Deploying and Optimizing the Next Generation Wireless Home

A Technical Paper prepared for SCTE/ISBE by

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Introduction

Delivering a seamless managed wireless and Wi-Fi experience for a residence or commercial subscriber is quickly becoming the de-facto standard when judging an MSO's services. The MSO's are shifting their attention to the quality of experience (QoE), proactive (e.g. PNM for Wi-Fi) wireless ecosystems and carrier grade versions of Wi-Fi for multimedia services like ultra-high definition (UHD), high definition (HD), audio and voice over Internet protocol (VoIP). The next generation wireless and Wi-Fi are being used to provide whole home coverage for cable subscribers. The wireless networks must be seamless, reliable and optimally designed to support multimedia services, faster data services (e.g., gigabit) and whole home connectivity.

When it comes to in-home wireless readiness, making sure that the customer's data, video, voice services along with low power long-range wireless Internet of things (IoT) (e.g., 802.15.4, Sigfox, LoRa wide area network, etc.) will run smoothly long after the technician has left the premises. Operators must also leverage the latest Wi-Fi amendments of 802.11x, address spectrum concerns and solve challenges with in-home wireless interoperability. In addition, the development of operational practices to not only identify the QoE throughout the home, but also characterize ways through analysis to improve the user experience when expectations are not met.

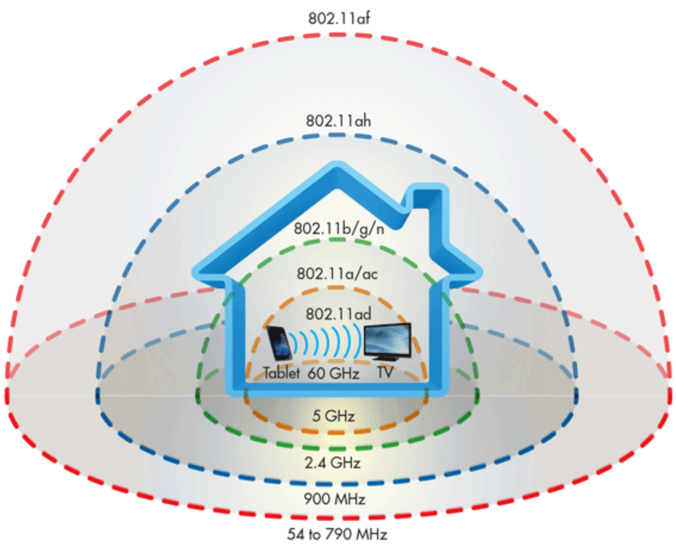


Figure 1 - Wireless at the Premises

A big part of the next generation home is wireless, in particular Wi-Fi. IEEE 802.11ac second wave access points or gateway routers (GWRs) are expected to dominate the global wireless local area network (LAN) market by 2018, with more than 80%[1] units shipped.

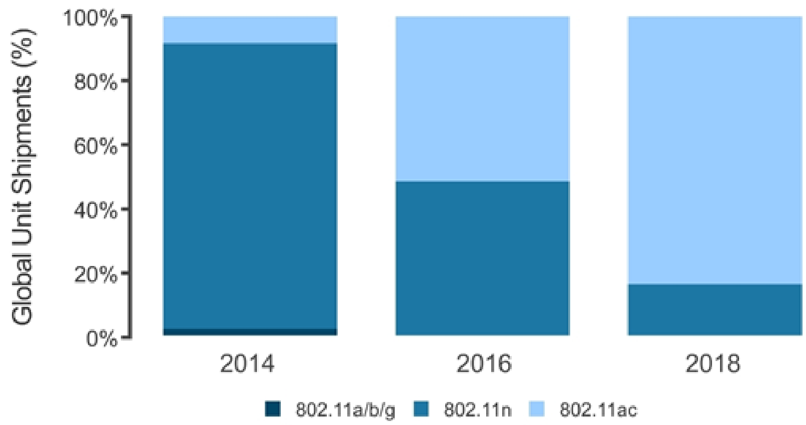


Figure 2 - 802.11ac GWRs Expected to Dominate the Global WLAN Market

Subscribers want a consistent wireless experience while operators are shifting to a managed carrier grade wireless experience. Carrier grade is not defined by the maximum throughput of a technology but by the minimum. Carrier grade key metric: supports up to four (4) simultaneous HD video programs, just as good as a quadrature amplitude modulation (QAM) channel over a hybrid fiber coax (HFC). This requires 40 Mbps minimum at a low packet error rate (PER) of 10^{-6} or better, 90% coverage or better of the living space on both 2.4 GHz and 5 GHz[2]. Multiple-input multiple-output (MIMO) and wider channels (40 MHz for 802.11n and 80 MHz for 802.11ac) allows a GWR to achieve higher rates for carrier grade metrics. Other technology that contributes to a delivery of a carrier grade experience is the network discovery and selection process; authentication and encryption methods used; and roaming features supported by a GWR. The Wireless Broadband Alliance (WBA) developed solutions and guidelines to improve the QoE for carrier grade Wi-Fi networks[3].

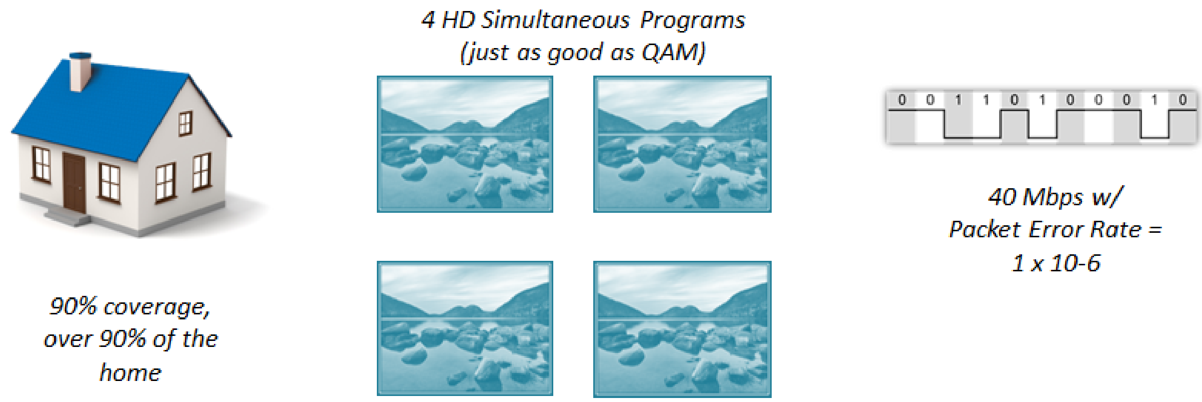


Figure 3 - Carrier Grade Wi-Fi

Managing the carrier grade Wi-Fi experience is equally as important in wireless communications. Cable operators will and must truly own the wireless ecosystem using managed devices (e.g., WGR) within the home. Coupling this with proactive network maintenance (PNM) for Wi-Fi (a working group within SCTE·ISBE), allows the operator to mitigate many of the problems associated with management of a wireless network. In addition, vendor incompatibles will degrade the QoE, driving the need for technologies like reference design kit for broadband (RDK-B). RDK-B is an open source software that allows MSOs to accelerate innovation in video and broadband networks[4]. The next generation subscriber will require the management of not just Wi-Fi but multiple low powered long-range wireless standards (e.g., ZigBee, Z-Wave, 802.11.15.4, Bluetooth Low Energy, LoRaWAN) requiring common access hubs or WGRs. Improved data collection is part of the service allowing the MSO to collect information via technical report (TR) 69, simple network management protocol (SNMP), Internet protocol detail records (IPDR), etc. Finally, the smartphone will be used as the central control point and gateway for these wireless devices.

802.11 Features

For an operator to provide the next generation managed carrier grade QoE, the features of the IEEE 802.11 amendments must be leveraged and deployment to the subscriber. The newer 802.11 standards and amendments improve RF multiplexing and modulation; support wider channels, more spectrum access, efficient media access control (MAC) layer communication and more spatial streams (multipath).

The current trend for the subscriber's home is to offer a gigabit wireless service to support a gigabit Internet modem service. Technologies like high throughput (HT) 802.11n will need to be replaced with newer WGR versions using 802.11ac, as most 802.11n devices offered 100 Mbps at best and few 802.11n devices offered the 600 Mbps as the maximum achievable of the amendment. 802.11ac offers a very high throughput (VHT) service, supports a roadmap to gigabit speeds of 7 Gbps and builds on 802.11n/g MIMO technology. However, most 802.11ac wave 1 WGRs come close to 1 gigabit while wave 2 WGRs will perform in the 2 Gbps range[5]. Operators are under pressure today to offer the newer waves of the 802.11ac amendment supporting 4x4 multi-user MIMO (MU-MIMO) and future 8x8 MU-MIMO.

802.11ac will allow dramatically faster broadband speeds, because of the physical changes in spectrum, multiplexing, modulation, channel sizes, spatial streams and efficient MAC. Additional spectrum may be leverage in 802.11ac over 802.11n, further opening the 5 GHz band, up to eight times the spectrum of the 2.4 GHz band[6]. Even though the 802.11ac amendment supports larger 160 MHz channels, it may be difficult to bond channels to support these size channels due to dynamic frequency selection (DFS) for radar usage. DFS limits a 5 GHz channel reuse, up to 16 channels may be used by radar systems. Other technologies like adaptive antenna technology, MU-MIMO, polarization features and channel optimization increase the potential for 802.11ac.

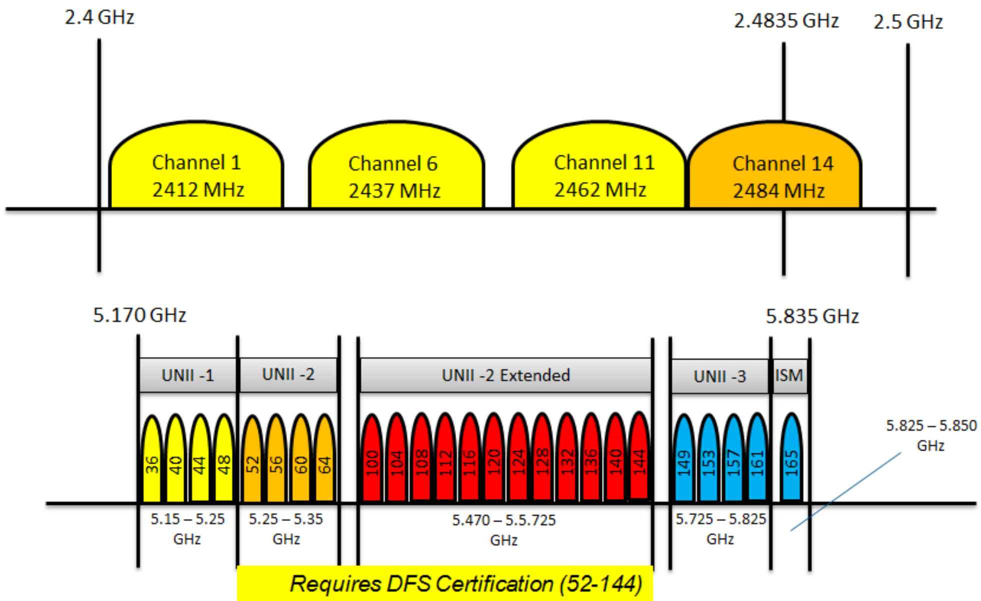


Figure 4 - 2.4 GHz and 5 GHz Channels (USA Only)

1. Multiple-In Multiple-Out (MIMO)

Multiple-in multiple-out (MIMO) radios were improved with 802.11n to provide better communication than earlier single-input single-output (SISO) communication. MIMO uses multipath RF propagation to increase the reliability and data rate of a Wi-Fi network. MIMO reliably allows multiple streams of data to be delivered to a subscriber's 802.11n customer premises equipment (CPE) using adaptive antenna diversity and multipath. In this example, the CPE must support more than a single antenna, a common issue for CPE. In addition, multipath might also create reflected streams, causing fading of a wireless signal where MIMO capability does not exist. The MIMO data rate function uses a technique known as spatial division multiplexing (SDM). In SDM, the data at the WGR is split into a number of spatial streams and transmitted through separate antennas to corresponding antennas at the receiver. The key here, is "corresponding antennas", most cable subscriber's 802.11n or earlier CPE did not support MIMO SDM.

In 802.11n MIMO, having three (3) spatial streams supports a data rate of 450 Mbps, enabling a far greater utilization of the available bandwidth if the CPE supports the feature. Since most operators want a balance of reliability with throughput achieving (3x3) or 450 Mbps is not possible using 802.11n as most customer owned devices offer around a 100 Mbps service. The current 802.11n standard allows for up to four spatial streams (4x4) or 600 Mbps, while 802.11ac allows eight spatial streams (8x) or 7000 Mbps.

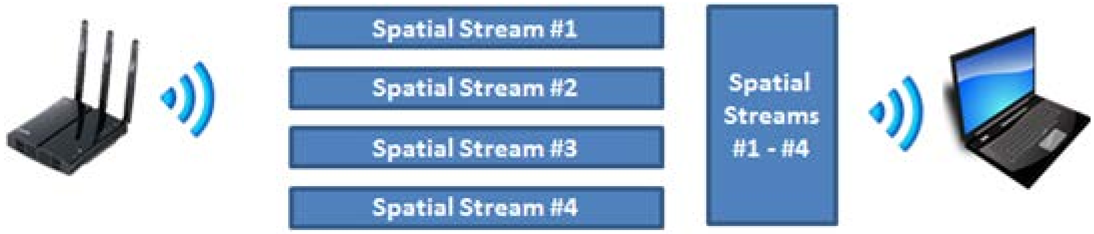


Figure 5 - 802.11n or 802.11ac 4x4 MIMO Example

802.11n’s MIMO capabilities were designed for a single user, or SU-MIMO. While 802.11ac’s MIMO is designed for multi-user or MU-MIMO to alleviate congestion delays. MU-MIMO allows more simultaneous bandwidth, instead of broadcasting the signal equally in all directions, the base station is only sending RF in the client's direction, the downstream direction only. However, just like in 802.11n clients and WGRs they need to support MU-MIMO. Initial waves of the 802.11ac amendment will support a 4x4 MU-MIMO, while 8x8 MU-MIMO technology may have a prohibitive cost model associated, making 4x4 more attractive.

Leverage technologies like MU-MIMO may add improved data rates for the subscriber. The modulation and coding scheme (MCS) index of a WGR is also an important factor for overall data throughput. The higher the MCS index the higher the potential data rate as shown in the table. A single MCS index applies to multiple guard intervals (GI) of 400 ns and 800 ns; and channel sizes as shown in the table. Just like the MU-MIMO feature both the client and WGR must support the same level of MCS, channel size and GI.

Table 1 - Theoretical Mbps Data Rate Sample of 802.11n and 802.11ac

IEEE	MCS Index	Spatial Streams	Modulation	Coding Rate	20 MHz 800 ns GI	20 MHz 400 ns GI	40 MHz 800 ns GI	40 MHz 400 ns GI	80 MHz 800 ns GI	80 MHZ 400 ns GI	160 MHz 800 ns GI	160 MHz 400 ns GI
802.11n	7	1	64 QAM	5/6	65	72.2	135	150	n/a	n/a	n/a	n/a
802.11ac	7	1	64 QAM	5/6	65	72.2	135	150	292.5	325	585	600
802.11n	15	2	64 QAM	5/6	130	144.4	270	300	n/a	n/a	n/a	n/a
802.11ac	15	2	64 QAM	5/6	130	144.4	270	300	585	650	1170	1300
802.11n	23	3	64 QAM	5/6	195	216.7	405	450	n/a	n/a	n/a	n/a
802.11ac	23	3	64 QAM	5/6	195	216.7	405	450	877.5	975	1755	1950
802.11n	31	4	64 QAM	5/6	260	288.9	540	600	n/a	n/a	n/a	n/a
802.11ac	31	4	64 QAM	5/6	260	288.9	540	600	1170	1300	2340	2600

2. Antenna Technology

Antenna technology provides three things to a WGR radio: gain (dBi, dBd), pattern and polarization.

When working with wireless equipment it is important to understand gain. Relative antenna gain is determined by two different scales. The first scale, dBi, describes the gain of an antenna relative to a perfect antenna that radiates in a 360º pattern called the theoretical isotropic radiator. The second scale, dBd, is antenna gain relative to a dipole antenna. Most antenna gain is measured in dBi, on occasion a dBd antenna gain may apear, just add +2.14 dB to the dBd value to determine the corresponding dBi value.

Antenna energy patterns may vary between WGRs. All antennas are referenced to an isotropic radiator or sphere, antennas are used to shape the RF energy pattern. There is no overall best or worst antenna. Each antenna type is designed to produce a different shape or energy pattern. There are three main types: omnidirectional, semidirectional and highly directional. Omnidirectional are the most common at a residential or small commercial location, operating similar to how light is radiated from a lamp. While the semidirectional is like a wall sconce light and the highly directional is like a spot light. The latter two types of antenna are more common in a CableWiFi™ or access network deployment.

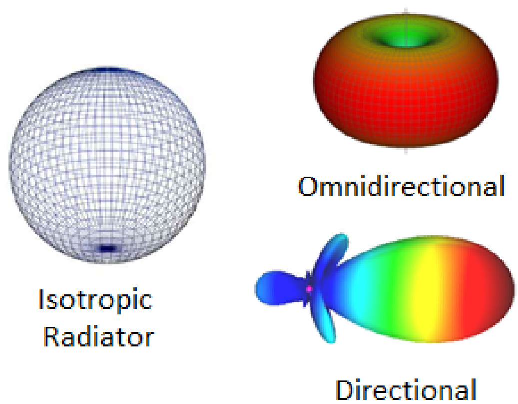


Figure 6 - Isotropic Radiator with Directional and Omnidirectional Patterns

Adaptive antenna technology or beamforming allows wireless RF energy to be shaped and directed in different ways for clients within a home or business to gain better capacity and data throughput. Adaptive antenna technology controls multipath effects (diversity) of wireless and is well suited for high-density venues worldwide. Adaptive antenna technology is also effective on strand mounted access points (APs) for CableWiFi solutions. Adaptive antenna technology may increase the signal gain at the user's device by as much as +6 dB, while improving S/N with reduced noise. The signal gains depend on the number of antennas and the algorithm being used by the WGR. Operators who deploy this technology may be able to improve the wireless QoE for the subscriber.

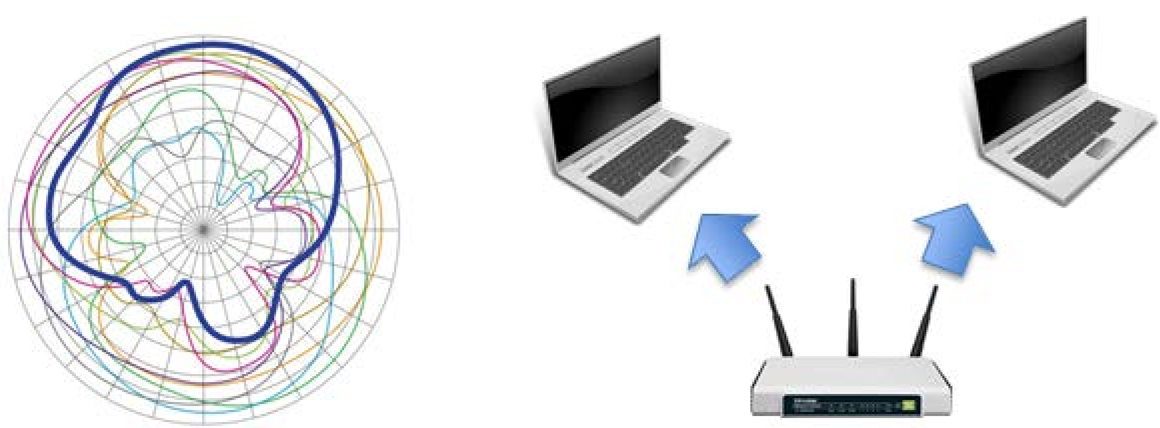


Figure 7 - Adaptive Antenna Technology or Beamforming

Another consideration when it comes to antenna technology is polarization. Antennas support horizontal and vertical polarization or orientation of the RF waves which is extremely important to successful wireless communications. Antennas are to be aligned with the same polarization, it is irrelevant if horizontal and vertical polarization is used[7]. It must be noted that some clients may not support both types of polarization.

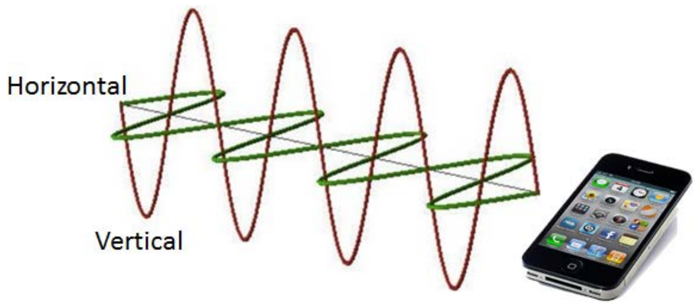


Figure 8 - Horizontal and Vertical Polarization

3. 802.11x

802.11, the Wi-Fi standard, was developed by the Institute of Electrical and Electronics Engineers (IEEE). The 802.11 designation is a set of wireless standards developed for the wireless local area network (WLAN). Many of the popular 802.11x standards are utilized at the customer premises (e.g., 802.11g, 802.11n and 802.11ac) while new emerging standards (e.g., 802.11ad, 802.11af, 802.11ah and 802.11ax) will start making their way into the home and business.

The HT 802.11n amendment was released in 2009 allowing wireless communication over the ISM 2.4 GHz and U-NII 5 GHz bands. The amendment increased data rates up to 600 Mbps using high throughput OFDM (HT-OFDM), MIMO spatial streams and channel bonding up to 40 MHz channels. The amendment is backward compatible with all 802.11 standards, but usually not 802.11 prime due to the speed limits of the amendment. 802.11n, as many of the previous versions of 802.11x Wi-Fi are no longer used or should be used to provide wireless services for gigabit service rates.

The VHT 802.11ac amendment was released in 2013 increasing data rates to 1,300 Mbps or 1.3 Gbps (wave 1 release), 3.5 Gbps (wave 2 release) and up to 7,000 Mbps or 7 Gbps (in future wave releases) – using strictly the U-NII 5 GHz bands. However, there are dual band options available supporting the legacy 2.4 GHz spectrum for subscribers. As mentioned to increase the data rate MU-MIMO was introduced along with wider bonded channels. Increased channel sizes of 80 MHz and 160 MHz allow for an increase in the data rates, however 160 MHz channels will be a challenge to implement.

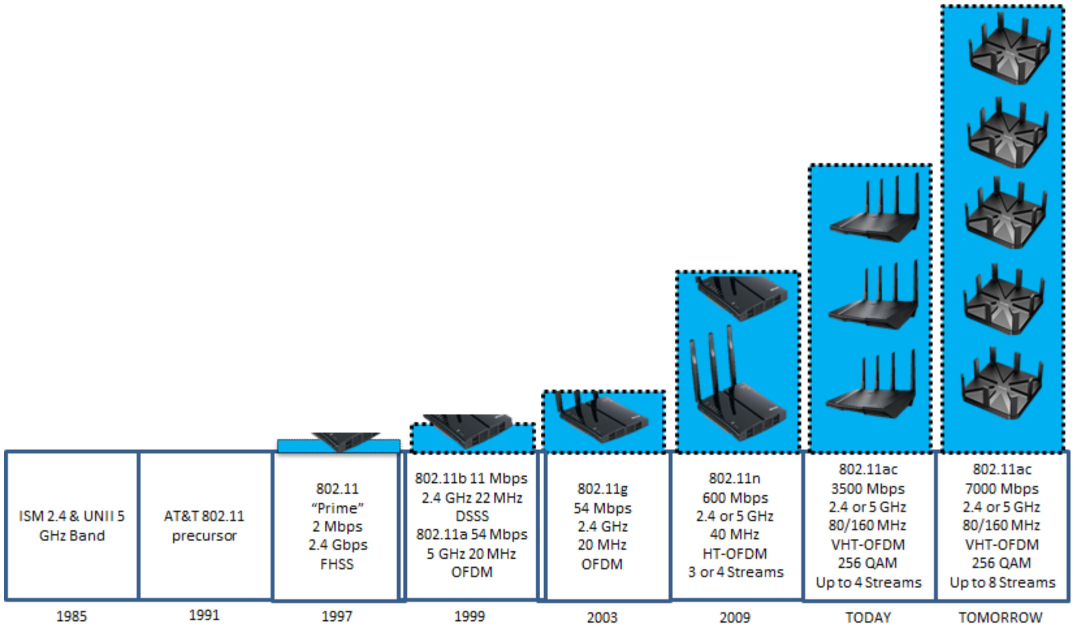


Figure 9 - 802.11 Amendments

In both 802.11n and 802.11ac, channel bonding is a possibility. Wider channels provide more data throughput in a wireless network. 802.11n supports 20 MHz and 40 MHz channels while 802.11ac supports 20 MHz, 40 MHz, 80 MHz and 160 MHz channels. Note, achieving 160 MHz wide channels over an 802.11ac network is not likely possible due to the limited amount of spectrum available to the WGR in the 5 GHz band.

The 802.11ad amendment was released in 2012, increasing data rates to 7 Gbps over the 60 GHz band, however over a short range. The amendment also supports legacy 2.4 GHz and 5 GHz bands using a fast session transfer feature. One idea for a wireless home is to use 802.11ad in a room (e.g., living room) while 802.11ac is the backbone between rooms.

A newer amendment 802.11ax or high efficiency WLAN (HEW) will be released in 2019 offering four (4) times the throughput of 802.11ac (up to 28 Gbps in the specification), using new multiplexing and modulation. The multiplexing is similar DOCSIS 3.1's upstream, called OFDMA. While the modulation moves from 256 QAM to 1024 QAM in 802.11ax.

The 2014 amendment, 802.11af, White-Fi or Super Wi-Fi allows wireless in the newly opened TV whitespace frequencies of 470 MHz to 710 MHz (Europe) and 54 MHz to 698 MHz (USA). Operators need to keep in mind, low bandwidth frequencies will produce lower data rates of 26.7 Mbps or 35.6 Mbps[7] depending on the width of the channel. To achieve higher data rates channel bonding will be a requirement for this amendment.

Similar to 802.11af where frequencies below 1 GHz are utilized, 802.11ah or HaLow will offer low power wireless for IoT or M2M. The new physical (PHY) layer that offers the low power will mean lower data rates, however much longer distances for sensor style networks.

To improve the above major amendments additional amendments were created to enhance wireless communications. To improve RF data collection and sharing (AP discovery), 802.11k provides radio resource management (RRM) to improve network performance (e.g., RSSI, utilization). 802.11h provides added value for 802.11k called transmit power control, or TPC, for the frequency bands. While 802.11r provides air interface fast basic service set (BSS) transition methodology that enables a device to have fast secure roaming. To allow improved secured roaming of a device the 802.11u amendment provides interworking with external networks, the basis for HotSpot 2.0. 802.11v provides wireless network management enhancements for network management (client config). Lastly 802.11e or Wi-Fi multimedia (WMM) defines procedures for packet classification and prioritization.

Table 2 - 802.11 Amendment Summary

Amendment	Feature
802.11n	Current version of Wi-Fi supporting up to 600 Mbps
802.11ac	Current version of Wi-Fi supporting up to 7 Gbps
802.11ax	Four (4) times the throughput of 802.11ac (up to 28 Gbps in the specification)
802.11ah	Low power wireless for IoT or M2M
802.11af	Wi-Fi over frequencies of 470 MHz to 710 MHz (Europe) and 54 MHz to 698 MHz (USA)
802.11k	RRM to improve network performance
802.11h	TPC for the frequency bands
802.11r	BSS transition, enabling fast secure roaming
802.11u	Internetworking with external networks
802.11e	Packet classification and prioritization
802.11v	Network management and client configuration

Challenges with In-home Wireless

1. Installation Concerns

A few of the top issues for MSOs with in-home wireless are range (requiring additional devices in the home), throughput/speed (packets/sec), interference, congestion (too many users/connections), lost credentials, configuration issues and wireless device age/compatibility. In addition, a workforce that fully understands the technology to deploy it right the first time is a major barrier as few field operation folks are certified in wireless[8].

Installation focus areas for MSOs are field operation staff education, customer education, pre-work, post-work, optimal RF propagation, using benchmarked devices, using operator managed devices (PNM for Wi-Fi and RDK-B[4]), following best practices for installation, easy customer installation and proper security configuration.

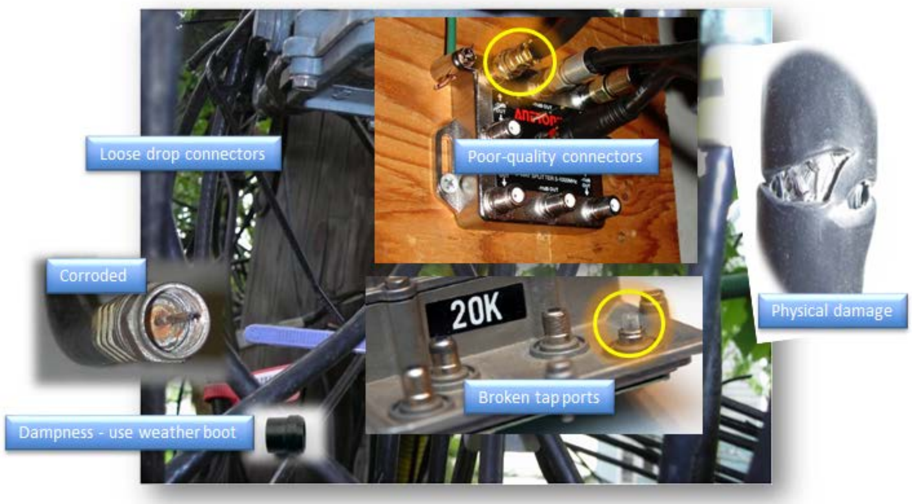
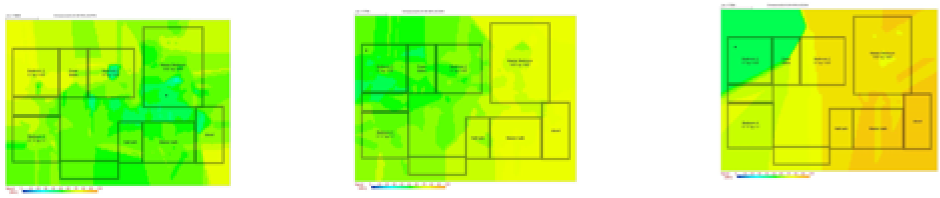


Figure 10 - No DOCSIS, NO Wi-Fi

Standardizing the installation focuses on several key areas that are important to a best in class subscriber QoE with a wireless network. Field operation staff must be prepared and trained to support wireless services at the premises. In addition to field operation training, customer education and the expectations on how the wireless network will operate as compare to the needs of the subscriber must be addressed.

As with any cable service installation, pre-work steps must be performed. Pre-work consists of qualifying the drop connection since wireless is a service that utilizes the HFC or optical distribution network (ODN) to send and receive data from the Internet or cable network. In addition to the drop, verification of the modem service is operating correctly as the wireless network will connect to the modem. Performing a wireless site survey to understand the operating environment and talking with the subscriber about the wireless coverage in the BSS area is a key step to providing a good wireless service. Identify items that may reduce RF coverage, range or performance for the wireless network and discuss with the subscriber. Site surveys are excellent troubleshooting tools, as they provide visibility into the network. Many survey tools are available for smart phones, relatively easy to deploy. The site survey results are used to determine optimal placement of the wireless WGR. Finally, make sure the CPE is matched to the wireless equipment being installed by the operator. Customer education is required in situations where older or non-compatible CPE exists at the premises.



Upstairs
"AP on Main"

Upstairs
"AP moved to Basement"

Upstairs 5 GHz
"AP moved to Basement"

Figure 11 - Survey Maps of 5 GHz

Operators should also perform post-work, such as an exit survey to verify RF coverage, interference and wireless channels are utilized correctly. All wireless CPE must have its connectivity verified with the customer before closing the job. Each of the installed WGRs will require continuous measurement and management by MSOs, on the same lines as how the industry monitors modem health. Tools like PNM for Wi-Fi and/or RDK-B are vital to the wireless QoE.

As previously mentioned, one of the device installation challenges include lack of device knowledge; how the CPE operates and what is the best way to troubleshoot CPE. Having the knowledge to perform manual input on wireless devices and the use of autoconfiguration scripts are equally important. These knowledge gaps may be due to inconsistent lack or poor tracking of field operation training - implementing formal standards and tracking for refresher training as new technologies are presented is recommended. For example, using online training programs such as SCTE·ISBE VirtuLearn, SCTE·ISBE LiveLearning and SCTE·ISBE Chapter Webinars to deliver training updates are excellent resources to keep current[8].

In addition to training, many operators are moving to deploying benchmarked devices, these are CPE that are tested and verified before they are deployed to the field. Understanding the features and limits of wireless devices will help ensure QoE. Benchmarking allows an MSO to understand when to use one wireless device over another device at the premises. Along with benchmarking, using consistent tools to verify wireless health is important to a consistent experience.

Define a customer-owned device support strategy, target devices with highest penetration. Educate field operation staff to support, troubleshoot and statically configure the highest penetrated devices. Always verify all devices that need to be connected to the wireless network.

Security configuration includes configuring Wi-Fi protected access (WPA)/WPA2, service set identifier (SSID), enabling Radius and disabling MAC-address filters as customer will want to change devices on the wireless network from time to time. WPA2/AES is the greatest security and preferred by operators. It is important for an operator to have an administration login to perform advanced level configuration and troubleshooting, even remote access by CSRs. Security may also create issues with lost credentials, a portal or application may alleviate subscriber frustrations here by providing methods to easily apply or reset security options.

2. Range and Coverage

Strive to place the WGR centrally at the premises, both vertically and laterally, and ensure that the antennas are directed so that there are no nulls (end of antennae) pointing at key coverage areas. Another consideration is switching the WGR to one with additional antennas to support new features like MU-MIMO and adaptive antenna technology. A WGR with MU-MIMO capability will improve the wireless range and coverage for a subscriber. Operators may add additional WGRs (e.g., MoCA to Wi-Fi devices) to cover remote parts of the premises, e.g. basements, outdoor suites/garages, etc. Finally ensure that there are no key blockages near the WGRs like chimneys, refrigerators, metal objects, or similar.

An important aspect to coverage is understanding wireless device's capability for range to provide the appropriate CPE for the MSO's data speed tier. In other words, will the device work at the location, size of home, number of devices, type of devices or offer features expected by the customer? One way to mitigate a poor installation in this scenario would be to have each wireless device brand benchmarked. Real-world wireless performance of MSO CPE must be tested and understood. The site survey will aid in determining the best way to provide wireless signals, boost wireless performance or selecting an alternative device such as an enterprise solution.

The WGR needs the capability to perform continuous measurement and mitigate immediate issues to optimize range and coverage, ongoing after the install is complete. Many of the newer WGRs include dynamic channel allocation (DCA), a feature that optimizes the capacity in entire network based on effect of interference. TPC changes operating channel if the RSSI can be improved by a sensitivity value (e.g., 5 dB). While other WGRs (with 802.11k/v) deal with the behavior of sticky clients that will not roam, clients that associate with a GWR and hang on rather than moving to a nearby WGR.

In addition, the latest WGRs have features to reduce co-channel interference (CCI), dealing with issues where one channel change can cause other WGRs in an MDU scenario or neighborhood to also change channel (RF channel ripple effect). Non-Wi-Fi interference mitigation detection systems should classify non-Wi-Fi interference as either persistent or spontaneous, blocking persistent channels. Note that many wireless clients typically do not choose the best channel or serving WGR without some help by the MSO or software algorithms.

3. Throughput / Speed

Especially for older wireless devices at the premises, data throughput and speed are a major concern of our subscribers. Many of the older devices have a varying level of support with latest 802.11x amendments. As mentioned, range was also a factor when it comes to customer throughput and speed, ensuring proper location of the WGR and understanding building construction will improve range/coverage related speed issues.

CPE such as a wired router between the AP and modem must also be considered when looking to improve performance for a subscriber. Wired routers must support the desired packet per second (PPS) rate of the operator's speed tier selected by the subscriber. Wired router configuration issues may rob speed (e.g., logging or firewall settings) too. To ensure a level of QoE and to improve the wireless capacity, install wired twisted pair connections to stationary devices like television displays, desktop computers, IP security cameras, etc.

Another area the affects throughput and speed is the MCS index supported by both the WGR and client. There are MCS index values for 20 MHz and 40 MHz wide communication over 802.11n while 802.11ac extends these index values for 80 MHz and 160 MHz channels. The wider and higher MCS index values support greater throughput and speeds as higher channels will use better orders of QAM (e.g., 256).

Also, collisions and/or packet back-offs due to non-persistent CSMA cause large throughput loss in wireless networks. Finally, congestion may occur where too many users or devices exist in the wireless network.

4. Interference

Understanding what affects wireless signals is important, and many lack a full understanding of signal characteristics that affect RF attenuation. There are many possible symptoms when interferes is encountered by a technician in the home or business. A common concern is low signal power levels coming from the WGR. These lower powered signals will not be able propagate when interferers exist in proximity to the network. Interferers will cause wireless signal dropping, even when close to a WGR, creating speeds much slower than Ethernet or MSO modem tiers. Subscribers consuming multimedia content will experience freeze frame viewing of video or stop/start of audio.

To install an unlicensed wireless network, it is important to determine the intentional and unintentional interferers at the customer premises by performing a site survey of the RF spectrum at the location. Since wireless, in particular Wi-Fi, is an unregulated spectrum with many devices now sharing this RF space it is a recommend step for installation. Intentional interferers are devices designed to send and receive RF signals such as laptops, Bluetooth devices, game controllers, untethered cameras, cordless phones, baby monitors, etc. In addition, some subscribers may have additional Wi-Fi devices on overlapping channels within the BSS. Unintentional interferers are devices that are not designed to send and received RF signals such as microwave ovens, florescent lamps, etc. Microwave ovens may reduce throughput and capacity of wireless access by as much as 50 percent[5].

Figure 12 - Common Interferers

Spectrum

1. RF Propagation

Radio frequency, or RF, is a term that refers to AC having characteristics such that, if a current is applied to an antenna, an electromagnetic (EM) field/wave is generated suitable for wireless communications. However, optimal RF propagation is determined by many factors.

Light waves like infrared have different characteristics than wireless RF waves, they require VLoS. Visual line of sight (VLoS) is where a field operation technician can see from one point to another point, a client to a WGR. RF energy may penetrate many types of substances in the home, and therefore visual LoS is not always required for an RF link such as Wi-Fi. Radio frequency line of sight (RFLoS) is when two RF transceivers (transmitter/receiver) can 'hear' one another. A good example of RFLoS is a WGR and smartphone client connection communicating in a home through wood/plaster walls.

One goal in wireless deployment is clear LoS between the WGR and its client when possible however, most of the time when a wireless RF signal travels over the air (OTA) it is weakened due to many effects such as attenuation (e.g., free space path loss or objects in the LoS), absorption, reflection, scattering, refraction, diffraction, Rician fading / multipath, Rayleigh fading, antenna polarization and low antenna gain. The idea for a quality wireless installation is to try to minimize these propagation impairments when selecting access point or WGR placement.

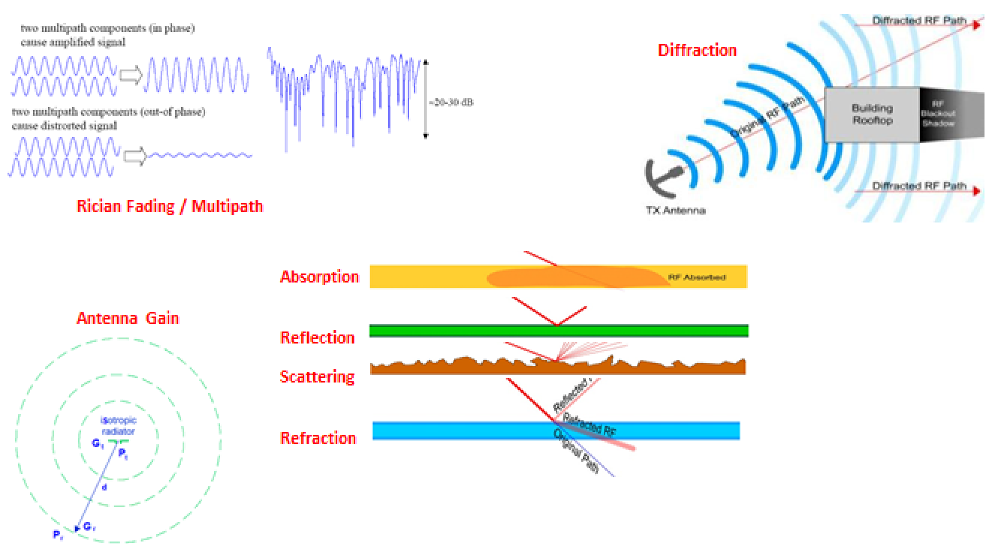


Figure 13 - RF Propagation Effects that Attenuate Signals

The spectrum of 2.4 GHz is only capable of handling 3 channels (shown below) of Wi-Fi (e.g., 1, 6 and 11). In addition, MSOs are using the RF space between these channels for low power 802.15.4 wireless communication. Due to the limitations of 2.4 GHz, the 5 GHz is a preferred band for Wi-Fi communications, offering 5x more spectrum than 2.4 GHz[6].

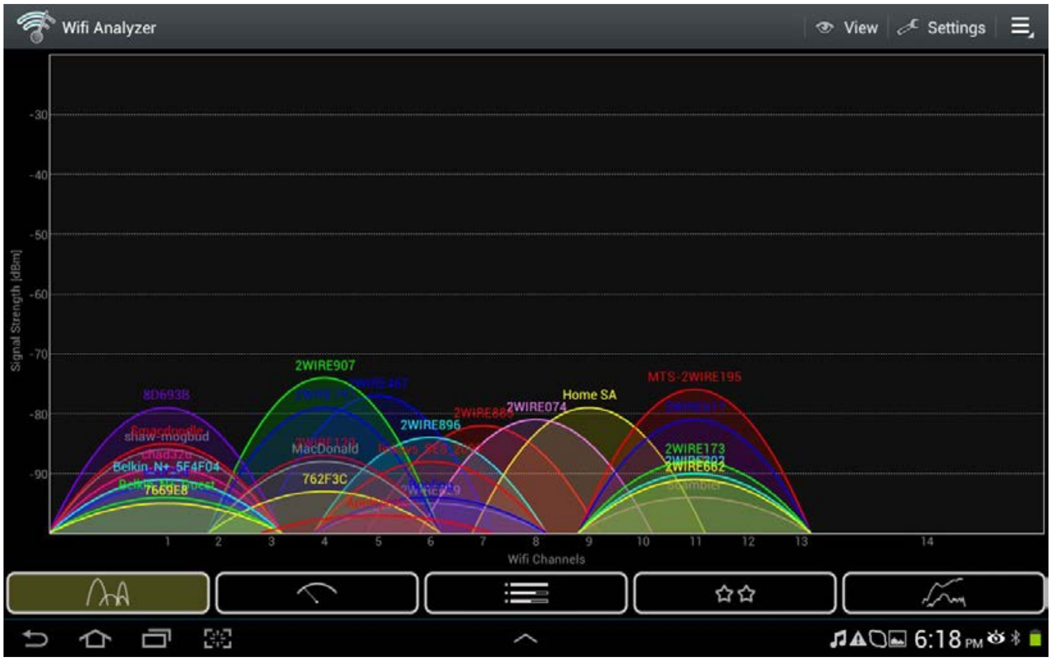


Figure 14 - Congested 2.4 GHz Band

There is a myth that there is no interference in 5 GHz band of Wi-Fi because there are less devices in the spectrum. While it may be generally true that fewer devices currently operate in the 5 GHz band that are causing interference as compared to 2.4 GHz devices, however this will evolve over time. Just as subscribers moved from 900 MHz to 2.4 GHz to avoid interference, the "band jumping" effect will catch up with the 5 GHz spectrum. Some signals already exist at 5 GHz, they include cordless phones, radar, perimeter sensors, and digital satellites. DFS is a process to detect radar signals and select alternate frequencies for communication over 5 GHz. DFS may limit an 802.11ac WGR's ability to achieve 160 MHz channels.

In addition to band jumping, higher frequencies like 5 GHz attenuate more than lower frequencies like 2.4 GHz. The reason cable operators introduce tilt into cable low and high RF transmission over a coax access network like the HFC. The higher attenuation of 5 GHz must be taken into consideration as it will reduce RF propagation, range and coverage.

Figure 15 - 2.4 GHz vs 5 GHz Coverage

One of the big items cited by the MSOs is the lack of a site survey performed at the subscriber premises, just dropping the WGR where the modem is located is not a best practice. This practice may create a sub-optimal location for RF to propagate throughout the premises. Proper attention to the location of WGR and modem are important to the QoE. Following company defined pre-installation steps, such as a site survey reveals information important to determining the location of the WGR.

Also, to note that wireless clients have a lower transmit power than a WGR and or obstacles create issues such as hidden node. A hidden node occurs when two clients cannot "hear" or "see" each other (e.g., obstacles, distance or technology) and their traffic causes collisions at the WGR.

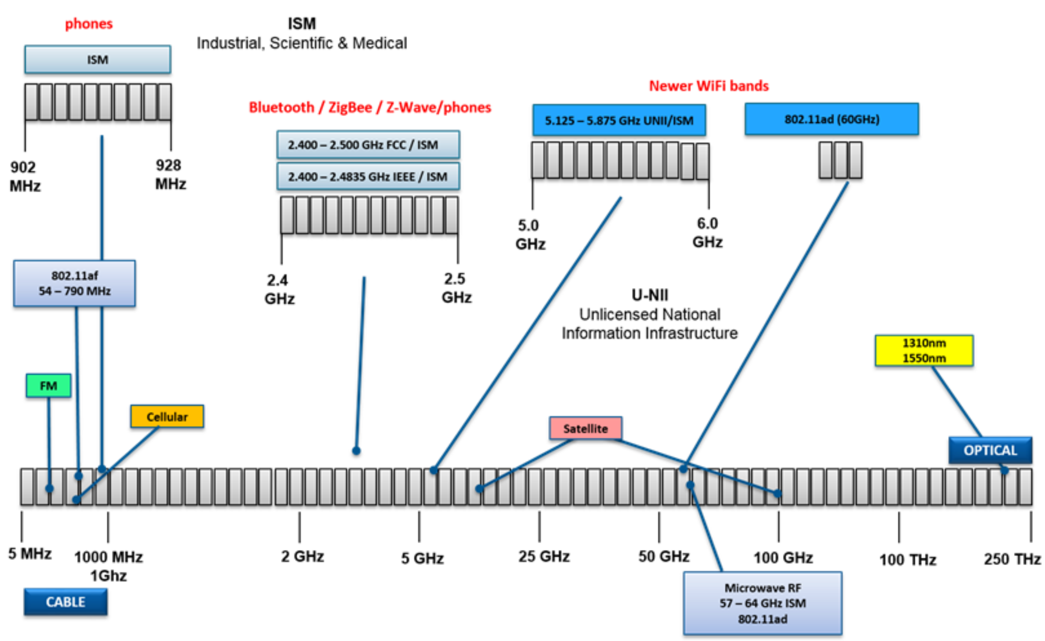


Figure 16 - Wireless Spectrum Used by Operators

2. Wireless 802.15.4

Wireless 802.15.4 is positioned to take over as the de-facto wireless standard in the connected home. Technologies like ZigBee, WirelessHART, ISA100.11a, 6LowPAN and Bluetooth and others (LoRaWAN, IC3, Nivis, etc). These devices provide network sensing communication-ability.

ZigBee is a full wireless protocol suit that many MSOs have adopted for IoT applications such as home security/lifestyle. ZigBee was built on top of the 802.15.4 standard and is defined by the ZigBee Alliance. IEEE Wi-Fi is too power intensive for most low power IoT applications, allowing ZigBee to offer a lower cost per chip. Low power wireless technology such as ZigBee offers a mesh topology, common for sensor networks utilized in the connected home that requires communication with a WGR.

ZigBee requires no existing or additional wiring for wireless clients. Additional connections may be made, beyond the four (4) port switch provided by most CE gateways.

802.15.4 technology suffers from many of the same Wi-Fi interferers like; baby monitors, cordless phones, microwaves, co-channel, metal, etc. Intermittent connections due to distance from WGR still exist in low powered networks. As with Wi-Fi, 802.15.4 requires proper training of wireless RF propagation theory to be properly installed. Finally, precautions need to be made for ensuring the security of these networks.

Wireless highway addressable remote transducer (WirelessHART) is an IoT standard also built on 802.15.4 for industrial automation. It is a self-organizing, self-healing and time-synchronized network.

ISA100.11a also is an IoT standard built on 802.15.4, supporting frequency hopping and mesh routing at the data link layer. ISA100.11a supports IPv6 along with reliable transport using TCP. While the 6LowPan network allows IP to be applied even on the smallest sensor devices.

To build IoT data collection devices and networks for smart cities and municipal organizations a protocol known as LoRaWAN is being trialed by some operators around the globe. Some of the other organizations include public utilities, automotive and healthcare.

User Experience

1. Video over Wi-Fi

Managed video cannot afford the issues of Wi-Fi, video is intensive and in many cases still using MPEG technology today. However more MSO are deploying IPTV and video over Wi-Fi. Operational savings can be realized if MSOs can rely on Wi-Fi for managed video distribution. If Wi-Fi is problematic, it will have catastrophic support costs – already seen in many initial Wi-Fi deployments for HSD throughout the world. Problematic Wi-Fi will create huge churn on video subscribers at a time that the MSO is trying to win them back and compete with consumer electronic (CE) and OTT user experiences. Video over Wi-Fi needs to be as reliable as QAM based video!

Video services over untethered devices is how many our customers will consume video content in the future. The speed tier must be checked for a subscriber account to verify the appropriate wireless device is chosen to support the video installation. In cases where devices do not meet expectations, appropriately set subscriber expectations through education about speed, range, security, device obsolescence, hardware (e.g., WGR), etc.

2. MoCA

MoCA is the foundation for distributing content around the home and jumps splitters to form a full mesh and peer to peer wired network in the home using existing coax cable. Gigabit Ethernet and MoCA will both consistently deliver DOCSIS 3.0 modem speeds of 400+ Mbps MAC throughput (MoCA 2.0) download and that 802.11n is also capable of delivering DOCSIS 3.0 cable modem speeds of 100+ Mbps download (802.11ac supports 500+ Mbps) under some circumstances while getting very close using a variety of client devices and in many locations throughout the home. Enhanced MoCA mode supports 800+ Mbps MAC throughput. MoCA to Wi-Fi extenders are used to improve the Wi-Fi QoE, designed for MSOs to boost/extend Wi-Fi coverage in home network for video and data installations.

3. Better Tools

The first step in improving the wireless environment is having eyes to see the Wi-Fi RF, such as channel IDs used, signal strength, 802.11 standard, S/N, co-channel interference (CCI), adjacent channel interference (ACI), overlapping channel, etc.

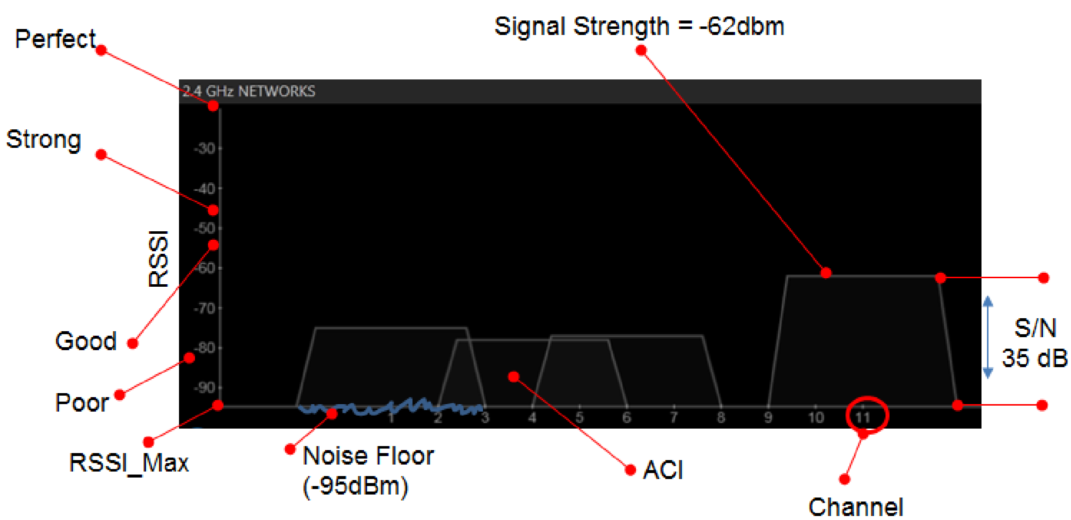


Figure 17 - Wi-Fi RF Spectrum Analysis

Take signal strength readings during the site survey using an analyzer before installation. Standardize wireless signal spectrum analyzers installed on laptops/smart phone to report consistent metrics across the MSOs footprint. For example, uses the standard RF meter as some vendors support wireless adapters kits for the meters. These tools must support the 5 GHz band, as more and more devices are moving into this spectrum. Tools may be used to verify whole home connectivity during the post installation steps. As with any new tool, it is important for field operation installers to understand the tools, how to properly use them to locate and identify information quickly.

Wireless signal spectrum analyzers need to identify co-channel interference (CCI) or in band noise as other signals maybe located in the same frequency band. In addition, wireless ACI must be characterized, as it produces interfering signals located in adjacent bands. Tools should account for inter-symbol interference (ISI) or zero ISI due to multipath of the wireless signal. To characterized overlapping channels, multiple system interference (MSI) must be accounted for due to interfering signals exploiting the same frequency band (e.g., Wi-Fi, 802.15.4)

At the packet level, collision must be minimized when two packets are transmitted simultaneously over a wireless network. Interference reduction will minimize collisions at the PHY layer (mitigation) and can be managed at the MAC layer (avoidance).

A measure of RSSI using power in dBm and typically shown as a negative (-) value provides indicators of interference, high noise floor or low S/N. One caveat about RSSI, vendors may implement this measurement differently (scale of 0-60, scale of 0-255) as it is not a standard. Most vendors recommend a -65 dBm value or better for RSSI[6] in the 2.4 GHz and 5 GHz bands to be optimized for untethered devices. Be sure to benchmark the devices and set a best practice for RSSI measurements. A higher S/N will produce a higher data rate, the same as a wired coax network. When using MU-MIMO and modulation orders beyond 802.11n, 802.11ac must have a significantly higher S/N, requiring cleaner spectrum and better WGR to client distances. To estimate a 30 dB S/N, take the noise floor (e.g., -95 dBm) minus the RSSI value (-65 dBm).

Table 3 - Sample S/N Values for 802.11n and 802.11ac

Protocol	MCS Index	Modulation	Channel Width (MHz)	Minimum S/N (dB)	RSSI (dBm) *NF = -95 dBm
802.11n/ac	5	16 QAM	20	18	-77
802.11n/ac	5	16 QAM	40	21	-74
802.11n/ac	6	64 QAM	20	20	-75
802.11n/ac	6	64 QAM	40	23	-72
802.11n/ac	7	64 QAM	20	25	-70
802.11n/ac	7	64 QAM	40	28	-67
802.11ac	8	256 QAM	20	29	-66
802.11ac	8	256 QAM	40	32	-63

4. Best Practice Summary

DOCSIS Layer – As like other services within the premises that operate on top of a modem service, verify the DOCSIS service is functioning correctly.

RF Surveying **-** Locate sources of interference using wireless analysis tools. Determine cause of weak RF signals; large premises, premises with several floors and long distances to WGR. Locate causes of signal loss; brick, concrete, block, metal duct work, etc. Metal studs or heating duct may have a loss of 26 dB! Location of WGR, LoS is the best, open area without obstructions and elevated to laptop working height. 5 GHz provides less coverage than 2.4 GHz. Conduct walkthrough of premises, measure signal strength and identify open channels. Place WGR in an ideal location(s).

Security – no WEP, no open networks; Some MSOs feel AES is best; Encryption compatibility is important with older clients; Understand security options available on devices (IPSec passthru, parental controls, firewall, etc.) Standard passphrase; combination of modem MAC address and phone number is an example. To improve security at the physical layer consider reducing the amount of RF power transmitted by WGR. MSO portal or app can be developed to help subscriber configure their own security features.

***WGR/Client Setup* -** Large premises, premises with several floors and long distances to WGR require multiple WGRs and both 2.4 GHz and 5 GHz bands; Use different RF channels on each of the WGRs. Operate in 5 GHz; Multiple devices and HD video applications work best with 5 GHz and good RF coverage; Speed tests at 24, 50 and 100 Mbps work best with 5 GHz and excellent RF coverage. eRouter specification from CableLabs offers MSOs control over the wireless eco-system, also allows PnP gateway (not installation). As part of post work test the installation with client devices and subscriber. Allow auto channel selection feature where possible, network is adaptable. Where possible directional antennas offer higher signal gain, omnidirectional may waste RF energy. Many mobile devices may have throughput limits, verify all client devices.

***Training* -** Training on the new wireless and Wi-Fi aspects; Everyone needs to be trained and certified to deploy, support and troubleshoot wireless networks; Schedule refresher training early and often. Utilize SCTE·ISBE working group, chapter and educational resources.

***Customer Education* -** Interview subscriber about the types of devices, number of devices, habits of usage, etc. Review all aspects of installation with the subscriber.

***Repeaters* -** Repeaters are often used to improve the user experience with wireless networks. The repeating devices act like an RF router: receiving a weakened RF signal, regenerating the RF power levels, and retransmit the RF signal. An important field tip, RF signals arriving at the repeater’s receiver must have a good S/N. Using repeaters properly many effectively double the coverage and extend the range.

Conclusions and Recommendations

Wireless communications in the home, business and access network are still evolving. Many challenges will still need to be solved, however it forces our industry to continually improve the experience. QoE and a carrier grade version of wireless is becoming more important than previous versions of best effort communication. The wireless experience will determine the MSO’s image, operator will need to own and manage the ecosystem.

Leveraging newer amendments like multiple radios, MU-MIMO, beamforming, interference mitigation, etc. will be critical to the QoE. Following best practices for deploying benchmark devices will be vital to customer satisfaction. Wireless deployments require better tools that provide key metrics and data (e.g., S/N, MCS, ACI, CCI, etc.) for both Wi-Fi and low powered wireless 802.15.4 radios. The 802.11ac amendment sets the foundation for carrier grade deployments while the 5 GHz band will alleviate some of the congestion issues with 2.4 GHz to improve the QoE.

Educating our field operations workforce in wireless is highly recommended and most important, due to large call volumes and truck rolls related to wireless technology in our industry. SCTE·ISBE has a working group that has been developing wireless best practices for our industry, free to join. SCTE·ISBE has a training and certification program for broadband professionals, learn more at SCTE.org/BWS. In addition, the SCTE·ISBE has partnered with the certified wireless network professional (CWNP.com) to provide a cable version of the CWNP wireless career path.

Abbreviations

AC	alternating current
ACI	adjacent channel interference
AES	advanced encryption standard
AP	access point
BSS	basic service set
CCI	co-channel interference
CPE	customer premises equipment
CSMA	carrier-sense multiple access with collision avoidance
dBd	decibel relative to a dipole antenna
dBi	decibel relative to an isotropic radiator
DCA	dynamic channel allocation
FSPL	free space path loss
Gbps	gigabit per second
GI	guard interval
HEW	high efficiency WLAN
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of things
ISM	Industrial, Scientific and Medical
M2M	machine to machine
MAC	media access control
MCS	modulation and coding scheme
MIMO	multiple-input multiple-output
MoCA	Multimedia over Coax Alliance
MU-MIMO	multi-user multiple-input multiple-output
ns	Nanosecond
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
OTT	over the top
PER	packet error rate
PNM	proactive network maintenance
QAM	quadrature amplitude modulation
QoE	quality of experience
RDK-B	reference design kit for broadband
RFLoS	radio frequency line of sight
RRM	radio resource management
RSSI	receive signal strength indicator
S/N	signal to noise ratio
SDM	spatial division multiplexing
SISO	single-input single-output
SSID	service set identifier
TPC	transmit power control
UNII	Unlicensed National Information Infrastructure
VLoS	visual line of sight
WGR	wireless gateway router

WLAN	wireless local area network
WMM	Wi-Fi multimedia
WPA	Wi-Fi protected access

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