How to Finally Conquer Wi-Fi in the Home: Service Provider Style

A Technical Paper prepared for SCTE•ISBE by

Nav Kannan
VP Product Management
ARRIS International plc
3871 Lakefield Drive, Suwanee GA 30030
+1 215 435 2231
nav.kannan@arris.com

Charles Cheevers
CTO CPE Products
ARRIS International plc
3871 Lakefield Drive, Suwanee GA 30030
+1 678 473 8507
charles.cheevers@arris.com

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Introduction

Service delivery over IP is now a reality, and in a home, most of these services are consumed with a wireless device. In addition, many of these services are overlays from Over-the-Top (OTT) content providers. service providers have to adapt to this changing world by being able to manage the optimal delivery of these services to the devices by offering "Wi-Fi" itself as a service, or they risk being relegated to the role of just the access provider, getting the bits in and out of the home at the point of termination, but having no control or even role in the distribution of the data inside the home. Wireless technology is inherently complicated and is also evolving at a more rapid pace than the access technologies that current cadence of device replacement for service providers. Retail devices are also now entering the market that are designed to cater for ease of use, coverage and rely typically on Multi Access Point S/W management and Mobile App to give the user features to manage connected devices. These devices offer consumers the promise of ease of set-up, manageability, and visibility, usually with the assistance of a mobile application. This is doubly painful for the service providers, in that they don't get to participate in the commercial transaction of these retail devices, while sharing an unfair burden of having to answer for the "poor Internet service" should any of these retail devices not stand up to the promise that they were offered. An additional downside to these retail devices is that they will also inhibit the service provider to roll out new IP services that rely on being able to manage and touch all end devices. Retail APs often provide their own DHCP scope addresses and NAT out the service provider.

The challenges presented above may seem to portray any solution process as a daunting task. However, there is a way that the service provider can compete and in particular adding tools to their arsenal to take advantage of and take control of the Wi-Fi in the home. To start with, let us look at the key performance requirements from the perspective of a subscriber:

Connectivity: 'I need to be able to seamlessly onboard and connect a variety of Wi-Fi devices'

Coverage: 'I need to be able to make use of my Wi-Fi devices throughout my home'

Performance: 'These Wi-Fi devices must adequately perform to meet my needs'

Happiness NPS "If the applications I use on Wireless devices work well – I'm a happy customer"

Figure 1 - Customer Expectations of Wi-Fi Speeds

In addition, customers who are now used to the new generation of mobile applications and retail devices want the ease and comfort of simple and intuitive ways to manage and control the various devices, while also wanting the reassurance that there will not be any compromise of either privacy or security. These expectations are hygiene factors and are listed below.

Security: 'I need the Wi-Fi devices to not compromise data security'

Manageability: 'I need to be able to control and manage these devices'

Visibility: 'I need to be able to visualize and monitor these devices to ensure they are working properly'

All of this while understanding that Wi-Fi is like a "Utility" and it really should just work. For a consumer to pick up a smartphone and use a mobile app to manage Wi-Fi it needs to be:

- Useful: Services like 'Mealtime mode' where all devices are paused on Wi-Fi
- Infrequent use but intuitive to use: Onboarding new Extenders or devices; Solving simple Wi-Fi issues
- Worthwhile: Adding security services to Wireless connectivity

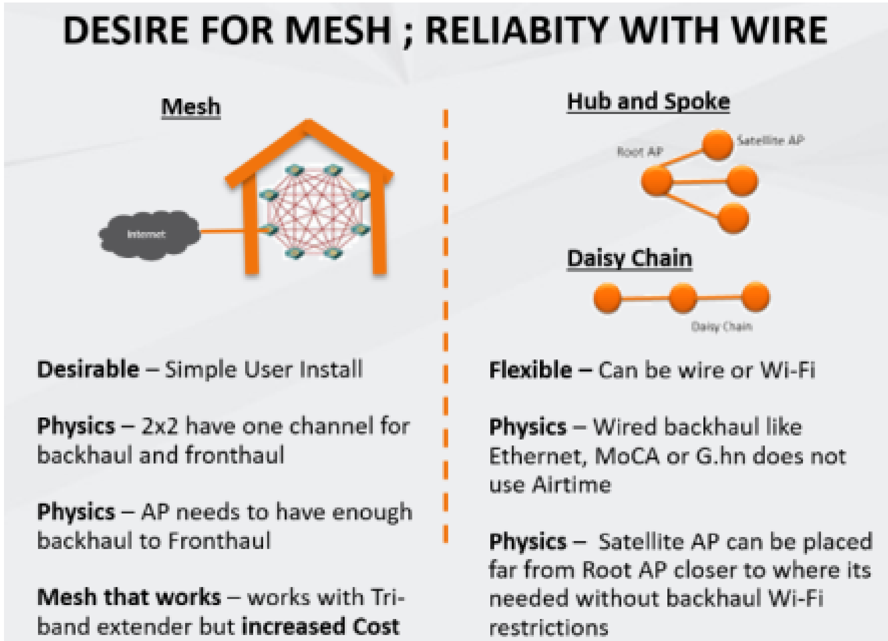
Practically all the above needs can now be adequately addressed by the Service provider. The Wi-Fi standards are rapidly evolving not just from the perspective of functionality, but also from the perspective of manageability and interoperability. New Wi-Fi goodies have arrived and it's time to unwrap them and take control of Wi-Fi. We now have what we need to make the Service Provider Access Points (APs) control the Wi-Fi clients in the home. Service provider class APs can now support 802.11k, v, r, u, and 'ai'. These IEEE letters allow the AP to be able to command the Wi-Fi clients to be able to move to any commanded AP, provide information on hidden AP, and better report their telemetry. Add the introduction of 802.11ax, and we also have even better control of client battery life.

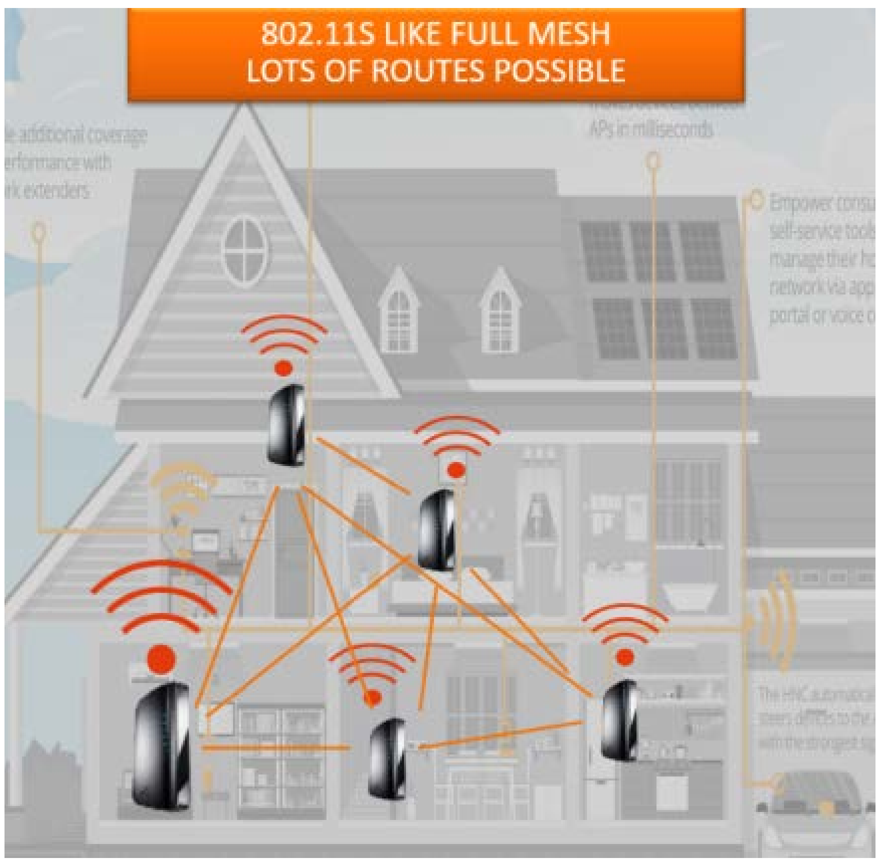
It is worth pausing here and reflecting on a couple of key points that are the fundamental decision points for service providers:

1. The right Multi Access Point strategy
    a. There is a huge desire to go to an all Wireless Mesh solution. Simplifies things for install. Makes performance more complex.
    b. There is also the question of how to architect the Wi-Fi mesh. True mesh technologies like full 802.11s implementations where all Wi-Fi nodes can see and reach all Wi-Fi nodes tend to be over complex for home solutions.
    c. The service provider path is probably aligned more with the regular path of being the care keeper for the home
        i. A single AP for lowest cost acquisition
        ii. Minimum number of devices for range
        iii. Minimum number of devices for performance

This tends to converge then to more of a hub (main Gateway) and spoke – direct attach extenders. The first one which typically solves issues to 95% of US homes. Additional spokes can also be added for 360 coverage.

For larger homes the addition of another multi hop extender is also simpler than true mesh solution.


DESIRE FOR MESH ; RELIABITY WITH WIRE
Mesh
Internet
Hub and Spoke
Root AP
Satellite AP
Daisy Chain
Daisy Chain
Desirable – Simple User Install
Physics – 2x2 have one channel for backhaul and fronthaul
Physics – AP needs to have enough backhaul to Fronthaul
Mesh that works – works with Tri-band extender but **increased Cost**
Flexible – Can be wire or Wi-Fi
Physics – Wired backhaul like Ethernet, MoCA or G.hn does not use Airtime
Physics – Satellite AP can be placed far from Root AP closer to where its needed without backhaul Wi-Fi restrictions


802.11S LIKE FULL MESH
LOTS OF ROUTES POSSIBLE

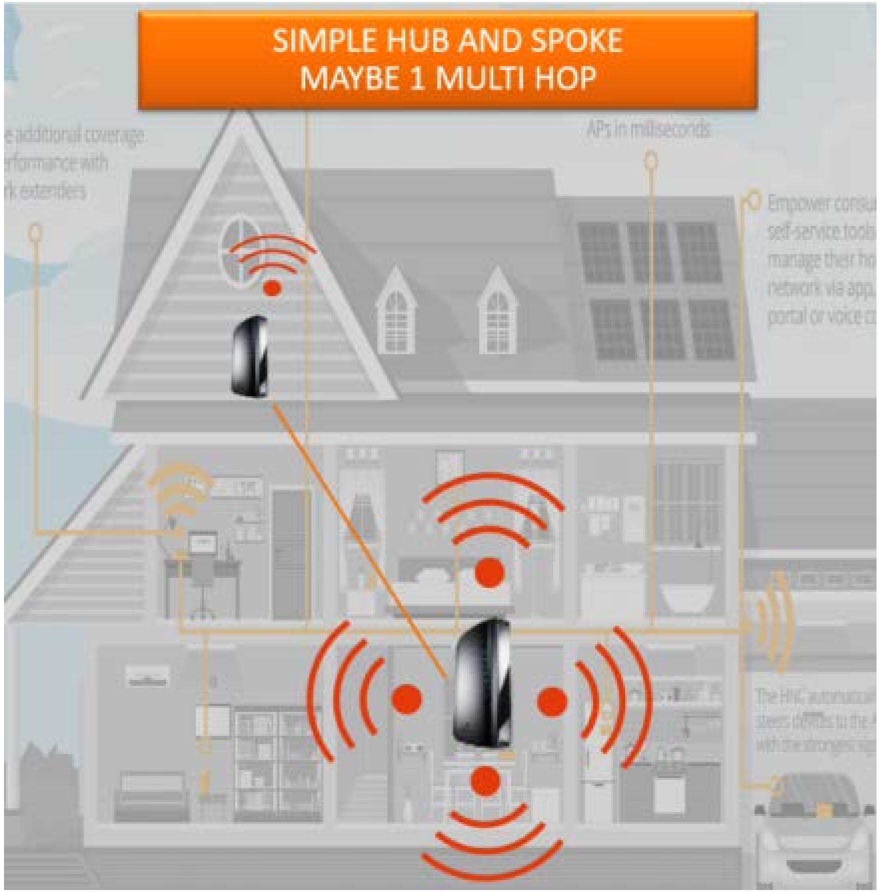


Figure 2 – Mesh Network with ‘Hub and Spoke’ as well as ‘Daisy Chain’ Topologies

2. The right set of tools to trouble shoot Multi-AP Wi-Fi. As you can see below transitioning from QAM video to IP video introduces complexity to troubleshoot. You can see below that QAM video has been simple to troubleshoot. TV is not working the problem is either into the STB or in the STB.

Figure 3 - Simplicity of QAM Video

If you add in a new Multi AP Wi-Fi architecture, now when the TV is not working – the broadband and in home Wi-Fi architecture are implicated with 6 points for failure to assess. It is therefore important for all Wi-Fi solutions to resolve packet loss to the multi hop or meshed architecture that is put in place.

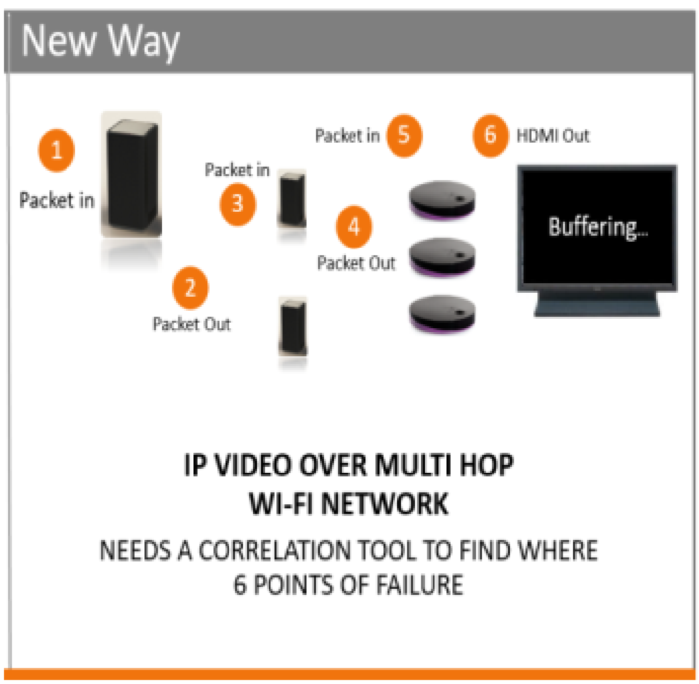


Figure 4 - Complexity of IP Video Making Troubleshooting Complicated

The Home Wi-Fi devices range from static high bandwidth devices like set-tops, to roaming devices, to critical Internet of Things (IoT) Wi-Fi devices. Using Data Mining and Machine Learning to create policies that maximize the performance of these devices through controlling Wi-Fi transmissions and client connections is now fully in the hands of the service provider back office solutions and gateway controllers. Add the recent standardization of the Wi-Fi Alliance (WFA) Multi Access Protocol to allow different vendor Wi-Fi AP devices to talk to each other in a common language and you have the perfect toolbox for service provider managed Wi-Fi services – just in time for the migration from Quadrature Amplitude Modulation (QAM) Video to Video over IP over Wi-Fi. This paper covers these topics in depth.

The Evolving Wi-Fi Home

1. Evolution of the Home Wi-Fi Network

The in-home Wi-Fi network and associated services are constantly evolving, and this presents both an opportunity and challenge for the service provider. The evolution is instigated by both the service providers and the consumers in parallel.

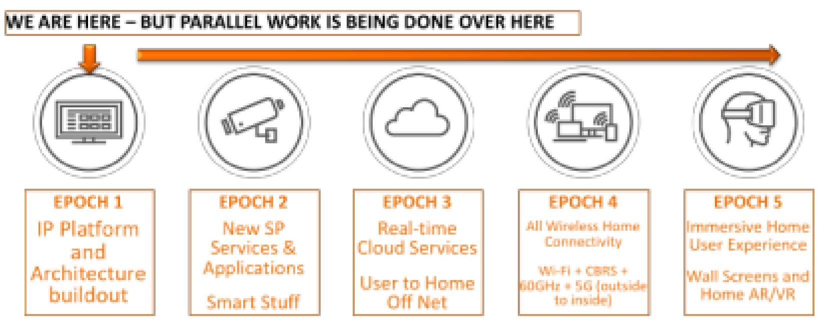


Figure 5 - The Home Network is Set to Evolve

The type of devices in the home are also diversifying and there is an increasing number of devices that have high capacity in terms of bandwidth consumption. A typical US household has 2.6 family members, and a distribution of the various device types is captured in the figure below:

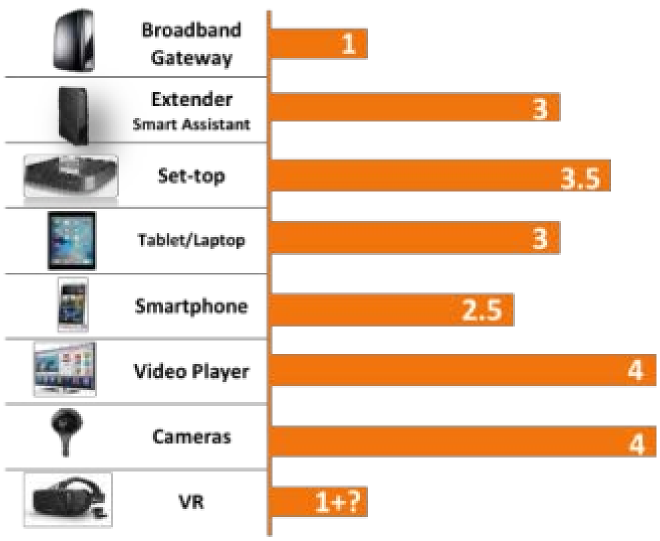


Figure 6 - High Capacity Device Increase

Of particular interest is the consumption of video, a technology which continues to evolve independently, with 4K, UHD and even 8K over time. Virtual Reality / gaming consume high bandwidth video, and the following figure shows the bandwidth consumption patterns.

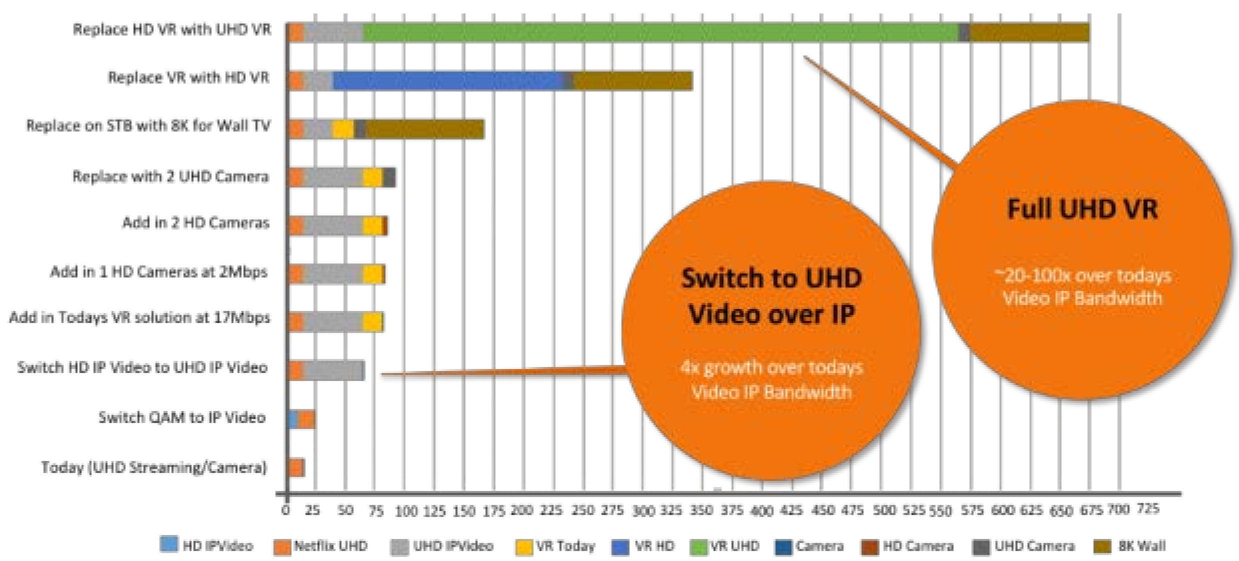


Figure 7 - Service Bandwidth Increase

While video and related services present the challenge of ever-increasing bandwidth requirements, the advent of Internet of Things (IoT) and associated services, there are now additional challenges. The evolving home with IoT is shown in the figure below.

Figure 8 - Smart Home / IoT Device Increase

2. Growing diversity of Wi-Fi devices in a residential setting

The ubiquitous adoption and the continuous improvement of the Wi-Fi standards has led to an increasing number of Wi-Fi enabled devices in the home. Consumers are now able to enjoy the practical benefits as well as the aesthetic appeal of not having to deal with the clutter of wires, irrespective of the nature of the use-case. Such is the appeal of the need to “get rid of the wires”, that we have a growing market for even wireless chargers for mobile phones.

The simplistic umbrella term ‘Wireless Device’ is also deceptive, since it hides the complexities that arise of the nature and use of the specific device. There is a growing diversity of these devices and consequently there is an ever-growing gap between the expectations of an end-user in terms of the functionality and performance of any ‘wireless device’, and the actual reality. If services that are provided by an entity such as a cable service provider, any issue due to a device will potentially taint the perception on the service itself. Since the trend of the subscriber is to shift as many devices to be wireless, it is inevitable that the onus of ensuring the wireless connectivity performance of all devices, whether provided by the service provider or bought directly by the subscriber will unfairly fall on the service provider.

The wide diversity of devices can be studied by grouping Wi-Fi devices into very simple categories.

Four main categories of Home Service for Wi-Fi are:

- **Video Players** – Highest bandwidth consumption and in the case of the SP’s own STB – the most likely to cause customer churn if it does not work properly
    - Additionally to add differentiated Video services like 4K HDR and 8K will require a robust Wi-Fi network above the level of OTT streaming solutions which rely on ABR
- **Broadband** – Emphasis changing to lower latency and Gbps burst to get the user a snappier experience as the lines blur between the benefits of 500 Mbps, 600 Mbps to 1 Gbps WAN SLA
- **Voice and Audio** – Small packet services that cannot have delay, crackles or drops – so high value and high customer churn if voice over Wi-Fi does not work properly
- **IoT** – Wi-Fi IoT security services like cameras become ‘must always work’ services. They can also drive hard demands on Wi-Fi if installed at range and outside home

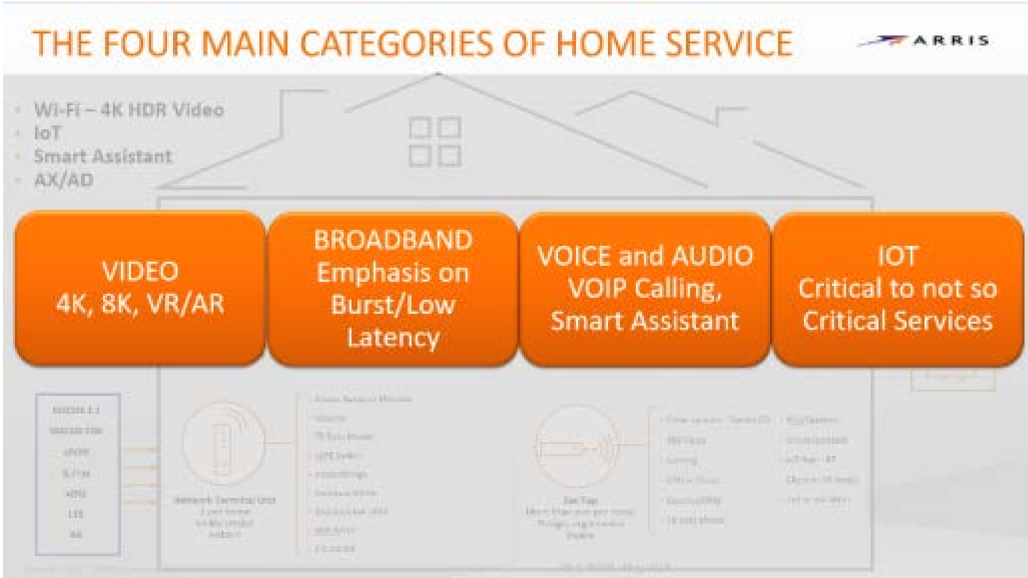


Figure 9 - The Four Main Categories of Home Service

There are also two basic groups of devices in the home as they relate to Wi-Fi:

- Static Devices – STB, Smart TV all the way to 4K Security cameras
- Mobile Devices – particularly smart phone tablets but also devices like Wi-Fi enabled vacuum cleaners

It is important for a service provider Wi-Fi solution to make this simple categorization of devices. In particular for example – STB need to be prioritized for quality video delivery. They are not expected to steer to other APs often and also may have specific policies to only work on 5 GHz bands. Additionally as AP utilization is a key metric of where clients attach in a Multi-AP home – the contribution to the AP utilization of a 4K STB makes it a client that forces other clients to steer off the AP when in high utilization levels.

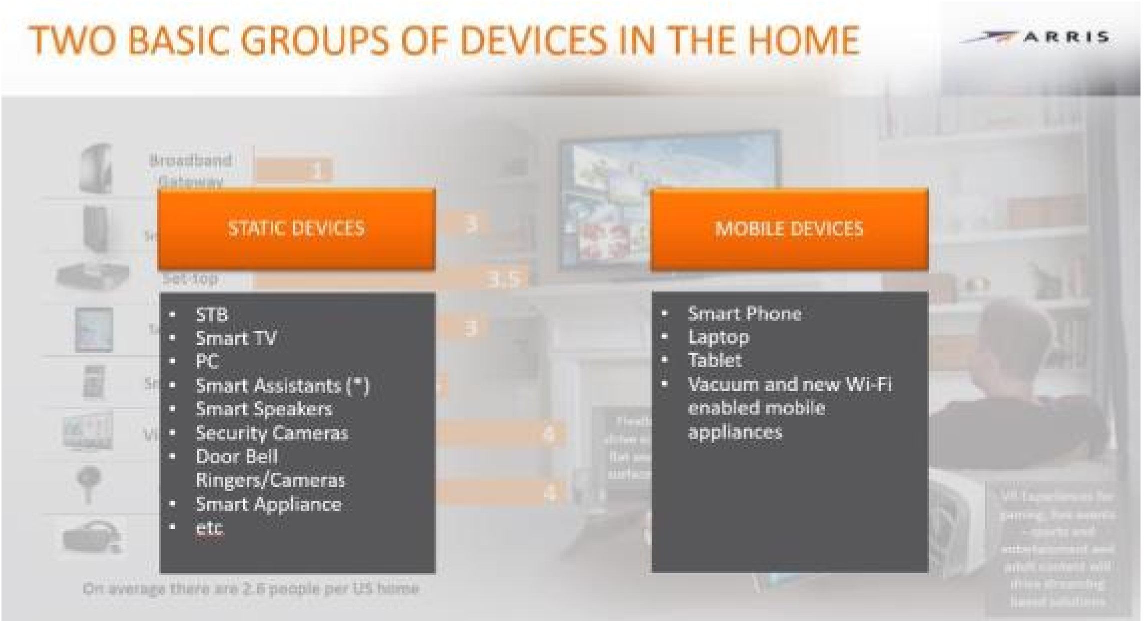


Figure 10 - Static and Mobile Device Groups

In these two basic groups it is important then for all Machine Learning and Wi-Fi algorithms to discern the location of these devices. One coarse subgrouping is

- Devices in house reasonably close to the AP(s)
- Devices exterior to the house or furthest away.

This is key because more and more the home has cliff edge Wi-Fi events that drive all the issues or the changes in Wi-Fi architecture. A simple example is the addition of a Wi-Fi based camera doorbell on the outside of the house. This then can generate a major change in Wi-Fi from

- Poor connectivity at the point of install driving an extender to be added
- Lower MCS device bringing down potential airtime for all the other devices
- A continually transmitting device that keeps adding to the AP utilization and always running – affecting even 802.15.4 and Bluetooth devices as they try and compete with Wi-Fi airtime transmission slots.

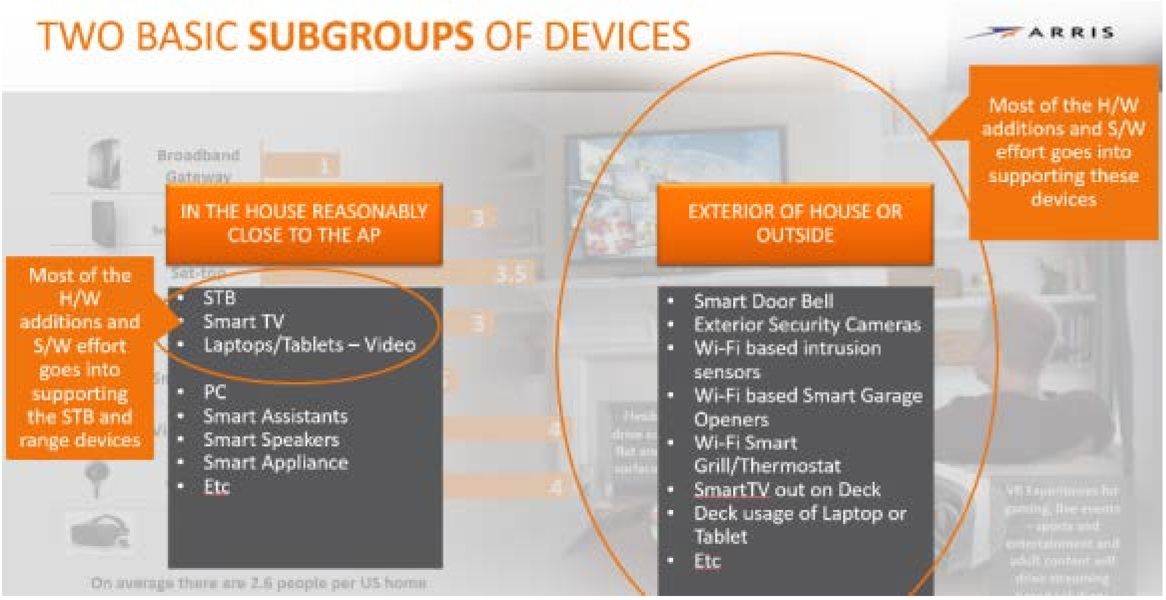


Figure 11 - Device Groups Based on Location of the Device

There are additional categories as well that any service provider Wi-Fi solution algorithm needs to also be cognizant of and use the inherent capability of the device, Service Overlay (if any, whether managed by the service provider directly or OTT applications that the subscriber uses) and finally the usage pattern. These three categories and the various choices or aspects within each result in a plethora of combinations, making the management challenge daunting. Let us examine the diversity in greater detail below.

The key parameters of this category include the:

- Generation of the Wi-Fi standard and associated advanced features that the device supports - determined to a large part by the Wi-Fi silicon capabilities
- Device-specific features based on hardware implementation including the number of spatial streams and the overall transmit power amplification and antenna design
- Support in software through device drivers for advanced features to aid the performance of the device

Since the start of the Wi-Fi standards evolution nearly two decades ago, there have been multiple generations of Wi-Fi standards, starting with 802.11, 802.11a, b, g, n, ac and now ax, that even today, 802.11n devices are extant.

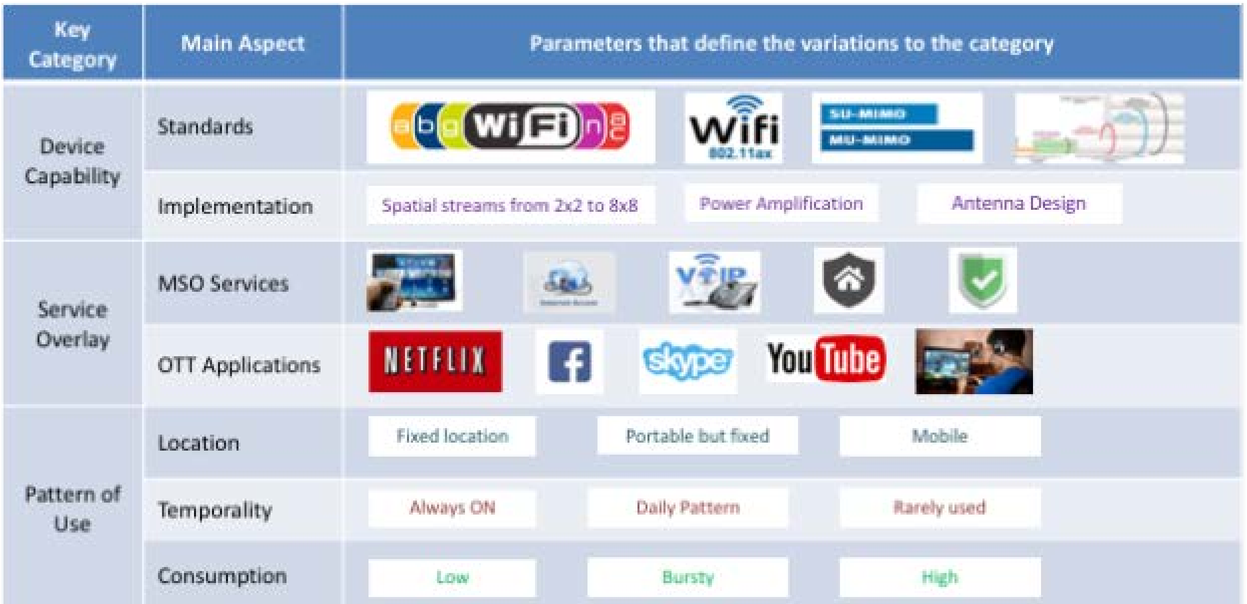
The second category is the nature of the Service Overlay. These could be explicit services provided by the MSO such as Linear and On-demand video, Telephony, Security, and Home management along with the basic data services.

The last category is the usage pattern, in terms of locality & mobility, temporality and consumption.

- Locality & mobility distinguish static clients such as a Wi-Fi set-top box in a fixed location, versus a portable device such as a laptop and a totally mobile client such as a smartphone which could move around even as it is being used.
- Temporality refers to the time-based usage pattern typically exhibited by the device. Some devices stay connected, but are rarely used for data consumption, as in a SMART TV which is

connected to an external device for source. Some others may be used during specific times of the day, and finally a few that are always on and transacting data, such as an IoT device.
- Consumption refers to the amount of data usage typically exhibited by the client, and may be broadly grouped as Low data usage, Bursty data usage, and Heavy data usage.

The figure shown below captures the diversity of the Wi-Fi Clients, and one can imagine the number of combinations, especially when factoring the manufacturer of the device.



Key Category	Main Aspect	Parameters that define the variations to the category				
Device Capability	Standards	a b g WiFi n ac	Wifi 802.11ax	SU-MIMO MU-MIMO		
	Implementation	Spatial streams from 2x2 to 8x8	Power Amplification	Antenna Design		
Service Overlay	MSO Services			VoIP		
	OTT Applications	NETFLIX	f	skype	YouTube	
Pattern of Use	Location	Fixed location	Portable but fixed	Mobile		
	Temporality	Always ON	Daily Pattern	Rarely used		
	Consumption	Low	Bursty	High		

Figure 12 - Diversity of Wi-Fi Client Devices

In addition to all of the above that relates to the nature and use of a given Wi-Fi client, the geographical location of the device, in relation to the Access Point (AP) is an exceedingly important factor in the performance. It is not just the distance, but the presence of walls and material that have an attenuating impact on the signal, directly affecting the maximum possible throughput that a device can hope to achieve. Another factor that has an impact on the Wi-Fi performance is the level of interference due to Wi-Fi signals in the house due to other devices within or from outside the specific residence.

The purpose of discussing the diversity of Wi-Fi client devices is to highlight that any solution must consider this reality. Knowledge of the exact nature of the device is essential for a more informed decision process, be that a manual one or an automated algorithm.

3. Customer Expectations and the Burden of Cable Service Providers

Cable service providers face the challenge of providing Internet service through the complicated medium of Wi-Fi. Should everything work as needed, most subscribers would assume this as the 'basic expectation being met'. However, at the first sign of any issue with connectivity, coverage, performance or such aspect, the service provider is drawn into the problem, notwithstanding that the source of the problem could be elsewhere in the home, unrelated to the internet service itself. As we have seen in the section before, connectivity, poor performance and coverage depend on a wide variety of factors.

Sub-optimal conditions can also affect the service overlay, and should the service be one that is offered by the service provider, then implications fall on the provider notwithstanding the device capability. It is for this reason that the providers as of now insist on equipment supplied by them to provide a specific service (such as a Wi-Fi set-top box to provide video over IP over Wi-Fi service) as opposed to relying on a device that is customer owned and managed (COAM) device.

Yet another factor that works against the incumbent service provider unfairly is the asymmetric expectation across modalities of service delivery. The same subscriber who is willing to allow IP video to an OTT device that occasionally buffers or has artifacts will not tolerate a freeze of video or reduced quality in linear video content provided by the customer. This increased tolerance level is due to the fact the subscriber is compensated somehow otherwise, as in the case of OTT video, the convenience of content selection or cost. This is not different than how consumers were willing to tolerate the poor quality of cellphone voice calls because of the advantage of mobility that the cellphones were able to provide. However, it is believed that Services providers will want to offer highest profile IP video to managed IP Video STB devices and not rely on Adaptive Bitrate to be the core of their service offering. This should differentiate the SP offering for HDR and immersive video services.

Perhaps the single biggest gap between customer expectations and reality is in terms of the performance of Wi-Fi throughout the home. The terms that we often encounter here are “Coverage”, “Performance at Range” and so on. It is important to dwell on this subject a bit. The problem space as well as the solution space is sufficiently complex, and we must expand on the statement made earlier in the introduction when we mentioned that customers need their Wi-Fi Speeds to match the Access Speeds (that they pay for).

Performance of a Wi-Fi client is highly dependent on how close the device is to the Access Point (considering obstructions to the RF signals, more than just distance). The effective distance (considering the obstructions, resulting in a normalized measurement called attenuation) is also referred to as “Range”. By the laws of physics, the signal strength (and therefore, the resultant performance) degrades over range, the fall off being more rapid and dramatic in the 5 GHz channels than with the 2.4 GHz channels. Given that 5 GHz channels offer higher throughputs, the fall over a shorter range is even more significant.

The following diagrams highlight the gap between expectations and reality visually, from the perspective of a typical home.

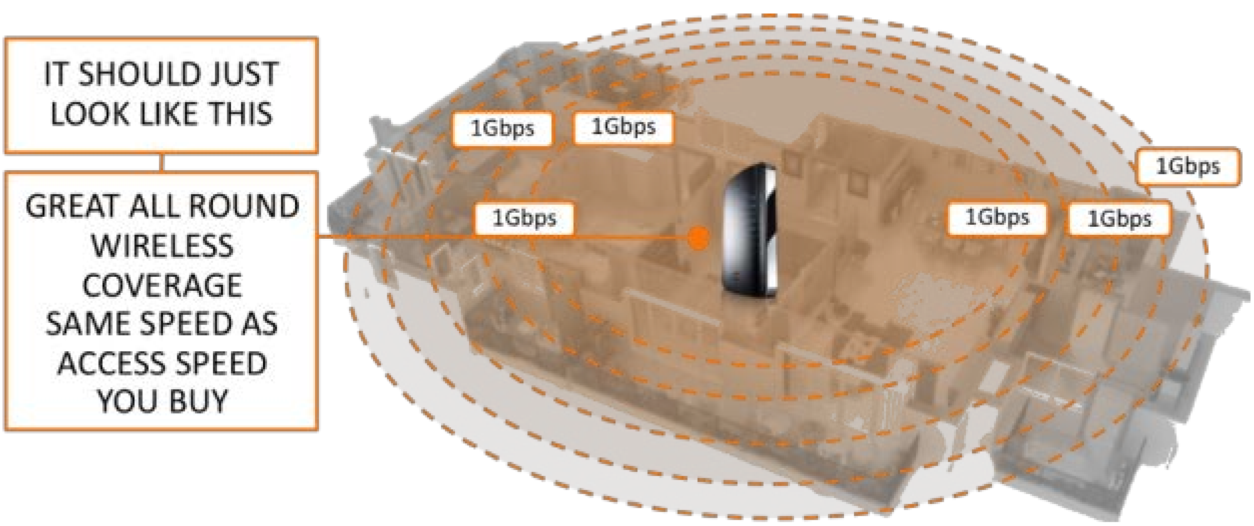


Figure 13 - Expectation: Wi-Fi Speeds = Access Speeds

From a purely commercial perspective, this seems very reasonable. A centrally placed access point (4x4 DBC or 4+4+4 TBC) can offer whole home Wi-Fi services to 500 Mbps speeds in 2,500-5,000 square feet homes. However, centrally placed APs and GWs are hard to engineer and often the AP is biased to the access network connection point at the outer wall of the home. This then typically necessitates a second AP to get the desired throughput to the extremes of where consumers' devices need Wi-Fi connection. After all, the Service Tiers that are advertised by the service provider are based on Access Speeds and given that the consumers pay steeper monthly access fees for increasing service tiers, there is a natural expectation of the availability of the same speeds on any device, at any location in the room.

Here is a picture of (what we would like) the current reality: The picture illustrates that additional APs are added – which increases the complexity of management and with Wi-Fi those devices also cause additional congestion and interference in home and to the neighbors' home unless properly managed:

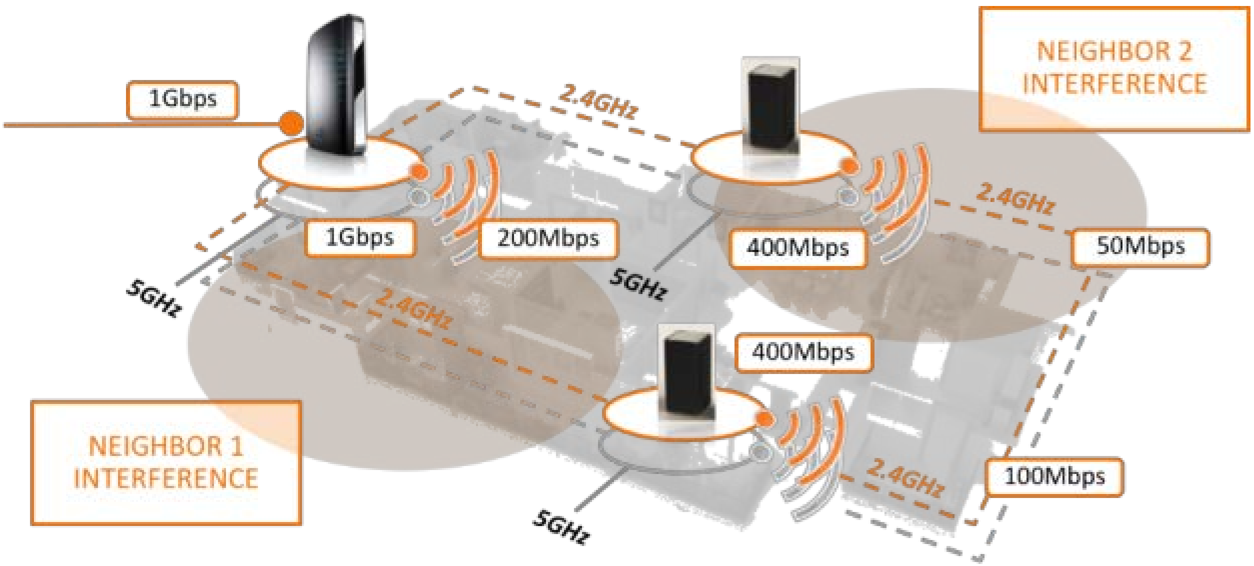


Figure 14 - Reality: Attenuation and Interference Affect Performance

Closing the gap between expectations and reality, with the use of additional access points in the home whose operations are coordinated for optimal performance – has been a focus of the industry for the last couple of years. It has spawned the following initiatives

- Retail Multi AP strategies to align with the consumers frustration when Wi-Fi goes wrong
- SP's own analysis for the right Multi-AP strategy – form and function of the extension AP
    - AC outlet mounted lower power 2x2 type managed repeaters
    - Tri-band 4+4+4 ultimate Extenders
- Wired vs Wireless Wi-Fi extension of backhaul
    - Wired works – but causes OPEX costs and dissatisfaction with consumer. Rarely self-install as it requires Ethernet wire pulls or potentially simple MoCA filter.
    - Wireless – lowest OPEX cost and minimal effort from consumer (when done right). Challenge to get a Wireless Mesh that is not a repeater and inefficient on the Wi-Fi airtime.
        - 2x2 Wireless Mesh devices – are still repeaters but can be made more efficient with mesh management software
        - Tri-band extenders are more ideal for the applications but have challenges of
            - Size and Cost

Table 1: Cost Delta with Tri-band Configurations

Extender Type	Cost	Comment
2+2+2	$	Can fit on AC outlet
2+2+4	$$	Needs a Fan or lower Power Wi-Fi
4+4+4	$$$	Maximizes 1W for range but table top only

- Software to manage the APs
  - Radio Resource Management (RRM) and Self-Optimization Networks (SON) initiatives
  - Cloud Wi-Fi analytics
- Standardization
  - Multi OEM and Multi Silicon solutions highly

Retail Wi-Fi devices that act as secondary or tertiary access points have entered the marketplace, promising easy setup, performance and management. This is a clear and present threat to the service providers, with the power to relegate their role to just an access provider, bypassing the complete data distribution. Without access to the devices beyond the network termination unit, the service provider will not be able to bundle services in the same manner as they are able to do now.

While the retail devices have acted as an interim solution for a consumer to Wi-Fi problems, they are not necessarily solving the full problem. Most solutions that are available today, while definitely slick on industrial design, ease of setup and deployment, and ease of self-service by the consumers, come nowhere near to addressing the full expectations of Wi-Fi Speeds matching access speeds.

The picture painted above, with the bewildering variation in the Wi-Fi clients as well as the tough road for incumbent service providers, is not necessarily one with a gloomy ending. There is help on many fronts: Standards are continuing to evolve, pushing performance boundaries, while also showing signs of maturity in terms of manageability and steps towards interoperability, signifying a ‘coming of age’ stage for the Wi-Fi technology. Concomitant availability of practical tools to take advantage of the advances in areas like Artificial Intelligence (AI), Machine Learning (ML) and Big Data will help drive complexity out of the solutions to solve the challenges. Finally, mature cloud-based solutions are available to help manage and visualize the connectivity, coverage, performance and other aspects.

In the following sections, we will examine the goodies that are available to us to ensure that the service provider can wrest the control back and provide meaningful managed Wi-Fi services to their subscribers.

Unwrapping the Goodies

The toolkit for enabling better management is now in our hands. We will examine developments along the following major categories, all of which are crucial to have a technically feasible and yet commercially viable set of solutions.

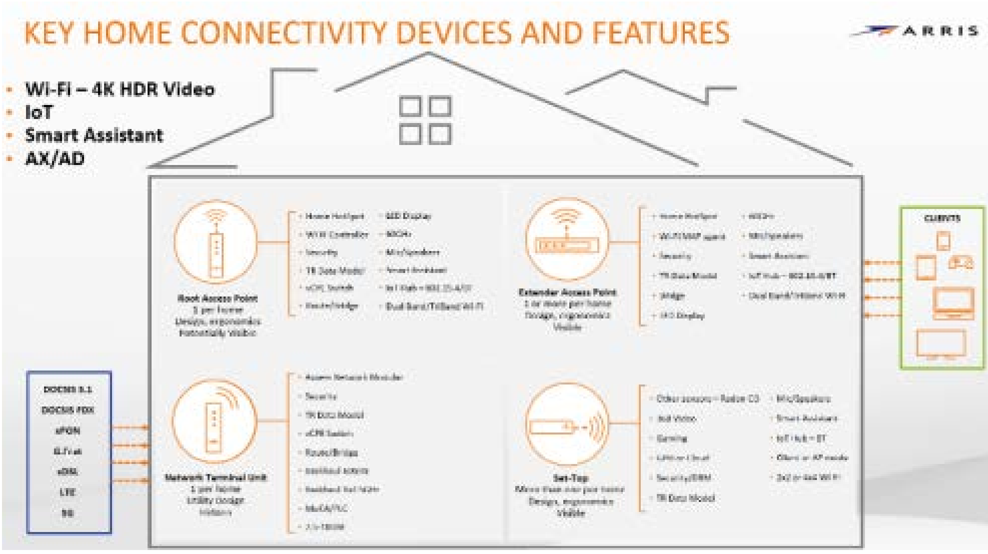


Figure 15 - Typical Wi-Fi Device Distribution in a Home

3.1. Choose Your primary AP

- All in one Access and Wi-Fi Gateway
    - o Lowest CAPEX for single smaller homes
    - o Tends to bias towards the wall for location
- 2 box solutions
    - o Standalone e-MTA and ONU
    - o Standalone AP device with Ethernet WAN
- Decisions then on what level of Wi-Fi to add to the Primary GW
    - o 4x4 DBC is now the standard -> moving to AX
    - o 4+4+4 Tri-band is a desire and moving towards with AX
    - o 8x8 DBC with ability to manage radios
    - o All have different performance and cost points and size constraints. The industry is trending towards Tri-band to
    - o Support high > 1 Gbps on Wi-Fi
    - o Allow one of the 5 GHz channels/radios to be allocated to Wi-Fi backhaul when additional extenders are added to a Multi-AP home

3.2. Choose Your Multi-AP Topology Strategy

- Wired AP solution – using Ethernet, MoCA, G.hn
- Wireless AP solution – using Wi-Fi meshing

3.3. Choose Your Multi-AP Device Architecture

- DBC – managed repeater
- TBC – optimized for airtime efficiency and performance
- Table top mounted AP
- AC outlet mounted AP
- Add additional services like IoT and Smart Assistant

3.4. Choose Your Meshing Solution

- In Gateway Wi-Fi controller only
- In Cloud Wi-Fi controller only
- Hybrid Wi-Fi Controller in GW and Cloud
- Full mesh 802.11s
- Partial mesh
- Hub and Spoke
- Hub and Spoke with Multi Hop (EasyMesh architecture)

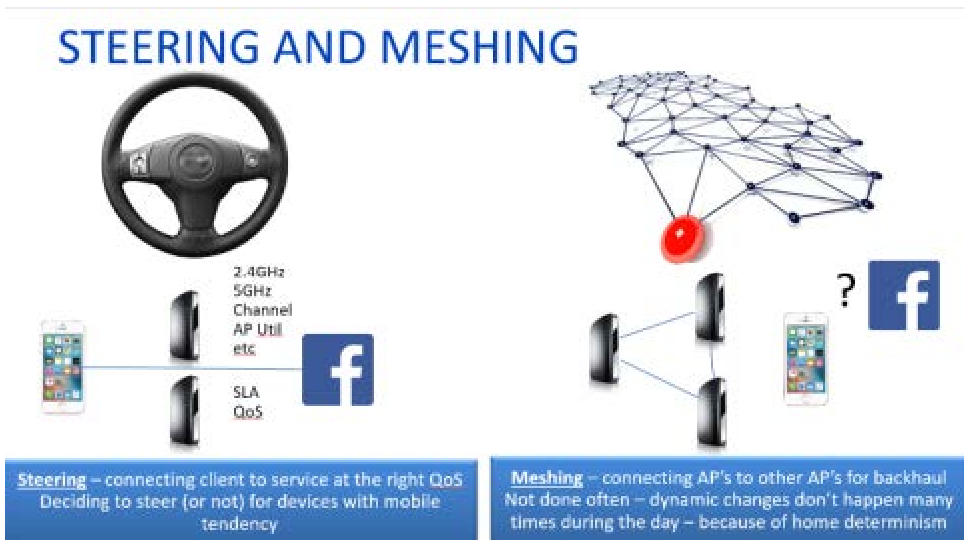


Figure 16 - Steering and Meshing: Defined

3.5. Choose Your Steering Solution

- Blacklisting
- BTM steering
- Fast Transition

3.6. Choose Your Cloud RRM/SON solution

- Cloud managed Wi-Fi RRM to manage across Home Wi-Fi domains or MDU
- Local GW based Dynamic Channel Selection solutions

3.7. Choose Your Wi-Fi Telemetry Strategy

- Choose your Wi-Fi data model in the AP and Extender devices
  - TR181+
  - WFA Data Elements
  - BBF USP
- Choose your pull and push strategy and Cloud Connection
  - RESTful

- WebPA
- USP
- COAP
- MQTT
- WFA Data Elements

Decide frequency of collection, what to collect, what to compress, and what to filter.

3.8. Add Your Machine Learning and AI Roadmap

- Analyzing Wi-Fi telemetry to update Gateway Controller policies for Wi-Fi steering, Device policies, service policies

4. Wi-Fi improvements Worth Noting

There are a number of areas that this paper will expand on – they fall into 3 categories below

- **Work of standards bodies** coming to implementation fruition. Sometimes seen as an undue constraint on the speed of innovation, this bridle is a necessary step in coordination across the entire industry, placing emphasis on interoperability and the importance of a viable ecosystem that will allow for network effects to take place and costs to be manageable.
- Group of three inter-related technologies of **Artificial Intelligence (AI), Machine Learning (ML) and Big-Data Analysis**. These technologies are now at a level of maturation to allow for their application to solving problems across multiple disciplines, and Wi-Fi management is no exception. We will examine specific problems in the area of Wi-Fi management as examples where the application of these technologies is apt.
- The third category is more a paradigm shift, than a specific technology. This involves moving the platform for solving several management challenges from the devices to the cloud. Headend and back-office infrastructure always existed, and cloud-based service or management is not new. What we identify here are specific examples where the visibility across homes, the availability of compute power and data storage, and the inevitable association with AI / ML and Big-Data Analysis.

5. In-Home Device Implementations Catch-up to Standards

One of the issues with Wi-Fi Controller/SON or RRM solutions was that they were proprietary in nature, agent based and while they flattered to allow potential porting to be done – in reality they did not allow this easily or at all. Standardization in this area was required and this spawned the work that ultimately ended up being certified by WFA as Wi-Fi CERTIFIED EasyMesh. Additionally SCTE 2018 marks the time when the most important thing to happen to Wi-Fi since it first emerged is now real and relevant – 802.11ax. An IEEE standard that forms the basis of 90% of all home connections. The following sections briefly outline the importance of these 2 standards to the service provider's strategy.

5.1. 802.11ax: Aimed at Improving Efficiency and Performance

Perhaps the most important standard that is being driven from an implementation perspective to fruition is the 802.11ax. There is enough material on this topic that in the context of this paper, we will just mention the importance of this, rather than explaining the technology itself.

Earlier in the paper, we noted that number of devices in the home, increasing bandwidth requirements of video, and the advent of IoT devices as key triggers to demand increased performance, and the 802.11ax standard strives to address all of these. There is a clear market demand and a causal connection that is illustrated in the diagram below:

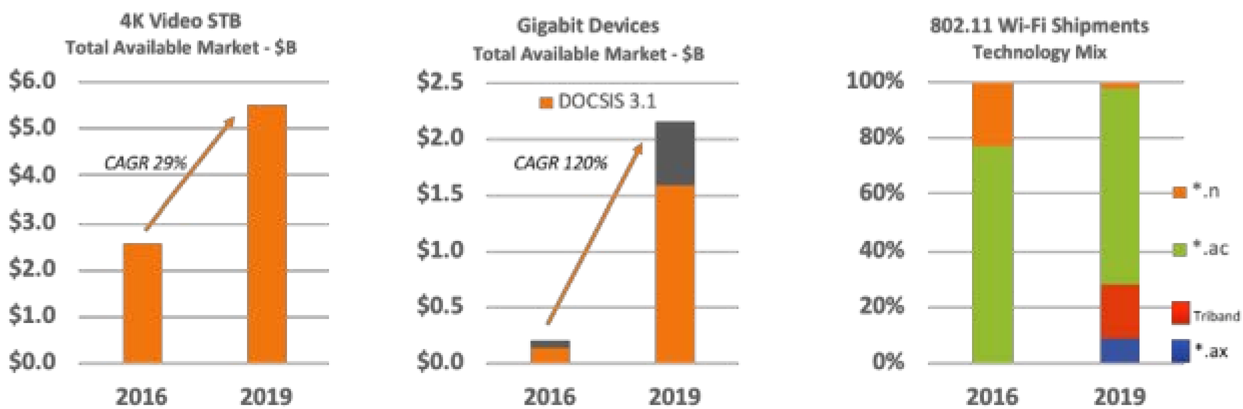


Figure 17 - New Technologies Demanding drive for Wireless Performance

The standard improves spectral efficiency in dense client environments (that should help when the number of Wi-Fi client devices in the home increases), with a concomitant increase in effective throughput, taking us closer to realizing the goal of Wi-Fi speeds matching access speeds. See the simple chart below that illustrates all the benefits of the new AX standard.

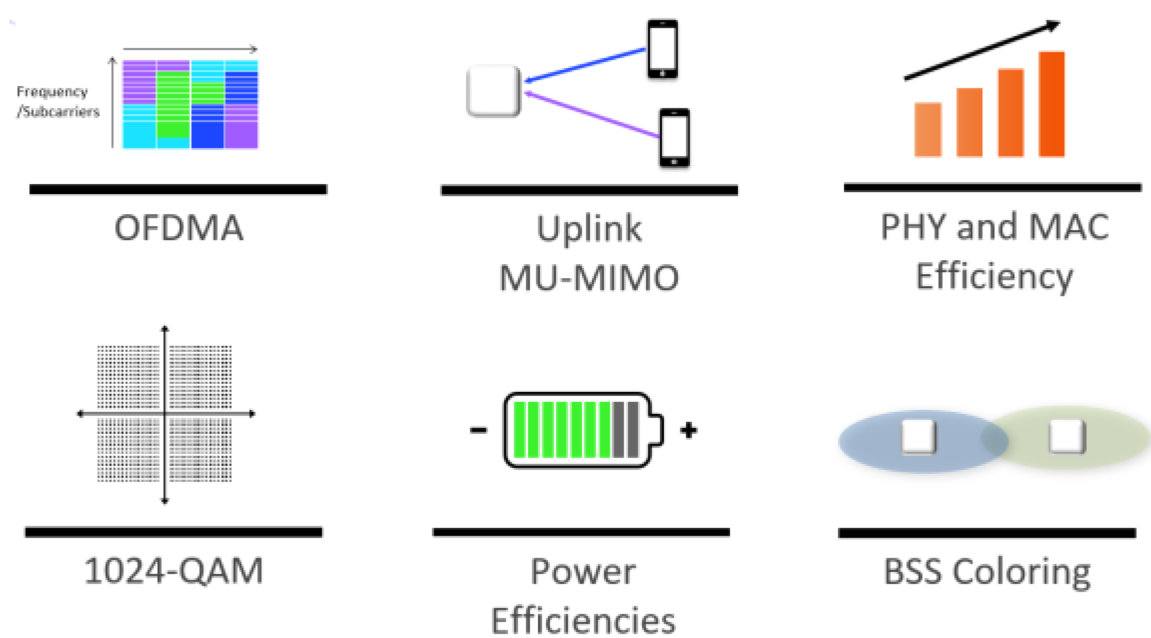


Figure 18 – Key Benefits of 802.11AX

However, the key feature of ax is the ~27% of improved efficiency over ax that can be immediately realized particularly in Multi-AP architectures. See the chart below – where we can achieve 1 Gbps thru 2 sheetrock walls vs 846 Mbps in 802.11ac. This is an enormous benefit for minimizing the number of extender APs and also increasing the flexibility of location of the extender device.

802.11ac Performance (5 GHz UNII-1 Band @ 30 dBm)
Balanced Client Device

Backhaul UNII-3	Link Rate to Root AP			
Configuration	0 Wall	1 Wall	2 Walls	3 Walls
80 MHz 4x4 ac	1290.27	1290.27	846.34	360.75
80 MHz 4x4 ax	1958.04	1538.47	1009.72	430.42
160 MHz 4x4 ac	2709.39	1763.04	736.27	355.55
160 MHz 4x4 ax	3711.18	2128.47	890.81	430.42

WARNING!!
160 MHz Channels Require use of DFS Frequency Band and Power

Backhaul DFS	Link Rate to Root AP			
Configuration	0 Wall	1 Wall	2 Walls	3 Walls
80 MHz 4x4 ac	1290.27	947.12	550.99	176.76
80 MHz 4x4 ax	1958.04	1129.83	657.41	210.80
160 MHz 4x4 ac	2709.39	1763.04	736.27	355.55
160 MHz 4x4 ax	3711.18	2128.47	890.81	430.42

Figure 19 - 802.11ax Performance Gains over 802.11ac

Another important design goal for 802.11ax is the consideration for devices (especially IoT devices) that are battery operated, by way of improving the efficiency of operations to allow for low power-consumption. 802.11ax allows for efficient allocation of low data-rate connections, and for improved battery life of sensors. Power savings modes have been enhanced, to include longer sleep intervals and scheduled wake times. Many IoT devices implement a 20 MHz channel only, and the standard now takes that into account to have a "20 MHz channel-only mode", to take such devices into account.

5.2. Wi-Fi EasyMesh

Even with 802.11ax and the increased efficiency, it is impossible to achieve full coverage across a large home with a single access point, however powerful it is, since it is usually hard to argue with the laws of physics. The introduction of multiple access points in the home immediately gives rise to several technical challenges.

The primary and foremost challenge relates to the problem of onboarding the additional access points to ensure that these units have the same SSID and passphrase as the main access point. After all, while the multiple access points can be utilized as separate entities, it is obviously not a meaningful proposition, since it would require the consumer to segregate the Wi-Fi clients and statically associate them to different access points, each of which have a different SSID. The obvious solution is for all the access points to share the SSID and Passphrase information seamlessly. This is in general referred to as "Auto Configuration" or "Zero Touch Configuration". The configuration should not only be done at initial set-up time, but also whenever there is a change in the configuration at the main access point (like the consumer changing the password), that these changes are propagated.

The process of auto configuration (or zero touch configuration) has to be solved independent of whether the secondary access points are connected to the main access point via a wired connection (such as Ethernet or MoCA), or a wireless connection either by sharing the 5 GHz band or a dedicated radio in Tri-band configurations.

The challenge cited above is not purely technical in nature but reflective of the need for interoperability. To ensure the setup and ongoing synchronization, there needs to be a common protocol for communication across the access points. While there have been proprietary solutions, true multi access point solution has relied on the development and adoption of a common protocol.

The Multi Access Point Protocol (MAP) started as a Special Interest Group activity, and since then has been adopted by Wi-Fi Alliance (WFA), the standards body. It has since been renamed as Wi-Fi EasyMesh™ and includes a certification process.

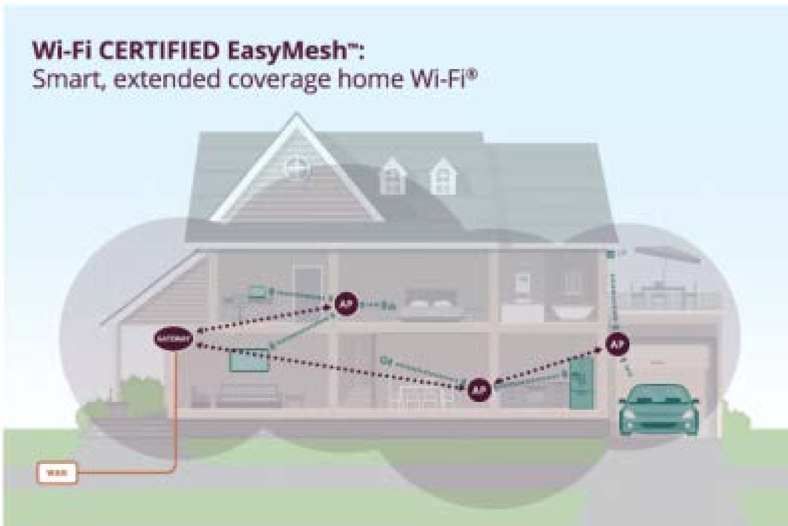


Figure 20 - Wi-Fi Certified EasyMesh™ (source: http://www.wi-fi.org)

The EasyMesh architecture supports both wired and wireless backhaul links from the secondary (additional) access points to a central gateway. The Gateway is that Access point which is connected to the WAN network. The architecture accounts for two software components, the ‘Agent’ and the ‘Controller’ and in general supports topology variations. The following diagram depicts a typical scenario.

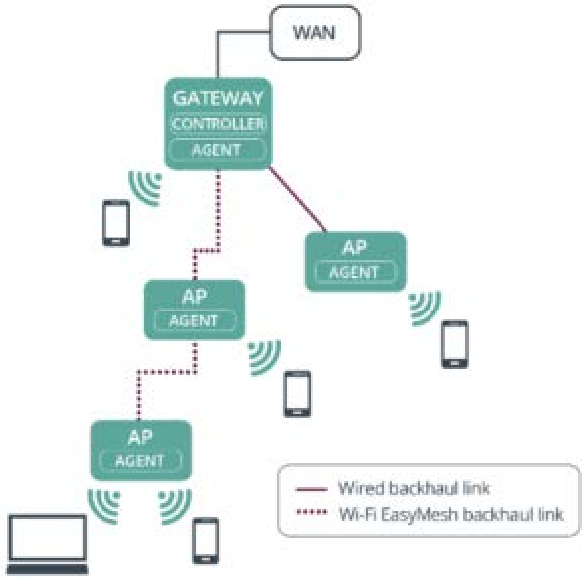


Figure 21 - Wi-Fi EasyMesh Architecture

The key communication protocol is the contract between the "Agents" that run on different platforms, and are responsible for discovery, onboarding and subsequent information exchange. The "Controller" typically runs on a gateway (as has been depicted in the diagram above and below) and manages the various network clients in the home. This standardization allows any EasyMesh compliant Extender to be managed by a nominated controller AP. This then allows a SP to mix and match Extender OEM and silicon providers easily.

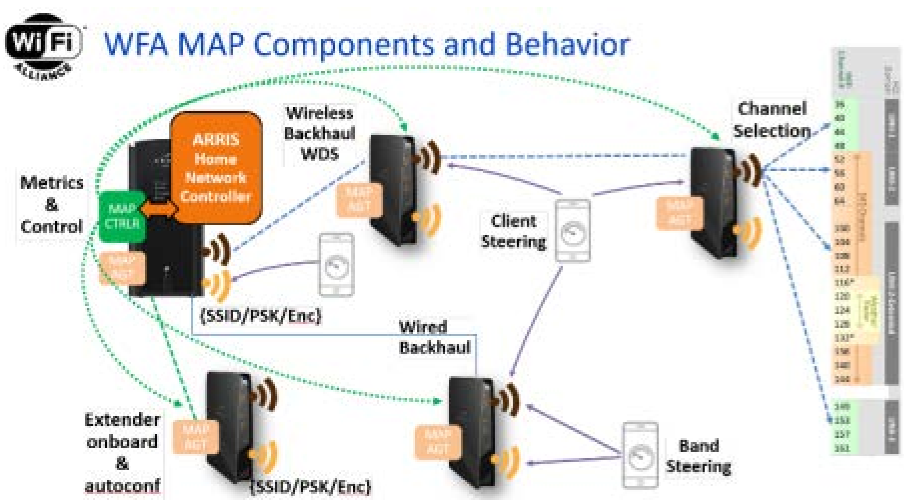


Figure 22 - Role of WFA Standards Based Components

The EasyMesh MAP (Multi-access Point) controller – creates the topology of all the agents APs in the discovered network. The MAP controller will coordinate sending information to and from the MAP agents. These commands are Wi-Fi telemetry and Wi-Fi commands such as change channel, band steer, change power – the suite of Wi-Fi control commands you would expect to have in a Wi-Fi AP network.

However, the MAP controller does not make Wi-Fi algorithmic decisions. It needs a Wi-Fi controller (algorithm) to tell it what to tell the MAP agent-based APs. This makes the algorithms agnostic of Wi-Fi command/control and allows the SP to select a Wi-Fi algorithm solution – as implementation in GW/AP above the MAP controller level.

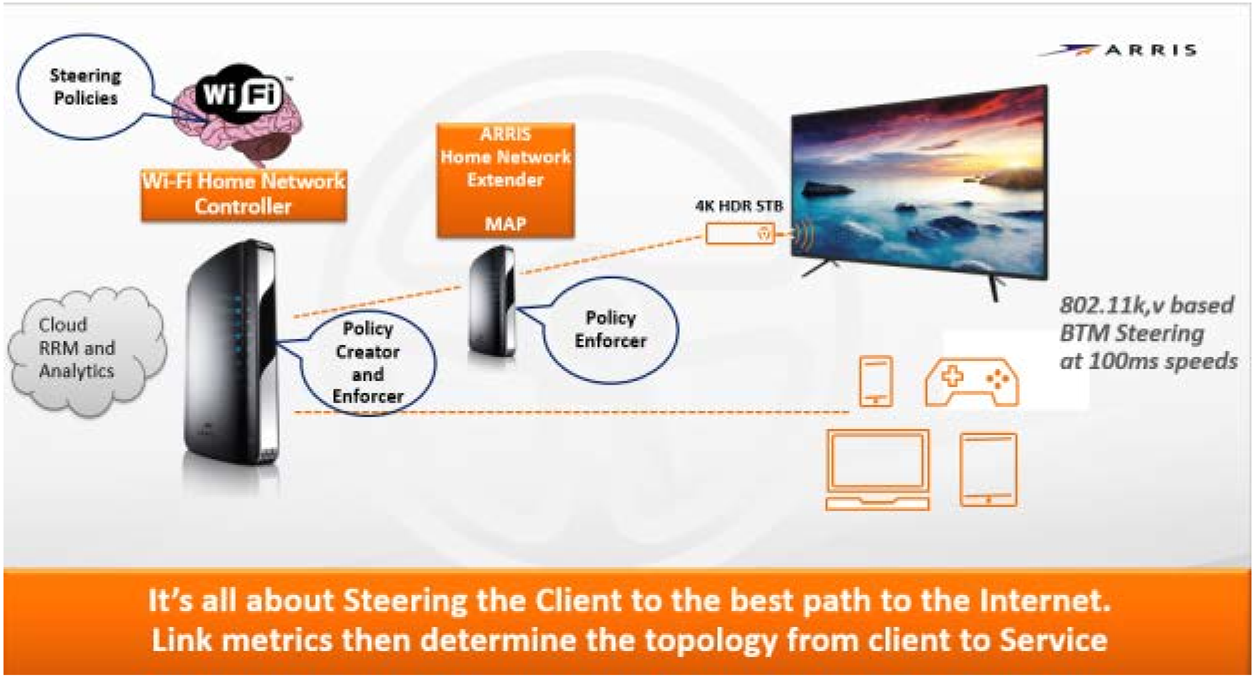


Figure 23 - Criticality of AP Steering

The architecture, while securing interoperability, is flexible enough to allow intelligent Radio Resource Management (RRM) and Self-Optimization Networks (SON) schemes to be implemented by solution providers to differentiate as well as address the diverse needs of the service provider community.

5.3. 802.11v and 802.11k to help "Roam (in) Sweet Home"

While Wi-Fi EasyMesh addresses the basic connectivity and information-exchange challenge across the multiple access points, the second level challenge is what is referred to as the "Sticky Client" problem. A mobile client that is associated with a given access point may move (who has not walked around the home while talking on the cellphone?) to another location in the house where the signal strength relative to the currently associated access point is so weak that it affects the performance of the said device. The presence of a nearby access point (which might offer a better signal), if not taken advantage of, will be absolutely useless.

Having the client be associated with the most appropriate client dynamically, without any action on the part of the user (a problem that is already solved in the enterprise space), becomes important. Moreover, when there are many clients, it may be prudent to balance the load on the various access points so that the load is equitably distributed. In addition, there may be preferential treatment to specific clients based on the services that are consumed by them.

In order to achieve these solutions, especially in a multi-vendor home ecosystem, it is imperative that the various access points (and the clients) share information that help and assist the seamless movement of the client association from one access point to another.

802.11k standard defines creation and transmission of neighbor report lists. Neighbor reports contain information about the neighboring access points (from the perspective of the AP providing the list), and are transmitted to a client that supports this protocol. These neighbor reports allows the client device to have a clearer picture of the Wi-Fi surroundings and allows the client device to prune the list of channels that it has to scan before finding a suitable candidate neighboring AP to associate with.

802.11v standard is aimed at smooth and fast transition of a client to another access point, directed by a controller. This transition is initiated by the Controller and allows for the use of intelligent algorithms to make such a decision. Access points that support 802.11v can direct clients (that support the 802.11v protocol) to roam to another AP which presumably is intended to provide a better Wi-Fi experience for the client device. The client devices will have to accept and respond to the Basic Service Set (BSS) Transition Management (BTM) frames.

The example highlighted below shows that BTM steering in particular allows the SP for the first time to control which AP the device connects to vs the device making all the decisions.

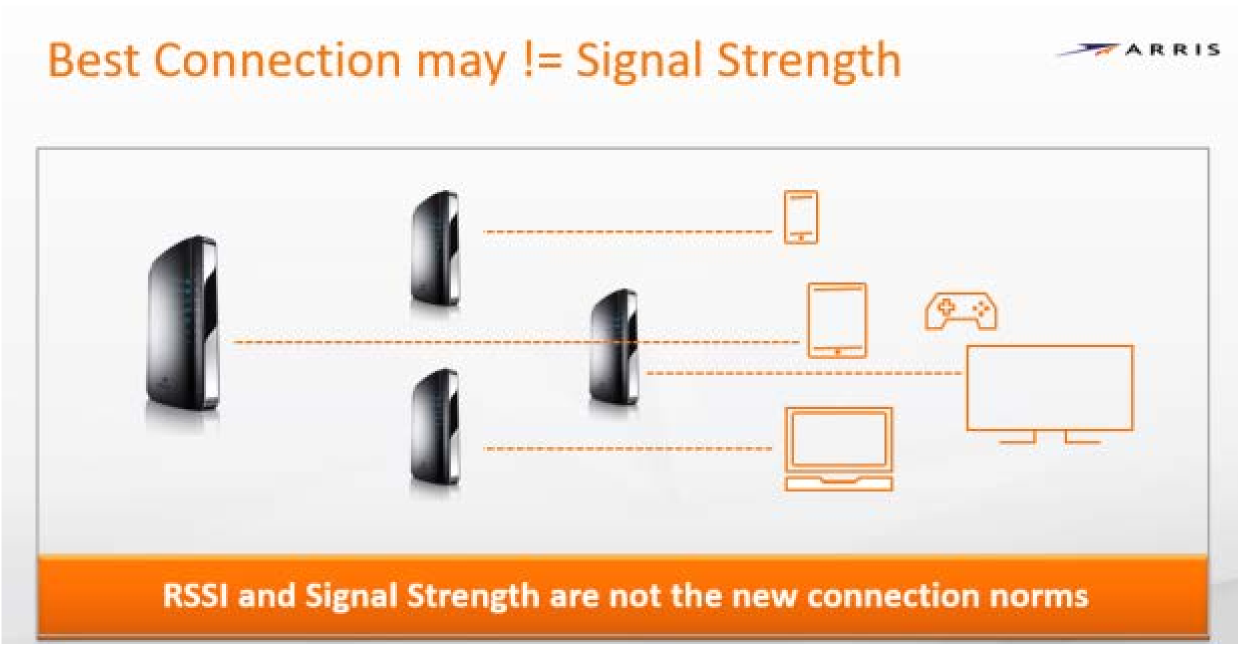
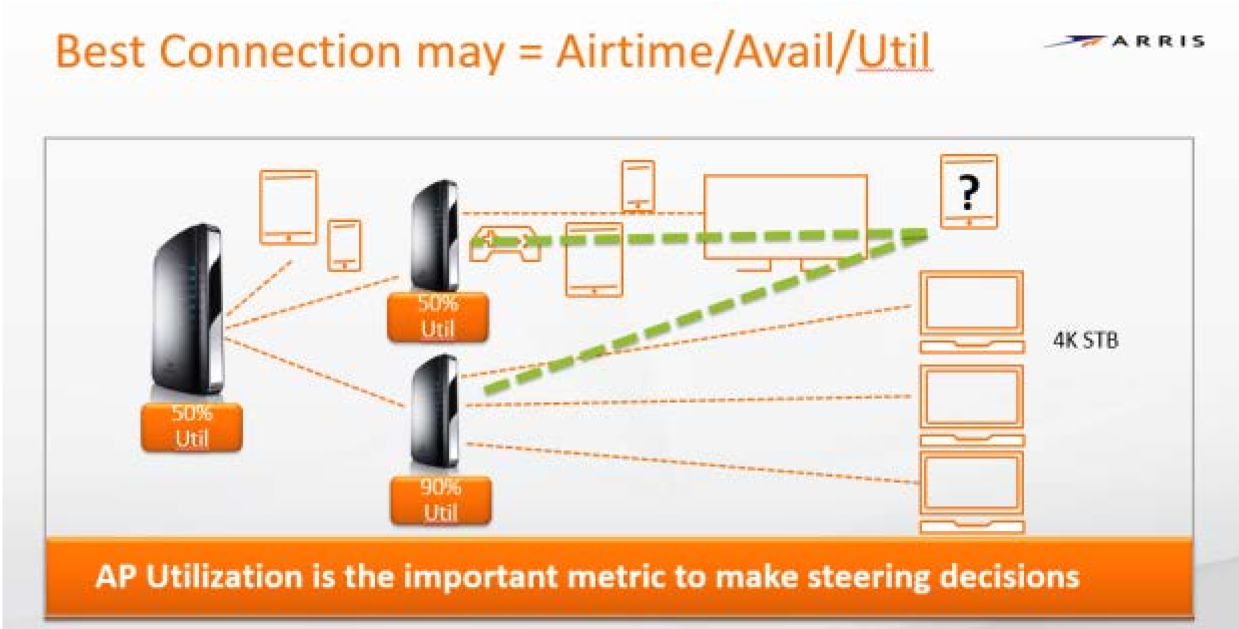


Figure 24 - Signal Strength Alone is not a Unique Determinant of Performance



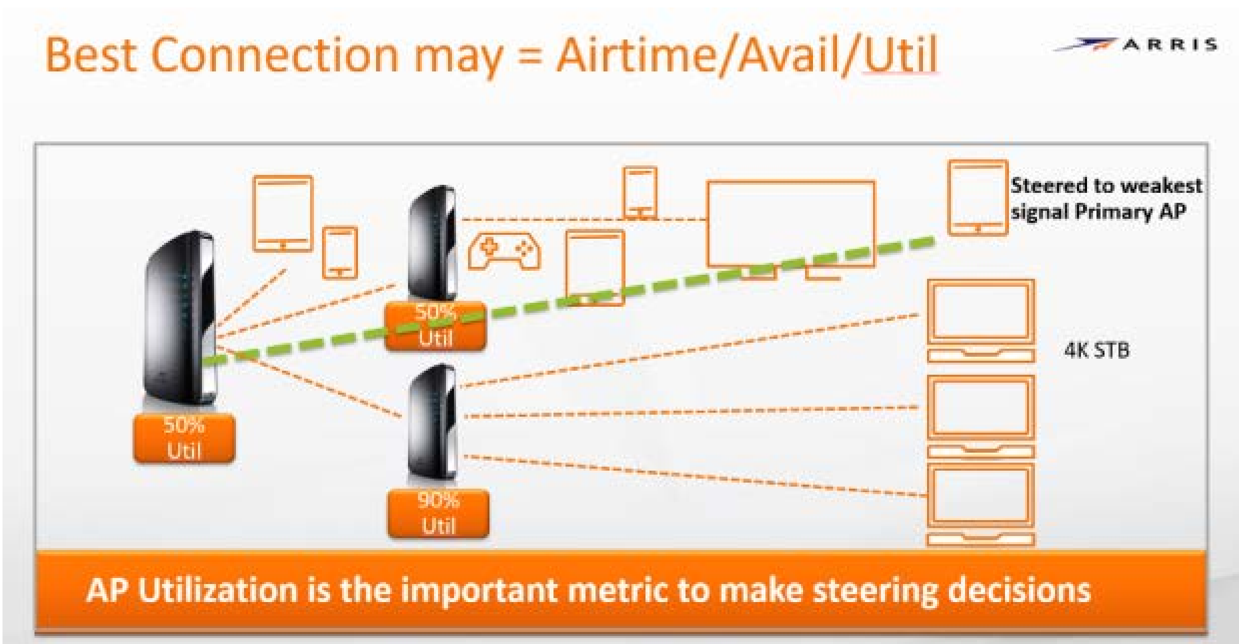


Figure 26 - Role of AP Utilization in Steering Decisions

5.4. Wi-Fi Easy Connect

While the standards listed above deal with the Access Point infrastructure inside the home, we need to turn our attention to adding the ever-growing list of Wi-Fi clients to the home network. Given the wide diversity of the clients, the onboarding of retail devices to the home network is anything but trivial. As engineers, we tend often tend to overlook the complexity involved for an average consumer. Onboarding a typical retail device to be a client of the home Wi-Fi network involves multiple steps and is often left to the retail device manufacturer to solve it in whatever manner that they consider the easiest.

Wi-Fi Easy Connect is an emerging standard that is part of the Wi-Fi Alliance set of emerging standards. The architecture proposed allows for a simple process that involves ‘one-touch provisioning’ assuming the various actors in the architecture follow the Device Provisioning Protocol Specifications that are available to WFA members.

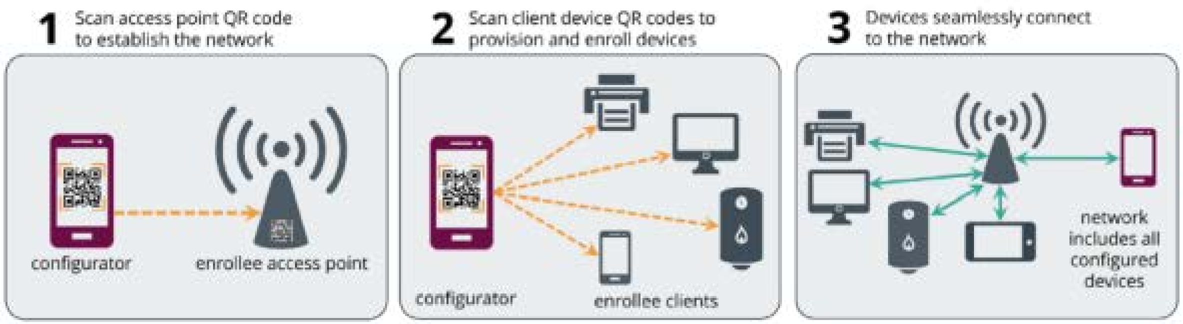


Figure 27 - Device Provisioning with Wi-Fi Easy Connect

There are requirements imposed on access points, clients, and a requirement on a configurator, which is typically a mobile application. Client devices are required to have QR code as part of the device, in order to be enrolled as clients to the AP. (Source: http://www.wi-fi.org)

Both EasyMesh and Easy Connect are examples of technologies that require a critical mass of supported products in the entire ecosystem in order for network effects to kick in and make them ubiquitously used.

6. AI / ML techniques

Artificial Intelligence, Machine Learning and Big-Data Analytic techniques are inter-related technologies that have moved from being just hype-phrases to providing practical toolsets to solve problems that are amenable to the use of such techniques. We don’t go into details here, given that these are huge subjects and any treatment will be not do any level of justice. Our main intention is to point out that some of the problems that we encounter in Wi-Fi management lend to solutions that utilize these techniques. And in particular to point out that Wi-Fi homes are extremely deterministic in nature and can be graded into a small subset of categories – that help with the management services to the home, again keeping with the simple theme – and the simple groupings of device types and service types above.

The human behaviors chart below shows that each person, household tends to have a specific signature:

- Number of people
- Number of devices
- Type of devices – high bandwidth, security, etc.
- Mobile usage
- Outdoor in garden usage
- Security cameras
- Times they are at home
- How they use their devices at times in the day
- How they set their home up on vacations
- And more

Figure 28 - Consumer Behavior

The STBs in the home in particular – need to use the Wi-Fi toolbox as a high need device. We know that if the consumer has any problems with primary TV viewing this can be a churn event. So these devices need to be signature found and policies applied to make them work better than OTT devices.

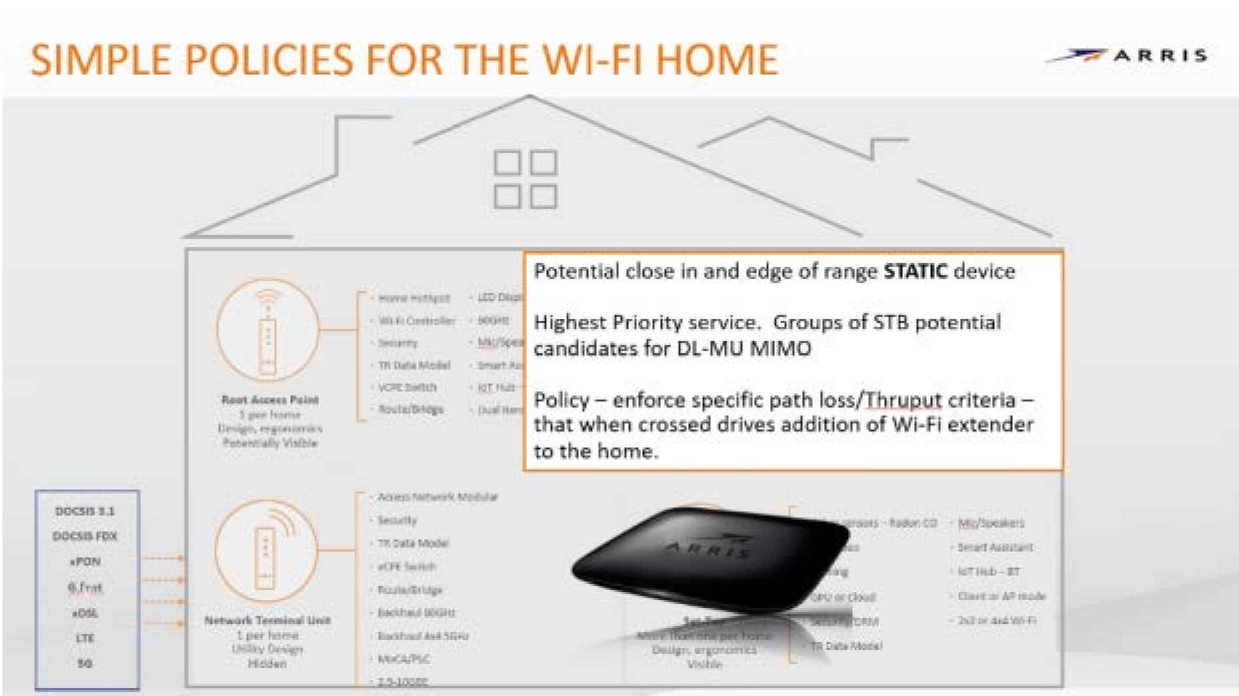


Figure 29 - Policy to Adopt for High-Bandwidth Set-top Box

Other static devices are OTT video consumption devices that are also high value and need the ML solutions to signature their use and setup management profile to work with them.

Figure 30 - Policy for Static High Definition TV

Mobility in the home and the assessment of the Mobility Index (how often people are mobile with traffic or not) is something that is also key for the machine learning elements of Wi-Fi management.

Figure 31 - Policy for High-Bandwidth Mobile Devices

Tools like the one below tracking the mobility of devices can also help to assess how to enforce steering and Wi-Fi policies as well as device architectures. The images below

- Color shows health – Green Good, Yellow Ok, Red below SLA
  Size of bubble – amount of data consumed on device
- Right to left bubble track – the RSSI location of the device

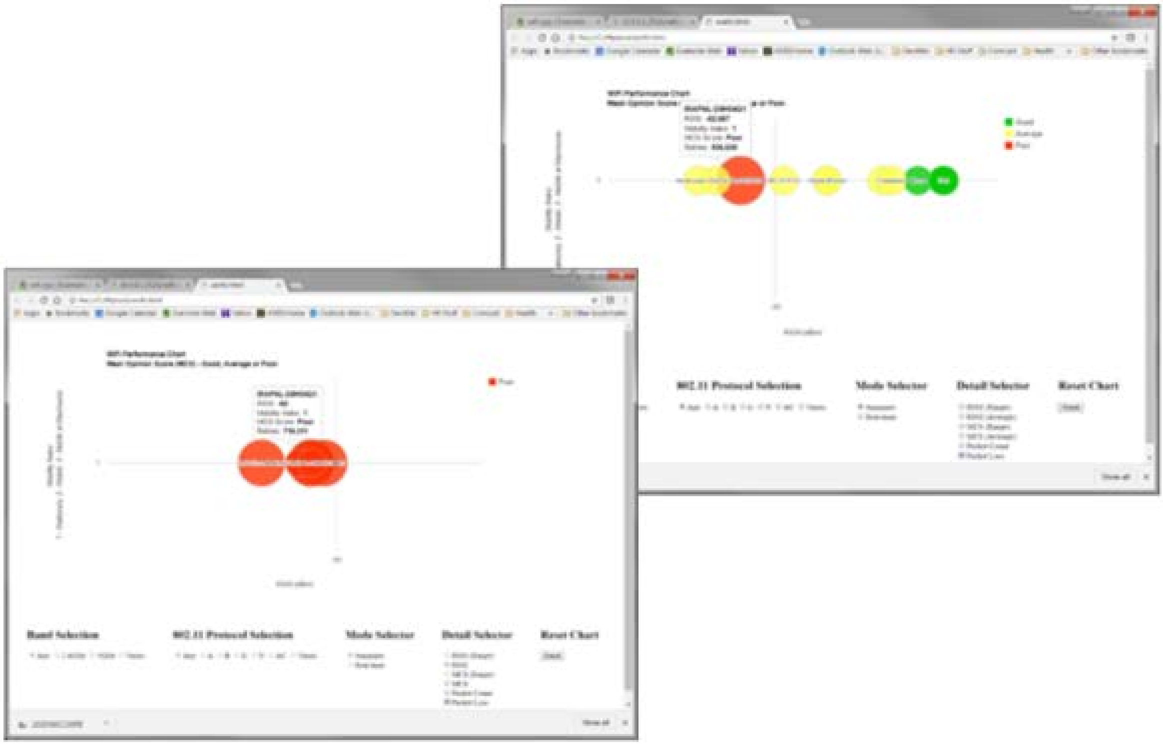


Figure 32 - Visual Representation of Device Coverage Health

The Machine Learning and AI policies also need to signature capture medical or security devices which have high worth metric and potential service SLAs on them. They need to get best Wi-Fi too.

Figure 33 - Policy for Static High-Priority Elements

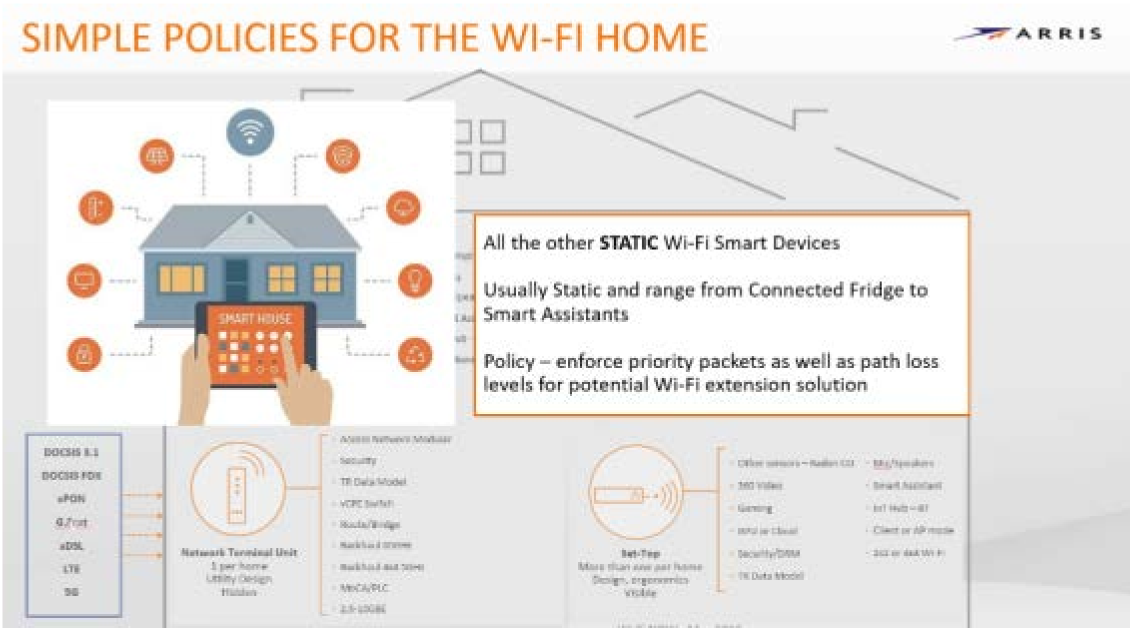


Figure 34 - Policy for IoT devices

The popularity of Wi-Fi devices like Ring doorbells and Wi-Fi controlled garage door openers has had a big effect on both Wi-Fi performance (long range low modulation bad apples when added to home) as well as driving the need for Wi-Fi extension additions. Many of the doorbells and cameras also prompt consumer to buy a same brand Wi-Fi extender to ensure that their service is optimized. The ML algorithms used need to grade/categorize the home – for this particular static device type and create special polices to manage.

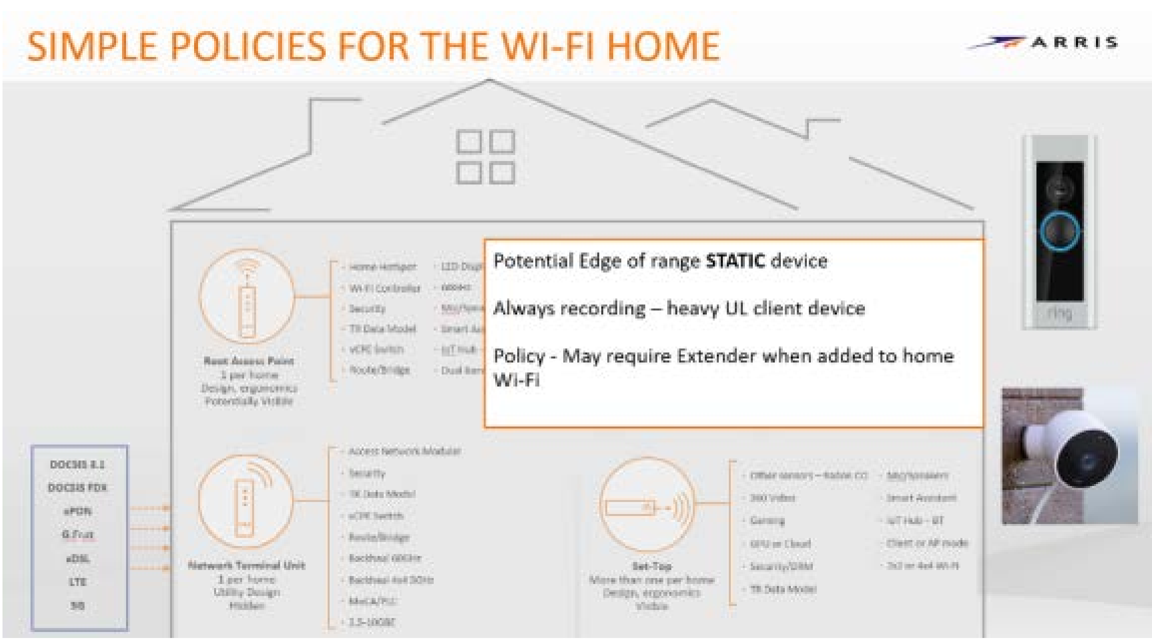


Figure 35 - Policy for Devices at the Edge of the Home

One of the other key machine learning and categorization of the home – is whether the consumer is using their Wi-Fi devices outside the range of the home. The garden and deck usage of mobile devices like tablets which are not permanently attached static outside security or IoT devices but through mobility to the back garden the consumer is getting a poor Wi-Fi experience – and will blame the SP for poor Wi-Fi. Using Wi-Fi location and trending of mobility performance – the ML algorithms can infer that the user is trying (maybe unsuccessful) to use mobile device with high bandwidth at extreme distance from the home.

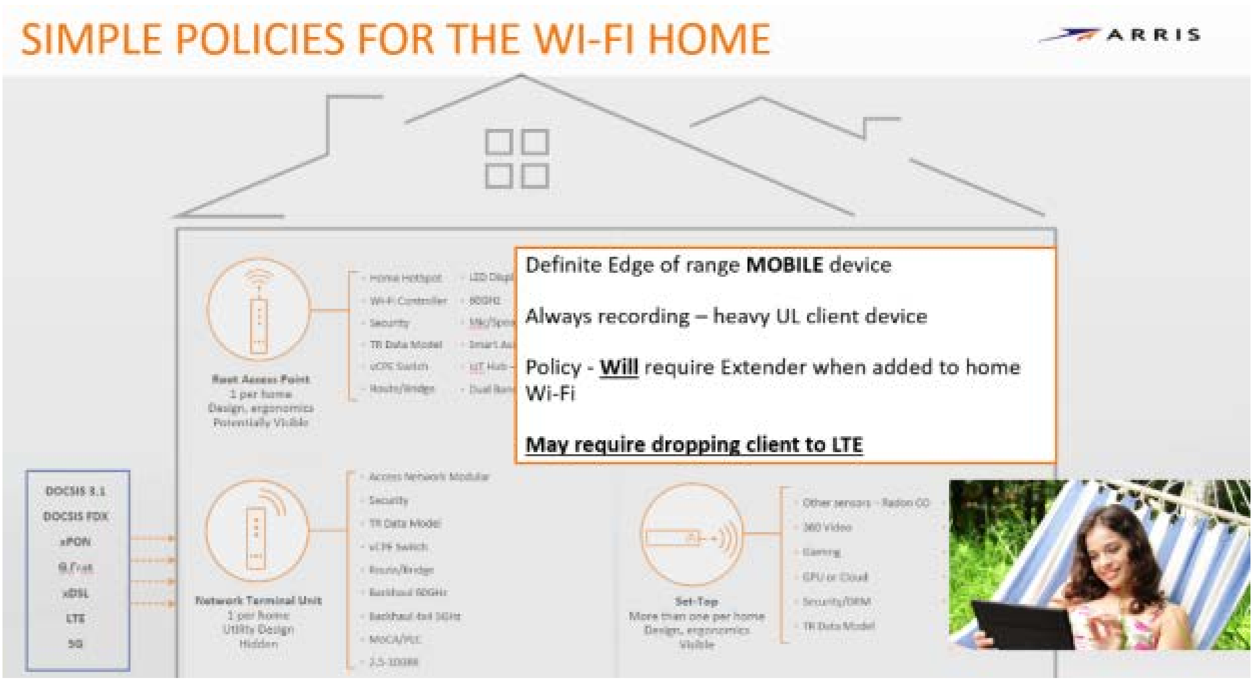


Figure 36 - Policy for Devices Outside the Home

The following table lists the data analysis categories that AI/ML tools excel at, and identifies potential applications relevant to Wi-Fi management:

Table 2: Categories of Data Analysis problems that Ai/ML Techniques Excel at ?

Analysis Category	Description	Potential Application
Classification	Identifying the category to which an object belongs	Device Fingerprinting
Regression	Predicting a continuous valued attribute associated with an object	User Behavior and prediction
Clustering	Automatic grouping of similar objects into sets	Device categorization; Resource Optimization
Dimensionality Reduction	Visualization and increased efficiency	Actionable Reports and Analytics
Model Selection	Comparing, validating. And choosing parameters and models	
Feature Extraction	Preprocessing and normalization	

There is a plethora of open source and commercial tools that offer a starting point for the development and fine-tuning of algorithms and solutions as applicable to the challenges in Wi-Fi management.

7. Cloud Based Analytics

Cloud-based SW architecture is not new. Back-office systems that support control Wi-Fi is not new either. In the Enterprise segment, Access Point controllers are traditionally based in the cloud and perform the management functions as a matter of routine. What we are highlighting here is the use of Cloud-based platform to help the analysis of data to support Wi-Fi management not only in a home setting, but also across multiple homes (like an MDU or neighborhood).

While Gateway based software-controllers offer low-latency and provide fast turnaround decisions for steering and roaming, they lack two crucial advantages that a cloud-based system can offer. The gateways don't have the compute power or the storage capacity to handle large amounts of data over time, to do time-series analysis for trend predictions and other such statistical analysis. Secondly, the gateways don't have visibility to other Wi-Fi devices such as neighboring access points and other wireless devices that will have an impact on the performance because of interference or such reasons. Lastly, without a cloud infrastructure, there is no way for one Gateway to learn from the knowledge, data or experience of other gateways.

For these reasons, a hybrid architecture where the local software-controller takes care of low-level execution, being informed of a management policy that gets articulated by a cloud-based system makes immense sense.

8. Goodie-Bag Summary

In the foregoing sections, we touched upon the various tools and standards that are available to us to be able to address the needs of the consumer in a meaningful way. In the next section, we will take each of the consumer needs and exemplify how the techniques and tools help us to tackle the challenges cited.

Addressing Consumer Needs with the Goodies

In the previous sections, we have seen in some level of detail, the challenges of Wi-Fi management, and also the tools and standards that are available for us to create the solutions. It is time for us to revisit each of the six critical needs that we stated as consumer needs for the Wi-Fi Home network. In this section, we go through each of these needs, and provide examples of how some of these needs are being addressed.

9. Connectivity & Security

The wide diversity of Wi-Fi clients imposed on us the challenge of onboarding as well ongoing management and maintenance of these clients.

In the section on Standards, we alluded to the upcoming standard for Wi-Fi Easy Connect via the WFA organization. However, there are many retail devices that are already in the field and many more that will be manufactured before the standards are implemented and the devices have the requirements (such as QR code meeting the specifications) met.

The problem itself can still be adequately addressed as long as the solution component includes a suitable tool for the role of the configurator such as a mobile application. The following diagram shows how a retail device that has either a QR code or a WPS button can be utilized along with an application to initiate simple onboarding process.

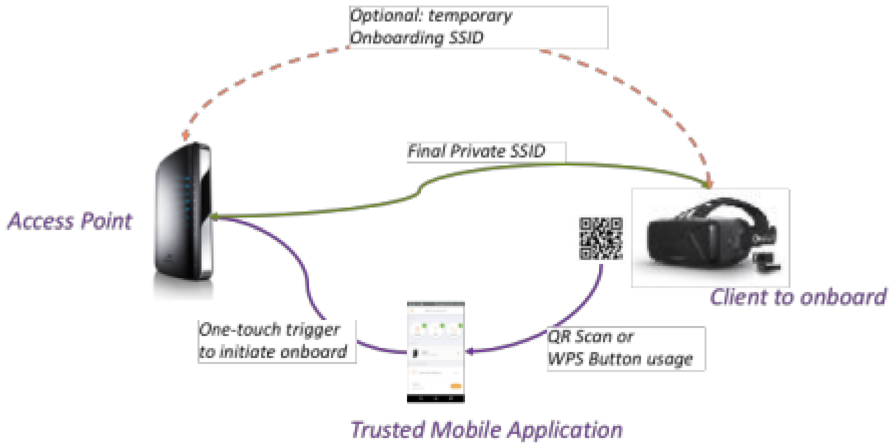


Figure 37 - Wi-Fi Client Onboarding Process

The use of the temporary onboarding SSID and the QR scan are intended to ensure that an arbitrary device will not be able to get onboard the home network. The arbiter here is the mobile application, which typically needs the administrative access to the access point for its operation, and hence assumed to be in possession of the custodian of the access point.

In case the device has a WPS button, there is still no need to have the device close to the access point to be able to press the WPS simultaneously, since the mobile application can be used to “soft initiate” the WPS action on the access point.

Ongoing maintenance of the client, in terms of its client association, data usage and other connectivity statistics are things that can be handled by the gateway and information provided to the mobile application for display.

While we are on the topic of clients, it is important to note that any of the solutions relative to coverage, security, performance and such need a clear understanding of the nature of the client. This cannot be achieved through simple device query, and in many cases may need to be deciphered based on the data traffic and other parameters. The process of identifying a device to a very fine degree of granularity is the process of “Device Fingerprinting”.

Figure 38 - Device Fingerprinting Essential with the Explosion of IoT devices

Device fingerprinting uses machine learning techniques and the learning process gets better as more and more clients across multiple homes are onboarded and recognized. This fundamental process comes in handy in correlating performance and security related functions.

As an example, consider a customer complaint about poor Wi-Fi performance from a specific Wi-Fi client device. If the system is able to figure out more detailed, granular information about the device (like its hardware capability or the lack thereof, software versions and such), a potential explanation could be provided explaining why the lack of performance is not due to any service provider-supplied device (such as the access point itself) but more to do with the client itself.

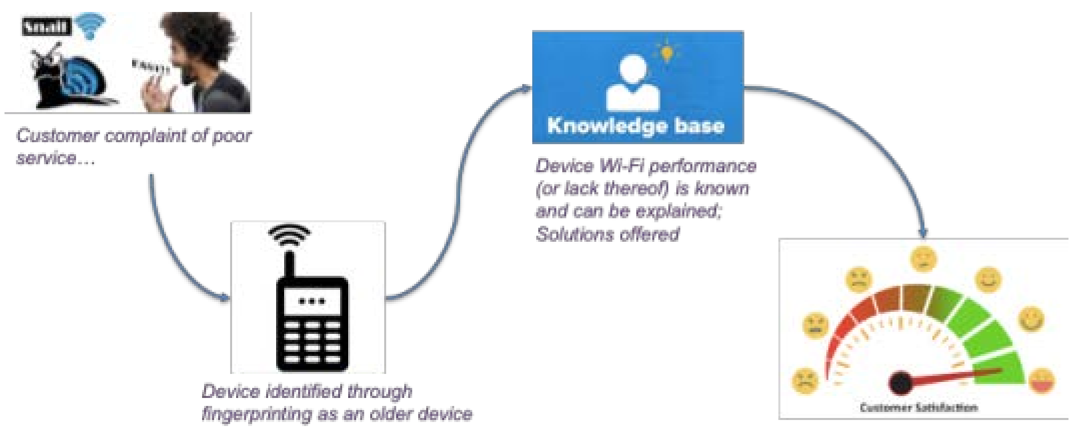


Figure 39 - Correlation of Poor Performance to Client Characteristics

Device fingerprinting is becoming an essential need in Wi-Fi management systems, especially when the management of IoT devices or security solutions are part of the service offering.

10. Coverage & Performance at Range

As we already noted, Coverage that goes hand in hand with “Performance at Range” is the touchiest subject given the customer expectations of ensuring Wi-Fi speeds are equal to the access speeds. We also noted that even with the upcoming 802.11ax specifications, a typical home needs to have multiple access points, and doing so, should solve the problems of auto-configuration and also allowing the clients to associate with the right AP through steering. In this section, we will examine one typical implementation that combines the use of standards and other techniques to solve the problem.

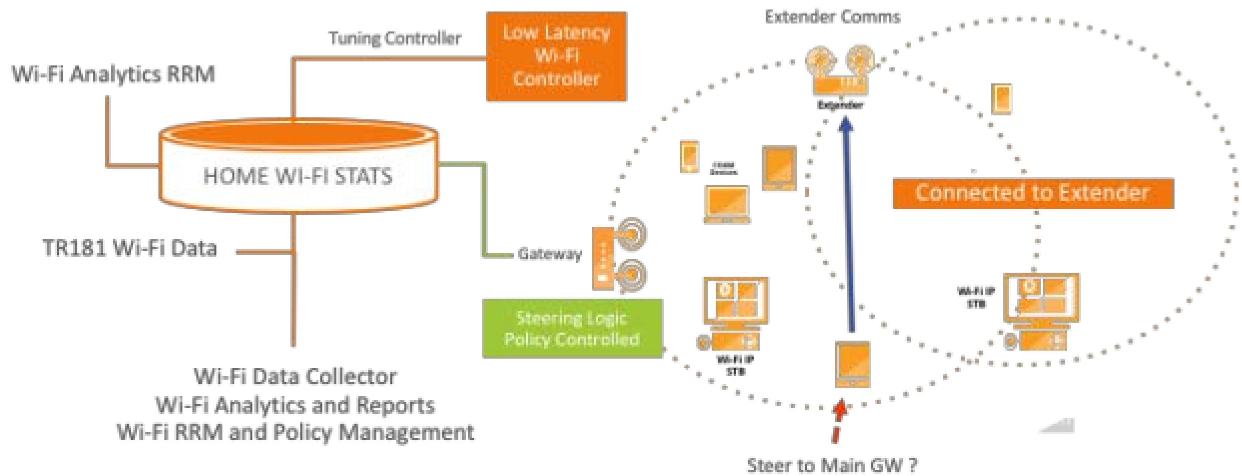


Figure 40 - Architecture of a Typical Cloud-Assisted Wi-Fi Management Solution

The above figure depicts the architecture of a typical cloud-assisted Wi-Fi management solution. There are three major software components: The controller & communication agent in the gateway, the communication agent in the secondary access points (extenders), and the cloud software modules. Let us examine the details of each of these entities and the role that they would play in enhancing the coverage. A typical architecture for the controller (along with the communication agent) in the gateway (or the main access point) is shown in the diagram below:

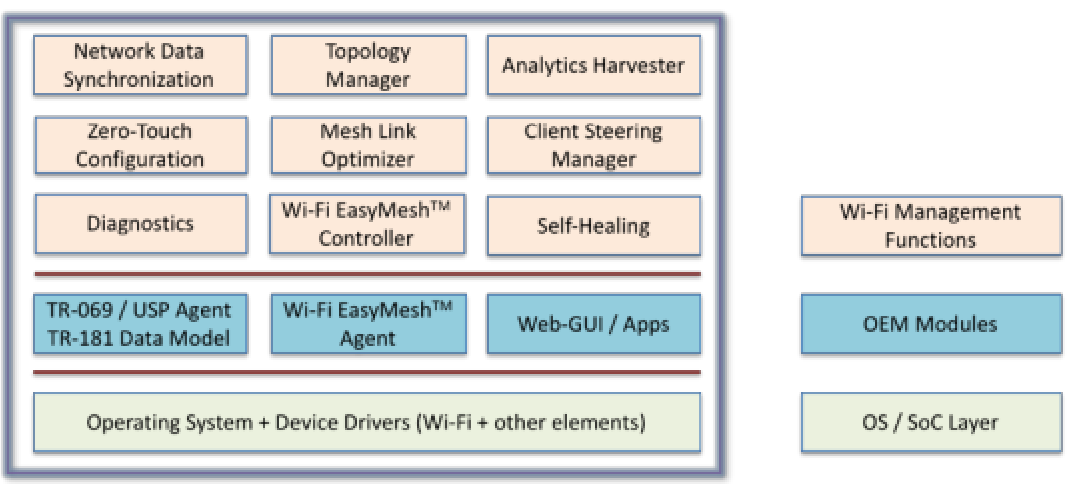


Figure 41 - Gateway Controller for Wi-Fi Management

The architecture depicted accounts for the controller software to be portable across multiple vendors. The OS/SoC layer typically brings the operating system and the associated device drivers, critical of which is the Wi-Fi device driver.

Typically, the OEM will have additional modules that are expected of any implementation given that these modules have a strong tie to the underlying operating system and device drivers. However, many of these should have standard north-bound APIs (and equivalent data elements) that allow for Value-added functions (like Wi-Fi management functions) to be developed on top of them. In this case, the TR-069 agent (or the Broadband-forum defined User Service Platform (USP) agent) acts as the module that is standards-based implementations that would talk to a TR-069 Auto Configuration Server (ACS) and interoperate with implementations of the ACS from multiple vendors. In addition, inter-AP communications should migrate to the use of Wi-Fi EasyMesh agent implantation that will allow for APs from different vendors to interoperate. The north-bound API for such an Agent is also well-defined, allowing for the implementation of the Wi-Fi EasyMesh controller, which can (and usually must) be enhanced to allow for intelligent control of clients inside the home.

The upper layer of software is where the real intelligence is, and these modules serve to implement the sophisticated algorithms that are used to make informed decisions to handle the Wi-Fi clients in the home. Typical functionality handled by these modules are listed below:

10.1. Multi-AP for Network Extender Communication

the gateway-based manager should be standards compliant. It manages the communication between all APs in the home and utilizes the Multi-AP 1905 protocol to discover and configure new access points on the home network. The onboarding process can be accomplished through Wi-Fi or wired Ethernet. The (Multi-AP) MAP Controller or a MAP Agent sends a 1905 Topology query message to the network and start with the MAP controller discovery. The auto configuration process starts according to MAP specifications.

10.2. Zero Touch Provisioning of New Wi-Fi Extenders

Once an access point is discovered, the zero-touch configuration manager provides zero-touch provisioning of the new Wi-Fi extender by synchronizing the extender's Wi-Fi SSID and password with the gateway's configuration to create a single Wi-Fi network in the home.

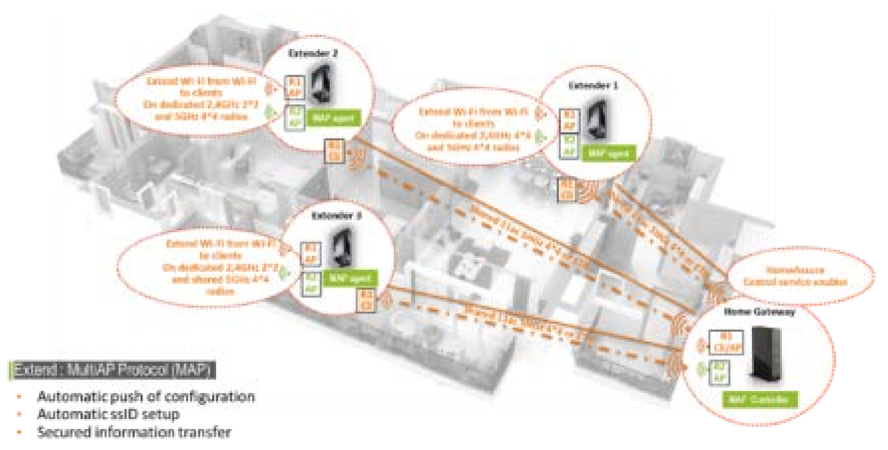


Figure 42 - Zero-Touch Configuration

10.3. Cloud Assisted and Policy-based Management

The gateway Wi-Fi manager resides on the residential gateway and communicates with extenders using MAP. The controller is configured remotely via TR-069 but makes autonomous policy decisions locally – because the policies that it enforces are local to the home and do not require remote support. Therefore, the policy decisions and actions are low latency and available even if there is a disruption of the broadband service.

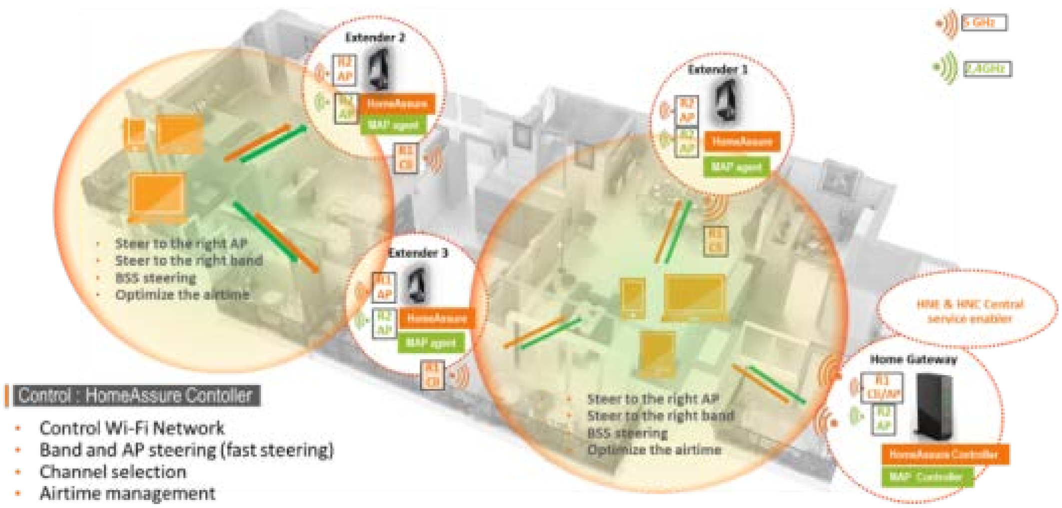


Figure 43 - An Example Implementation of Wi-Fi Management Function

Policy events, such as steering actions or channel changes, are logged such that they may be retrieved and used as telemetry to troubleshoot problems and as feedback to optimize policy configuration in the cloud server.

10.4. Roaming and AP Steering

Many mobile devices exhibit the ‘sticky client problem’, where they maintain an association with an AP until the last gasp of connectivity is available – regardless of whether there is a better candidate AP to associate with.

The client-steering manager solves the sticky client problem by evaluating link quality to detect this condition and then forcing a client device with a low link quality to move to an AP with a stronger signal.

Clients are also steered to alternate APs to reduce contention. For example, when an AP is highly utilized by an individual client, other clients associated to that AP may be moved to another to balance the network and optimize performance.

10.5. Band Steering

The client-steering manager provides band steering to solve performance, throughput, and quality problems caused by Wi-Fi congestion by moving impacted clients to a different band. This feature is relevant even in homes with only one access point since most modern residential gateways are dual band.

10.6. BSS Steering

BSS steering enables service providers to establish separate BSS to separate the Wi-Fi policies and authentication credentials e.g. for community hotspots, guest Wi-Fi and STB streams. This is where the standards such as 802.11k and 802.11v come into play, as they make the fast transition of active clients possible without any additional incurred delays.

10.7. Dynamic Channel Selection

Some access points select the best channel on boot, some perform regular scans to determine if conditions have changed and there is a clearer channel that should be used. However, even those devices often don't scan if they are busy – when a channel change may be needed the most.

The Self-Healing module scans regularly, regardless of how busy it is. A typical scan requires using the antennae for 10 ms, minimizing disruption with the benefit that a clearer channel may be available and switched.

10.8. Mesh Link Optimization

The Mesh-Link Optimization module performs policy-based management of mesh topology. Rather than leaving backhaul selection to individual devices making ad-hoc decisions, the EasyMesh Manager uses its knowledge of the topology, device capabilities, and loading of the network to select backhaul links and thereby optimize traffic flow across the mesh.

10.9. Airtime Management

Airtime fairness is well known to prevent clients that are slow or have poor connectivity from monopolizing airtime and starving other clients. However, airtime configuration can also be used to reserve airtime for certain devices, which establishes a minimum quality of service. For example, airtime can be reserved for Wi-Fi set-top boxes to ensure that managed video has sufficient airtime to ensure a quality user experience.

11. Subscriber Visibility & Device Management

From the perspective of the subscriber, there is an increasing need for having a clear view of the devices in the home and having some level of control over the devices to the extent that they are entitled to handle. Increasingly, functions like the ability to perform speed tests, to be able to control Internet access as part of parental control or just being able to draw all members of the family to dinnertime and being able to understand bandwidth usage patterns.

An ideal application will provide sufficient detail to the subscriber and even if not used frequently, can serve to be the first place that a subscriber would go before picking up the phone to call the customer. We depict here a few sample screens from a typical application for Wi-Fi management that includes many of the features described above.

Figure 44 - Mobile Application Screens to Highlight Data Usage

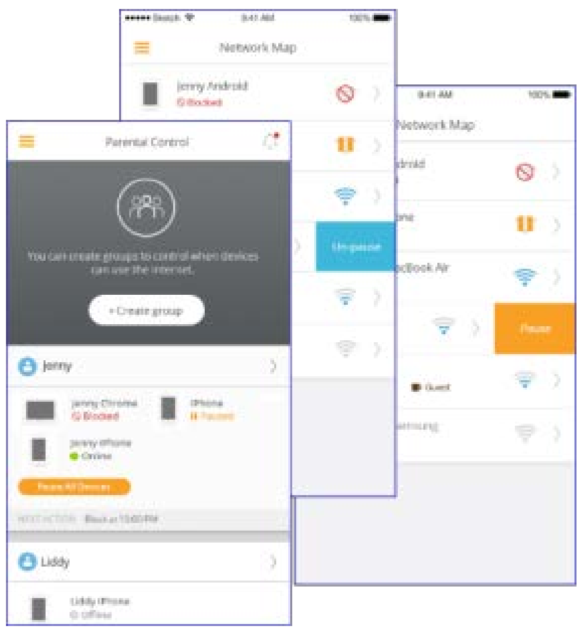


Figure 45 - Mobile Application Screens for Parental Control and Device Access Restrictions

Conclusion

Wireless Technology, given the inherent nature of physics and being intangible to start with, creates an enormous challenge for the service providers. The accelerated adoption of the technology by the consumer, and the concomitant pace with which innovations have unfolded in this space, while exhilarating for the enthusiast, is also one that is fraught with challenges from the perspective of a service provider. With consumer expectations of ease of use, performance, and visibility evolving rapidly, there is a gap between such expectations and what can reliably be addressed by the service provider in a meaningful may. Disruptive players are ready to step in, especially given that control of the home for service and other content delivery is highly valued. Additionally, retail players are out to make most of the situation with well-designed products that at least superficially address coverage and connectivity.

Challenging as the situation may be, we also have tools at our disposal, and there are more and more devices that are implementing standards that allow interoperability across multiple vendors. With standards, availability of tools that leverage AI and ML techniques, and the general paradigm shift to cloud-based technologies, the service provider can deploy intelligent software solutions and wrest control of the Wi-Fi management challenge.

Abbreviations

AC	Alternating current
ACS	Auto Configuration Server (In the context of TR-069 protocol)
AI	Artificial Intelligence
AP	Access Point
API	Application Programming Interface
AX	802.11ax (AX for short)
bps	bits per second
BSS	Basic Service Set
BTM	BSS Transition Management
CAPEX	Capital Expense
COAM	customer owned and managed
DBC	dynamic bonding change
Gbps	Gigabits Per Second
GHz	Gigahertz
GW	Gateway
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IP	Internet Protocol
ISBE	International Society of Broadband Experts
MAP	Multi Access Point Protocol
Mbps	Megabits per second
MCS	Media & Communications Systems
MDU	Multiple Dwelling Unit
ML	Machine Learning
MoCA	Multimedia Over Coax Alliance
ms	Millisecond(s)

MTA	Multimedia Terminal Adapter
OEM	Original Equipment Manufacturer
ONU	Optical Network Unit
OPEX	Operating expense(s)
OS	Operating System
OTT	Over-the-Top; refers to service overlay on top of data services
QAM	Quadrature Amplitude Modulation
QR	Quick Response
RRM	Radio Resource Management
SCTE	Society of Cable Telecommunications Engineers
SLA	Service Level Agreement
SoC	Silicon on Chip
SON	Self-Optimization Networks
SP	Service Provider
SSID	Service set identifier
STB	Set-top Box
UHD	Ultra High Definition
USP	User Service Platform
WAN	Wide Area Network
WFA	Wi-Fi Alliance
WPS	Wi-Fi Protected Setup

Bibliography & References

Wi-Fi CERTIFIED EasyMesh™ Technology Overview; https://www.wi-fi.org/discover-wi-fi/wi-fi-easymesh

Multi-AP Specification v1.0; https://www.wi-fi.org/discover-wi-fi/wi-fi-easymesh

Wi-Fi CERTIFIED Easy Connect™ Technology Overview; https://www.wi-fi.org/discover-wi-fi/wi-fi-easy-connect

Device Provisioning Protocol Specification v1.0; https://www.wi-fi.org/discover-wi-fi/wi-fi-easy-connect

802.11ax and other WLAN related documents; http://www.ieee802.org/11/

