Developing Installation Guidelines For Wi-Fi Managed Devices

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

The proliferation of MSO-managed Wi-Fi devices has created a new set of challenges to define best install practices, capacity and troubleshooting. Modeling and characterizing capacity, as it pertains to multiple devices creating diverse traffic models, is challenging and evolving. Overcoming difficulty in the translation of a repeatable test lab environment, as a baseline to real world customer experience, will be discussed. This paper will focus on approaches to provide recommended device installation guidelines through a four-prong approach of prototyping, characterizing, baselining and real world testing.

This paper loosely follows the steps that Comcast took prior to the launch of the first wireless video settop. While Wi-Fi was not new, its application to a managed device was novel to the organization. Installation guidelines, much like those that existed for coaxial-connected devices, had to be developed based on new metrics which needed to be standardized across the various device combinations. Similarly, device settings needed to be adapted for this new medium through a cycle of prototyping and testing. Lastly, a new approach to whole home testing had to be taken to account for these new devices in the ecosystem.

2. Problem Statement

MSO-provided services over Wi-Fi create a unique set of challenges. On the radio interface, connected devices compete for resources. It is imperative to create a framework to bound the services that could be provided to a given home based on their type of service and equipment. Many Wi-Fi products are ubiquitous and have intensive bandwidth demands. Each MSO business unit looking to maximize its offerings to maximize its competitiveness – offer more devices with higher resolutions. Having a capacity model that translates to customer experience is imperative for scalable hardware and software support in a connected home. That capacity model must evolve in both terms of connected devices in a home as well as connected device traffic profiles and must be bound by installation guidelines.

3. Key Metrics

Through our research and testing we decided to use AirTime as the metric to quantify "how much Wi-Fi" a device or a service should be allowed in a home when installed at the recommended RSSI level.

3.1. AirTime

Wi-Fi began as a listen-before-talk service where only 1 device on the given channel can "talk" at a time. When a device is allowed to "talk" it will require a finite amount of time, AirTime, to complete its data transaction. The ability to transmit and/or receive data quickly and efficiently will determine how much AirTime a client will consume in a home.

3.1.1. Wi-Fi 6

The charter for IEEE's latest standard, Wi-Fi 6, benchmarks efficiency for high density Wi-Fi deployments. No longer was the goal to increase a given device's bandwidth, but rather to have provisions in place to maximize the mechanisms to be as efficient as possible in high density environments. Features such as MU-MIMO and OFDMA are highly anticipated to aid in capacity demands on Wi-Fi's radio interface. While OFDMA is not a new concept, it is new for Wi-Fi 6. This is a long awaited feature, where multiple client station devices can utilize airtime as a group, so as to be more efficient in an overcrowded environment. This will result in more throughput with less airtime.

Table 1 below shows some sample data collected from the analysis of a Wi-Fi5 Xfinity Camera in an RF chamber operating in 2.4GHz. The signal from a conducted Access Point (AP) is radiated in an RF chamber containing with various degrees of attenuation to emulate distance and/or obstructions between the AP and the device under test. This type of anlysis allows us to understand the relationship between an installation closer to the AP (lower signal attenuation and higher RSSI) and the AirTime that the device will consume at that range.

Table 1. Xfinity Camera AirTime utilization versus RSSI analysis

Chamber Attenuation dB	RSSI (Average) dBm	SNR (Average)	Average Channel Utilization (%)	Channel Utilization 90th Percentile (%)	Channel Utilization (%) Max	Channel Utilization (%) Min	Channel Utilization (%) STDEV	TX Rate (Max) Mb/s	TX Rate (Min) Mb/s	RX Rate (Max) Mb/s	RX Rate (Min) Mb/s
0	-56	49.28	6.26	8.1	24.7	3.1	3.09	144	122	144	78
5	-61	44.5	5.81	6.9	17.6	3.9	2.02	144	132	130	77
10	-67	38.5	5.98	7.3	11.3	4.7	1.42	144	121	129	78
15	-71	34.2	5.93	7.3	11.3	3.1	1.31	144	117	124	78
20	-68	37.3	6.72	9.0	22.3	3.5	3.42	144	133	116	77
25	-72	32.97	6.19	7.4	20.0	3.9	2.36	143	121	103	58
30	-76	28.69	6.07	7.1	16.5	3.5	2.25	125	106	89	52
35	-81	24.15	7.45	11.3	21.9	3.9	3.60	102	82	77	39
40	-86	19.86	8.60	12.3	16.0	3.5	3.08	69	56	52	29
45	-90	15.91	10.65	18.3	42.7	3.5	6.69	58	54	26	13
50	-93	15.06	13.06	23.4	41.2	5.8	8.01	52	44	26	6

Understanding not only the bandwidth requirements of the devices in a connected home, but also the time is takes on the air to get the required bandwidth, is a key metric for building a diverse capacity model. Breaking down what components are included in that measurement is pivotal. *Figure 1* below illustrates the various tasks consuming air time in the communications between an Xfinity Camera and AP and contrasts the differences between two beamforming settings. This analysis can help understand what elements, if any, beyond the data traffic are significantly contributing to the AirTime consumption of a given client. In this case, for a static device like the Xfinity Camera, the shorter beamforming interval was not only unnecessary but harmful to the overall performance of the home network by greatly increasing AirTime consumption.

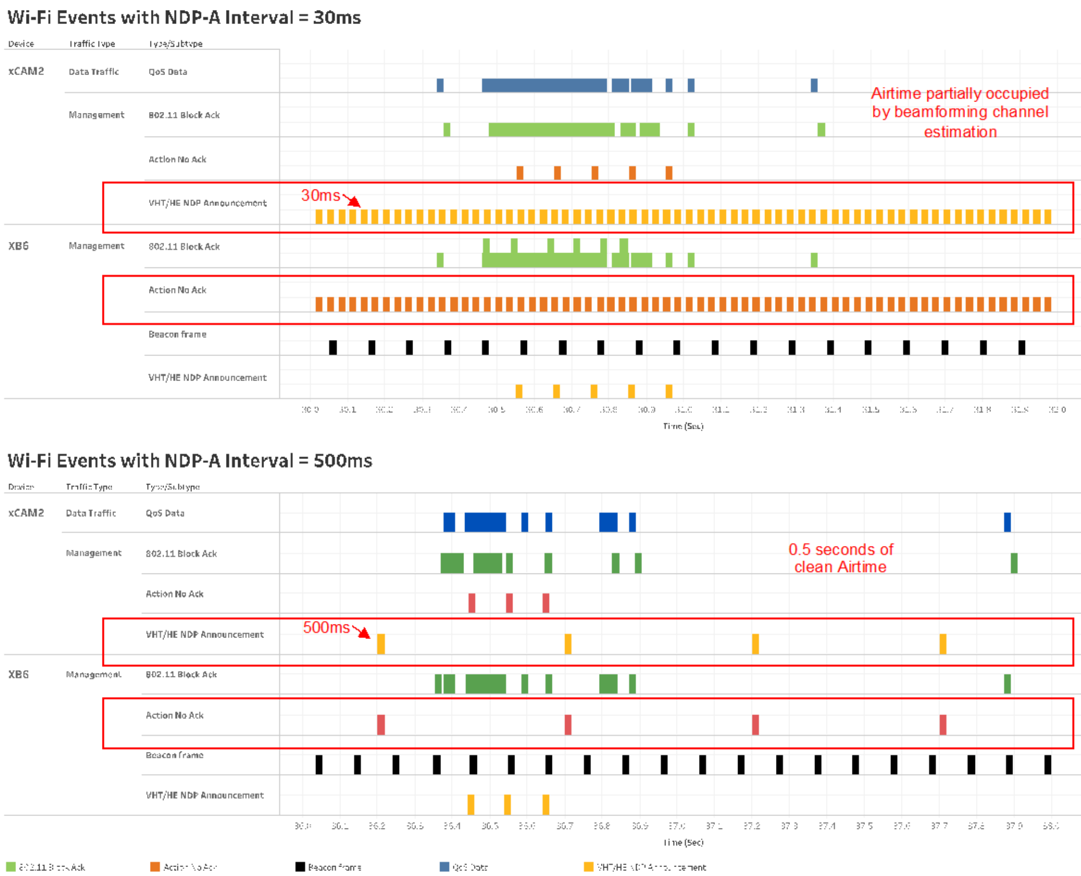

Figure 1 - AirTime Analysis Between Xfinity Camera and AP with Different Beamforming Settings

Once the AirTime model is properly measured it will provide a foundation for install guidelines. Airtime utilization has some nuances for the measurement across SoC platforms. Often SoC vendors report the AirTime consumed by their devices differently. By including variance of metrics into their reporting such as, management overhead frames inclusive of NAV times, probe responses, beacons, SIFC intervals, the collected data may have to be normalized as a result.

3.2. Received Signal Strength Indicator (RSSI)

More complex than defining "how much Wi-Fi" a device should be allocated was finding an installation guideline metric that would be both easily accessible and consistent across the various System On Chip (SoC) vendors that our devices employed. This metric needed to not only be easily understood by our customers, but also accessible to our technicians, via telemetry and/or on-screen diagnostics. RSSI measured from the access point (AP) can be used to determine the given attenuation in a model and is the basis for install guidelines. RSSI at the STA could be used but it is often more difficult to use for IoT devices that are not connected to a screen. Comcast agreed to use RSSI understanding its limitations.

With an understanding of the AirTime consumption of a managed device, or devices, at a given RSSI level it is possible to begin to model the approximate theoretical Free AirTime (FAT) available to a consumer that subscribes to various services.

4. Prototyping

Early device prototyping became an integral phase of our characterization efforts, as it allowed us to verify our RF architectural decisions (2x2 / 3x3 / 4x4) as well as to begin the process of fine-tuning the settings of our devices firmware for an optimal user experience. Ensuring that the device hardware is capable of the theoretical maximum values provides the first step in Wi-Fi hardware verification. This is typically completed in a conducted laboratory setting. Adding attenuation to these test suites will yield valuable data points to build foundational measurements. These are usually referred to Rate vs Range (RvR) testing and Rate vs Orientation (RvO). At this prototyping phase, changing variables, such as driver settings and traffic models, is essential to qualify device behavior. Testing different protocols, such as TCP vs UDP, or modifying frame sizes, help prototype the device behavior.
Default driver settings for a Wi-Fi device can dramatically change the experience, depending on the overall desired application requirements. *Figure 2* below shows the impact of Wi-Fi frame size on the throughput capabilities of various Xfinity managed video clients. It is important to understand these impacts and bound the settings so that the devices will operate within their most efficient range.

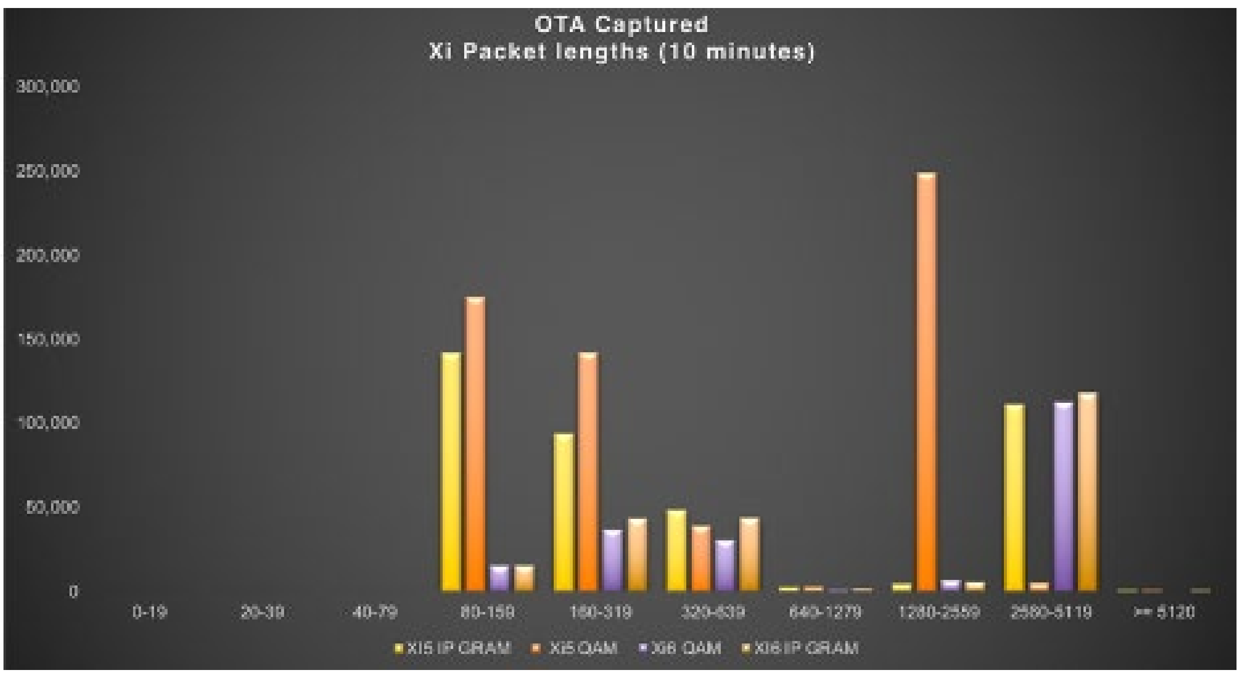

Figure 2 - Throughput Versus Frame Size Performance for Various Xfinity Managed Video Clients

Another setting we found to have a significant impact on the Wi-Fi performance of a device and/or home is frame aggregation. Wi-Fi uses frame aggregation to be more efficient with regards to airtime. This can come at a price. It noisy environments, there is a higher chance for a collision or error, which results in all aggregated having to be retransmitted again. This will take longer in an already overcrowded space. Some SoCs will have algorithms in place to dynamically measure the environment and aggregate only when the conditions are satisfactory.

Figure 3 and *Figure 4* below illustrate the differences in throughput for a given AP when Frame Aggregation is enabled or disabled. It is important to understand the tradeoffs of this setting for various system load levels and frame sizes.

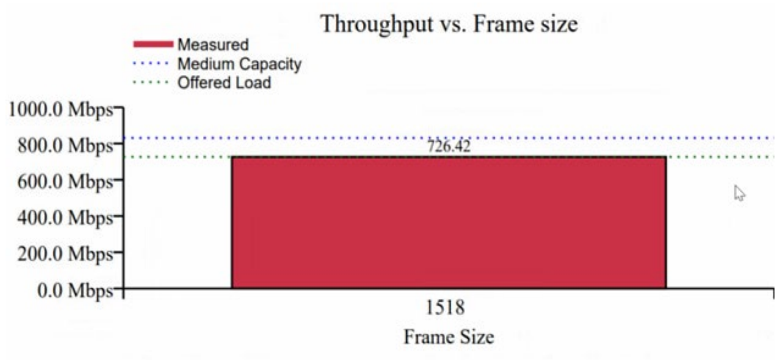

Figure 3 - AP Throughput Versus Frame Size - Frame Aggregation Enabled

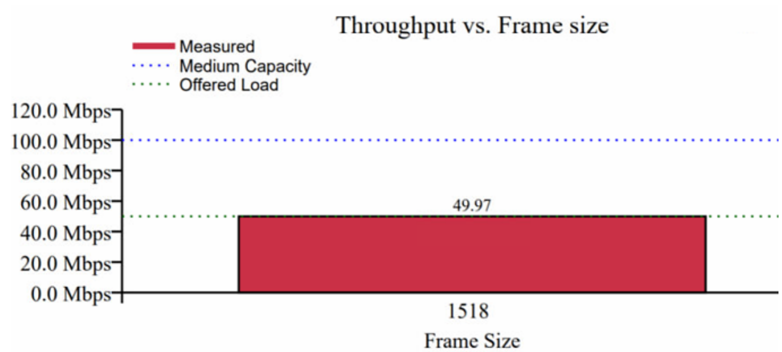

Figure 4 - AP Throughput Versus Frame Size - Frame Aggregation Disabled

5. Characterizations

Understanding how devices behave with the various APs and extenders is foundational for an operator to understand. Modeling can be challenging, given all the combinations and variables possible. In the prototyping phase, Wi-Fi specification compliance is mandatory. Achieving those theoretical maximum values will validate the hardware and the default driver settings for the conducted testing phase. In the IEEE Wi-Fi specifications there are also plenty of optional and other settings that can be tuned to achieve desired output, such as maximizing throughput or minimizing latency. As stated earlier, these settings can be adversely affected in noisy or crowded environments. How different settings affect the in home experience can produce different results, given the variety of different connected clients at varied RSSI levels. We instituted a rigorous and formal program to characterize each of our managed devices, (a) on its own with each of our APs and Extenders and (b) in the presence of our other managed devices. Individual characterization is performed pre-launch and frequently thereafter, as firmware, in either the managed device or APs, evolves. Whole home characterization is performed periodically in a radio silence test house such as one shown in *Figure 5* where all the metrics for the various devices are monitored and compared against the individual values.

Figure 5 - Comcast Test House. Whole Home Setup. Cross-sectional view.

6. Baselining

Through the characterization of the various devices the relationships between AirTime consumption and installation range, through the measure of RSSI, become apparent. This data in combination with the business goals allows the Product and Business owners to begin to define combinations of managed clients with a given AP that strike a balance between capacity and customer experience. This somewhat iterative, and often evolving process, will create baseline device configurations that can be reliably deployed and installed.

7. Testing

The capacity models and installation guidelines drawn from the characterization and baselining efforts need to corroborated in real world scenarios. This can be achieved via (a) controlled Test House tests and (b) device telemetry. A radio silent Test House can be converted into a real world scenario with the injection of noise and/or Wi-Fi traffic; device combinations can be tested against various APs with given software builds to confirm the recommended guidelines. Similarly, the real time telemetry provided by our APs can provide information to illustrate how given a device combination is performing under less controlled and more random scenarios. This test and telemetry data can be used as a feedback mechanism to further refine the characterization and baselining of the devices and software under design.

8. Conclusion

In spite of Wi-Fi being a live, shared medium, it is possible for an MSO to deterministically provide bounds to the number of managed devices and services based on Wi-Fi Airtime and RSSI installation guidelines.

A device design process based on prototyping, characterization, baselining and real world testing will provide product teams with the necessary information to provide capacity and installation recommendations that maximize both the number of services provided, and the customer experience.

Abbreviations

AP	access point
bps	bits per second
IEEE	Institute of Electrical and Electronics Engineers
MIMO	Multiple In Multiple Out
MSO	Multiple Services Provider
MU-MIMO	Multi User MIMO
OFDMA	Orthogonal Frequency Domain Multiple Access
FAT	Free AirTime
RSSI	Received Signal Strength Indicator
RvO	Rate versus Orientation
RvR	Rate versus Range
SoC	System on Chip
SCTE	Society of Cable Telecommunications Engineers
Wi-Fi	Wireless Fidelity

