/history-of-wireless-standard-802-11g-816556) - 54 Mbps standard, 2.4 GHz signaling (2003)
* 802.11h - enhanced version of 802.11a to support European regulatory requirements (2003)
* 802.11i - security improvements for the 802.11 family (2004)
* 802.11j - enhancements to 5 GHz signaling to support Japan regulatory requirements (2004)
* 802.11k - WLAN system management
* 802.11l - skipped to avoid confusion with 802.11i
* 802.11m - maintenance of 802.11 family documentation
* [802.11n](https://www.lifewire.com/802-11n-wireless-network-818281) - 100+ Mbps standard improvements over 802.11g (2009)
* 802.11o - skipped
* 802.11p - Wireless Access for the Vehicular Environment
* 802.11q - skipped
* 802.11r - fast roaming support via Basic Service Set transitions
* 802.11s - ESS mesh networking for [access points](https://www.lifewire.com/how-many-devices-can-share-a-wifi-network-818298)
* 802.11T - Wireless Performance Prediction - recommendation for testing standards and metrics
* 802.11u - internetworking with 3G / cellular and other forms of external networks
* 802.11v - [wireless network](https://www.lifewire.com/join-a-wireless-network-from-any-device-818263) management / device configuration
* 802.11w - Protected Management Frames security enhancement
* 802.11x - skipped (generic name for the 802.11 family)
* 802.11y - Contention Based Protocol for interference avoidance

**2.4 GHz 802.11 channels**

There is a total of fourteen channels defined for use by Wi-Fi 802.11 for the 2.4 GHz ISM band. Not all of the channels are allowed in all countries: 11 are allowed by the FCC and used in what is often termed the North American domain, and 13 are allowed in Europe where channels have been defined by ETSI. The WLAN / Wi-Fi channels are spaced 5 MHz apart (with the exception of a 12 MHz spacing between the last two channels).

The 802.11 Wi-Fi standards specify a bandwidth of 22 MHz and channels are on a 5 MHz incremental step. Often nominal figures for the channel bandwidth of 20 MHz are often given. The 20 / 22 MHz bandwidth and channel separation of 5 MHz means that adjacent channels overlap and signals on adjacent channels will interfere with each other.

The 22 MHz channel bandwidth holds for all standards even though 802.11b WLAN standard can run at variety of speeds: 1, 2, 5.5, or 11 Mbps and the newer 802.11g standard can run at speeds up to 54 Mbps. The differences occur in the RF modulation scheme used, but the WLAN channels are identical across all of the applicable 802.11 standards.

When using 802.11 to provide Wi-Fi solutions for offices, general use hotspots, or for any WLAN applications, it is necessary to ensure that parameters such as the channels are correctly set to ensure the required performance is achieved.

**2.4 GHz Wi-Fi channel frequencies**

The table given below provides the frequencies for the total of fourteen 802.11 Wi-Fi channels that are available around the globe. Not all of these channels are available for use in all countries.

| **2.4GHz Band Channel Numbers & Frequencies** | | | |
| --- | --- | --- | --- |
| **Channel Number** | **Lower Frequency MHz** | **Center Frequency MHz** | **Upper Frequency MHz** |
|  |  |  |  |
| 1 | 2401 | 2412 | 2423 |
| 2 | 2406 | 2417 | 2428 |
| 3 | 2411 | 2422 | 2433 |
| 4 | 2416 | 2427 | 2438 |
| 5 | 2421 | 2432 | 2443 |
| 6 | 2426 | 2437 | 2448 |
| 7 | 2431 | 2442 | 2453 |
| 8 | 2436 | 2447 | 2458 |
| 9 | 2441 | 2452 | 2463 |
| 10 | 2446 | 2457 | 2468 |
| 11 | 2451 | 2462 | 2473 |
| 12 | 2456 | 2467 | 2478 |
| 13 | 2461 | 2472 | 2483 |
| 14 | 2473 | 2484 | 2495 |

**2.4 GHz WiFi channel overlap and selection**

The channels used for WiFi are separated by 5 MHz in most cases but have a bandwidth of 22 MHz. As a result channels overlap and it can be seen that it is possible to find a maximum of three non-overlapping channels. Therefore if there are adjacent pieces of WLAN equipment that need to work on non-interfering channels, there is only a possibility of three. There are five combinations of available non overlapping channels are given below:

2.4 GHz Wi-Fi channels, frequencies etc, showing overlap and which ones can be used as sets.

From the diagram above, it can be seen that Wi-Fi channels 1, 6, 11, or 2, 7, 12, or 3, 8, 13 or 4, 9, 14 (if allowed) or 5, 10 (and possibly 14 if allowed) can be used together as sets. Often WiFi routers are set to channel 6 as the default, and therefore the set of channels 1, 6 and 11 is possibly the most widely used.

As some energy spreads out further outside the nominal bandwidth, if only two channels are used, then the further away from each other the better the performance.

It is found that when interference exists, the throughput of the system is reduced. It therefore pays to reduce the levels of interference to improve the overall performance of the WLAN equipment.

With the use of IEEE 802.11n, there is the possibility of using signal bandwidths of either 20 MHz or 40 MHz. When 40 MHz bandwidth is used to gain the higher data throughput, this obviously reduces the number of channels that can be used.

IEEE 802.11n 2.4 GHz Wi-Fi 40 MHz channels, frequencies & channel numbers.

The diagram above shows the 802.11n 40 MHz signals. These signals are designated with their equivalent centre channel numbers.

**2.4 GHz Wi-Fi channel availability**

In view of the differences in spectrum allocations around the globe and different requirements for the regulatory authorities, not all the WLAN channels are available in every country.

**3.6 GHz WiFi band**

This band of frequencies is only allowed for use within the USA under a scheme known as 802.11y. Here high powered stations can be used as backhaul for networks, etc.

**5 GHz WiFi channels & frequencies**

As the 2.4 GHz band becomes more crowded, many users are opting to use the 5 GHz ISM band. This not only provides more spectrum, but it is not as widely used by Wi-Fi as well as many other appliances including items such as microwave ovens, etc.

**Additional bands and frequencies**

In addition to the more established forms of Wi-Fi, new formats are being developed that will use new frequencies and bands. Technologies employing white space usage, etc. and also new standards using bands that are well into the microwave region and will deliver gigabit transfer speeds are being developed and introduced. These technologies will require the use of new spectrum for Wi-Fi.

| **Additional Wi-Fi Bands & Frequencies** | | |
| --- | --- | --- |
| **Wi-Fi Technology** | **Standard** | **Frequencies Bands** |
|  |  |  |
| White-Fi | 802.11af | 470 - 710MHz |
| Microwave Wi-Fi | 802.11ad | 57.0 - 64.0 GHz ISM band (Regional variations apply) Channels: 58,32, 60.48, 62.64, and 64.80 GHz |

As Wi-Fi technology use has increased out of all proportion and the data transfer speeds have risen significantly, so too has the way in which the bands are used.

Originally the 2.4GHz band was favoured for Wi-Fi, but as the technology for the 5GHz band fell it came into much greater use in view of its wider channel bandwidth capability.

As other Wi-Fi technologies come to the fore, many other frequencies are being used. Other unlicensed bands that are below 1 GHz as well as white space for White-Fi using the unused TV spectrum and also now increasingly higher frequencies into the microwave region where even greater bandwidths are available, but at the cost of shorter distance.

Each Wi-Fi technology has its own frequencies or bands and sometimes a different use of the channels available.