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Wi-Fi Fundamentals

Technical Guide

Wi-Fi Fundamentals

Benefits of Wireless vs. Wired Networks

Home networks have historically been primarily wired, where cables of various types (coax, Ethernet, home wiring) are used to transmit data and signalling. Although wired networking will always have its place, the technology behind Wi-Fi networking continues to advance in both performance and reliability. Most consumer devices, commonly referred to as network clients (such as mobile phones, laptops, and tablets), have Wi-Fi capability. The ability to use these devices anywhere within a home without the need for wiring is achievable.

The capability for high-quality mobile internet access while moving around the house has become an expectation for most customers, who are increasingly "wirelessly" connected. However, the performance of Wi-Fi networks, unlike wired networks, is susceptible to a wide range of factors which reduce, often very significantly, the speeds seen by the user.

The global value of Wi-Fi products is currently $2 trillion, and the next generation of products (Wi-Fi Certified 6) are being readied for launch during 2019.

The HCN Fibre Router brings advanced Wi-Fi capability, employing 802.11n or 802.11ac radios for enhanced throughput, flexibility and range optimised for the home network.

However, the performance you receive in each room if the only device is your HCN fibre router in a single location, can deteriorate quite dramatically. Understanding, then using, the suggestions in this document will allow you to improve your experience significantly, but additional spend on your home network is likely to be necessary if you want to achieve peak throughput everywhere.

You should also remember the old adage 'horses for courses'. If your need in the more distant parts of your house is some simple web browsing or email, the perceived difference in speed is negligible, but it may cost you substantially to get the performance back to that delivered at the router. You may well find that the cost of improving your home network to maximise the figures shown on a speedtest totally outweighs the perceived experience. You should also note that many smartphones, laptops or tablets that are over a couple of years old will not themselves run at the 100 Mbps HCN supplies when measured at the router.

About the IEEE 802.11 Standard

Standards governing Wi-Fi were developed by the IEEE and released in 1997 as "802.11". There have been numerous additions and revisions to the standard since that time, and the IEEE has assigned alphabetical suffixes to each revision. Most of them are minor and remain relatively unknown, but some of them have resulted in significant changes to the operating protocol, and these are the familiar standards that we know as 802.11"a", "b", "g", and "n". Each of these major revisions has added significant improvements in capability to Wi-Fi networks (see table below). In addition, each newer standard is required to support devices operating at the older standards (called "legacy" devices) for backwards compatibility. Although older standards are supported, legacy devices cannot take advantage of any of them.

IEEE 802.11 PHY Standards						
Release Date	Standard	Band (GHz)	Bandwidth (MHz)	Modulation	Advanced Antenna Technologies	Maximum Data Rate (PHY Rate)
1997	802.11	2.4	20	DSSS, FHSS	N/A	2 Mbps
1999	802.11a	5	20	OFDM	N/A	54 Mbps
1999	802.11b	2.4	20	DSSS	N/A	11 Mbps
2003	802.11g	2.4	20	DSSS, OFDM	N/A	54 Mbps
2009	802.11n	2.4, 5	20, 40	OFDM	MIMO (up to 4 spatial streams)	600 Mbps
2013	802.11ac	5	40, 80, 160	OFDM	MIMO, MU-MIMO, (up to 8 spatial streams)	6.93 Gbps

About the 2.4 GHz Wi-Fi Band

The 2.4 GHz frequency band, also known as the Industrial, Scientific, and Medical (or ISM) band, was internationally set aside in 1947 for unlicensed applications. It was not originally intended for communications but rather for any purpose that could make use of this spectrum and coexist with the natural radio frequency radiation used for heating (for example, microwave ovens). With the development of spread-spectrum technology, communication devices were designed that could coexist with the microwave radiation at 2.4 GHz, and the development of communication technologies that were usable in this unlicensed band proliferated. These technologies developed into the communication protocols that we know of today as Wi-Fi, Bluetooth, and Near-Field Communication (NFC), among others.

There are numerous information sources that offer advice about choosing any unused Wi-Fi channel much like choosing an available open channel on a walkie-talkie. Such guidance does not take into account the overlap of the channels and the nature of the interference that this overlap causes. Adhering to the 1, 6, or 11 channel plan for all access points is important for the optimum operation of multiple access points who are sharing airspace. If the access point is being operated in an area devoid of other Wi-Fi access points, the choice of channel selection does not matter.

Wi-Fi channels are a shared medium and utilise a media access control protocol called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). Access points and clients (or "stations") take turns sending data to each other, and pass messages to each other -- coordinating when each has a turn to transmit, or "talk". Clients avoid collisions by cooperatively asking for airtime, waiting for a turn, and avoiding transmissions when other devices are transmitting on the same channel. This degree of cooperation only occurs when the radios are all on the same channel and can "hear" each other. When an access point is set to an overlapping channel, this channel cooperation ceases to occur and the radios begin talking over each other. It's like a conversation where everyone talks at once and the listener (or receiver) has a difficult time making out what is being said.

Proper channel selection is a critical component of a robust network and should be carefully reviewed before implementing your Wi-Fi network. Note also that your home network may well be supporting a wide variety of devices — for example, printers, scanners, connected Fitbits or other monitoring devices — which compete for available wi-fi throughput within the home network..

About the 5 GHz Wi-Fi Band

The 5 GHz frequency band has considerably more available spectrum than the 2.4 GHz band, and none of the 20 MHz-wide channels overlap (unlike the channels in the 2.4 GHz band). 5 GHz channels can be chosen freely without being concerned about over-lapping channel interference with another user. There are gaps between some of the channels, and there are 3 different allowable transmit power levels depending upon the sub-band. Many countries require special certification to operate in certain Wi-Fi channels that are shared with weather and military radars. These channels are called Dynamic Frequency Selection (DFS) channels which are located in the centre of the 5 GHz band. Most commercial Wi-Fi access points avoid these channels whereas the HCN Fibre Routers take advantage of this valuable Wi-Fi 'real estate'.

Choosing the Proper Frequency

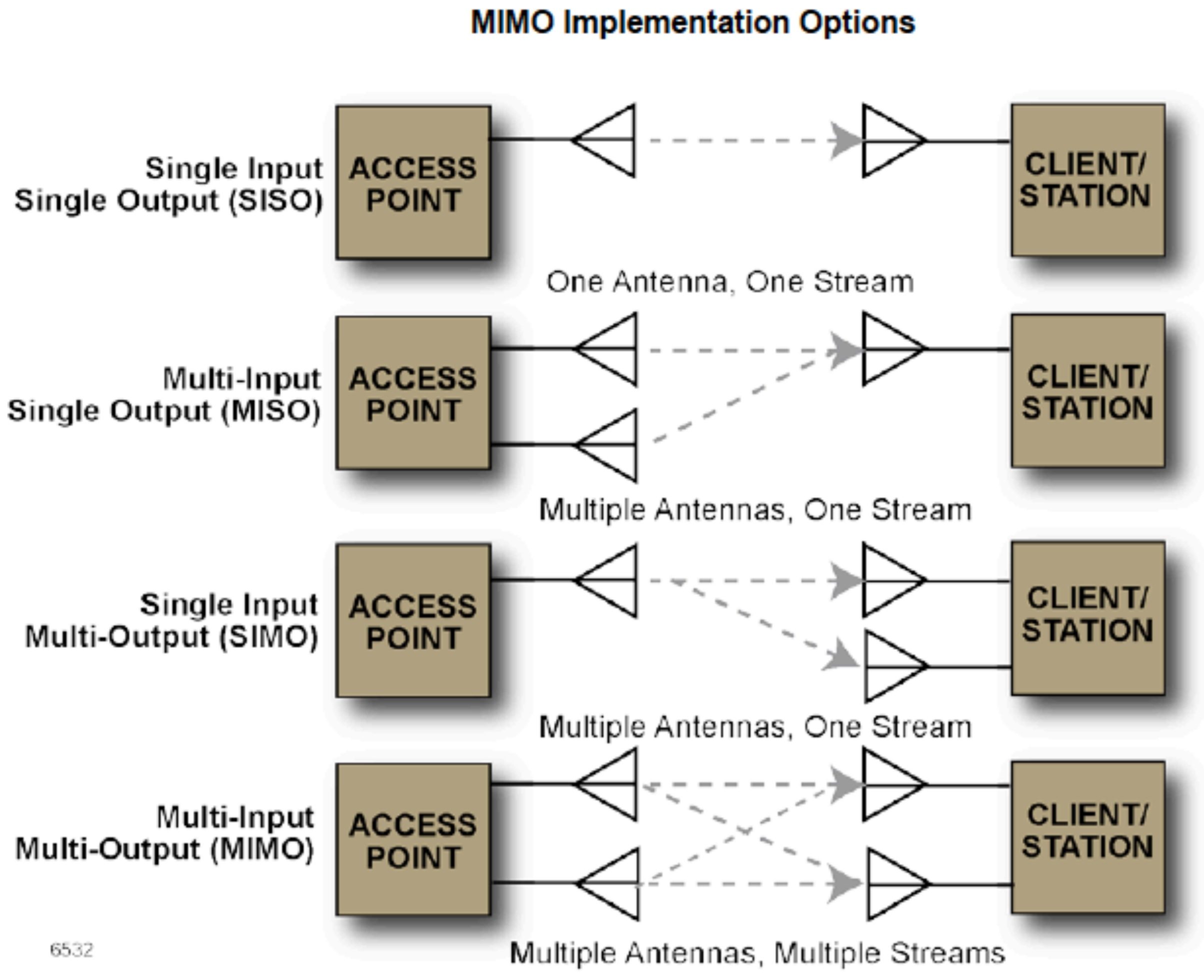
The 2.4 GHz band generally offers better transmission through air and walls, and has a slightly better range than signals in the 5 GHz band. However, the limited number of available channels and the potential user saturation in this band makes the 5 GHz band an attractive option if best throughput and less interference are desired. In practice, some handheld devices and some devices like wireless printers only operate at 2.4 GHz, thereby limiting your options as to what frequency to use. However, the HCN Fibre Router supports simultaneous dual band operation so legacy devices can use 2.4 GHz and more advanced devices can use the 5 GHz band.

About 802.11n and MIMO

The Wi-Fi radios in HCN Fibre Routers are 802.11n-capable for the 2.4 GHz band and 802.11ac capable for 5 GHz. IEEE 802.11n is a well-established high-performance Wi-Fi protocol that is backwards compatible with legacy 802.11 protocols including 802.11a, b, and g. The 802.11n radio in the HCN Fibre Router supports a maximum theoretical link rate (called a PHY rate) of 300 Mbps.

Note importantly that PHY, or link rates, are measured differently that the fibre data rates supplied with HCN services. A user rate specified at 100/100 at the fibre router means that the device is capable of supporting 100 Mbps in each direction simultaneously. By contrast, a link rate of 100 Mbps means that the total traffic on that link is the sum of the speed in each direction — hence for example a 100 Mbps service would theoretically support a maximum of 50 Mbps download and 50 Mbps upload simultaneously. In the real world, this would actually be significantly less owing to traffic collisions, re-sends and dropped packets.

The 802.11n standard introduced several new features that dramatically increased the performance potential of Wi-Fi. The most notable (and widely adopted) of these is the implementation of MIMO. MIMO specifies the number of radios and antennas in use (see figure



overleaf). Multiple radios/antennas can be used to one's advantage in a variety of ways to improve wireless performance.

Unfortunately, these techniques have fallen under the umbrella of a single term, MIMO. MIMO in the form of spatial multiplexing is capable of doubling (or more) the bandwidth of Wi-Fi if the proper channel conditions permit.

Note: Spatial data stream capacity is set by the device with the minimum number of antennas. For example, a 3 x 3 access point connected to a 1 x 1 client supports only 1 data stream.

In addition to MIMO, 802.11n also introduced channel bandwidths that can be up to twice as wide as the standard Wi-Fi channel; that is, the classic 20 MHz channel bandwidths in 802.11a, b and g could be doubled in size to 40 MHz. Unfortunately, 40 MHz channels are of limited use in the 2.4 GHz band because a single 40 MHz channel uses two-thirds of the total available spectrum. The 2.4 GHz band is (by far) the most heavily used unlicensed spectrum so it is reasonable to discourage 40 MHz channel usage in congested areas, and avoid monopolising the frequency band.

The 5 GHz spectrum is much larger and is more accommodating to 40 MHz channels. The double wide channels provide twice the bandwidth in virtually all conditions. This must be contrasted with Spatial Multiplexing (MIMO), which requires certain channel conditions to achieve theoretical performance advantages.

Additional Notes on 802.11.a/b/g/n/ac Networks

- In the 2.4 GHz band, HCN does not recommend provisioning of 40 MHz channels since any other WAP that overlaps with an access point will cause the Fibre Router to automatically revert to a 20 MHz channel.
- 802.11n and 802.11a clients may communicate with 802.11ac networks in the 5 GHz band (mixed-mode operation). Less efficient, these legacy clients will use up more capacity by occupying channel air time due to lower throughput speeds. However, due to the IPTV QoS prioritisation feature of the Fibre Router, video service to set-top boxes is not disrupted provided the priority IPTV SSID is in use. If data services are used in this instance, HCN recommends using the primary SSID (achieving priority over "Guest" SSID clients).

IMPORTANT: 802.11ac network clients must revert to 802.11n in the 2.4 GHz band since 802.11ac is defined only for the 5 GHz band.

About DFS

Dynamic Frequency Selection (DFS) certification enables the use of a specific range of channels that may have embedded (associated) radar signals. Usually these frequencies are not occupied by radar and can be used by the Fibre Router. The Fibre Router vacates channels with embedded radar as is the requirement for certification. The DFS channels comprise 60% of the 5 GHz channels and as such, DFS frequencies are an important part of the 5 GHz spectrum. They are often referred to as "beach front property" since most mass market broadband routers are not DFS certified, thus being incapable of taking advantage of this nearly empty spectrum. If radar is not detected in the vicinity of the home, the DFS channels will generally have minimal interference. Even if radar is in the vicinity, the other 5 GHz channels may be used.

Not all Wi-Fi enabled devices are capable of operating in DFS channels. All STBs designed for IPTV support DFS (as well as many other clients). There are clients such as certain USB dongles that have not been certified to operate in DFS channels by the manufacturer. There are also a few mobile phones that support 5 GHz but not DFS channels. Going forward, there will be more and more clients that support DFS channels as more access points support them.

Note: Clients that do not support DFS channels will not "see" an access point that is operating in a 5 GHz DFS channel and must associate in the 2.4 GHz band instead. Many clients do support using DFS if they first hear an Access Point on a DFS channel.

Note: HCN recommends connecting clients at 2.4 GHz if the client does not support DFS. If a subscriber nonetheless wishes to connect a non-DFS-supported client at 5 GHz, the Fibre Router can be set to an auto channel mode that will bypass DFS channels. A non-DFS-supported client will not have initial visibility to the 5 GHz radio if the Fibre Router is operating on a DFS channel, until the Fibre Router is re-configured to a non-DFS channel.

Due to the limited number of access points that support DFS today, it is extremely rare to see any usage of DFS channels where the 2.4 GHz band is extremely crowded and the rest of the 5 GHz band is only moderately used. This is what makes the DFS channels such prime "beach front" property. In other words, the DFS channels will be relatively free of congestion for the foreseeable future, when compared to the non-DFS channels.

About Beam-forming

Beam-forming is a technology that concentrates Wi-Fi power on the client rather than spreading the power across the house where there are no clients. This capability is important in reaching set top boxes located on the edge of the home, such as in upper floor bedrooms. By concentrating the energy, the Fibre Router achieves better coverage and higher performance. Moreover, by directing the Wi-Fi power toward the correct client, interference with other clients on neighbouring access points is minimised.

Beam-forming makes use of learned Channel State Information (CSI) on a per-client basis. This information must be learned over a number of sounding attempts to obtain the CSI. The CSI is used to compute a per-client "steering matrix."

Only 802.11ac clients support beam-forming in a mixed vendor environment. The 802.11n standard included explicit beam-forming, but in practice require matched chipsets on each end. The 802.11ac standard defines only one beam-forming protocol, so while beam-forming is optional in 802.11ac, it is supported by the large majority of chip vendors.

Another version of beam-forming called legacy (also known as universal or implicit beam-forming) uses standard MAC layer ACKs to obtain "soundings" to fine tune the beam-forming coefficients. The client does not need to have any knowledge of beam-forming and this universal beam-forming achieves about half of the gain of explicit beam-forming. The Fibre Router supports universal beam-forming as well as explicit beam-forming.

Note: Explicit beam-forming has approximately twice as much gain as universal beam-forming.

Note: Beam-forming resources are allocated on a first come, first served basis during association.

About Carrier Class Wi-Fi

HCN Fibre Routers, unlike the majority of Home Hubs and similar ISP products available in the UK, are defined as being “Carrier Class” Wi-Fi. Carrier Class Wi-Fi establishes a higher level of Wi-Fi performance and a more predictable level of performance throughout subscribers’ homes. Wi-Fi performance is dependent on many variables and a controlled yet realistic test environment is difficult to standardise. Carrier Class Wi-Fi power levels are substantially increased in the Fibre Routers (up to regulatory limits), while adding 4x4 antennas in the 5GHz band for maximum MIMO and beam-forming benefits. In addition, Wi-Fi performance measurement tools have been developed to assist in field troubleshooting of Wi-Fi performance.

Carrier Class Wi-Fi is measured using a combination of seven unique attributes:

- **802.11ac (5 GHz)** - This relatively new Wi-Fi standard includes the frequency band where linear broadcast IPTV is transmitted over Wi-Fi. Other vendors suggest that carrier class services are achievable using the 802.11n standard at 5 GHz however this requires a totally defined "end-to-end" solution. However, only 802.11ac offers Carrier Class Wi-Fi on an interoperable basis and achieves this by using a technique called *explicit beam-forming* in which the Fibre Router and the client work together to establish beam-forming.

- **4x4 Multi-User MIMO with Beam-forming** - HCN Fibre Routers incorporate this technology which provides very high speeds and whole home coverage to clients and set top boxes with high power 3x3 or 4x4 clients.
- **Quality of Service (QoS)** - QoS technology enables carrier class Wi-Fi to control traffic prioritisation.
- **Smart Channel Selection (SCS)** - With SCS, the Fibre Router dynamically changes channels when interference reaches pre-defined thresholds.
- **Dynamic Frequency Selection (DFS)** - The HCN Fibre Router is certified DFS compliant. This enables the Fibre Router to operate on the DFS channels in the 5 GHz spectrum, more than doubling the available channels.
- **Inter-operability with IPTV set-top systems** - With carrier class Wi-Fi, IPTV services are supported without the need for expensive CAT5 or CAT6 wiring.
- **Wi-Fi Analytics** - measurement of signal strength and channel capacity are critical in determining the over-all capabilities of your Wi-Fi network. The Fibre Router includes a broad range of analytics for this purpose.