Putting a Box Around Wi-Fi Performance

Characterizing Performance and Setting Expectations

A Technical Paper prepared for SCTE/ISBE by

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Introduction

Arthur C. Clarke said, "Any sufficiently advanced technology is indistinguishable from magic." For most consumers, wireless and Wi-Fi approach magic so myths and misunderstandings crop up. Sometimes it is difficult for a consumer to separate all the contributing factors that go into, for example, the performance of a streaming video. Contributing factors can include:

- The actual app
- Wi-Fi performance of the mobile device
- Wi-Fi performance of the home AP/Gateway
- Congestion of the home Wi-Fi environment
- Home broadband connection performance

This paper will look at some commonly available data on APs or gateways that can reliably suggest Wi-Fi issues. Actual examples from a field study of two gateway deployments will be reviewed to illustrate the power of available data. We will also review aspects of Wi-Fi technology that can contribute in unexpected ways to the actual performance experienced by a consumer to make Wi-Fi look a bit less like magic.

Understanding Wi-Fi Performance

Characterizing Wi-Fi performance is challenging because of the wide variety of factors that can influence the actual Wi-Fi throughput of a device as well as the consumer's perception of that performance. We will also consider other metrics that might not be as readily available but could be helpful for evaluating the health of a home Wi-Fi network or diagnosing problems.

Thanks to two operators who have shared monitoring data, we will also look at putting that analysis into practice using some recent data from two gateway deployments.

1. What is Good Performance?

To set up key performance indicators (KPIs), performance targets need to be understood and measureable. Setting reliable Wi-Fi KPIs is a struggle because good Wi-Fi performance for a consumer often means that Wi-Fi is invisible. Breaking consumer expectations down into easily measured quantities like data rate or packet latency is challenging.

From a more technical perspective, the average consumer's Wi-Fi expectations are not always compatible with the limitations of the technology. Consumers want their devices to associate quickly and remain connected while their owner is using them. But when conditions change, they also want their devices to switch to a better network easily, even though a Wi-Fi device may have trouble determining when a problem is 'temporary' and when it needs to move on. The number of Wi-Fi devices in consumer homes has been steadily increasing, but at least one study has shown that after 25 devices, current Wi-Fi protocols begin to break down [1]. Consumers may not understand the number of devices on a Wi-Fi network can affect its performance, even if individually the traffic from each device is small.

The data rate needed to provide good performance is also hard to characterize. For example, when the device is a mobile phone, the required data rate is usually much lower than watching video on a wireless set-top box from a cable operator or viewing Over-the-Top (OTT) programming on a laptop. On the other hand, the consumer might be testing their connectivity using a web speed test portal and want to see the absolute highest number possible. When a consumer is having an issue with their Wi-Fi, it can be challenging to explain to a customer that a high speed throughput may only be achievable when just one high performance client device is connected or that moving from a wired connection to a wireless connection means that upstream and downstream traffic is now contending for the same wireless bandwidth.

Finally, other intangibles may creep into a discussion of Wi-Fi performance. For example, is a consumer willing to trade off the speed with which their device moves between APs for improved privacy? To protect their privacy, a consumer may want the content of their communications encrypted or even to make use of MAC address obfuscation. Additional layers of security can make it harder for a device to migrate seamlessly. At least some consumers seem to be willing to trade a level of personal information for improved Wi-Fi performance and mobility – such as by using an operator's network of hotspots.

For a better understanding of the technical causes of many Wi-Fi performance issues, we will next look at factors that affect Wi-Fi

2. What Factors Can Affect Wi-Fi performance?

As was mentioned earlier, a consumer's experience of Wi-Fi performance can be affected by many factors. Untangling the effects from their causes can be challenging.

We will divide our analysis into three main categories as shown in Figure 1:

- Device characteristics, capabilities and regulations
- Environmental conditions
- Service characteristics and expectations

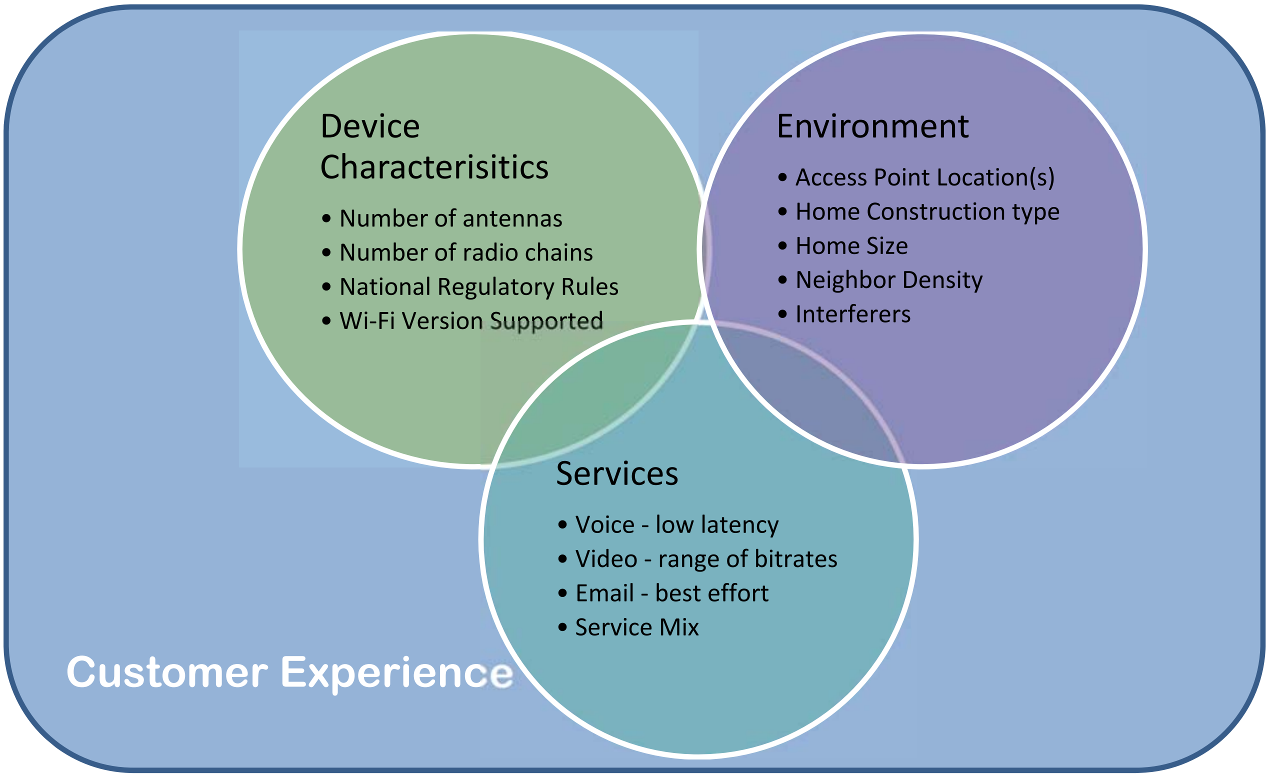

Figure 1 - Factors Affecting Wi-Fi Customer Experince

2.1. Device Characterisitics

The characteristics of the access point (AP) and station devices used in a home obviously can affect the quality of the services delivered over Wi-Fi. If a client device is only a 1x1 radio supporting a single spatial stream, then its top data rate will be about half that of a 2x2 client device that can support two streams. If a new access point deployed into a home is a state of the art dual band concurrent 4x4 IEEE 802.11ac Wave 2 system, but the consumer only has older 2.4 GHz IEEE 802.11n devices, the performance of the Wi-Fi network is set by the IEEE 802.11n devices and the 5 GHz radio is entirely unused. A consumer might see some improvement just due to increased receiver sensitivity or a faster processor, but it will not really be related to the Wi-Fi network performance. A more subtle effect is that a mixed network of old and new devices will tend to perform worse because the older devices will tend to consume more airtime for the same bitrate, leading to the entire network under-performing when older devices are active.

Device transmit power is an important factor to consider. Most APs are set up with their transmit power level as close as possible to the regulatory limits, but it is important to keep in mind for the 5 GHz band that the allowed levels across the band are not uniform in many countries. The maximum allowed transmit power for both the 2.4 GHz and 5 GHz bands also varies from country to country.

The regulations are often written in terms of conducted power, or how much power a radio is allowed to send to its antenna(s). Some countries also regulate how tightly the antenna(s) of a wireless device concentrate the radiated power as compared to a true isotropic radiator. This improvement or deviation from an isotropic radiator for an antenna is measured in dBi (decibels from isotropic). For example, the United States allows up to 1W of conducted power with a 6 dBi antenna for 5 GHz channels in the U-NII-

1 band with a resulting Effective Isotropic Radiated Power (EIRP) of 36 dBm. If an AP moves from the U-NII-1 band to the U-NII-2A band, for example from channel 42 to channel 58, it must cut its power by 6 dB since it can transmit at most 30dBm EIRP in that band. Figure 2 shows the variety of power levels and EIRP restrictions with which an AP or client must comply.

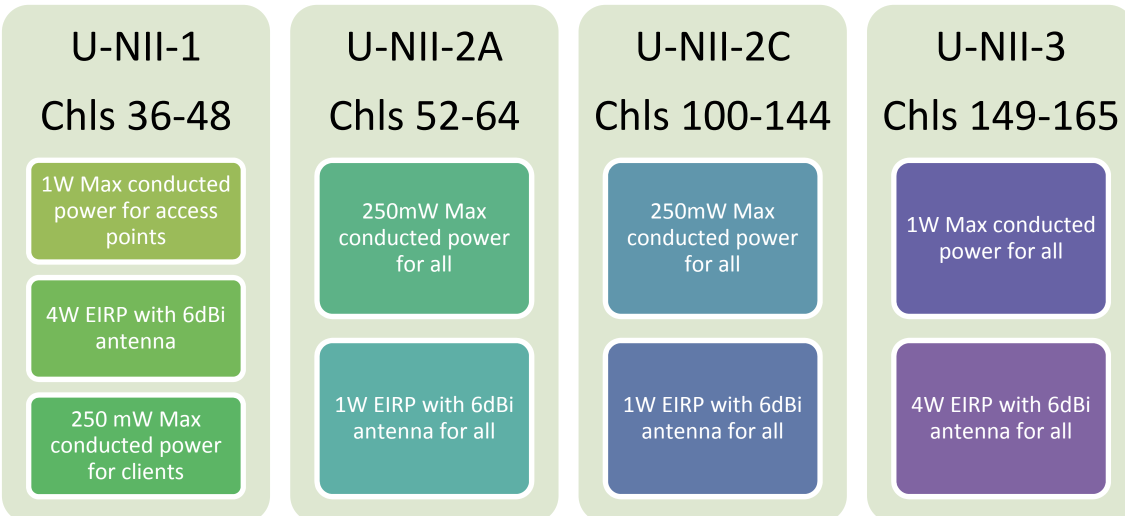

Figure 2 - North American Transmit Power Rules for 5GHz

Most European countries have reduced power limits compared to the US and Canada. For instance, if that same AP discussed earlier was in Great Britain, its power limit would have been 200 mW or 23 dBm for both bands. The 2.4 GHz band usually has a single maximum transmit power level, though the level does vary from country to country. For example, the 2.4 GHz level in Great Britain is 100mW, while in North America it is 1 W.

In addition to the variations in allowed output power, the allowed channels also can vary from country to country. Until a short time ago, weather radar was the sole user of some parts of the 5 GHz band. Once technology was available that could demonstrate the detection and avoidance of those radar signals, many countries opened those bands to APs that could demonstrate the ability to quickly leave the spectrum when it is being used by radar, but the rules are not uniform and the technology is still unevenly deployed. One technology is Dynamic Frequency Selection (DFS) that enables an AP to detect radar and rapidly vacate the channel. Another technology required in some countries to access 5 GHz bands is called Transmit Power Control (TPC). TPC limits transmission power so that the accumulated power of the active radios will not interfere with far away radar systems whose power may not be high enough to reach the local devices' DFS limits.

The Wi-Fi version supported by a device directly influences its maximum throughput, but as mentioned earlier, it can also affect the overall throughput of the home Wi-Fi network if it is congested. Based on surveys of devices connected to gateway APs in the field, people do tend to gradually eliminate older devices from their home networks. In an interesting result, a group of newly deployed operator gateways were compared to a group of older existing units in the same geographic area. The new gateways had fewer devices connected to them, even though the older units were single band and the new units supported 2.4 GHz and 5 GHz. One possible explanation is that people were less likely to bother to update all of their older devices to a new AP and SSIDs, though they might not necessarily have bothered to remove those devices from their existing network.

2.1.1. Addressing Device Characteristics

To address the variation in power across a band and the variation in allowed power between the 2.4 GHz and 5 GHz bands, the default settings of an AP may choose the highest power bands first. In some areas, if the congestion of those bands is too high, considering a switch to a lower power channel might be worthwhile, but in many cases the higher power channel will still allow much better performance. A difference of 6 dB in the transmit power can be the difference between 256 QAM and 64 QAM, or 200 Mb/s in 40 MHz versus 120 Mb/s. On the other hand, when more than 25 stations are contending for airtime, the overall efficiency of the channel decreases rapidly [1].

The addition of DFS and TPC, where required to access additional 5 GHz bands, can provide real advantages to APs with that technology. The number of usable channels is increased, and the number of potential interferers is often still quite low. In the long term, these advantages may fade as others also deploy equipment that can enter the higher bands, but in the short term, deploying DFS and TPC capable equipment allows more flexibility and gives the potential for higher bit rates.

Encouraging a consumer to stop using older equipment is difficult, but if a home Wi-Fi network tends to be congested during prime-time each day, the consumer may be interested to hear that their old 1x1 IEEE 802.11n tablet is taking up 30% of their network during peak times. Data about congestion and airtime utilization is not yet standard on every gateway or AP. But when channel utilization information is available, it can be very helpful to determine if a home Wi-Fi network is struggling. More sophisticated analysis of channel utilization can differentiate between other Wi-Fi signals and noise. This level of analysis can provide information about whether a Wi-Fi networking issue might be due to interference, like a microwave oven, or if too many other APs and clients are causing congestion.

A good way to communicate network utilization information to a consumer may be to present a bar graph or pie chart summarizing the last 5 minutes or last hour of traffic by the percentage of airtime used by each client device versus the packets or bytes consumed or sent by each device. People tend to think in terms of the bits or bytes crossing the network, but for Wi-Fi, the aggregate time that a device occupies the wireless network can be a better indicator of problem devices.

2.2. Environmental Factors

For this paper, we will consider environmental factors to include the surroundings of the AP and its client devices that the Wi-Fi network is working within.

When considering factors that affect Wi-Fi performance, home construction characteristics is an obvious factor that might restrict the availability of high performance Wi-Fi. The type of dwelling can also play a major role as well. For instance, in an area with single family dwellings, a Wi-Fi signal might have to traverse at least two walls to go between two houses, while between two apartments, the signal may only have to traverse a single wall or floor. If the home is very large, an AP may have to traverse several walls within the home to reach a device. For each wall or floor that has to be crossed, the modulation rate will drop, and accordingly the bit rate will drop as well. A large home may require additional access points if a high bit rate is desired. The variation in building materials from region to region and country to country is also a factor to keep in mind. The average U.S. household internal wall is just drywall and some wooden studs, while in other parts of the world those internal house walls might be cinder blocks reinforced with rebar.

Using 2.4 GHz bands will generally give lower speeds but provide a longer reach than 5 GHz, but there are an enormous number of factors that can affect the actual truth on the ground of that statement. For example, what wireless devices does the consumer have? If the consumer still mostly has 2.4 GHz devices, then higher 5 GHz speeds are meaningless (though they look great in **BOLD** on the packaging). Many building materials have different transmission characteristics at 5 GHz than 2.4 GHz. A 5 GHz transmission may be attenuated less or reflected better than a 2.4 GHz transmission even though the 5 GHz signal experiences more free space loss. Unexpected transmission characteristics can mean that it is difficult to predict whether a device will perform better at 2.4GHz or 5 GHz.

Related to the challenges of construction and material variations is the placement of the AP within the home. If an AP is placed centrally, then its signal will encounter on average fewer walls than if it is placed on the edge of the home or in a basement as shown in Figure 3. Even less obvious placement issues can cause problems. In one case, a customer complained about a gateway placed inside a centrally located solid wood cabinet. When the gateway was placed on top of the cabinet while troubleshooting, its signal level became 10 dB higher.

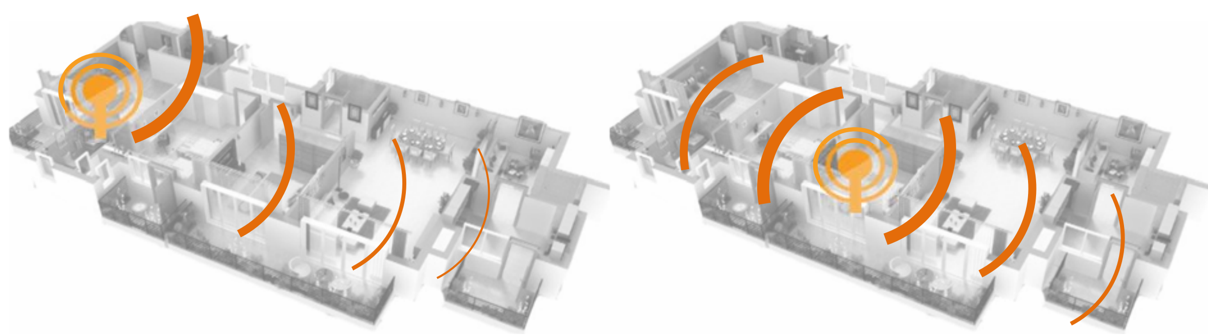

Figure 3 - Central versus Edge of Home Placement

Interference from other APs is pervasive in the urban and suburban residential environments. In the 2.4 GHz band, the problem of neighboring access points is more severe because the band only has 3 non-overlapping 20 MHz channels. While with 802.11n the option for 40 MHz channels was added to the 2.4 GHz band, realistically few APs have that option in deployments.

A recent ARRIS study compared two groups of APs. One group was in the United Kingdom and the other was in Canada. We used AP scans to estimate Wi-Fi channel availability. Figure 4 shows the results from the NA site in the 2.4 GHz band. Only about 12% of the North American (NA) gateways had the option to run a 40 MHz channel in the 2.4 GHz band. Looking at that same group of NA gateways, only 37% had at least one 20 MHz channel available without any other APs present.

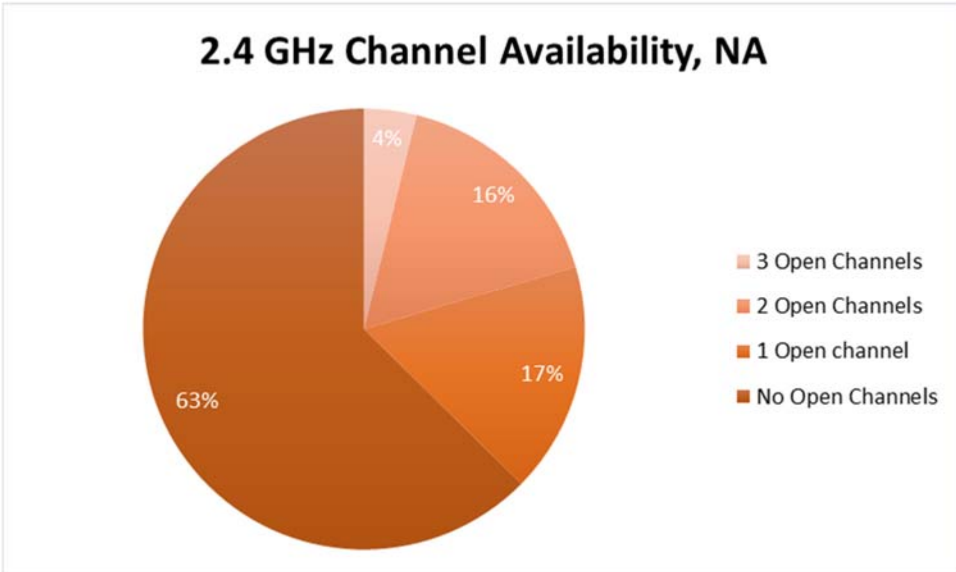

Figure 4 - 2.4 GHz Channel Availability, NA

The majority of APs had to contend with at least low level interference and congestion on their chosen channel. Figure 5 below shows the overall distribution of the Overlapping Basic Service Set (OBSS) signals seen by two groups of APs under study.

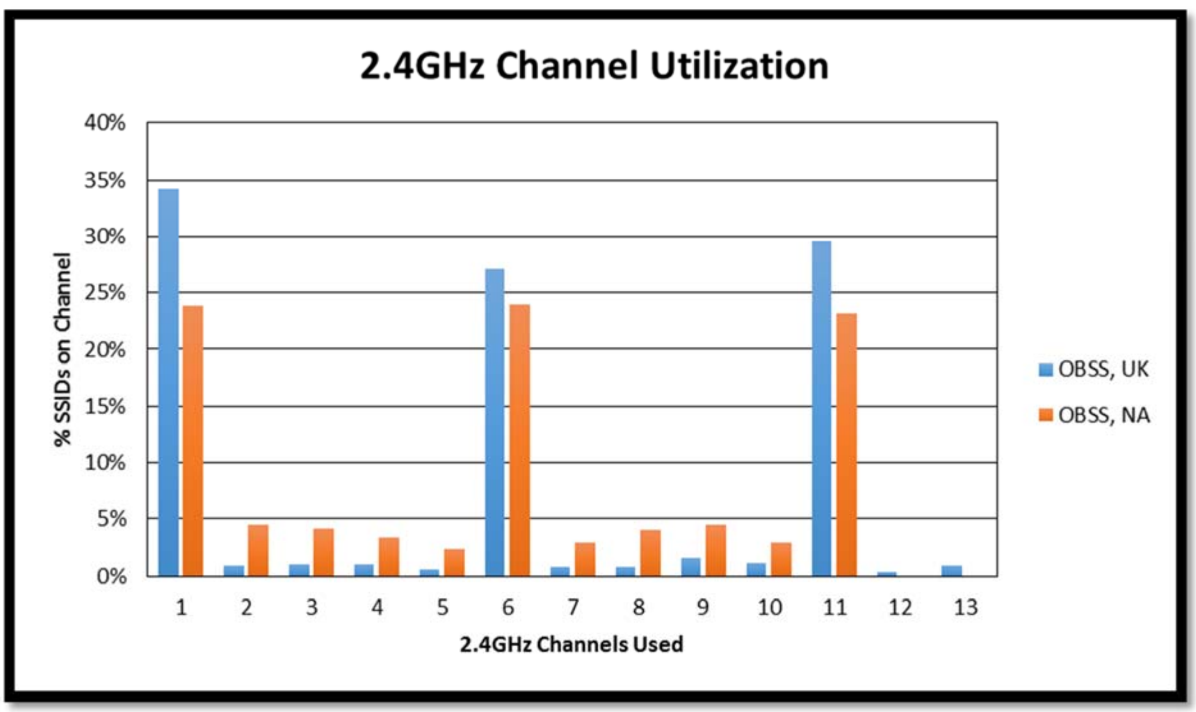

Figure 5 - Comparison of 2.4 GHz Channel Utilization

One interesting difference between the two sites was that the North American site had more OBSS signals in the interfering channels between 1, 6, and 11, the only non-interfering channels. Many consumers do not realize that a 20 MHz Wi-Fi channel takes up several "channel" numbers. A web GUI may show that there are many APs on channel 1 and 6 and none on channels 2 through 5, so a consumer may think that going in between 1 and 6 will let them access unused spectrum. Unfortunately, while several APs on the same channel will detect each other's transmissions and share the channel, an AP that is on a different channel will not have its transmissions synchronized by Wi-Fi protocols and its transmissions will appear as noise to any other channels that it overlaps.

While overall throughput can be degraded by the presence of several APs on the same channel, the throughput is reduced because of contention, time spent by the various stations contending for air time. When the air has been seized by a station, it is (theoretically at least) capable of reaching the highest bit rates supported by its components and the overall channel because all the APs and clients can detect its transmissions and back off appropriately. When the OBSS is between the non-overlapping channels, its transmissions appear as noise to the other channels, degrading the overall throughput possible for all stations in channels that overlap that OBSS's channel choice.

Widespread use of the 5 GHz band is still relatively recent compared to the 2.4 GHz band. In most countries, it also provides more bandwidth than the 2.4 GHz band. In the same gateway field survey, all NA gateways had at least one 40 MHz channel with no other APs, and almost all gateways (99.8%) had at least one 80 MHz channel without any contention. Figure 6 below illustrates that the larger number of channels available for unlicensed use in NA allows OBSS interference to be reduced compared to the UK distribution which had only just allowed additional channels above the lowest 5 GHz band (U-NII-1).

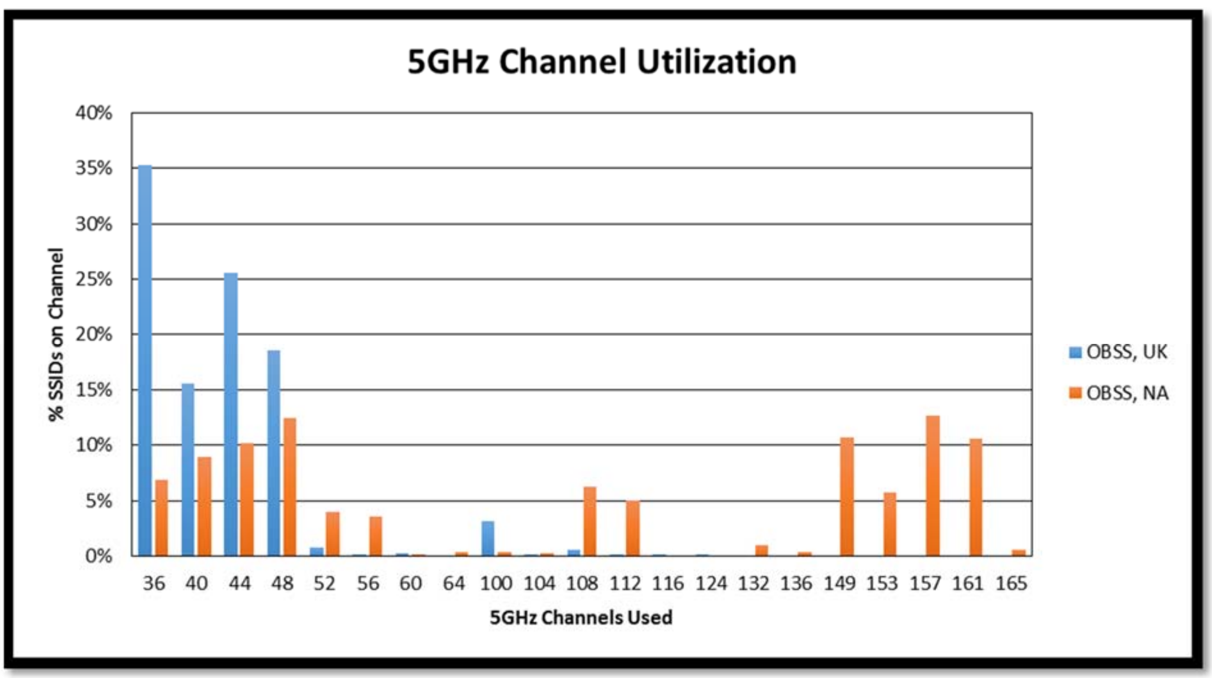

Figure 6 - Comparison of 5 GHz Channel Utilization

As Figure 6 suggests, the UK gateways on average saw more interference. Roughly 60% of the gateways could hear at least one other BSS, with about 14% of the gateways potentially experiencing substantial competition for the air from another co-channel AP.

2.2.1. Addressing Environmental Factors

Education and good installation protocols for installation technicians are great ways to address many environmental factors. During installation, the reach of an AP can be verified to cover the parts of the house important to the consumer. Installation is also a great time for the technician to educate the consumer about possible issues. It is important to realize that while most people in the cable industry have at least a general idea about how radio frequencies work – that is not a good assumption for the general public. The prevalence of interfering 2.4 GHz channel assignments in NA shows that more education is needed to promote good wireless practices. The problem of APs in the overlapping channels also suggests that more thought could be put into the options that users are given. Since an overlapping channel is likely to cause problems, those choices could be removed from the user interfaces.

Addressing crowded Wi-Fi areas, such as apartment buildings can be challenging. As mentioned earlier, getting the latest technology that allows an AP to have the most flexibility to search out an unused or lightly used band is important. Though TPC is not mandated in all countries, its use may also help in crowded environments, such as apartment buildings. If each set of radios actively seeks a lowest useful operating power level, the overall levels can improve. Also, IEEE’s latest standard in development for Wi-Fi, 802.11ax, is specifically chartered to improve dense environments, though its improvements will probably only show up in the marketplace gradually over the next 2-4 years.

2.3. Services

The services provided over Wi-Fi are continually evolving, just like the larger Internet. The continuing pressure to improve Wi-Fi coverage and speeds is in part due to the continuing demand for mobility and video. It is important to note that the individual demands of each specific service can influence the Wi-Fi technology needed. Some Wi-Fi network operators also support multiple services divided by SSID or use different packet tags for different services.

When considering a service with strict Quality of Service (QoS) requirements, some of the flexibility and fluidity of Wi-Fi may cause problems. While a standard Wireless Multi-Media (WMM) priority marking will provide an overall service level, problems with interference or congestion can still result in sub-par service. A WMM prioritization gives a packet a statistical edge on transmission over other competing packets, but it does not provide strict priority scheduling. Proprietary solutions have been floated to provide more deterministic solutions for demanding services such as live video or voice. But without a standardized solution offering coordination across multiple vendors, these approaches can be of limited help in dense deployments.

Some of the new technology proposed for 802.11ax, mentioned earlier, may be used to provide more deterministic scheduling since it adds OFDM transmission to multiple recipients from an AP and scheduled OFDMA transmissions to the AP from multiple recipients. This ability to schedule upstream transmission particularly could lend itself well to improved QoS rather than the current system which is almost entirely contention based. However, it remains to be seen how much of the standard will be implemented in the commercial chipsets. QoS features have been included many times in Wi-Fi standards, but have not been mandatory.

From a device's MAC address, a database lookup in the connected cloud could provide information about the device type, probable use cases, and sometimes even the antenna configuration and optimal setup parameters. A more elaborate system might even monitor a device's behavior in real time to notice web-based speed tests or other special applications that need particular treatment. By using factors like the device MAC address and service characteristics as well as any available device history, a Wi-Fi management system can often predict the mean data rate a device would need to provide what the end user would consider good service.

2.3.1. Addressing Service Concerns

Planning is critical to a successful service deployment. If a new service is planned as an overlay to existing APs and possibly known clients, any opportunity to characterize the current service levels should be taken. Because Wi-Fi is at its heart a protocol based on statistical analyses, the performance on any one service cannot be guaranteed at all times.

Based on characterization of the services provided, the intelligent use of built-in monitoring tools can help to quantify the current performance of a home Wi-Fi network or an outdoor hotspot network.

Using QoS parameters to shape traffic flows can improve the performance of the overall Wi-Fi system in the home. Ensuring that hotspot traffic has a minimal effect on home user traffic is an obvious use case. More subtle issues can arise if open access regulatory considerations are taken into account. For example, is it also acceptable to prioritize traffic to an operator's STB over other traffic? Should the end user be able to set the prioritization levels? It is difficult to have a simple answer to these questions when the regulatory uncertainty for operators is also taken into consideration.

3. Putting it all together

Most APs and Wi-Fi enabled gateways can provide information about their connected clients as well as other information about the wireless surroundings. That information can allow an operator to understand the typical deployment situations of their Wi-Fi products. It may allow an operator to segment their market to better customize the products deployed to match the situations of different market segments. We will return to the analysis of recent field data from two product deployments to illustrate some of insights that can be gleaned.

Most APs can provide a client data table. It commonly includes a wealth of information about the clients such as the client MAC addresses and client capabilities, as well as information about client data transfers over the network, such as frames or packets transferred and error frames. One useful field is the RSSI or Received Signal Strength Indication. It provides insight into the signal level that an AP receives from each of its associated clients. It is not an absolute reference, since different models of APs may have different antenna configurations or other factors that influence the RSSI, but it is a good indication of the relative performance of different clients on an AP.

Figure 7 shows an example of an RSSI analysis from field results that shows the impact of regulatory limits and environmental factors, such as construction materials. Two groups of clients were compared. Both were connected to similar 3x3 dual band concurrent gateway APs. One group was in the UK, the other group was in North America. The 5 GHz results were quite similar, reflecting that the power limitations for client devices in the U-NII-1 band are very similar in both areas. The 2.4 GHz results were dramatically different, reflecting at least in part the difference in allowed client transmission levels. The 2.4 GHz results may also have been influenced by the different home construction methods. Generally walls in Europe tend to be thicker and provide more loss in the 2.4 GHz band. The thicker walls in Europe may impact the 5 GHz results differently since some building materials such as cinder blocks provide more reflected signal at 5 GHz than the US standard gypsum dry wall [2] but the difference in client transmit power is 10 dB alone.

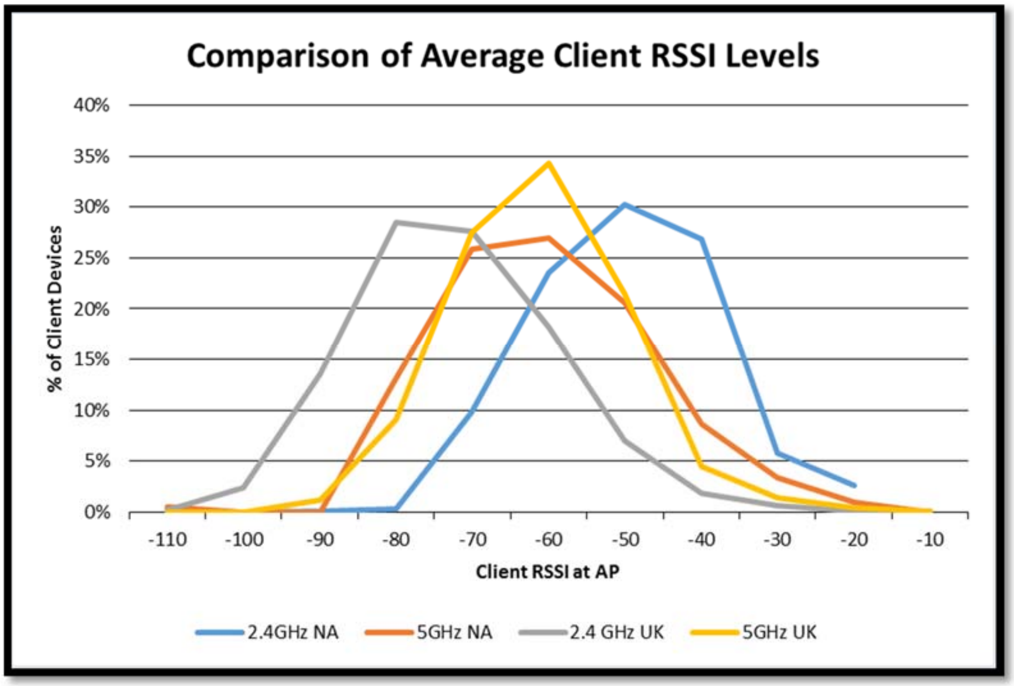

Figure 7 - Comparison of Average Client RSSI Levels

The RSSI values could also be sorted by the type of residential housing development to provide insight into the possible need for additional APs to extend service. If the clients from outdoor hotspots were analyzed, an operator might be able to determine if the coverage provided by existing hotspots was sufficient in an area or if another hotspot should be deployed to provide more uniform coverage over a certain area.

The utilization of the two bands can also be related to the power levels seen by the AP and the client devices. As mentioned earlier, some devices can shift from one band to another independently. As a part of the study described above, client devices activity was also tracked. We mentioned earlier studying periodic scans of the two deployments showed the comparative levels of congestion in both bands. Both areas had high levels of overlapping APs seen in the 2.4 GHz band and lower levels in the 5 GHz band. We looked at how many devices moved from band to band and how many tended to remain in a single band. Not surprisingly, the results differed quite a bit between the two markets as shown in Figure 8.

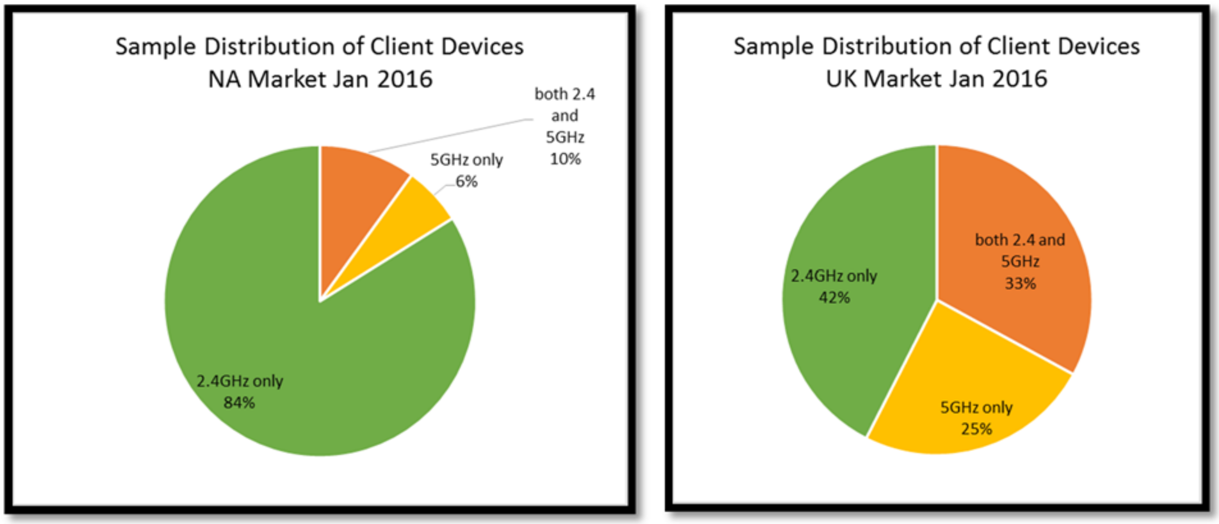

Figure 8 - Comparison of Client Distribution across 2.4 and 5 GHz Bands

In the NA market, where the allowed power levels are much higher for 2.4 GHz, relatively few devices shifted to the 5 GHz band either temporarily or permanently. In contrast, the UK group of devices were more evenly split between the two bands, with a third of clients shifting between the 2.4 GHz band and the 5 GHz band during the study period.

Other factors may play into these trends, but studying a representative sample of devices in similar situations can be leveraged into providing real deployment insight. In this case, a North American operator may want to concentrate on improving the 2.4 GHz experience since most devices reside there. An operator in the UK may want to consider 5 GHz augmentation at least as much as 2.4 GHz improvements since it is likely to provide the most visible improvement to their consumers. From a practical perspective, it could mean that a NW operator might favor 2.4GHz extenders when a person reports coverage issues, while a UK operator would want to consider dual band extenders.

Conclusion

We have considered components of the deployment challenges of Wi-Fi networks, including the Wi-Fi devices themselves, the environment the Wi-Fi network operates in, and the service expectations of the end consumer. The consumer's expectations of simple ubiquitous coverage were compared to the more complicated real world. Several examples from an analysis of two field deployments were given to illustrate the utility of existing MIB/Object data. We considered examples of actionable intelligence that can be gleaned from data analysis such as monitoring client distribution across the unlicensed bands and examining the spread of client RSSI levels. We also discussed how DFS and TPC can provide access to lightly used parts of the 5GHz band as well as potentially helping to control the overwhelming crush of activity in dense environments.

Wi-Fi networks are challenging to characterize and understand because they have countless factors affecting them, but with patience and method, they can be improved.

Abbreviations

AP	Access Point
DFS	Dynamic Frequency Selection
EIRP	Effective Isotropic Radiated Power – a measure of the total power emitted by a device compared to an ideal isotropic radiator
GHz	Giga Hertz
HFC	hybrid fiber-coax
HD	high definition
Hz	Hertz
IEEE	Institute of Electrical and Electronic Engineers®
MAC	Media Access Control
MIB	Management Information Base – SNMP database element
NA	North America
OBSS	Overlapping Basic Service Set
OTT	Over the Top video service – example Hulu® or Netflix®
RSSI	Receive Signal Strength Indication
SSID	Service Set IDentifier
TPC	Transmit Power Control
UK	United Kingdom
WMM	Wireless Multi-Media

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