Phone: 01635 800 360
Email: support@hampshirebroadband.co.uk
Website: www.hampshirebroadband.co.uk

User guide to Wi-Fi

Wi-Fi fundamentals

Benefits of wireless v. wired networks

Home networks have been wired, historically, 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 experienced 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 Hampshire Community Broadband (HCB) Fibre Optic Router brings advanced Wi-Fi capability, employing 802.11n or 802.11ac radios for enhanced throughput, flexibility and range, optimized for the home network.

However, if the only device is your HCB router in a single location, the performance you receive in each room can deteriorate quite dramatically. Understanding and using the suggestions in this document will allow you to improve your experience significantly, but some additional spending 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 will be negligible, but it may cost you substantially to get the same performance to that delivered at the router. The cost of improving your home network to maximize the figures shown on a speed test may outweigh 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 100Mbps HCB supplies, when measured at the router.

About the IEEE 802.11 standard

Standards governing Wi-Fi were developed by the Institute of Electrical and Electronics Engineers (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 are minor and remain relatively unknown, but some have resulted in significant changes to the operating protocol, and these are the familiar standards that we know as 802.11 a/b/g/n. Each major revision 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 2.4GHz Wi-Fi band

The 2.4GHz frequency band (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 2.4GHz, and the development of communication technologies proliferated. These technologies developed into the communication protocols that we know 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, that are sharing airspace. If the Access Point (AP) 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 utilize 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 – co-ordinating when each has a turn to transmit, or 'talk'. Clients avoid collisions by co-operatively asking for airtime, waiting for a turn, and avoiding transmissions when other devices are transmitting on the same channel. This degree of co-operation 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 co-operation ceases to occur and the radios begin talking over each other. It is 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 5GHz Wi-Fi band

The 5GHz frequency band has considerably more available spectrum than the 2.4GHz band, and none of the 20MHz-wide channels overlap (unlike the channels in the 2.4GHz band). 5GHz channels can be chosen freely without being concerned about overlapping channel interference with another user. There are gaps between some of the channels, and there are three 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 5GHz band. Most commercial Wi-Fi access points avoid these channels whereas the HCB router takes advantage of this valuable Wi-Fi 'real estate'.

Choosing the right frequency

The 2.4GHz band generally offers better transmission through air and walls and has a slightly better range than signals in the 5GHz band. However, the limited number of available channels and the potential user saturation in this band makes the 5GHz 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 2.4GHz, thereby limiting your options as to what frequency to use. However, the HCB router supports simultaneous dual band operation so legacy devices can use 2.4GHz and more advanced devices can use the 5GHz band.

About 802.11n and MIMO

The Wi-Fi radios in the HCB Fibre Optic Router are 802.11n-capable for the 2.4GHz band and 802.11ac-capable for 5GHz. 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 HCB router supports a maximum data rate (called a PHY Rate) of 300Mbps.

Note that importantly PHY, or data rates, are measured differently from the fibre data rates supplied with HCB services. A user rate specified at 100/100 at the Fibre Optic Router means that the device is capable of supporting 100Mbps in each direction simultaneously. By contrast, a data rate of 100Mbps means that the total traffic on that link is the sum of the speed in each direction – for example a 100Mbps service would theoretically support a maximum of 50Mbps download and 50Mbps upload simultaneously. In the real world, this would 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 Multi-Input, Multi-Output (MIMO). MIMO specifies the number of radios and antennas in use (see figure overleaf). Multiple radios/antennas can be used to advantage in a variety of ways to improve wireless performance.

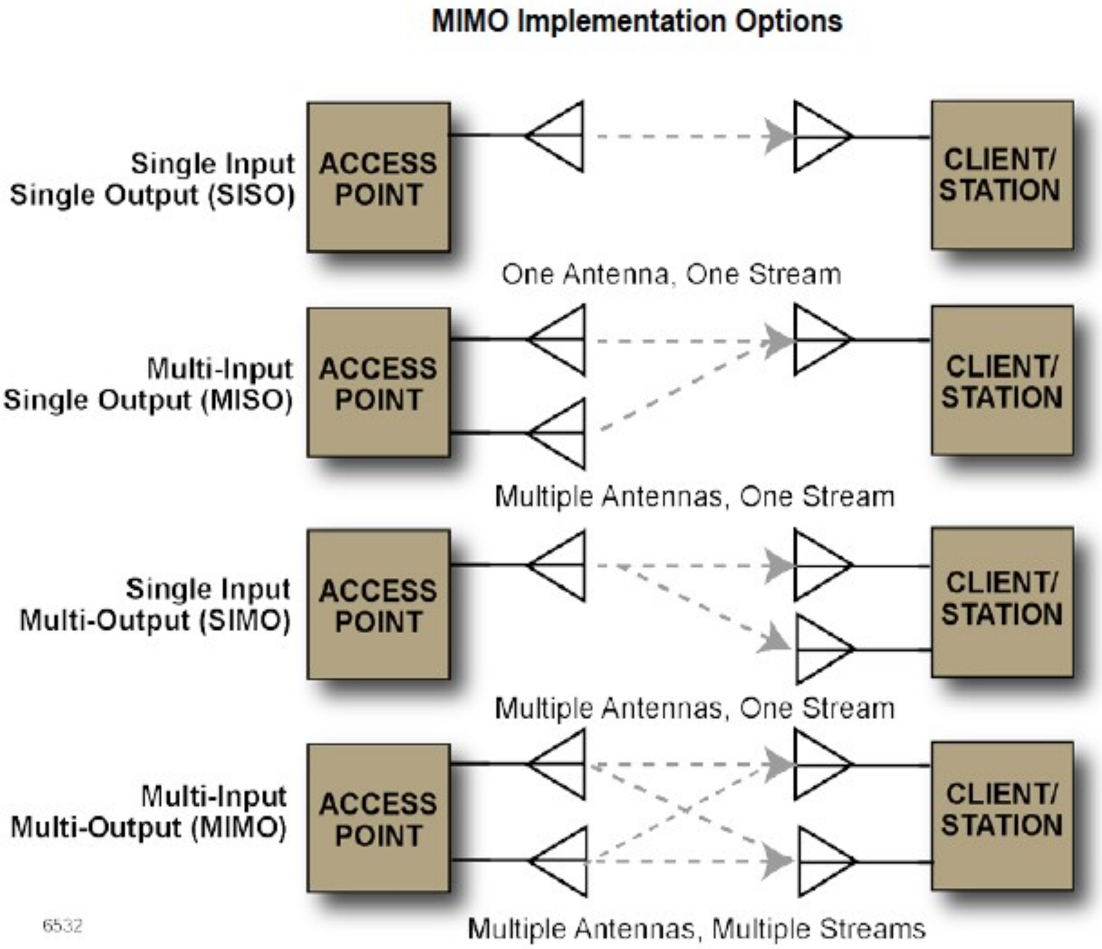
Unfortunately, these techniques have fallen under the umbrella of a single term, MIMO. MIMO in the form of spatial multiplexing is capable of doubling (or more) the bandwidth of Wi-Fi if the proper channel conditions permit.

Note: Spatial data stream capacity is set by the device with the minimum number of antennas. For example, a 3x3 Access Point connected to a 1x1 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; the classic 20MHz channel bandwidths in 802.11a, b and g could be doubled in size to 40MHz. Unfortunately, 40MHz channels are of limited use in the 2.4GHz band because a single 40MHz channel uses two-thirds of the total available spectrum. The 2.4GHz band is (by far) the most heavily used unlicensed spectrum so it is reasonable to discourage 40MHz channel usage in congested areas and avoid monopolizing the frequency band.

The 5GHz spectrum is much larger and is more accommodating to 40MHz channels. The double width 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 802.11a/b/g/n/ac networks

- In the 2.4GHz band, HCB does not recommend the provision of 40MHz channels since any other Wireless Access Point (WAP) that overlaps with an access point will cause the Fibre Optic Router to automatically revert to a 20MHz channel.

- 802.11n and 802.11a clients may communicate with 802.11ac networks in the 5GHz 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 Internet Protocol for Television (IPTV) QoS prioritization feature of the 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, HCB recommends using the primary SSID (achieving priority over 'Guest' SSID clients).

Important: 802.11ac network clients must revert to 802.11n in the 2.4GHz band since 802.11ac is defined only for the 5GHz 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 Optic Router. The router vacates channels with embedded radar as is the requirement for certification. The DFS channels comprise 60% of the 5GHz channels and as such, DFS frequencies are an important part of the 5GHz spectrum. They are often referred to as 'beach front property' since most mass market broadband routers are not DFS certified, 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 5GHz channels may be used.

Not all Wi-Fi enabled devices are capable of operating in DFS channels. All Set-Top Boxes (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 5GHz 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 5GHz DFS channel and must associate in the 2.4GHz band instead. Many clients do support using DFS if they first hear an access point on a DFS channel.

Note: HCB recommends connecting clients at 2.4GHz if the client does not support DFS. If a subscriber nonetheless wishes to connect a non-DFS-supported client at 5GHz, the Fibre Optic 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 5GHz radio if the router is operating on a DFS channel, until the 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 2.4GHz band is extremely crowded, and the rest of the 5GHz 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 settop boxes located on the edge of the home, such as in upper floor bedrooms. By concentrating the energy, the Fibre Optic 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 minimized.

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 requires 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 Optic 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

The HCB Fibre Optic Router, unlike the majority of Home Hubs and similar ISP products available in the UK, is 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 standardize. Carrier Class Wi-Fi power levels are substantially increased in the Fibre Optic Router (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 trouble-shooting of Wi-Fi performance.

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

- **802.11ac (5GHz)** - 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 5GHz, however, this requires a totally defined 'end-toend' solution. However, only 802.11ac offers Carrier Class Wi-Fi on an inter-operable basis and achieves this by using a technique called *explicit* beam-forming in which the router and the client work together to establish beam-forming.

- **4x4 Multi-user MIMO with beam-forming** – The HCB Fibre Optic Router incorporates 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 prioritization.

- **Smart Channel Selection (SCS)** - With SCS, the Fibre Optic Router dynamically changes channels when interference reaches pre-defined thresholds.

- **Dynamic Frequency Selection (DFS)** - The HCB Fibre Optic Router is certified DFS compliant. This enables the router to operate on the DFS channels in the 5GHz 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 cabling.

- **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 Optic Router includes a broad range of analytics for this purpose.

Extending and enhancing your home network

Choosing the right environment based on device type

Choosing what type of network to use in various environments is a critical step during in-home network planning.

Wired network

While wireless connectivity is approaching the performance of wired connections, wired connections are typically superior where speed, reliability, and security are concerned.

Whenever an Ethernet port is accessible, or devices that are to be interconnected are within the reach of an Ethernet cable, the Ethernet network connection should be your first choice even if WiFi capability exists. This also minimizes the number of wireless clients, ensuring optimum performance of the wireless network.

If the device, such as a laptop, has dual network adaptors and is experiencing network instability and/or slow connectivity, the Wi-Fi adaptor should be disabled. *Windows* does not automatically disable the Wi-Fi port when the Ethernet port is active and may not prioritize between Wi-Fi or cabled connections.

Wireless network

The wireless network is ideal for connecting mobile network devices such as smartphones, laptops, and tablets, or other Wi-Fi enabled devices that may be remotely located from the residential Router/Gateway without nearby wired Ethernet access. Wireless connectivity should be reserved for 'best effort' network access where reliability and security are not critical or where the device itself is inherently 'mobile' by design but still requires network connectivity.

Fibre Optic Router

The HCB Fibre Optic Router provides Wi-Fi connectivity via either an 802.11n 2x2 MIMO radio or an 802.11ac 4x4 MIMO radio with beam-forming gain. The router supports both 2.4GHz and 5GHz Wi-Fi bands (simultaneously) - configuration is accomplished using the router's Embedded Web Interface (EWI).

Many devices can be operated in the 5GHz band, which has more available channels and tends to have better performance if the Wi-Fi environment becomes congested in the 2.4GHz band. To ensure peak performance, use the 5GHz band for higher bandwidth applications, such as IPTV.

Expanding Wi-Fi coverage/reach

One of the primary considerations when deploying Internet capable devices in the home is the cost and inconvenience of hardwiring connections to each device's location. Wi-Fi removes this obstacle and enables the deployment of smart devices without wires to simplify network setup. These devices are deployed in every possible location inside and outside the home and users expect these devices to connect seamlessly wherever they are used. In the past, when the enduser had less than a handful of Wi-Fi devices on the home network, the location of the Wi-Fienabled Router/Gateway was easily optimized. Now, with the proliferation of wireless devices, along with the interference from other appliances, radio, etc. and factors as seemingly benign as adjacent street lights, it can be a challenge to provide coverage in all environments. To make matters worse, not all homes are the same size or use the same construction materials/methods and the preferred demarcation point for the ONT/Wi-Fi Router/Gateway within the home may not always coincide with the best location for Wi-Fi coverage.

The ability to establish a connection via Wi-Fi is directly associated with the strength of the Wi-Fi signal. It is affected by many factors including distance and the type of materials that the signal must pass through. Low or no signal strength can lead to dead zones where the Wi-Fi enabled device cannot connect to the home Wi-Fi enabled Router/Gateway. As end users migrate outside, they expect these mobile devices (iPad, smartphone, laptop) to remain connected to the Wi-Fi network, eliminating the need to rely on more expensive 3G/4G data plans. Newer Wi-Fi devices with up to 4x4 Multiple Input, Multiple Output (MIMO) and beam-forming features (such as the HCB Fibre Optic Router) have greatly expanded the coverage within the home, however a certain percentage of homes may still have dead zones. To eliminate this additional Wi-Fi elements may be needed.

There are multiple ways to build an expanded Wi-Fi network. Two currently accepted practices are:

- An additional Wi-Fi Repeater/Extender
- One or more Wireless Access Points (WAP) or Wi-Fi Bridges (existing Wi-Fi Router reconfigured as a WAP).

A brief discussion follows on these two technologies.

Wireless repeaters or extenders

A wireless repeater or extender is a device that receives the Wi-Fi signal from the Wi-Fi enabled Router/Gateway and retransmits it. On the far end, the repeater receives the Wi-Fi signal from the mobile client(s) and retransmits the signal back to the Wi-Fi enabled Router/Gateway.

Note: Wi-Fi by its nature is half-duplex, which means the single channel is used for both Transmit and Receive, however both cannot occur simultaneously.

When a repeater is introduced into the network, transmissions will double and delays are potentially introduced. This occurs due to the nature of the repeaters catch and forward design. In other words, for every packet it receives, the repeater must process it, and then forward it out from its internal transmitter. This has the effect of cutting the performance in half for traffic going through the repeater. Depending upon the nature of the application, this may or may not be an issue and is considered to be a better alternative than providing no connectivity at all.

Depending upon the capabilities of the repeater, it can use the same Service Set Identifier (SSID) or a different SSID. The SSID is the name that uniquely identifies one Wi-Fi network from any neighbouring networks. The SSID allows users to control what network they want to connect to.

Both single and multiple SSID deployments are supported with the following differences:

- A single SSID allows the mobile client to access only configuration information for the main WiFi enabled Router/Gateway, including all other mobile devices that are connected. A single SSID may enhance the client's ability to roam from the extender to the AP and back depending on movement of the client within the home.

- When two SSIDs are used, the user can control and know which wireless host they are connected to. In addition, some of the units that support a second SSID will use a different channel for that second SSID. To accomplish this, the repeater must have dual radios. The use of a second channel allows the repeater to receive and transmit simultaneously and eliminates the halving of the bandwidth.

There are many varieties of Wi-Fi repeater and extenders available however they all are designed to support the basic repeater function. As an alternative to wireless repeaters, there are devices with the ability to support additional wired interfaces such as:

- Ethernet
- Multi-Media Over Cable Alliance (MOCA)
- Powerline Networks
- Home Phone Network Alliance (HPNA)

These higher-end devices are used to inter-connect hardwired devices and backhaul the traffic to the Wi-Fi enabled Router/Gateway over a Wi-Fi channel. These higher-end repeaters or extenders closely resemble WAPs/Routers and are available in a similar price range

Gateway/Repeater physical deployment

Communication to and from the repeater is accomplished via a Wi-Fi channel (through the air) and as such, it is important to correctly place this equipment. For optimal performance, the repeater should be located where it has the highest possible connectivity to the Wi-Fi enabled Router/Gateway. If placed at the outer limits of effective communication with respect to the Router/Gateway, there may be a tendency for performance issues due to retransmissions caused by the low signal strength.

Managing repeater capabilities

The management capabilities associated with this class of repeaters fall into the following categories:

- Wi-Fi Protected Set-up (WPS) - Enters set-up mode via a ‘learn’ button that is temporarily open for set-up.
- Embedded Web Interface (EWI) - May include a full-suite of management features for all devices on the network.
- Remote Management via TR-069 - third party management utilities are supported using standards-based TR-069 to monitor, configure, and remotely re-boot network devices.

Given the nature of what repeaters are designed to do, most of them do not include or need extensive management interfaces, with vendors typically highlighting how simple the devices are to deploy. From a service provider perspective, the best practice is to recommend an additional WAP or Wireless bridge, however if a Repeater/Extender is needed, the recommendation is to select a repeater with TR-069 capabilities. This allows the service provider to configure the repeater as another network element, being visible in network architecture diagrams.

The benefits of this network architecture are:

- Since all communication is done via Wi-Fi, no additional infrastructure is needed.
- Plug-n-Play nature, manageable elements are typically auto-detected.

Conversely, this network architecture poses a few challenges:

- By their nature, repeaters or extenders insert twice as much traffic onto the airways which effects throughput.
- The client may attach to the repeater (inefficient at one-half the speed) when attaching directly to the Router/Gateway would be more efficient (better).
- Physical obstructions in the home may block the Wi-Fi signal (such as embedded radiant floor heaters).
- By their nature they add delay and some applications (typically video) are very sensitive to packet delay and jitter.
- Most commercial repeaters or extenders are typically not robust from a management perspective. It is more difficult to know that these elements exist in the network, making troubleshooting more difficult.

- Solution does not scale well for multiple reasons:
  Potential channel re-use
  Distance limitations
  Cascading of repeaters or extenders is typically not allowed
  Puts the burden on end users to manage the complexity of dual SSID networks when needed.

WAPs or Wi-Fi Bridges

As opposed to wireless repeaters or extenders, one of the fundamental differences when using Wireless Access Points (WAPs) or Wi-Fi Bridges is how the additional Wi-Fi elements are connected to the Wi-Fi enabled Router/Gateway. With WAPs or Bridges, the elements are hardconnected via Cat5 cable. Alternatively, the WAP may be connected to the Router/Gateway using Ethernet to MoCA/HPNA, or Powerline adaptors. This additional infrastructure can be costly and is certainly more complex than 'over-the-air' Wi-Fi circuits. However, for the additional cost and complexity, users typically enjoy increased performance, network simplicity, flexibility, and control.

To support this architecture, additional network configuration is needed but once configured, this high-performance network uses a single SSID end-to-end.

The benefits of this network architecture are:

- Each of the two Wi-Fi devices (Router/Gateway and WAP/Wi-Fi Bridge) use different channels, maximizing throughput and minimizing interference.

- Packets to and from the mobile clients are always a single wireless link away and therefore are not transmitted twice.

- End users only see a single SSID. Mobile client can seamlessly roam between the two wireless spaces.

- Extremely scalable solution - can easily add more WAPs as needed.
- Given the hardwired nature of the backhaul from the remote WAP to the primary Router/Gateway, link speeds between them are not limited by Wi-Fi 802.11a/b/g/n/ac standard speeds.

- To handle the complexity of configuring and administering the network, TR-069 management solutions can be leveraged. This greatly simplifies network administration for both the end user and the service provider.

The challenges of this network include:

- If re-purposing an existing Router/Gateway as a Wi-Fi Bridge, it must be set up as a bridge and any Layer-3 features such as Network Address Translation (NAT) and Dynamic Host Configuration Protocol (DHCP) must be disabled.

- There is the additional cost of the wired backhaul and additional WAP/Router/Gateway. In some cases these costs may be minimal or zero, provided the infrastructure already exists on site.

- If devices are not TR-069 manageable, the end user must configure and administer these devices manually.

About client roaming and sticky clients

Regardless of the wireless LAN standard you plan to deploy, a potential problem exists in that Wireless Access Point (WAP) to AP roaming for Wi-Fi has historically been the decision of the client with no clear rules defined as to which host to connect to. With the introduction of 802.1n standard, additional capabilities were added where the Wi-Fi WAP can give guidance to the mobile Wi-Fi client and suggest that they roam to a different AP.

These additional capabilities are further confined to deployments incorporating the 802.11n standard since 802.1a/b/g devices are not currently supported. The good news is that these older mobile clients will eventually be retired and replaced with new clients that support the latest wireless standards, mitigating the issue. In addition, the standards bodies are introducing support for controls that allow a network of WAPs to communicate between themselves. This allows roaming decisions to be made at multiple points in the network. This will prove beneficial in that signal strength decisions can then be considered as well as packet load and channel capacity decisions on individual WAPs in the network.

The problem of the ‘sticky’ client is worse with the Repeater/Extender approach since the client has no way of knowing that communication through the repeater is less efficient as compared to directly connecting to the Router/Gateway. As a result, a connection may be selected based on signal strength alone, which may not always be the desired approach.

Until these new capabilities are prevalent within your network, HCB recommends using only the single SSID model in your configurations.

What to deploy?

The decision as to what type of Wi-Fi network to deploy is not always cut and dried, however from a best practice standpoint, the following variables must be considered:

- What system provides the overall highest value?
- What system provides the best performance?
- What solution provides the least amount of risk?
- What deployment gives the Internet service provider the highest degree of control?
- What system provides for remote management via TR-069?

Taking into account the above variables, it is clear that a Wi-Fi network incorporating hard-wired Wireless Access Points or Wired is the de-facto best practice model as opposed to the Repeaters or Extender model. Whether an enterprise network or a simple home network, building a distributed Wi-Fi network using standards-based functionality with additional capabilities (such as WAP directed client steering and enhanced roaming) is highly desirable.

In addition, most of these devices support TR-069 clients which allow the Internet service provider a view of what is connected to the home network and how the end users mobile resources are utilizing the Wi-Fi infrastructure. This allows service providers who have home networking TR-069 ACS solutions (such as HCB) to offer managed services with access to a set of tools for troubleshooting, configuring and maintaining these resources.

In general, better throughput, better coverage, and increased inter-operability are the benefits of an 802.11ac system.

- 802.11n is limited to 40MHz wide channels, while the Fibre Optic Router can use 80MHz wide channels for much higher throughput in nearby areas where beam-forming is not used.

- 802.11ac also supports 160MHz channels, although HCB has not implemented this on the Fibre Optic Router as chip sets have yet to be introduced that simultaneously support both 160MHz and 4 spatial streams, though this may change soon.

- 802.11ac supports explicit and inter-operable beam-forming, doubling the amount of gain from beam-forming compared to 802.11n. This significantly increases coverage in hard to reach places at the edge of the home network.

- 802.11ac supports higher Quadrature Amplitude Modulation (QAM) (256 v. 64) levels for higher throughput.

General Wi-Fi best practice

Keep the following in mind when planning or implementing your Wi-Fi network:

- When two Wi-Fi capable devices connect to one another and have different characteristics (for example, a MIMO 4x4 device talking to a MIMO 2x2 device), the lowest Wi-Fi capable device's performance is obtained.
- For all Wi-Fi radios within range on the 2.4GHz band, the 40MHz wide band is only used if no other competing 2.4GHz band devices are present. Similarly, for the 5.0GHz band, the 80MHz channel is only used if no other competing 5.0GHz band devices are present.
- A Wi-Fi connection is only as 'fast' as the slowest connected device (everyone must wait their turn). In other words, while the Fibre Optic Router may support four spatial streams, a 1x1 STA can only support one stream so the additional streams available from the router are 'wasted'.
- **Exception:** Multi-user MIMO devices running at 5GHz can communicate at the same time (mobile phones communicating on the 5GHz HSI SSID). In this case, four 1x1 clients would each receive one stream from the Fibre Optic Router and use the air time and capabilities of the router to the maximum.
- For networks running 802.11g and below, you should expect a 40-70% drop in throughput.
- HCB strongly recommends using the auto-channel selection feature on the Fibre Optic Router. Set both radios to 'On' for auto-channel selection.
- On the 2.4GHz band, if auto-channel selection is not used, preset the channels to 1, 6, or 11 only to reduce co-channel interference with other networks in your area (such as neighbouring houses).
- For homes using wireless set-top boxes, make sure these devices are set to the default highest priority 5.0GHz IPTV SSID.

Note: As a best practice, HCB recommends that DVRs be hard-wired via Cat5 or better Ethernet cables to the residential gateway.

- Where available, enable DFS.
- Generally speaking, wireless cameras always utilize the 2.4GHz band (not configurable). Make sure the SSID assigned to this service has a high priority using WMM for 2.4GHz and SSID prioritization for the 5GHz band.

Fibre Optic Router placement

The Fibre Optic Router is designed to be placed within an interior, temperature-controlled environment. Use the available installation guides for instructions on the proper mounting of the HCB Fibre Optic Router. Also, review the guidelines for orientation of the unit as found in the following section.

Certain building materials are particularly effective at blocking Wi-Fi signals (see table overleaf) and should be considered when locating a Wi-Fi Access Point. Line of sight is not necessary since MIMO technology takes advantage of reflections in the over-the-air path to carry additional data.

However, HCB recommends that when possible, the router should be placed in a centralized location within the home to yield the best possible results for Wi-Fi coverage.

Building Materials and Their Effect on Wi-Fi Signals	
Material	**Wi-Fi Attenuation**
Wood, Drywall, Particle Board, Tile	Low
Glass	Low
Water	Medium
Bricks, Cinder Block	Medium
Plaster, Stucco	High
Concrete	High
Elevator Shafts	High
Tinted or Low-E Glass (metalized)	Very High
Metal	Very High
Note: Low attenuation is considered to be best performance.	

About 2.4GHz and 5.0GHz interference

Most interference in wireless networks occurs in the 2.4GHz band. The tables below give a partial list of 'interferers' and their relative effect on Wi-Fi signals. As you gain experience with your particular environment, this list can be expanded as necessary.

2.4 GHz Device Interferers and their Effect on Wi-Fi Signals		
Very High Interferers		
Microwave Oven	2.4 GHz Cordless Phone	Neighbors Wireless Devices
Other Interferers		
Proximity Sensors	Wireless Mouse	Set-top Boxes
Wireless Audio Devices (headsets or speakers)	Bluetooth Devices	Wireless Video/Surveillance Cameras
Outdoor microwave links	Fluorescent Lights	WiMAX
Loose electrical connections	RF leakage (Satellite TV)	Baby Monitors
ZigBee devices	Certain External monitors and LCD displays (typically 2.4 GHz band near Channel 11)	Elevator Motors

5.0 GHz Device Interferers and their Effect on Wi-Fi Signals		
Very High Interferers		
5 GHz Cordless Phone	Nearby 802.11a or 802.11n WLANs	Radar (Weather or Military), DFS Channels only
Other Interferers		
Digital Satellite Transmissions	Outdoor wireless 5 GHz bridges	Perimeter sensors

Fibre Optic Router orientation

Fibre Optic Router

The HCB Fibre Optic Router uses internal antennas, making for a more attractive, maintenance free product while preserving Wi-Fi performance. The 5GHz antennas are located along the top edge while the 2.4GHz antennas are located along the side nearest the LEDs. HCB recommends orienting the router's antennas up or out to the right where they are most effective. In the photos below the 'Wall Mount' shows the unit with the antennas facing out (into the room or dwelling). The 'Tabletop Mount' means the 5GHz radios are facing up while the 2.4GHz radios are facing out to the right.

Note: Due to the location of the radios, do not mount the Fibre Optic Router flat upon a desktop or flush against the ceiling. In addition, HCB recommends orienting the router such that the LEDs are facing the areas of coverage. The unit can be mounted vertically or horizontally and will provide excellent Wi-Fi coverage in either orientation. However, every structure is unique in its construction and you may find that the desired coverage can be optimized by changing the orientation of the router.

Wall Mount - Horizontal	Wall Mount - Vertical
	

Tabletop Mount


Mitigating common interferers

The primary method of avoiding interference is to move away from channels that have interference and migrate to channels with no or less interference.

Note: Although moving to channels with little to no interference seems intuitive, this approach is more effective in the 5GHz band than in the 2.4GHz band due to number of overall channels available.

Channel selection is accomplished in one of two ways:

Channel Selection at start-up - Using this method, a channel is manually selected for a given radio. Once a client or client attaches to that channel, the channel is locked until there are no clients or clients present. Once a channel is clear, another channel can be selected. This method is commonly used on the 2.4GHz band due to the limited number of channels available.

Dynamic Channel Selection - Using this method, the Access Point (AP) can change its channel whenever the opportunity presents itself to increase throughput. This occurs independently of attached clients or clients and the AP is constantly looking to occupy the 'cleanest' spectrum with the least amount of interference.

Automatic channel selection or 'hopping' can be configured at start-up or it can occur dynamically (during operation). Wi-Fi radio manufacturers often incorporate dynamic channel hopping for the 5GHz band because it is highly effective with a wide range of channel options to 'hop' to. For the 2.4GHz band, it is likely that manufacturers only provide automatic channel selection upon startup (since there are typically only three channels to choose from). The reason 2.4GHz dynamic hopping is not commonly used is that it can cause more problems than it solves. The act of hopping channels is sometimes more disruptive than the interference itself and if all the 2.4GHz channels are crowded, hopping serves no benefit.

Note: The HCB Fibre Optic Router follows the approach described above. That is, the 5.0GHz band is configured for dynamic channel selection during operation, whereas the 2.4GHz band uses manual channel selection at start-up.

It is also possible to judiciously use manual channel selection in a designed deployment strategy.

Other interference mitigation can be done by desensitizing the receiver and for narrow band interference (cordless phones and baby monitors) by manipulating the Optical Frequency Division Multiplexing (OFDM) sub-carriers. The router has automatic interference mitigation using these two techniques, where the mitigation is only done when interference is detected.

About SSID naming

If seamless roaming between 2.4GHz and 5GHz radios is desired, set-up identical SSID names and passwords and assign them to both bands.

Note: In a high-density environment, this may be less desirable as clients should be utilizing the 5GHz band wherever possible. Generally, clients select the band by whichever SSID has the highest signal strength. By having different SSID names (i.e. Smith_2_4GHz and Smith_5GHz), clients could have control over the band the client is currently in.

Managing expectations

The 5GHz band is definitely the future of high-reliability and high-performance Wi-Fi. While there are many legacy 2.4GHz only clients, there are very few of these requiring high speeds. If customers expect to stream high definition video, they should realize that the 5GHz band is the preferred spectrum for HD video. In short, all clients that can use 5GHz should be moved to the 5GHz band.

In addition, while enabling Dynamic Frequency Selection (DFS) channels in the Fibre Optic Router more than doubles the available 5GHz spectrum, it is important to note that not all clients can tune to DFS channels. Some lower cost Wi-Fi clients (such as USB dongles) do not support DFS channels. In these cases, the operator may wish to turn off DFS channels for users who have clients that do not support DFS channels, but at the same time realize that the 2.4 GHz band may not be adequate for their needs.

High Density Wi-Fi best practice

To recap the salient points concerning Wi-Fi best practice, keep the following in mind:

- **Manage expectations** – 2.4GHz should be considered 'best effort' while the 5GHz band should be used for high speed and high reliability needs.
- **Channel selection** – For the 5GHz band, HCB recommends using dynamic auto-channel selection; for the 2.4GHz band, a manual channel selection plan with three channel frequency re-use may be needed. Always use only Channels 1, 6 and 11 for the 2.4GHz band.
- **Channel width** – In any 2.4GHz high density environment, 40MHz channels should never be used. The 'good neighbour' rule prevents use of 40MHz channels if there is an overlapping channel, which there always will be in any high-density environment. For the 5GHz band, it may be possible to use 80MHz channels but 40MHz channels are preferable to avoid interference.
- **DFS spectrum** – If possible, DFS channels should be enabled for 5GHz as this spectrum will more than double the number of available channels and reduce the probability for interference. This is especially true for IPTV deployments. For subscribers that have clients that cannot access DFS channels and want to operate on the 5GHz band with no IPTV services, DFS channels in the auto-selection mode may be disabled for that subscriber.

- **Transmit power** – For the 2.4GHz band, it may be beneficial to reduce the transmit power to reduce interference. However, this should be balanced against the reduced range that will result with reduced transmit power. For 5 GHz, the radio has dynamic power reduction built in (based on how close a given client is to the router).

PHY Rate v. data throughput

The PHY Rate is the rate often quoted by manufacturers to describe the throughput speed of any Wi-Fi access point. PHY Rate is the theoretical link rate that is determined by the number of spatial streams, modulation type, channel bandwidth, and the like. In reality, usable data transmission is usually about one-half of the PHY Rate due to overhead in the 802.11 protocol (headers, retransmissions, management frames) that are carried as Wi-Fi data in addition to the user data. Other impairments also lower the available data transmission rate as detailed in the next section of this guide. Since IEEE 802.11 is a highly adaptive protocol, it is difficult to predict actual throughput rates in any given environment. For this reason, PHY rates are typically used to describe and compare the throughput capability of a Wi-Fi access point.

Note: Poor PHY Rate results are often caused by poor downstream signal strength and/or interference. Move the client closer to the router or move the router to a more advantageous location within the home.

Wireless network behaviour

The adaptive nature of the 802.11 protocol allows the radio to change its transmission characteristics to maintain data integrity. Known as 'rate adaptation', various techniques are used by Wi-Fi radios to determine the optimal data transmission rate based on existing environmental conditions.

Different manufacturers employ different algorithms, however, all of them monitor the same channel conditions (including detected interference, data error rates, and number of retransmissions) and will lower the data rate until error rates are below acceptable levels. When conditions improve, the algorithms also allow for an increase in the data rate (up to the maximum level), in optimum conditions. This accounts for the variations that users see in the available PHY Rate reported by their device.

Due to rate adaptation, the PHY Rate of the radio can be used to determine the quality of the Wi-Fi link. The rate adaption algorithm reports the rate that the radio is capable of supporting, given the signal quality. In the presence of data errors, the PHY Rate begins dropping in incremental steps (as opposed to a continuous, steady drop) until an acceptable data error rate is reached. The radio may also decrease the rate further by changing the modulation type to a less interference prone and slower scheme. When conditions improve, rate adaptation allows the radio to raise its PHY Rate, improving throughput, as long as data integrity is maintained (up to its maximum PHY Rate).

Trouble-shooting Wi-Fi performance

There are many reasons why your wireless network may not be fully optimized, causing performance to suffer. In this chapter, we will outline the probable causes of performance problems.

Note: Items in this chapter are listed in order _ most severe impact to least severe impact.

Interference

If you are experiencing poor performance on your Wi-Fi network despite being within range of the access point (router), the most likely cause is interference. The spectrum that Wi-Fi operates within is unlicensed and everyone is free to use it. The Radio Frequency (RF) energy used by microwave ovens falls within the 2.4GHz frequency band, which was the initial reason that the spectrum was unlicensed. Wi-Fi is designed to inter-operate with competing RF energy sources and devices, but their presence may affect the data rates and range of the Wi-Fi network by periodically blocking users and access points from accessing the shared air medium, sometimes dramatically.

Adaptations to the modulation type and coding by the Wi-Fi access point to improve data quality impacts performance of over-the-air transmission, and these adaptations are reflected in the PHY Rate. In addition, the 802.11 protocol allows for retransmissions of data packets. These retransmissions are independent of the 802.3 Ethernet networking protocol and will exist whether the data is Transmission Control Protocol (TCP) or User Datagram Protocol (UDP). Interference triggers 802.11 retransmissions and, if severe enough, communication ceases, regardless of the PHY Rate. High interference levels create a ‘catch-22’ where the radio slows its data rate, which in turn exposes the data transfer to even longer periods of interference. This is another benefit of optimizing the throughput rate as much as possible, because it minimizes transmission time in the air medium. See *Wireless network behaviour* above for a further discussion of how the radio adapts its modulation and coding to preserve communication under less than ideal conditions.

The 2.4GHz band is subject to the most interference due to its heavier Wi-Fi usage (co-channel and adjacent channel interference) and wider range of non-802.11 interference. Understanding interference and procedures for minimizing their effects on your wireless network are also covered here. Keep in mind that the implementation of the 802.11 protocol can be sophisticated and very adaptive and has many mechanisms for mitigating interference. The performance of wireless networks even in the presence of interference is improving all the time as the technology evolves.

Co-channel interference

Co-channel interference refers to the reduction in capacity of a channel due to the number of other users sharing the channel. Having multiple clients on the same channel competing for transmit time is called ‘interference’ but is in fact a co-operative exchange, with the competing clients taking their turns communicating to the access point – much like a conversation within a group of people. In 802.11 these are not interferers, per se, because the 802.11 protocol allows for a co-operative and reasonably fair sharing of the airtime. The more users that are sharing the channel, the less time allocated to any one particular user – so the individual user’s access to the network is reduced. This is a well-managed function of 802.11 and is much less an impairment than the other forms of interference.

Co-channel interference can be minimized by choosing the channel with the least number of users on it. There are several utilities available to help you choose a lightly used channel.

Overlapping channel interference

Radios operating on an overlapping channel generate what is called 'overlapping channel interference' and are in fact truly interfering with other channels on the Wi-Fi network. An example of this is one network operating on 2.4GHz channel 1, and another network on channel 2. These channels overlap in terms of their RF spectrum use, but clients on channel 1 cannot decode frames from clients on channel 2.

No one is taking turns, and the transmissions of each of the radios simply trample the transmissions of the other. The data transmission of both networks is seriously degraded. For this reason co-channel interference is much preferable to overlapping channel interference. In some cases, even adjacent (non-overlapping) channels may cause interference if the adjacent signals are high enough, so that the receiver filter cannot eliminate the interference.

Overlapping channel interference is avoided by adhering to the regimen of operating all access points that are sharing the local environment only on channels 1, 6, or 11. For a complete explanation, refer to *Wi-Fi fundamentals* discussed earlier in this guide.

Another type of interference, Adjacent Channel Interference, refers to non-overlapping channels (2.4GHz channels 1, 6, and 11) where strong signals present on one channel may leak into another channel due to insufficient filtering. This type of interference will present similar symptoms to Overlapping Channel Interference, namely, higher noise present on the adjacent channels.

Interferers in the 2.4GHz frequency band

The 2.4GHz unlicensed ISM band has a wide variety of *interferers* that may affect the operation of your Wi-Fi network or devices. Some of these may or may not be 802.11-based.

Some examples include:

- Microwave oven (major offender)
- 2.4GHz cordless phones
- Proximity sensors
- Wireless mouse
- Wireless bridge
- Set-top boxes
- Wireless audio devices: headsets, headphones or speakers
- Bluetooth devices
- Wireless video/surveillance cameras
- Outdoor microwave links
- Wireless game controllers
- Fluorescent lights
- WiMAX
- Bad electrical connections
- RF leakage from Direct Satellite Service (satellite TV)

- Baby monitors
- Neighbour's wireless devices
- Certain external monitors and LCD displays (may emit harmonic interference, especially in the 2.4GHz band near Channel 11)
- Fluorescent bulbs
- Lift motors
- Wireless Internet Service Providers (WISPs)

Using one of the following strategies can help minimize the effect of these *interferers* on your Wi-Fi network:

1. Set the channel selection on your Fibre Optic Router to 'auto' via the EWI and reset the unit. Upon start up, the radio scans for and uses the channel with the lowest amount of interference.
2. Manually change the channel selection to see if another channel improves your performance.
3. Operate your router on the 5GHz band (if your client devices are 5GHz capable).
4. Minimize the number of nearby Bluetooth wireless devices. These could include a wireless mouse or printer.
5. Avoid proximity to any suspected interference generator such as a microwave oven – for both the access point and the client. Particular care should be taken near the access point as it generally stays in a fixed location. This location should be as optimal for your wireless network as possible.

Interferers in the 5GHz frequency band

The 5GHz band also has their share of *interferers*, although the list is much shorter, and their presence is less likely. Potential sources of interference in the 5GHz bands include:

- 5GHz cordless phones
- Radar (weather or military), limited to the DFS channels
- Perimeter sensors
- Digital satellite
- Nearby 802.11a or 802.11n WLANs
- Outdoor wireless 5GHz bridges

Attenuation and weak signals

Wi-Fi signals experience attenuation due to the distance from their source just like any other radio. This signal attenuation subsequently causes the radio to be less effective and throughput suffers. Eventually, connectivity is lost when the signal becomes too weak. There are essentially two factors that affect signal attenuation between the access point and the client, and those are range (or distance), and attenuation due to obstructions.

Range

The amount of distance or range that can be tolerated between an access point such as the Fibre Optic Router and any client device is affected by several factors. Some of these factors are built into the hardware of the receiving and sending devices, such as power amplifiers on transmitters to boost power, and low noise amplifiers on the receivers to make them more sensitive. Transmit power can only be increased so far, due to regulation, in which case most access points operate at the maximum power legally allowed for transmission. An overly sensitive receiver also picks up more interference, so there is a balance point where transmit power and receiver sensitivity are optimized for a specific application whether it be in a business environment or a subscriber's home.

Physical obstruction interference

To maximize range and reception, it is helpful to know what structures and materials affect Wi-Fi signals. Router placement, orientation, and turn-up details common building materials and their effect on Wi-Fi signals. Understanding these variables and building your network with an awareness of the effects of physical obstructions will minimize problems in this area. HCB recommends following these guidelines when optimizing your Wi-Fi signal path:

- Metal structures reflect and scatter Wi-Fi signals. These can include anything with metal framing, like ductwork, electrical panels, metal roofs, mirrors, cubicle walls, metal furniture, or less obvious materials like concrete or stucco that are reinforced with metal mesh. Transmission through building structures that have continuous walls that are lined with metal coatings or foil may be extremely limited. Metal is most problematic when it is located in close proximity to the access point (router) as it may also affect the radiation pattern of the antennas. Wi-Fi signals will not penetrate metal enclosures.

- Your wireless connection may have a shorter range or a slower speed through walls made of non-porous materials.

- Tinted glass panes (such as low e windows) have metallic coatings and can attenuate Wi-Fi signals.

About client device limitations

Client devices generally have less sophisticated Wi-Fi capabilities than the access point (router) due to size and cost limitations. While an access point may have multiple antennas, MIMO technology, and the ability to support both frequency bands (resulting in a high available throughput rate), client devices are often limited to a single antenna and the 2.4GHz frequency band. Wi-Fi throughput rates are determined by the least-capable device in the link which is usually the client. Because of their compact construction and (usually) single antenna, client devices such as smartphones and tablets can be more sensitive to device orientation and may suffer slow throughput because of poor reception. This is inherent in the design of these devices and needs to be accommodated by the user staying within a reasonable range of the access point.

More capable Wi-Fi clients such as laptop computers often have multiple antennas, MIMO technology, and dual band radios. These clients are specifically designed to operate effectively over a wireless network and will be able to take best advantage of the data throughput provided by the access point.

Summary 2.4GHz Optimization

From a best practice standpoint, HCB recommends following the procedure below to optimize 2.4GHz Wi-Fi performance.

Optimizing performance

1. From the Fibre Optic Router EWI, navigate to Wireless > 2.4GHz > Radio Setup.
2. Ensure the Wireless Radio is 'On'.
3. Ensure Wireless Channel is set to 'Auto'. **Note:** If interference persists, manually selecting channels is recommended until you achieve the best performance.

4. Ensure your 'mission critical' applications are using the 5GHz band. **Note:** Ensure any subtended wireless devices are 5GHz band compatible (802.11ac).
5. Avoid proximity to suspected *interferers* (on page 19).

- Bluetooth printers
- Microwave ovens
- Ensure the router is in an optimal location and is not susceptible to random movement.

Sample throughput rates

Real world throughput rates will be dictated by the type of client that is communicating with the Fibre Optic Router. The move to 802.11ac clients with higher levels of MIMO will certainly increase over the next few years however, many consumers still have older devices that may negatively impact their user experience. In theory, a 3x3 client can expect about 75% of the speeds demonstrated with 4x4 based client; a 2x2 client can expect 50%; and a 1x1 25% of the 4x4 speed. The table below summarizes best case speed expectations for 802.11n and 802.11ac networks over the 5GHz band for each level of MIMO client.

Maximum Client Performance at 5 GHz (optimal)		
MIMO Level	**802.11n (40 MHz Channel)**	**802.11ac (80 MHz Channel)**
1 x 1	65 Mbps	190 Mbps
2 x 2	130 Mbps	375 Mbps
3 x 3	195 Mbps	560 Mbps
4 x 4	258 Mbps	730 Mbps
Note: Values shown above are estimated and may vary based on your specific environment.		

The results above reflect a maximum expected performance level since Wi-Fi is impacted by both distance and the physical environment of the house. Wi-Fi performance over distance depends heavily on the transmit power and receive sensitivity of the clients. Maximum coverage is achieved when both the router and the client are transmitting at the maximum regulatory levels and both use high performance LNAs (Low Noise Amplifiers) to obtain maximum receiver sensitivity. This is generally not the case for battery operated devices due to battery-life issues and the added cost to support the maximum regulatory levels. With the lower power clients, the Wi-Fi range may be dictated by the failure to acknowledge uplink requests (ACKS). Client sensitivity is also important and by using LNAs, improved sensitivity of 5-6dB is generally obtained. Again, this consumes more power and has increased cost, and as a result, may not be available on many clients, particularly battery-operated devices. Moreover, these compact designs may not have the adequate package size to support multiple antennas or placement of the antennas in the most advantageous configuration. If a particular house still requires better coverage due to challenging Wi-Fi environments (reinforced concrete, stucco, in-floor heating systems), HCB recommends the use of Wi-Fi devices available with Ethernet or USB connections that use high performance 3x3 or 4x4 radios.

Additional reading

The Wi-Fi Alliance (a trade association promoting and certifying Wi-Fi technology) has articles and videos about understanding 802.11n – go to https://www.wi-fi.org/.