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Energy Management Subcommittee

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Key Performance Metrics: Energy Efficiency & Functional Density of Wi-Fi Infrastructure Equipment

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1. Introduction

1.1. Executive Summary

This document is the next in a series providing the cable operator with a standard reference to determine how well a piece of equipment performs in terms of minimizing the power required to do its particular job. In addition, this standard provides the means to quantify the amount of useful work the equipment provides per physical space. This part of the series focuses on Wi-Fi equipment serving the cable industry including Wi-Fi Controllers, Access Points, and Gateway Servers.

1.2. Scope

Cable operator networks are large expansive networks that involve hundreds if not thousands of miles of coaxial or fiber cable powered by power supplies in the outside plant and connecting customers to critical infrastructure facilities such as hubs, headends, data centers, regional, and national distribution datacenters. In these facilities is a vast array of equipment responsible for the production and support of the cable operator's products and services such as voice, video, data, home automation and security, and Wi-Fi. The importance of powering all of these devices in the critical facilities is ever increasing as the customer expectation is for 100% availability due to the critical nature of the services being provided to business and residential customers. This document defines how to use a standard methodology to measure the density of hardware to meet the needs of optimizing critical space, as well as measuring energy consumption for the various network element classes. This part of the series focuses on indoor critical facility Wi-Fi equipment types, Gateway Servers and Wi-Fi Controllers as well as outdoor strand-mounted Wi-Fi Access Points.

1.2.1. Applicability to Critical Facilities

The energy efficiency and functional density metrics in this document apply to critical facilities used by cable operators. Critical facilities are defined in section 5.2.

1.2.2. Hardware Service Feature Density Metrics

This standard defines the method to calibrate product density, in terms of service features per amount of space utilized.

1.2.3. Energy Consumption Metrics

This standard defines the method to calibrate energy consumption based on service features such as Watts per Client, Watts per Throughput, or similar for cable headend, hub, and certain cable access network equipment.

1.2.4. Applicable Equipment

The energy efficiency and functional density metrics in this standard apply to indoor equipment used in critical facilities that functions as one or more of the following:

- Wi-Fi Controllers (various forms)
- Gateway Servers - including "legacy" Policy Enforcement Router (PEF) as well as Wireless Access Gateway (WAG) equipment
- Wi-Fi Access Points - limited to strand-mounted forms with integrated cable modem (CMAP) and which draw their power from the cable plant

1.2.5. Non-Applicable Equipment

The energy efficiency and functional density metrics in this standard do NOT apply to the following equipment classes.

- Customer Premises Equipment (CPE)
- Facilities equipment covered by SCTE 184, such as:
    - Generators and line-power back-up systems
    - Building HVAC control and monitoring equipment
    - Logistical and physical support such as lighting, fire alarming, and security systems, etc.

1.3. Benefits

This standard defines energy and functional density specific performance metrics based on service features that are inherent to the type of equipment. Standard metrics such as watts per Client and watts per Throughput for cable network equipment are identified. This standard will contribute to improve the overall energy footprint by enabling engineering driven decisions that reduce energy consumption at the source of power consumption.

1.4. Intended Audience

Cable operator headend, hub, and outside plant engineers, procurement teams, and operations staff.

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

Future generations of Wi-Fi access points will be considered for inclusion in a later version of this standard. One possible example might be an access point powered from the cable plant but using a direct fiber feed.

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

- [SCTE_General_Test_Procedures] *ANSI/SCTE 231 2016, General Test Procedures for Evaluation of Energy Consumption Metrics and in Support of Functional Density Metrics*; http://www.scte.org/SCTEDocs/Standards/ANSI_SCTE%20231%202016.pdf

2.2. Standards from Other Organizations

- [ATIS-0600015.2013] *Energy Efficiency for Telecommunication Equipment: Methodology for Measurement and Reporting – General Requirements*, May 2013.

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

- [ANSI/SCTE 210 2015] *Performance Metrics for Energy Efficiency & Functional Density of Cable Data Generation, Storage, Routing, and Transport Equipment*, http://www.scte.org/SCTEDocs/Standards/SCTE%20210%202015.pdf
- [SCTE 226 2015] *Cable Facility Classification Definitions and Requirements*
- [SCTE 238 2017] *Operational Practice for Measuring and Baselining Power Consumption in Outside Plant Equipment and Power Supplies*

3.2. Standards from Other Organizations

- [DOCSIS MULPIv3.0] *Media Access Control and Upper Layer Protocols Interface Specification*, CM-SPMULPIv3.0-I26-150305, March 5, 2015, Cable Television Laboratories, Inc., *http://www.cablelabs.com/specification/docsis-3-0-mac-and-upper-layer-protocols-interface-specification/*
- [DOCSIS DEPI] *Downstream External PHY Interface Specification*, CM-SP-DEPI-I08-100611, June 11, 2010, *http://www.cablelabs.com/specification/downstream-external-phy-interface-specification/*
- [ATIS-0600015.03.2009] *Energy Efficiency for Telecommunications Equipment: Methodology for Measurement and Reporting for Router and Ethernet Switch Products*, July 2009.
- [DOCSIS DRFI] *Downstream Radio Frequency Interface Specification*, CM-SP-DRFI-I14-131120, November 20, 2013, Cable Television Laboratories, Inc., https://www.cablelabs.com/specification/downstream-rf-interface-specification/
- [DOCSIS PHYv3.1] *DOCSIS 3.1, Physical Layer Specification*, CM-SP-PHYv3.1-I08-151210, December 10, 2015, Cable Television Laboratories, Inc., https://www.cablelabs.com/specification/physical-layer-specification/
- [DOCSIS PHYv3.0] *DOCSIS 3.0, Physical Layer Specification*, CM-SP-PHYv3.0-I12-150305, March 5, 2015, Cable Television Laboratories, Inc., https://www.cablelabs.com/specification/docsis-3-0-physical-layer-interface-specification/
- [EN 300 429] *ETSI EN 300 429 V1.2.1: Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems*, April 1998.
- [ITU-T J.83-B] *Annex B to ITU-T Rec. J.83 (12/2007), Digital multi-program systems for television sound and data services for cable distribution*.

3.3. Published Materials

- [DOCSIS CCAP] Converged Cable Access Platform Architecture Technical Report, CM-TR-CCAP-V03-120511, May 11, 2012, *http://www.cablelabs.com/specification/ccap-architecture-technical-report/?v=3*
- [DOCSIS MHA] *Data-Over-Cable Service Interface Specifications Modular Headend Architecture - EQAM Architectural Overview Technical Report*, December 9, 2008, *http://www.cablelabs.com/wp-content/uploads/specdocs/CM-TR-MHA-V02-081209.pdf*
- [European Broadband CoC] *European Commission Joint Research Centre: Code of Conduct on Energy Consumption of Broadband Equipment*, Version 5.0, December 20, 2013,

http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/files/documents/ICT_CoC/cocv5-broadband_final.pdf

4. Compliance Notation

shall	This word or the adjective "***required***" means that the item is an absolute requirement of this document.
shall not	This phrase means that the item is an absolute prohibition of this document.
forbidden	This word means the value specified shall never be used.
should	This word or the adjective "*recommended*" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighted before choosing a different course.
should not	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
may	This word or the adjective "*optional*" means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.
deprecated	Use is permissible for legacy purposes only. Deprecated features may be removed from future versions of this document. Implementations should avoid use of deprecated features.

5. Abbreviations and Definitions

5.1. Abbreviations

Abbreviation	Description
AAA	Authentication, Authorization, and Accounting
ACL	Access Control List
A-TDMA	Advanced Time Division Multiple Access
AP	Access Point
bps	bits per second
CAPWAP	Control And Provisioning of Wireless Access Points
CCAP	Converged Cable Access Platform
CGNAT	Carrier Grade Network Address Translation
CMAP	Cable Modem Access Point
CMTS	Cable Modem Termination System
DAA	Distributed Access Architecture
DEPI	Downstream External PHY Interface
DHCP	Dynamic Host Configuration Protocol
DOCSIS	Data Over Cable Service Interface Specifications
DPoE	DOCSIS Provisioning of EPON
DS	Downstream
DTI	DOCSIS Timing Interface

EPON	Ethernet Passive Optical Network
EQAM (edge-QAM)	Edge Quadrature Amplitude Modulator
EUT	Equipment Under Test
FEC	Forward Error Correction
GBPS	Gigabits Per Second
GPS	Global Positioning System
GRE	Generic Routing Encapsulation
HVAC	Heating, Ventilation and Air Conditioning
HE	Headend
I-CMTS	Integrated Cable Modem Termination System
IP	Internet Protocol
KPM	Key Performance Metric
L2TP	Layer 2 Tunneling Protocol
LTE	Long Term Evolution
LWAPP	Lightweight Access Point Protocol
NC	Narrowcast
NDC	National Data Center
NSI	Network Side Interface
NTP	Network Time Protocol
M-CMTS	Modular Cable Modem Termination System
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PEF	Policy Enforcement Router
PIC	Physical Interface Card
PTP	Precision Time Protocol
QAM	Quadrature Amplitude Modulation or Quadrature Amplitude Modulator
QoS	Quality of Service
RF	Radio Frequency
SC-QAM	Single Carrier Quadrature Amplitude Modulation or Single Carrier Quadrature Amplitude Modulator
SDV	Switched Digital Video
SeGW	Security Gateway
US	Upstream
VLAN	Virtual Local Area Network
VoD	Video on Demand
VPN	Virtual Private Network
WAG	Wireless Access Gateway

5.2. Definitions

Term	Definition
Critical facility	The network, facility, and/or building responsible for the reliable delivery of information services.
Key Performance Metric	A standard of measurement for the efficiency of use of energy or rack and space/volume for cable equipment in critical facilities
Channel Utilization	The amount of data traffic passing through a downstream or upstream QAM channel on a sustained basis expressed as a percentage of the channel's maximum theoretical throughput.

6. Wireless Equipment Overview

6.1. Description of Equipment

The following briefly describes the various network elements present in an end to end wireless network and system architecture.

6.1.1. Wireless Network Overview

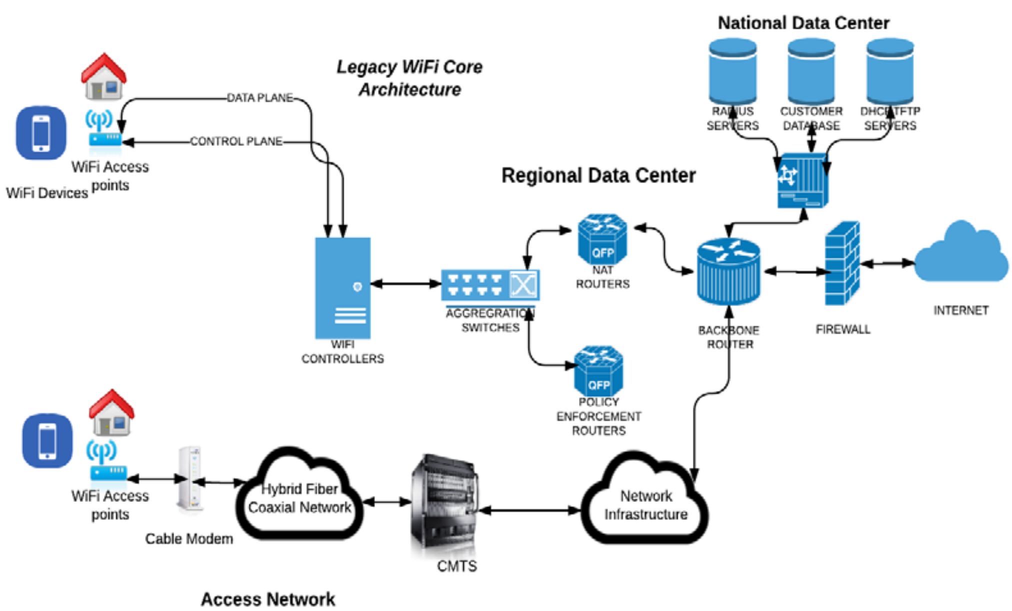

Figure 1 - Legacy Wi-Fi Core Architecture

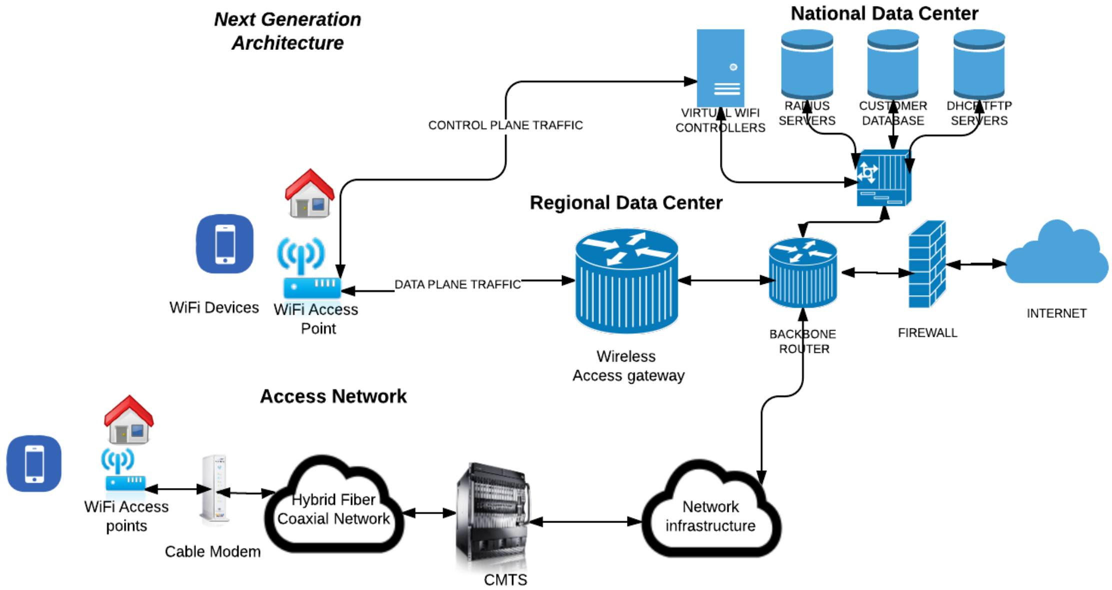

Figure 2 - Next Generation Wi-Fi Architecture

*Note: Access Points can be deployed using different mediums (CMTS, Fiber, Ethernet, and Mesh) and for the purpose of this document only CMTS-based deployment is considered for test iterations.

The Wi-Fi network Architecture consists of several elements as shown in the above figures. In Current deployment there are two different architectures that are supported by various ISPs.

1. Legacy Wi-Fi Core Architecture
2. Next Generation Wi-Fi Core Architecture

The legacy core utilizes individual network elements for switching, policy enforcement, and NAT services, whereas in the next-gen core all of these functionalities are performed in a single box solution i.e. Wireless Access Gateway (WAG). Data plane traffic would be tunneled from access point to WAG in the next-gen core whereas in the legacy architecture, data plane traffic is tunneled from Access points to Wi-Fi Controller.

All the elements in the regional and national data centers have two units for the same network element (Aggregation switches, Policy Enforcement Routers, Wireless Access Gateways & Authentication servers) one serving as primary and the other as secondary. Wi-Fi Traffic is load balanced equally across both primary and secondary server instances in a few designs and in other architectures the secondary units don’t carry any user traffic until there is a failure on the primary network elements. The amount of power consumed on secondary elements and failures in data centers in Wireless architecture can be saved by introducing new power savings techniques.

Wi-Fi access points tend to broadcast beacons for every 100ms and these are broadcasted even without the presence of Wi-Fi Clients. The amount of power consumed by Wi-Fi access points can be saved by introducing new power saving techniques.

Below is the description of a few elements in the Wi-Fi Architectures.

Access network: This generally consists of wireless Access Points and underlying backhaul transport (DOCSIS, Ethernet, and EPON). The Access network provides end user connectivity for Wireless subscribers using 802.11 a/b/g/n/ac standards. Any failure in the Access network will cause the clients to be disassociated from the network.

Access Point: Device that allows wireless connections when connected to a router or switch over a wired network. The 802.11 standard protocols allow the wireless clients to connect to the Access Point over the air and the transport of the traffic is passed through a tunnel formed between the WAP and controllers. Tunnel types that are commonly used in today's Wi-Fi architecture are CAPWAP, LWAPP, L2TP and others.

Cable Modem: All of the wireless Access Points connect to either an embedded or external cable modem. The Cable Modem acts as a layer 2 bridge and receives IP connectivity from the CMTS after successful registration. During the initial boot up stage, configuration files are pushed to the CM from the CMTS for various parameters such as bandwidth, COS, IP connectivity & provisional codes. Any failure in the cable modem will cause the Access Points to be disassociated from the network.

If failures occur in the Access network, clients may not be able to authenticate and may not become associated with the network. Power saving techniques will be relatively complex as each vendor supports different protocols for transport.

Regional Data Center: Generally consists of aggregation switches, Wi-Fi Controllers, Policy Enforcement Routers and Wireless Access Gateways. The Regional Data Center serves as a back bone to the network, providing IP connectivity to clients, session management, and policy enforcement. Wi-Fi Controllers are used to manage all Access Points within the same network. Access Points will establish a tunnel (vendor proprietary protocol) with a Wi-Fi Controller to pass user traffic.

Wi-Fi Controllers: A Wi-Fi Controller is a hardware/virtual device that provides a single point of management for all of the Access Points in a network; those Access Points connect to the Wi-Fi controller, which then connects to the wireless network. The Wi-Fi Controller provides the Access Point its configuration and also functions as a switch for all of the wireless traffic. The Wi-Fi Controller also consolidates management for the entire wireless network in one place.

Aggregation Switches: Provides the functionality of forwarding user traffic between various parts of the Access network and the transport network. VLANs will be created on the Aggregation switches to reduce the broadcast domains and to minimize security issues.

The Policy Enforcement Router and Wireless Access Gateway equipment types will be referred to generically as Gateway Servers in this document to maintain consistent terminology across the legacy and next generation Wi-Fi core architectures.

Policy Enforcement Routers (Gateway Servers): The functionality of this device is to verify whether a user is authenticated and authorized to use specific network services. These devices perform the following key aspects of subscriber management:

Subscriber identification
Service and policy determination
Session policy enforcement
Session life-cycle management
Accounting for access and service usage
Session state monitoring
Network Address Translation service

Any failures in the regional data center may result in client connectivity issues and internet service may be interrupted.

Wireless Access Gateway (Gateway server): This device serves as the aggregation point for all wireless subscriber traffic. Ethernet over GRE (EoGRE) protocol is a new aggregation solution for aggregating Wi-Fi traffic from hotspots. This solution enables customer premises equipment (CPE) devices to bridge the Ethernet traffic coming from an end host, and encapsulates the traffic in Ethernet packets over an IP GRE tunnel. When the IP GRE tunnels are terminated on a service provider broadband network gateway, the end host's traffic is terminated and subscriber sessions are initiated for the end host. This feature allows the separation of Control Plane and Date Plane on the controllers to enhance independent scalability. In addition, various core functions such as DHCP, CGNAT, QoS, ACLs, Wi-Fi Session Management may be converged to reduce operational complexity in a single box solution. These routers are capable of managing approximately 5-10 million concurrent wireless subscriber devices actively passing traffic.

These routers are being deployed by all the Cable MSO partners for various deployment scenarios such as:

Broadband Network Gateway for residential service delivery with advanced subscriber management
Multiservice Edge Router for business VPN, Cloud and data center interconnect services
Mobile Backhaul Aggregation Router to address the needs of macro, small cell and heterogeneous networks
Mobile Gateway for the mobile packet core (2G, 3G and LTE)
WLAN Gateway for carrier Wi-Fi networks supporting carrier Wi-Fi mobility including cellular interworking and advanced subscriber management
Security Gateway (SeGW) for macro and small cell and carrier Wi-Fi networks

National Data Center:

Radius Servers: Authentication, authorization, and accounting (AAA) is a term for a framework for controlling access to network resources, enforcing policies and providing necessary usage information to watermarking and billing services.
First Authentication provides a way of identifying a user; users provide their credentials manually through the captive portal or the user's device mac address before gaining access to the network. AAA server compares the user's credentials against a stored user database / directory. Access to the network is granted only when the credentials match with the database. If the credentials are at variance, authentication fails and network access is denied to the subscriber.

Authorization is the process of enforcing policies. After successful authentication, the authorization process determines whether the user has the authority or privileges to access certain resources in the network.
The Final process in the AAA framework is Accounting, which measures / reports network resources utilized by the user during the session. This includes the data usage, network resources, and time duration of the session or other measurable parameters. The information is reported and consumed by billing and analysis departments.

Backend Data servers: Provide a directory which creates and stores subscriber information.

DHCP server: DHCP servers are used to provide IP dynamically to all the cable modem and wireless clients associated with the Access Points.

Any failure in the NDC will cause the client to be in an unauthenticated state and will not be allowed to use Wi-Fi services.

7. Wi-Fi Controller Equipment

7.1. Description of Equipment

See section 6.1 above.

Two separate classes of equipment are accounted for:

a. Equipment with just “control plane” functionality
b. Equipment with both “control plane” and “Client Data Traffic” functionality

7.2. Energy Metrics for Wi-Fi Controller Equipment

7.2.1. Introduction

The following sections specify the metrics to be used for determining the power consumption for entities associated with the corresponding equipment type.

7.2.2. Power Consumption Metrics for Wi-Fi Controller Equipment with just “control plane” Functionality

7.2.2.1. Power per Access Point for Wi-Fi Controller Equipment with just “control plane” Functionality

Power consumption per Access Point for Wi-Fi Controllers with just “control plane” functionality ***shall*** be determined with the following metric:

$$\frac{Wi - Fi\ Controller\ Total\ Chassis\ Power\ (Watts)}{Maximum\ Number\ of\ Supported\ Access\ Points}$$

Wi-Fi Controller Total Chassis Power ***shall*** represent the total power consumption (in watts) of the Wi-Fi Controller chassis as determined by measurements at the power entry point just outside the chassis.

Maximum Number of Supported Access Points ***shall*** represent the highest number of Access Points that can be supported in the chassis.

7.2.2.2. Power per Client for Wi-Fi Controller Equipment with just "control plane" Functionality

Power consumption per client for Wi-Fi Controllers with just "control plane" functionality ***shall*** be determined with the following metric:

$$\frac{Wi - Fi\ Controller\ Total\ Chassis\ Power\ (Watts)}{Maximum\ Number\ of\ Supported\ Clients}$$

Wi-Fi Controller Total Chassis Power ***shall*** represent the total power consumption (in watts) of the Wi-Fi Controller chassis as determined by measurements at the power entry point just outside the chassis.

Maximum Number of Supported Clients ***shall*** represent the highest number of clients that can be supported simultaneously in the chassis.

7.2.3. Power Consumption Metrics for Wi-Fi Controller Equipment with both "control plane" and "Client Data Traffic" functionality

Multiple metrics are to be evaluated for this type of Wi-Fi Controller as specified below. The three metrics specified in the below subsections are to be used to evaluate the power consumption characteristics of Wi-Fi Controllers that support both "control plane" as well as "client data traffic" functionality. It is important to note that evaluation and consideration of all three metrics is required in order to ensure a comprehensive understanding of these characteristics.

7.2.3.1. Power per Access Point for Wi-Fi Controller Equipment with both "control plane" and "Client Data Traffic" functionality

Power consumption per Access Point for Wi-Fi Controllers with both "control plane" and "Client Data Traffic" functionality ***shall*** be determined with the following metric:

$$\frac{Wi - Fi\ Controller\ Total\ Chassis\ Power\ (Watts)}{Maximum\ Number\ of\ Supported\ Access\ Points}$$

Wi-Fi Controller Total Chassis Power ***shall*** represent the total power consumption (in watts) of the Wi-Fi Controller chassis as determined by measurements at the power entry point just outside the chassis.

Maximum Number of Supported Access Points ***shall*** represent the highest number of Access Points that can be supported in the chassis.

7.2.3.2. Power per Client for Wi-Fi Controller Equipment with both “control plane” and “Client Data Traffic” functionality

Power consumption for Wi-Fi Controllers with both “control plane” and “Client Data Traffic” functionality per client ***shall*** be determined with the following metric:

$$\frac{Wi - Fi\ Controller\ Total\ Chassis\ Power\ (Watts)}{Maximum\ Number\ of\ Supported\ Clients}$$

Wi-Fi Controller Total Chassis Power ***shall*** represent the total power consumption (in watts) of the Wi-Fi Controller chassis as determined by measurements at the power entry point just outside the chassis.

Maximum Number of Supported Clients ***shall*** represent the highest number of clients that can be supported simultaneously in the chassis.

7.2.3.3. Power per Throughput for Wi-Fi Controller Equipment with both “control plane” and “Client Data Traffic” functionality

Power consumption per throughput for Wi-Fi Controllers with both “control plane” and “Client Data Traffic” functionality ***shall*** be determined with the following metric:

$$\frac{Wi - Fi\ Controller\ Total\ Chassis\ Power\ (Watts)}{Maximum\ Downstream\ Throughput\ (Gbps) + Maximum\ Upstream\ Throughput\ (Gbps)}$$

Wi-Fi Controller Total Chassis Power ***shall*** represent the total power consumption (in watts) of the Wi-Fi Controller chassis as determined by measurements at the power entry point just outside the chassis.

Maximum Downstream Throughput ***shall*** represent the maximum downstream payload[1] throughput (i.e. rate of data traffic) supported by the chassis in Gbps as determined by measurements at the downstream *egress* interfaces with the following conditions. The maximum downstream throughput ***shall*** be supported with a downstream packet loss not to exceed 0.01% (i.e. approximating non-blocking operation). If the packet loss exceeds the above limit then the downstream throughput ***shall*** be decreased until the limit is met.

Maximum Upstream Throughput ***shall*** represent the maximum upstream payload[1] throughput (i.e. rate of data traffic) supported by the chassis in Gbps as determined by measurements at the upstream *egress* interfaces with the following conditions. The maximum upstream throughput ***shall*** be supported with an upstream packet loss not to exceed 0.01% (i.e. approximating non-blocking operation). If the packet loss exceeds the above limit then the upstream throughput ***shall*** be decreased until the limit is met.

[1]Payload throughput as defined in this standard does *not* include Ethernet and IP header bits.

7.3. Functional Density Metrics for Wi-Fi Controller Equipment

7.3.1. Functional Density Metrics for Wi-Fi Controller Equipment with just "control plane" Functionality

The "Access Point" Functional Density for Wi-Fi Controller Equipment with just "control plane" functionality ***shall*** be determined with the following metric:

- *Maximum Number of Access points per Wi-Fi Controller rack unit*

The above metric ***shall*** be evaluated by dividing *Maximum Number of Access Points supported by the chassis* (as specified in section 7.2.2.1) by the total number of chassis rack units.

The "Client" Functional Density for Wi-Fi Controller Equipment with just "control plane" functionality ***shall*** be determined with the following metric:

- *Maximum Number of Supported Clients per Wi-Fi Controller rack unit*

The above metric ***shall*** be evaluated by dividing *Maximum Number of Supported Clients* (as specified in section 7.2.2.2) by the total number of chassis rack units.

7.3.2. Functional Density Metrics for Wi-Fi Equipment with both "control plane" and "Client Data Traffic" functionality

The "Access Point" Functional Density for Wi-Fi Controller Equipment with both "control plane" and "Client Data Traffic" functionality ***shall*** be determined with the following metric:

- *Maximum Number of Access points per Wi-Fi Controller rack unit*

The above metric ***shall*** be evaluated by dividing *Maximum Number of Access Points supported by the chassis* (as specified in section 7.2.3.1) by the total number of chassis rack units.

The "Client" Functional Density for Wi-Fi Controller Equipment with both "control plane" and "Client Data Traffic" functionality ***shall*** be determined with the following metric:

- *Maximum Number of Supported Clients per Wi-Fi Controller rack unit*

The above metric ***shall*** be evaluated by dividing *Maximum Number of Supported Clients* (as specified in section 0) by the total number of chassis rack units.

The "Throughput" Functional Density for Wi-Fi Controller Equipment with both "control plane" and "Client Data Traffic" functionality ***shall*** be determined with the following metric:

- *Maximum Throughput per Wi-Fi Controller rack unit*

The above metric ***shall*** be evaluated by dividing the maximum throughput (in Gbps) supported by the Wi-Fi Controller chassis by the total number of chassis rack units. The maximum throughput per Wi-Fi Controller chassis unit ***shall*** be determined using the guidance provided in sections 7.2.3.3 and 10.5.

8. Access Point Equipment

8.1. Access Point Equipment Description

See section 6.1 above. The scope of Access Point equipment for this standard ***shall*** be limited to "strand-mounted" (aka "CMAP") devices that draw their power from the cable plant and contain an integrated Cable Modem.

8.2. Access Point Power Consumption Metrics

The three metrics specified in the below subsections are to be used to evaluate the power consumption characteristics of Access Point equipment. It is important to note that evaluation and consideration of all three metrics is required in order to ensure a comprehensive understanding of these characteristics.

8.2.1. Access Point Power Consumption per Throughput

Power consumption per throughput for Access Point equipment ***shall*** be determined with the following metric:

$$\frac{Access\ Point\ Total\ Enclosure\ Power\ (Watts)}{Maximum\ Downstream\ Throughput\ (Gbps) + Maximum\ Upstream\ Throughput\ (Gbps)}$$

Access Point Total Enclosure Power ***shall*** represent the total power consumption (in watts) of the Access Point as determined by measurements at the power entry point just outside the Access Point enclosure.

Maximum Downstream Throughput ***shall*** represent the maximum downstream payload[1] throughput (i.e. rate of data traffic) supported by the Access Point in Gbps as determined by measurements at the downstream *egress* interfaces with the following conditions. The maximum downstream throughput ***shall*** be supported with a downstream packet loss not to exceed 0.01% (i.e. approximating non-blocking operation). If the packet loss exceeds the above limit then the downstream throughput ***shall*** be decreased until the limit is met.

Maximum Upstream Throughput ***shall*** represent the maximum upstream payload[1] throughput (i.e. rate of data traffic) supported by the Access Point in Gbps as determined by measurements at the upstream *egress* interfaces with the following conditions. The maximum upstream throughput ***shall*** be supported with an upstream packet loss not to exceed 0.01% (i.e. approximating non-blocking operation). If the packet loss exceeds the above limit then the upstream throughput ***shall*** be decreased until the limit is met.

[1]Payload throughput as defined in this standard does *not* include Ethernet and IP header bits.

8.2.2. Access Point Power Consumption per Client

For Access Point equipment, the power consumption per client ***shall*** be determined with the following metric:

$$\frac{Access\ Point\ Total\ Enclosure\ Power\ (Watts)}{Maximum\ Number\ of\ Supported\ Clients}$$

Access Point Total Enclosure Power ***shall*** represent the total power consumption (in watts) of the Access Point as determined by measurements at the power entry point just outside the Access Point enclosure.

Maximum Number of Supported Clients ***shall*** represent the highest number of clients that the Access Point can support simultaneously.

8.2.3. Access Point Power Consumption per Tunnel

For Access Point equipment, the power consumption per Tunnel ***shall*** be determined with the following metric:

$$\frac{\textit{Access Point Total Enclosure Power (Watts)}}{\textit{Maximum Number of Supported Tunnels}}$$

Access Point Total Enclosure Power ***shall*** represent the total power consumption (in watts) of the Access Point as determined by measurements at the power entry point just outside the enclosure.

Maximum Number of Supported ***shall*** represent the highest number of Tunnels that the Access Point can support simultaneously.

8.3. Access Point Functional Density Metrics

The “Throughput” Functional Density for Access Point equipment ***shall*** be determined with the following metric:

- *Maximum Throughput per Access Point*

The above metric ***shall*** be evaluated by determining the maximum throughput (in Gbps) supported by the Access Point. The maximum throughput per Access Point ***shall*** be determined using the guidance provided in sections 8.2.1 and 10.5.

The “Client” Functional Density for Access Point equipment ***shall*** be determined with the following metric:

- *Maximum Number of Clients per Access Point*

The above metric ***shall*** be evaluated by determining the maximum number clients supported by the Access Point.

The “Tunnel” Functional Density for Access Point equipment ***shall*** be determined with the following metric:

- *Maximum Number of Tunnels per Access Point*

The above metric ***shall*** be evaluated by determining the maximum number tunnels supported by the Access Point.

9. Gateway Server Equipment

9.1. Gateway Server Equipment Description

See section 6.1 above.

9.2. Gateway Server Power Consumption Metrics

9.2.1. Gateway Server Power Consumption per Session

The Gateway Server power consumption per Session ***shall*** be determined with the following metric:

$$\frac{\textit{Gateway Server Total Chassis Power (Watts)}}{\textit{Maximum Number of Sessions supported by the chassis}}$$

Gateway Server Total Chassis Power (Watts) ***shall*** represent the total power consumption (in watts) of the Gateway Server chassis as determined by measurements at the power entry point just outside the chassis.

Maximum Number of Sessions supported by the chassis ***shall*** represent the highest number of Sessions that can be supported in the chassis.

a. For a Wireless Access Gateway (WAG), each Access Point has a single tunnel to/from a WAG. A client connects to the Access Point then the session is formed (there is one session per client). The Access Point sees the first client and the tunnel to/from the WAG is then formed.
b. For a Policy Enforcement Router (legacy), there are no tunnels – only Wi-Fi sessions. A session is a client association with an Access Point (also involving DHCP operations to obtain and IP address).

9.2.2. Gateway Server Power per Throughput

Power consumption per throughput for Gateway Server equipment ***shall*** be determined with the following metric:

$$\frac{Gateway\ Server\ Total\ Chassis\ Power\ (Watts)}{Maximum\ Downstream\ Throughput\ (Gbps) + Maximum\ Upstream\ Throughput\ (Gbps)}$$

Gateway Server Total Chassis Power ***shall*** represent the total power consumption (in watts) of the Gateway Server chassis as determined by measurements at the power entry point just outside the chassis.

Maximum Downstream Throughput ***shall*** represent the maximum downstream payload[1] throughput (i.e. rate of data traffic) supported by the chassis in Gbps as determined by measurements at the downstream *egress* interfaces with the following conditions. The maximum downstream throughput ***shall*** be supported with a downstream packet loss not to exceed 0.01% (i.e. approximating non-blocking operation). If the packet loss exceeds the above limit then the downstream throughput ***shall*** be decreased until the limit is met.

Maximum Upstream Throughput ***shall*** represent the maximum upstream payload[1] throughput (i.e. rate of data traffic) supported by the chassis in Gbps as determined by measurements at the upstream *egress* interfaces with the following conditions. The maximum upstream throughput ***shall*** be supported with an upstream packet loss not to exceed 0.01% (i.e. approximating non-blocking operation). If the packet loss exceeds the above limit then the upstream throughput ***shall*** be decreased until the limit is met.

[1]Payload throughput as defined in this standard does *not* include Ethernet and IP header bits.

9.3. Gateway Server Functional Density Metrics

The "Session" Functional Density for Gateway Server equipment ***shall*** be determined with the following metric:

- *Maximum Number of Sessions per Gateway Server rack unit*

The above metric ***shall*** be evaluated by dividing the maximum number of sessions supported by the Gateway Server chassis by the total number of chassis rack units. The maximum number of sessions per Gateway Server chassis rack unit ***shall*** be determined as specified in section 9.2.1.

The "Throughput" Functional Density for Gateway Server equipment ***shall*** be determined with the following metric:

- *Maximum Throughput per Gateway Server*

The above metric ***shall*** be evaluated by determining the maximum throughput (in Gbps) supported by the Gateway Server. The maximum throughput per Gateway Server ***shall*** be determined using the guidance provided in sections 9.2.2 and 10.5.

10. Test Procedures

10.1. General Requirements and Methodology

The general requirements and methodology specified in [SCTE_General_Test_Procedures] for measuring power consumption ***shall*** be applied to the testing of all equipment types. That document includes requirements for aspects such as environmental, measurement equipment calibration, equipment stabilization, and general power measurement guidelines. However, for **Access Point equipment**, [SCTE_General_Test_Procedures] ***shall*** be applied with the exception of the voltage requirements of section 6.2.4. Voltage requirements for Access Point equipment are covered in this document in section

10.2. General Equipment Configuration

The following general equipment configuration ***shall*** be applied to the testing of all equipment types:

- All testing ***shall*** be performed on a fully-loaded chassis, as defined by the referenced application.
- All ports ***shall*** be in an active state and passing or ready to pass traffic.
- System software ***shall*** be properly configured prior to the test and all the necessary hardware components installed. Hardware and software ***shall*** be representative of a production unit.
- There is no EUT configuration change allowed any time beyond preparation phase. This includes (but not limited to) external configuration commands, scripts executing configuration commands on EUT during testing, etc.

Configuration ***shall*** include redundancy if supported by the particular EUT.

For any configuration or functionality that is not supported by the EUT, the equipment vendor ***shall*** provide a reasonable substitution and the particular substitution details ***shall*** be recorded along with the test results.

10.2.1. Packet Length Distribution for Wi-Fi testing

The following distribution of packet lengths ***shall*** be applied to the testing of Wi-Fi equipment.

10.2.1.1. Downstream Packet Length

Packet Length (bytes)	Percentage of Total Traffic (%)
64	10
220	10
1000	65
1514	15

10.2.1.2. Upstream Packet Length

Packet Length (bytes)	Percentage of Total Traffic (%)
64	15
70	25
200	50
1483	10

10.3. General Measurement Procedure – 70% Utilization

The 70% Utilization procedure ***shall*** consist of the following steps.

1. Pre-conditions:
    a. Prior to the actual test, the EUT ***shall*** be exposed to the environmental conditions specified in [SCTE_General_Test_Procedures].

2. Configuration and Stabilization:
    a. Prior to testing, the EUT ***shall*** be powered and configured according to the requirements and loading defined in the test procedures section for the particular equipment type as listed below.
        i. Wi-Fi Controller equipment – Section 10.6 and 10.7
        ii. Access Point equipment - Section 10.8
        iii. Gateway Server equipment - Section 10.9
    b. Traffic generators are used to simulate traffic and collect the performance-related results according to the test conditions for the equipment type under test. Generators ***shall*** be configured for the specified traffic mix and traffic profile. Traffic generation ***shall*** be configured such that all configured data and control plane interfaces into and out of the EUT (including Wi-Fi radio channels in the case of an Access Point) are utilized at **70% ± 0.5%**. This utilization ***shall*** be sustained with a packet loss not to exceed 0.01% (i.e. approximating non-blocking operation). If the drop rate exceeds 0.01% then, if possible, additional resources ***shall*** be installed to increase the capacity.
    c. Allow the equipment to stabilize in this mode for 15 minutes.
3. Measure and record the chassis power consumption for a period of 15 minutes. The measurement ***shall*** be in Watts as determined with a Power Meter at the power entry point just outside the EUT. If the power varies over the 15 minute measurement time interval, an average of the measurement ***shall*** be calculated.
4. Evaluate the appropriate equipment power consumption metrics (see list below) and record the results.
    a. Wi-Fi Controller equipment with just “control plane” functionality – Sections 7.2.2.1, 7.2.2.2
    b. Wi-Fi Controller equipment with both “control plane” and “Client Data Traffic” functionality – Sections 7.2.3.1, 0
    c. Access Point Equipment – Sections 8.2.2, 8.2.3
    d. Gateway Server Equipment – Section 9.2.1
5. Repeat steps 2 – 4 for each applicable configuration scenario defined in the test configuration section for the equipment type under test.

10.4. General Measurement Procedure – Idle Test

The purpose of this procedure is to evaluate the power consumption metrics while the system is not passing traffic. The Idle test procedure ***shall*** consist of the following steps.

1. Pre-conditions:
   a. Prior to the actual test, the EUT ***shall*** be exposed to the environmental conditions specified in [SCTE_General_Test_Procedures].
2. Configuration and Stabilization:
   a. Prior to testing, the EUT ***shall*** be powered and configured according to the requirements and loading defined in the test procedures sections for the particular equipment type. In particular, the EUT ***shall*** still be *capable* of performing its normal functions (e.g. passing traffic, registering Access points, etc.) across its full set of resources.
      i. Wi-Fi Controller equipment – Section 10.6 and 10.7
      ii. Access Point equipment - Section 10.8
      iii. Gateway server equipment - Section 10.9
   b. The traffic generators ***shall*** be configured as follows:
      i. Traffic generation ***shall*** be configured such that all configured data and control plane interfaces into and out of the EUT (including Wi-Fi radio channels in the case of an Access Point) are utilized at **0%** with a tolerance of **0.1%**.
   c. Allow the equipment to stabilize in this mode for 15 minutes.
3. Measure and record the chassis power consumption for a period of 15 minutes. The measurement ***shall*** be in Watts as determined with a Power Meter at the power entry point just outside the chassis. If the power varies over the 15 minute measurement time interval, an average of the measurement ***shall*** be calculated.
4. Evaluate the appropriate equipment power consumption metric (see list below) and record the results.
   a. Wi-Fi Controller equipment with just “control plane” functionality – Sections 7.2.2.1, 7.2.2.2
   b. Wi-Fi Controller equipment with both “control plane” and “Client Data Traffic” functionality – Sections 7.2.3.1, 0
   c. Access Point Equipment – Sections 8.2.2, 8.2.3
   d. Gateway Server Equipment – Section 9.2.1
5. Repeat steps 2 – 4 for each applicable configuration scenario defined in the test configuration section for the equipment type under test.

10.5. General Measurement Procedure – Power Per Throughput

The Power per Throughput measurement procedure ***shall*** consist of the following steps.

1. Pre-conditions:
    a. Prior to the actual test, the EUT ***shall*** be exposed to the environmental conditions specified in [SCTE_General_Test_Procedures].

2. Configuration and Stabilization:
    a. Prior to testing, the EUT ***shall*** be powered and configured according to the requirements and loading defined in the test procedures section for the particular equipment type as listed below.
        i. Wi-Fi Controller equipment – Section 10.6 and 10.7
        ii. Access Point equipment - Section 10.8
        iii. Gateway Server equipment - Section 10.9

    b. Traffic generators are used to simulate traffic and collect the performance-related results according to the test conditions for the equipment type under test. Generators ***shall*** be configured for the specified traffic mix and traffic profile. The traffic rate ***shall*** be configured such that the measured downstream and upstream EUT payload[1] throughputs achieve their highest possible sustained values with a packet loss not to exceed 0.01% (i.e. approximating non-blocking operation). If the packet loss exceeds the above limit then the downstream throughput ***shall*** be decreased until the limit is met.

    The downstream payload throughput ***shall*** be measured at the downstream egress interfaces of the particular EUT. The upstream payload throughput ***shall*** be measured at the upstream egress interfaces of the particular EUT.
    For example:
        i. For Access Points, the downstream payload throughput ***shall*** be measured at the egress radio interfaces. This effectively measures the rate of traffic that the EUT forwards to Wi-Fi clients.
        ii. For Access Points, the upstream payload throughput ***shall*** be measured at the (network-side) egress interfaces. This effectively measures the rate of traffic from Wi-Fi clients that is forwarded by the EUT.

    Allow the equipment to stabilize in this mode for 15 minutes.

3. Measure and record the chassis power consumption for a period of 15 minutes. The measurement ***shall*** be in Watts as determined with a Power Meter at the power entry point just outside the chassis. If the power varies over the 15 minute measurement time interval, an average of the measurement ***shall*** be calculated.
4. Evaluate the appropriate equipment power consumption metric (see list below) and record the results. Note that the Power per Throughput metric does not apply to Wi-Fi Controller equipment with just "control plane" functionality.
    - Wi-Fi Controller equipment with both "control plane" and "Client Data Traffic" functionality – Section 7.2.3.3
    - Access point Equipment – Section 8.2.1
    - Gateway Server equipment – Section 9.2.2
5. Repeat steps 2 – 4 for each applicable configuration scenario defined in the test configuration section for the equipment type under test.

[1]Payload throughput as defined in this standard does *not* include Ethernet and IP header bits.

10.6. Power Consumption Test Procedures for Wi-Fi Controller Equipment with just "control Plane" Functionality

10.6.1. Configuration for W-Fi Controller Equipment with just "control plane" Functionality

The Wi-Fi Controller Chassis ***shall*** be configured with the maximum number of supported access points and the maximum number of supported Wi-Fi clients.

The Wi-Fi Controller Chassis ***shall*** be configured with all control plane ports enabled.

10.6.2. Applicable Test Procedures for Wi-Fi Controller Equipment with just "control plane" Functionality

The following power consumption test procedures for Wi-Fi Controller EUT with just "control plane" Functionality ***shall*** be performed:

a. 70% Utilization Test – Section 10.3
b. Idle Test – Section 10.4

10.7. Power Consumption Test Procedures for Wi-Fi Controller Equipment with both "control Plane" and "client data traffic" Functionality

10.7.1. Configuration for W-Fi Controller Equipment with both "control Plane" and "client data traffic" Functionality

The Wi-Fi Controller Chassis ***shall*** be configured with the maximum number of supported access points and the maximum number of supported Wi-Fi clients.

The Wi-Fi Controller Chassis ***shall*** be configured with all control plane and data plane ports enabled.

10.7.2. Applicable Test Procedures for Wi-Fi Controller Equipment with both "control Plane" and "client data traffic" Functionality

The following power consumption test procedures for Wi-Fi Controller EUT with both "control Plane" and "client data traffic" Functionality ***shall*** be performed:

c. 70% Utilization Test – Section 10.3
d. Idle Test – Section 10.4
e. Power per Throughput Test - Section 10.5

10.8. Power Consumption Test Procedures for Access point Equipment

10.8.1. Access Point Environmental Requirements

Access Point equipment ***shall*** be evaluated in accordance with the Temperature, Humidity, and Barometric Pressure requirements specified in [SCTE_General_Test_Procedures] – section 6.2.4.

Access Point equipment ***shall*** be evaluated with a source providing the following voltage conditions:

- Power over cable (40-90 VAC ± 5% quasi-square wave, 47-63 Hz ± 1%) through common 5/8" hardline or F connector.

10.8.2. Access point Configuration

The Access point ***shall*** be configured for the maximum supported number of concurrent Wi-Fi clients (i.e. clients) and a mix of clients to be used for testing (802.11b, g, n &ac).

The Access point ***shall*** be configured for the maximum supported number of concurrent tunnels.

The Access Point ***shall*** be configured to handle client communications with the following mixture of radio standards:

Mix of Client's Radio Standards
802.11b = 3%
802.11g= 7%
802.11n = 30%
802.11ac = 60%

The following Access Point radio configuration ***shall*** be applied:

Downstream:

- Configure Wi-Fi channel in the 2.4 GHz band to channel 11 and in the 5 GHz band to channel 149 and perform tests for both 802.11n and 802.11ac in both the bands.

Upstream:

- Configure Wi-Fi channel in the 2.4 GHz band to channel 11 and in the 5 GHz band to channel 149 and perform tests for both 802.11n and 802.11ac in both the bands.

The following Access Point encryption technology ***shall*** be configured: "WPA-PSK (AES).

10.8.3. Access Point Applicable Test Procedures

The following power consumption test procedures for the Access Point EUT ***shall*** be performed:

a. 70% Utilization Test – Section 10.3
b. Idle Test – Section 10.4
c. Power per Throughput Test - Section 10.5

10.9. Power Consumption Test Procedures for Gateway Server Equipment

10.9.1. Gateway Server Configuration

The Gateway Server EUT ***shall*** be configured for the maximum supported number of Wi-Fi sessions and maximum Access points tunnels carrying data plane traffic.

10.9.2. Gateway Server Applicable Test Procedures

The following power consumption test procedures for the Gateway Server EUT ***shall*** be performed:

f. 70% Utilization Test – Section 10.3
g. Idle Test – Section 10.4
h. Power per Throughput Test - Section 10.5

10.10. Recording of Results

Results ***shall*** be documented in accordance with [SCTE_General_Test_Procedures].

If the chassis supports redundancy, equipment vendors ***shall*** submit a user-doc level description of their support for redundancy. Fail-over times may optionally be provided, however the description should give a sense for how long a redundant card will take to become fully operational. For example, are all cable modems served by the redundant card required to re-register?

See section 10.2. If it was necessary for the vendor to provide a substitution for configuration or functionality that is not supported by the EUT, the equipment vendor ***shall*** document the particular substitution details.

Additional functionality implemented in the EUT which may not have been exercised during the specified tests (for example, functionality included for future-proofing) *should* be itemized by the vendor.