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S T A N D A R D S

Network Operations Subcommittee

SCTE OPERATIONAL PRACTICE

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Operational Practice for Home Wi-Fi Deployment

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1. Introduction

1.1. Executive Summary

The world of consumer devices is now a wireless world, with many devices using Wi-Fi® technology for communications.¹ Many cable subscribers no longer differentiate wireless operation from wired cable service – whether the wireless equipment is personally owned or is part of the equipment provided by the cable company – and often simply consider wireless and wired service to be the same thing. This document seeks to provide useful recommendations to enable cable operators to provide outstanding wireless services for their customers.

1.2. Scope

While many of the general principles and concepts discussed in this operational practice apply to the broader subject of wireless data service deployments, the primary focus is on residential Wi-Fi installations.

1.3. Benefits

The guidelines in this operational practice will help cable operators provide better residential wireless service and understand some of the more common problems and issues that can affect the quality of wireless service in the subscriber premises.

1.4. Intended Audience

The intended audience for this operational practice includes installers, technicians, engineers, and others who work with or are interested in the deployment of residential Wi-Fi services.

1.5. Areas for Further Investigation or to be Added in Future Versions

Topics that might be of interest for addition to future versions of this document, or part of new, standalone operational practices and similar documents include managed wireless services, commercial wireless service deployments, and outdoor wireless services.

2. Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this document. At the time of Subcommittee approval, the editions indicated were valid. All documents are subject to revision; and while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

2.1. SCTE References

- No normative references are applicable.

¹ Wi-Fi® is a registered trademark of the Wi-Fi Alliance (www.wi-fi.org)

2.2. Standards from Other Organizations

- No normative references are applicable.

2.3. Published Materials

- No normative references are applicable.

3. Informative References

The following documents might provide valuable information to the reader but, are not required when complying with this document.

3.1. SCTE References

- No informative references are applicable.

3.2. Standards from Other Organizations

- IEEE 802.11-2016 - <https://ieeexplore.ieee.org/document/7786995/>

3.3. Published Materials

- Wi-Fi Certified Home Design Public Info: <https://www.wi-fi.org/discover-wi-fi/wi-fi-home-design>
- WFA Members: The MRD's and Test Plans

4. Compliance Notation

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<i>shall not</i>	This phrase means that the item is an absolute prohibition of this document.
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5. Abbreviations and Definitions

5.1. Abbreviations

ACS	auto configuration server
ACS	auto channel selection
AP	access point
BPSK	binary phase shift keying
BSS	basic service set
BSSID	basic service set identifier
CSMA/CA	carrier sense multiple access with collision avoidance
CPE	customer premises equipment
CPU	central processing unit
CRC	cyclic redundancy check
dB	decibel
dBm	decibel milliwatt
DBC	dual band concurrent
DCF	distributed coordination function
DFS	dynamic frequency selection
DOCSIS	Data-Over-Cable Service Interface Specifications
DRS	data rate shifting
DS	downstream
DSL	digital subscriber line
DSSS	direct sequence spread spectrum
FHSS	frequency hopping spread spectrum
FSPL	free space path loss
GHz	gigahertz
GUI	graphical user interface
GW	gateway
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of things
IP	Internet protocol
IPDR	Internet protocol detail record
ISBE	International Society of Broadband Experts
ISI	inter-symbol interference
ISM	industrial, scientific, and medical
IT	information technology
ITU	International Telecommunication Union
KPI	key performance indicator
LAN	local area network
LED	light emitting diode
LTE	long term evolution
MAC	media access control
Mb/s (Mbps)	megabits per second
MCS	modulation and coding scheme
MDU	multiple dwelling unit
MHz	megahertz
MIMO	multiple input multiple output

MoCA	Multimedia over Coax Alliance
MSO	multiple system operator
MU-MIMO	multi-user MIMO
ns	nanosecond
OBSS	overlapping basic service set
OD	outdoor
OFDM	orthogonal frequency division multiplexing
OUI	organizationally unique identifier
PC	personal computer
PHY	physical layer
PIN	personal identification number
QAM	quadrature amplitude modulation
QPSK	quadrature phase shift keying
RDK	reference design kit
RF	radio frequency
RSSI	received signal strength indicator
RX	receive (also receiver)
SCTE	Society of Cable Telecommunications Engineers
SNMP	Simple Network Management Protocol
SNR	signal-to-noise ratio
SSID	service set identifier
STA	station
TV	television
TX	transmit (also transmitter)
U-NII	unlicensed national information infrastructure
US	upstream
USB	universal serial bus
VoIP	Voice over Internet Protocol
VPN	virtual private network
WFA	Wi-Fi Alliance
WMM	Wi-Fi Multimedia
WPS	Wi-Fi protected setup

5.2. Definitions

access point (AP)	A device or circuit that provides an interface between a wired local area network and radio transmitter/receiver circuitry to enable over-the-air transmission of data to and from various Wi-Fi capable devices.
amplitude	The signal level, or more specifically, the power of an electromagnetic signal.
attenuation	See <i>loss</i> .
decibel (dB)	A logarithmic-based expression of the ratio between two values of a physical quantity, typically power or intensity. The decibel provides an efficient way to express ratios which span one or more powers of the logarithmic base, most commonly 10. Mathematically, the ratio of two power levels P_1 and P_2 in decibels is $\text{dB} = 10\log(P_1/P_2)$.
decibel milliwatt (dBm)	Unit of power, defined as decibels relative to 1 milliwatt, where 0 dBm equals 1 milliwatt. Mathematically, $\text{dBm} = 10\log_{10}(\text{value in mW}/1 \text{ mW})$.

frequency	The number of times (typically per second) that a repetitive event happens; that is, the rate of oscillation of an electromagnetic signal. Frequency is measured in units of hertz, which is the number of cycles or waves per second.
gain	An increase in the power of a signal or signals, usually measured in decibels. Expressed mathematically, $G_{dB} = 10\log_{10}(P_{out}/P_{in})$, where G_{dB} is gain in decibels, P_{out} is output power in watts, P_{in} is input power in watts, and $P_{out} > P_{in}$. When signal power is stated in dBmV, $G_{dB} = P_{out(dBmV)} - P_{in(dBmV)}$.
gigahertz (GHz)	A unit of frequency equal to one billion (10^9) hertz. See also <i>hertz</i> .
hertz (Hz)	A unit of frequency equivalent to one cycle per second.
interference	A collective term that describes unwanted signals, noise, intermodulation distortion, or other disturbance that may degrade or otherwise change the quality or performance of a desired signal or signals.
loss	A decrease in the power of a signal or signals, usually measured in decibels. Expressed mathematically, $L_{dB} = 10\log_{10}(P_{in}/P_{out})$, where L_{dB} is loss in decibels, P_{in} is input power in watts, P_{out} is output power in watts, and $P_{out} < P_{in}$. When signal power is stated in dBmV, $L_{dB} = P_{in(dBmV)} - P_{out(dBmV)}$.
megahertz (MHz)	A unit of frequency equal to one million (10^6) hertz. See also <i>hertz</i> .
multipath	A phenomenon in which an electromagnetic signal from a transmitter travels via more than one route to the receiver. For example, a Wi-Fi signal transmitted from an access point might travel directly to the receiver, and some of the same transmitted signal might also be reflected by nearby objects before arriving a fraction of a second later at the receiver.
radio frequency (RF)	That portion of the electromagnetic spectrum from a few kilohertz to just below the frequency of infrared light.
signal-to-noise ratio (SNR)	A general measurement of the ratio of signal power to noise power, usually expressed in decibels.
service set identifier (SSID)	An up to 32-character string of letters and/or numbers used to name a wireless network.
Wi-Fi	A term that describes technology that uses over-the-air radio waves for wireless local area networking based on IEEE 802.11.

6. Introduction

6.1. Wi-Fi Introduction

Wi-Fi is a term that describes technology that uses over-the-air radio waves for wireless local area networking. Wi-Fi enabled devices – which implement the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards – have become almost ubiquitous in homes, businesses, and elsewhere, functioning as extensions of wired networks.

In its simplest form, a Wi-Fi network includes a device called an access point (AP) or wireless router (or wireless gateway), which provides an interface between a wired local area network (LAN) and radio transmitter/receiver circuitry to enable over-the-air transmission of data to and from various Wi-Fi capable devices (also called clients or stations); refer to Figure 1. Wi-Fi APs can be standalone devices connected to cable modems and digital subscriber line (DSL) modems using a length of Ethernet cabling,

or built-in to those modems. Wi-Fi capable user devices such as smart phones and tablets, laptops, desktop personal computers, printers, smart TVs, and so on use a built-in wireless adapter to communicate with the access point. Older equipment – especially older desktop PCs – that doesn't have a built-in wireless adapter can often use an external wireless adapter that plugs in to an available Ethernet port or universal serial bus (USB) port.

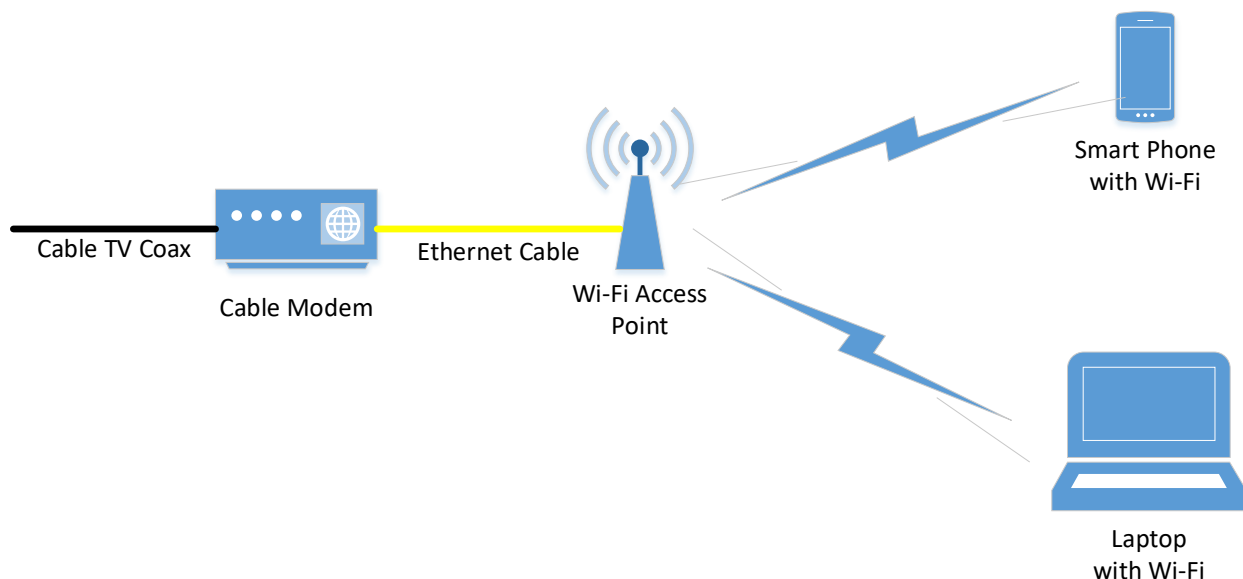


Figure 1 - Example of a simple Wi-Fi network

Wi-Fi technology most commonly uses the 2.4 GHz and 5 GHz radio frequency (RF) bands for wireless transmission of data. As such, Wi-Fi operation is subject to the usual impairments that affect over-the-air radio communications: weakening or blockage of the signal over distance, and as it passes through walls, floors, doors, furniture, and other obstructions in the signal path; reflections – also called multipath (similar to ghosting in analog TV pictures); and interference from other services or devices – including other Wi-Fi devices – operating on or near the same frequency. One example of the latter is interference from microwave ovens, which operate in the same 2.4 GHz band that Wi-Fi uses. Some baby monitors and cordless phones also operate in the 5GHz spectrum.

Additional information about Wi-Fi is available online at <https://computer.howstuffworks.com/wireless-network.htm> and <https://en.wikipedia.org/wiki/Wi-Fi> and <http://wi-fi.org>.

A significant percentage of a cable company's service calls is related to Wi-Fi problems. Section 6.7 of this document lists the top 10 home user Wi-Fi issues reported by cable operators. In general, the reported issues can be categorized into three major areas: subscriber education, Wi-Fi RF performance issues, and wireless network congestion.

It is probably useful to begin by considering the top sources of wireless discontent and then to consider how those sore points can be addressed and hopefully avoided altogether.

The Wi-Fi radio signals occupy unlicensed spectrum in the 2.4 GHz and 5 GHz bands. Allocations for industrial, scientific and medical (ISM) equipment in these bands have been useful for low power local area wireless networks based on Wi-Fi technology. There is no protection from interference in these bands so Wi-Fi device operation near microwave ovens, baby monitors, and Bluetooth devices, which also use this unlicensed spectrum, may result in impaired performance.

6.2. Wi-Fi Data Rates and Client Performance

Wi-Fi data rate is the connection rate from Wi-Fi client to serving access point. The throughput is the total amount of data transferring from access point to Wi-Fi client at any moment in time. The 802.11 standards offer data rate shifting (DRS) to manage availability of the Wi-Fi link under changing RF interference and client density conditions in the earlier 802.11g specifications.

Similar to modulation profiles in DOCSIS, the 802.11n specification introduced high throughput (HT) multiple modulation profiles with the potential to support simultaneous encoded streams which means multiple transmit and receive capabilities with per-stream unique modulations possible.

802.11n also introduced for the first time, Wi-Fi channel operation over 20 MHz and 40 MHz of radio frequency. These modulation profiles are known as modulation coding scheme (MCS).

The MCS is determined by radio capabilities in terms of simultaneous radio stream processing capability and the potential to independently modulate these streams.

For example, MCS 0 supports one spatial stream, modulated using BPSK at $\frac{1}{2}$ coding rate and offers 7.2 Mb/s in 20 MHz or 15 Mb/s in 40 MHz on a 400 ns guard interval.

The mobile phone located somewhere near or on you is usually a single spatial stream or 1x1 capable device and typically supports 802.11n or 802.11ac in 20 MHz channels.

At the high end of 802.11n, MCS 31 employs four simultaneous spatial streams, at 64-QAM, $\frac{5}{6}$ coding rate, offering 289 Mb/s in 20 MHz and 600 Mb/s in 40 MHz on a 400 ns guard interval.

The 802.11ac standard further enhanced MCS operations by introducing very high throughput (VHT) multiple modulation profiles with the potential to support up to eight simultaneous encoded streams. It specifies wider RF bandwidths up to 160 MHz, more MIMO spatial streams up to eight, downlink multi-user MIMO up to four clients, enabling use of nulls in airtime to establish up to streams, each to a 1x1 client device, and high-density modulation up to 256-QAM. A full list of MCS values for 802.11ac may be viewed at <http://www.mcsindex.com>.

802.11n			Data Rate (MHz)								802.11ac
HT	Spatial	Modulation & Coding	Data Rate	Data Rate	Data Rate	Data Rate	Data Rate	Data Rate	Data Rate	Data Rate	VHT
MCS	Streams		GI = 800 ns	SGI = 400 ns	GI = 800 ns	SGI = 400 ns	GI = 800 ns	SGI = 400 ns	GI = 800 ns	SGI = 400 ns	MCS
Index			20 MHz	20 MHz	40 MHz	40 MHz	80 MHz	80 MHz	160 MHz	160 MHz	Index
0	1	BPSK 1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65	0
1	1	QPSK 1/2	13	14.4	27	30	58.5	65	117	130	1
2	1	QPSK 3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195	2
3	1	16-QAM 1/2	26		54	60	117	130	234	260	3
4	1	16-QAM 3/4	39	43.3	81	90	175.5	195	351	390	4
5	1	64-QAM 2/3	52	57.8	108	120	234	260	468	520	5
6	1	64-QAM 3/4	58.5	65	121.5	135	263.3	292.5	526.5	585	6
7	1	64-QAM 5/6	65	72.2	135	150	292.5	325	585	650	7
n/a	1	256-QAM 3/4	78	86.7	162	180	351	390	702	780	8
n/a	1	256-QAM 5/6	n/a	n/a	180	200	390	433.3	780	866.7	9
8	2	BPSK 1/2	13	14.4	27	30	58.5	65	117	130	0
9	2	QPSK 1/2	26	28.9	54	60	117	130	234	260	1
10	2	QPSK 3/4	39	43.3	81	90	175.5	195	351	390	2
11	2	16-QAM 1/2	52	57.8	108	120	234	260	468	520	3
12	2	16-QAM 3/4	78	86.7	162	180	351	390	702	780	4
13	2	64-QAM 2/3	104	115.6	216	240	468	520	936	1040	5
14	2	64-QAM 3/4	117	130.3	243	270	526.5	585	1053	1170	6
15	2	64-QAM 5/6	130	144.4	270	300	585	650	1170	1300	7
n/a	2	256-QAM 3/4	156	173.3	324	360	702	780	1404	1560	8
n/a	2	256-QAM 5/6	n/a	n/a	360	400	780	866.7	1560	1733.3	9
16	3	BPSK 1/2	19.5	21.7	40.5	45	87.8	97.5	175.5	195	0
17	3	QPSK 1/2	39	43.3	81	90	175.5	195	351	390	1
18	3	QPSK 3/4	58.5	65	121.5	135	263.3	292.5	526.5	585	2
19	3	16-QAM 1/2	78	86.7	162	180	351	390	702	780	3
20	3	16-QAM 3/4	117	130	243	270	526.5	585	1053	1170	4
21	3	64-QAM 2/3	156	173.3	324	360	702	780	1404	1560	5
22	3	64-QAM 3/4	175.5	195	364.5	405	n/a	n/a	1579.5	1755	6
23	3	64-QAM 5/6	195	216.7	405	450	877.5	975	1755	1950	7
n/a	3	256-QAM 3/4	234	260	486	540	1053	1170	2106	2340	8
n/a	3	256-QAM 5/6	260	288.9	540	600	1170	1300	n/a	n/a	9
24	4	BPSK 1/2	26	28.9	54	60	117	130	234	260	0
25	4	QPSK 1/2	52	57.8	108	120	234	260	468	520	1
26	4	QPSK 3/4	78	86.7	162	180	351	390	702	780	2
27	4	16-QAM 1/2	104	115.6	216	240	468	520	936	1040	3
28	4	16-QAM 3/4	156	173.3	324	360	702	780	1404	1560	4
29	4	64-QAM 2/3	208	231.1	432	480	936	1040	1872	2080	5
30	4	64-QAM 3/4	234	260	486	540	1053	1170	2106	2340	6
31	4	64-QAM 5/6	260	288.9	540	600	1170	1300	2340	2600	7
n/a	4	256-QAM 3/4	312	346.7	648	720	1404	1560	2808	3120	8
n/a	4	256-QAM 5/6	n/a	n/a	720	800	1560	1733.3	3120	3466.7	9

Figure 2 - MCS Rates for 802.11n and 802.11ac (up to 4 of 8 spatial streams)

Receive sensitivity is the measurement of the receiver's ability to demodulate the transmission at a given level above the noise floor of the operating channel. The negotiated throughput from client to access point can be related to the receive signal strength indication (RSSI) value, which in part drives modulation coding scheme (MCS) selection.

The highest mutually supported MCS value is, generally speaking, the best throughput the access point and client can achieve. From the perspective of understanding conditions related to per-client Wi-Fi performance, the current RSSI and negotiated MCS are key performance indicators.

6.3. Wi-Fi Provisioning

Two examples of Wi-Fi provisioning used by the cable industry include TR-069 and Web Protocol Adapter or "WebPA." More information about these two can be found at the following link:

<https://en.wikipedia.org/wiki/TR-069>

Wi-Fi Data collection and PNM is enabled through WFA's Data Elements <https://www.wi-fi.org/discover-wi-fi/specifications>

In-depth information about these (and other) provisioning methods is beyond the scope of this document.

6.4. Power Management

Coordinated power management of both the beacon and all wireless communication from an access point becomes a key building block to managing Wi-Fi experience when multiple uncoordinated home devices are offering Wi-Fi connectivity. Note the coordinated mesh systems (Wi-Fi EasyMesh™) self-manage these power issues.

The further a client is from its access point, the lower its overall bandwidth will be and beacon overreach issues start to happen.

As the distance increases, there is less signal energy to overcome the surrounding noise and interference in the channel. Further, because the power output of most modern clients is less than that of the access point, at a certain distance the access point will no longer be able to receive the transmissions back from the client.

Looking once again at the use of TR-069 or webPA and their current objects related to Wi-Fi Radio and SSID operations there are some useful parameters that can be set. In TR-069 Device Wi-Fi Radio {i} offers visibility to Operating Frequency Band, Channel, Operating Channel Bandwidth and may offer Wi-Fi Associated Device information including Downlink and Uplink data rate, Signal Strength and Retransmission.

This information is valuable as part of the back office in terms of historical knowledge and possibly snapshot reports that may assist in troubleshooting certain issues. Essentially, we can learn how much bandwidth at a given moment in time was available at the radio, a general sense if there were some quality concerns from retransmission values however we are unable to understand why the radio is operating at the bandwidth advertised.

6.5. 802.11ac

More and more subscribers are demanding improved connectivity from their wireless home network. Streaming video, voice over Wi-Fi, gaming, and other interactive applications are driving the need for more reliable wireless connectivity within the home/business. Broadband subscribers are more connected than ever, and their bandwidth requirements and number of connected devices continue to increase. In fact, the average user in the United States had 7.4 connected devices in 2014 and that number is projected to grow to 13.8 by 2019². With the increased demand being placed on subscribers' Wi-Fi networks, broadband service providers and their subscribers are routinely installing 802.11ac devices to enhance wireless performance. 802.11ac, the fifth generation of Wi-Fi, was developed to provide faster and more scalable wireless networks, with performance commensurate with wired gigabit Ethernet networks. This section highlights some of the advantages of 802.11ac technology, describe how 802.11ac differs from other 802.11 technologies, and identifies potential issues that may be experienced by technicians deploying 802.11ac devices in the subscriber's home/business.

² Cisco, (2015) *VNI Global IP Traffic Forecast, 2014 – 2019* www.cisco.com/c/en/us/solutions/service=provider/visual-networking-index-vni/index.html