NEXT GENERATION NETWORKS FOR MULTIPLE DWELLING UNITS (MDU)

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TABLE OF CONTENTS

OVERVIEW

The high-density multiple dwelling unit (MDU) market may see a significant value in offering very high speed internet (VHSI) services. Consequently, MSOs will need an architecture that is capable of supporting the data capacities of today and the much higher data capacity needs of the future.

It is estimated that 30 percent of North Americans live in multiple dwelling units (MDUs), which includes apartment complexes, condo associations, townhouses, mobile home parks, retirement homes, dormitories, and fraternity and sorority houses" [1]. In some emerging economies worldwide, this percentage is even higher. It is estimated that approximately 90 percent (90%) of Chinese urban households are in multiple dwelling units (MDUs).

The worldwide MDU market for advanced telecommunication services may be under increased threat for cable operators. The threat is coming from traditional competitors like telcos and direct broadcast satellite (DBS) as well as new competitors that are targeting the high-density MDU market. The competitors are increasing focus on the MDU market; this market represents highly concentrated areas for investment where cable may have dominance. The increase competition in the MDU market worldwide may have several contributing factors, such as government influences, new market entrants, and new technologies enabling competition in the MDU.

As the cable industry prepares for very high speed internet and IPTV services over next few years, the MDU market has already started. The paper will examine the market for IPTV as well as very high-speed internet services in high-density multi-dwelling units (MDUs). The paper will examine the market opportunities, technologies, as well as network and system architectures. The paper will consider the operational strategies and business models.

The paper will examine:

1. MDU market drivers
2. MDU targeted for very high speed Internet service
3. Copper Twisted Pair solutions (e.g. VDSL2 and G.fast)
4. Coax to the unit solutions (e.g. DOCSIS 3.1)
5. Fiber to the unit solutions for Passive Optical Networks (PONs) such as Gigabit PONs (GPONs), Ethernet PONs (EPONs), and 10G EPONs
6. Category 5 (Cat 5) cable solutions
7. Centralized and distributed access architectures
8. A side-by-side comparison of the MDU technologies and architectures

MDU MARKET DRIVERS

The MDU market for advanced telecommunication services may be under increased threat for cable operator's worldwide market share. The threat is coming from traditional competitors like Telcos and Direct Broadcast Satellite (DBS) as well as new competitors that are targeting the high-density MDU market. Additionally, Over-the -Top (OTT) video and telephone providers remain a threat.

The increased competition in the MDU market worldwide may have several contributing factors, such as government influences, new market entrants, and new technologies enabling competition in the MDU. In the US market, the 2009 D.C. Circuit Court of Appeals upheld a Federal Communications Commission (FCC) ruling prohibiting exclusivity agreements between multichannel video programming distributors (MVPDs) – particularly cable operators – and owners of multiple dwelling units (MDUs) [1,2]. This ruling is creating competition in the MDU voice, video, and data market. Another major factor placing pressure on the MDU market worldwide for cable operators is the advancement in data networking technology targeted at MDUs. Additionally, the increased adoption of IPTV technology to enable video services over broadband networks is adding to the competitive pressures MSOs are facing in the MDU market [3,4]. In fact, DIRECTV announced plans to deliver video, broadband Internet, and VoIP within high-density MDUs using Alcatel Lucent VDSL 2 technology over phone lines [3]. Verizon has an established plan to bring fiber-to-the-building and target the large MDUs [4].

The MDU may have better economics when compared to the rest of the residential market for network access layer upgrades. The economics may be better for MSOs when compared with other service providers. The MSOs' use of the existing coaxial network supporting voice, video, and data services over one network may offer an advantage. In an article describing Verizon's plan to bring fiber to the MDU, a significant challenge remained, which is to "pull anything up the risers, it can be expensive" [4].

However, Verizon has overlaid their twisted pair network with fiber to the home (FTTH) using B-PON or G-PON technology serving the single family unit (SFU) market. In the MDU, the cost of pulling fiber-to-the-user/unit (FTTU) remains a challenge. As Verizon focuses on the MDU market with voice, video, and data services, the use of VDSL2 technology over existing twisted pair may be the preferred network access layer technology [4]. The use of VDSL provides about 75 Mbps of downstream, when within about 500 feet from the MDU-based GPON optical network termination (ONT) with a digital subscriber line access multiplexer (DSLAM) in the basement and the VDSL modem in the unit [4]. This 75 Mbps connection may support IP Video-on-Demand [4]. VDSL2 performance varies widely in published reports, as explained in the network technology section of this paper.

This paper will examine access network media options such as the in-building wiring network used to connect each unit. It will also examine the technology options that may be used across each media type. The paper will consider the network architectures options when using the technology. In addition to the MDU market, the hotel and hospitality markets could use the in-building network access options discussed here to connect to the guest rooms and conference rooms for data and IPTV services.

MDU TARGETED FOR VERY HIGH SPEED INTERNET SERVICE

The definition of very high-speed Internet (VHSI) services will vary, as the definition of broadband service did for many years. The United States FCC report in 2010, defined "Basic Broadband" as data transmission speeds of at least 4 Mbps downstream and 1 Mbps upstream [5]. The FCC's National Broadband Plan report stated as goal number one, "The United States must lead the world in the number of homes and people with access to affordable, world-class broadband connections. As such, 100 million U.S. homes should have affordable access to actual download speeds of at least 100 Mbps and actual upload speeds of at least 50 Mbps by 2020 [6]." Furthermore, "As a milestone, by 2015, 100 million U.S. homes should have affordable access to actual download speeds of 50 Mbps and actual upload speeds of 20 Mbps [6]." Per a recent Broadband China strategy announcement, by 2015 250 million households (HHs) will have realized broadband access, the average speed in urban areas will exceed 20 Mbps, and in the countryside will exceed 4 Mbps.

So, the term 'very high-speed Internet' service is meant to distinguish the service significantly above what is being offered to many subscribers today. This will likely exceed 100 Mbps target set by the FCC for 2020. This paper predicts that high-speed Internet services offered to consumers in both the downstream and upstream direction will exceed the goals of the FCC. In the section of this paper titled Network Capacity Predictions, the analysis based on a nearly 30 year history predicts that by the year 2020 the Internet service tiers offered to consumer will be about 1.5 Gbps downstream and nearly 300 Mbps upstream. In fact, some service providers in the year 2011 were already trialing 1.3 Gbps to 1.5 Gbps downstream and up to 150 Mbps upstream [7].

OVERVIEW OF FIXED WIRELINE TECHNOLOGIES FOR THE MDU

MDUs are making investments to upgrade their access networks to provide higher data network capacity to single-family units (SFUs). The MDU markets are making investments in network infrastructure upgrades addressing the in-building wiring system and the electronics used to enable very high-speed data service. The access network technologies used for the SFUs market are different for cable operators and telcos. In fact, even within the telco industries there are differences in the technologies deployed, namely media (wire) and overall access network architecture. The solutions by cable operators may range from DOCSIS solutions over Hybrid Fiber Coax (HFC) or Radio Frequency over Glass (RFoG) and, in a few corner cases, EPON for residential services. Some telcos may use several DSL technology variants. The DSL network architecture may place the digital subscriber line access multiplexer (DSLAM) in the central office (CO), or DSLAM in the node, or even in the MDU. Other telcos may use several passive optical network (PON) technology variants requiring FTTx to be deployed, and the optical line terminal (OLT) would reside in a CO location or conditioned space typically not more than 20 KM from the end user locations.

This section will review some the media technologies or in-build wiring options for the MDU. The wiring options are a critical component of the data access layer architecture. Additionally, this section will examine the technologies possible across several media types. Although there are many technology options for the delivery of data services in the MDU, this report will seek to highlight some of the leading technologies possible across several media types. This is a forward-looking paper that seeks to ensure the MDU management companies and service providers can make an informed decision for future investment in their MDU network.

This paper will examine technologies that are defined by industry recognized standards organizations; therefore, proprietary solutions will not be examined in this paper. This report will examine technologies from published standards materials and trade publications. It should be noted that some of the technologies have deviated from the standard while not necessarily being out of compliance with the original standard. The material found in this report may not align with the stated standard. In other words, a chip or system supplier may have modified the technology or architecture to improve throughput, distance, support more customers, use a different media/wire type, etc. Every attempt will be made to cite the key information in our analysis. Additionally, the material below may have different data than readers may have seen in published supplier material and press reports. However some of the claims may have assumed a network environment that may not be possible in real-world deployments.

The technologies are changing at a rapid pace and the author encourages the readers to gather updated material from industry publications and system suppliers regarding the current capabilities of these technologies and systems. The technologies reviewed below have been positioned as network access layer options for the MDUs in parts of the world, though some may be garnering more support by certain countries and service providers.

Each of the following sections examines the following:

- Media type / wiring for a given technology
- Overview of the standard and brief background of the technology
- Data network capacity (downstream and upstream)
- Distance between aggregation/access device and the customer devices
- Number of customers per service group
- Spectrum or frequency usage/allocation
- MDU services supported

Note for all data found in the tables in this paper: The Service Tier and Traffic predictions are estimates based on current trending that may not actual be met. The network capacities are just estimates actual wiring conditions will impact throughput. The network capacity estimates may not reach current equipment system performance and future systems may not support estimated throughput. The material in this document is used for discussion purposes only; please consult your system suppliers for actual performance capabilities.

COPPER TWISTED PAIR SOLUTIONS

Copper 'twisted pair' is another term for telephone lines. Copper twisted pair may be used for data, voice, and video services in the MDUs. The use of twisted pair in the MDU network will provide data access to the entire building if the units are within the distance limitation of the selected technology. The main driver for the use of twisted pair is the economic value of using the existing wiring that is in every unit. The use of twisted pair has many dependencies in determining the viability for use for video services and very high bit rate Internet services. The main dependency is distance from the access network device and to the unit. Distance is the single biggest determining factor when determining the viability of using existing phone lines to meet the needs of the MDU or Hospitality markets. Another factor is the condition of the phone lines; this may impair the data signals.

Finally, a factor that will determine the viability of using phone lines will be the number of pairs of phone lines run to each unit. This will also determine the long-term viability for supporting the triple play delivery across the phone network. Most residential single-family units have two pairs of telephone cables to each home. It is unknown how many pairs of twisted pair cable are present at each unit of the MDU market. The major factors affecting the long-term viability of the use of twisted pair cable will be the number of cables per unit, distance between the unit and the termination point (often the basement or wiring closet), and the amount of high speed data and video traffic required to each unit.

VDSL2 Solution

The telecommunications industry has invested resources in the development of many standards utilizing twisted pair over the last two decades. Very-high-bit-rate digital subscriber Line 2 (VDSL2): The International Telecommunication Union (ITU), specifically the ITU-T, has defined a recommendation (standard) for very-high-bit-rate digital subscriber line 2 (VDSL2) for the use over the twisted pair phone lines. The standard was defined with the intention of support “super’ triple play of video, Internet and voice services at speeds up to ten times faster than standard ADSL” according to a press release from the ITU, May 27, 2005 [11].

The VDSL2 protocol is known as ITU-T G.993.2, and was released in February of 2006. The VDSL2 standard builds on previous ITU-T standards in the DSL technology area known as ADSL, ADSL2+, and VDSL. The backwards compatibility of these technologies may be vendor-dependent as some suppliers support what is referred to as ‘fall back’, whereby a particular port VDSL2 port may support ADSL2+.

The capacity of VDLS2 technology varies widely in published reports and vendor materials [4,10,11,12,13,14]. In fact, in one published report, VDSL2 performance was listed at 910 Mbps, 825 Mbps, 700 Mbps, 390 Mbps, and 100 Mbps [14]. In some cases, the published reports of the data throughput rates may omit key factors that may determine the applicability in real-world environment and applications. The variation in the published performance data is because VDSL2 performance, like all DSL technologies, is impacted by distance of copper wires between the DSLAM and CPE. Additionally, the use of channel bonded copper pairs will also increase the throughput numbers stated in published reports. Channel bonding is referred to in many network technology areas, such as VDSL, T1, and DOCSIS. This is the process of combining physical or logical channels to essentially create a larger pipe (data channel) by sending traffic over these channels simultaneously. However, channel bonding more than two copper pairs may not be possible in real-world applications [14].

There are additional technologies that leading systems vendors in the VDSL space are developing to increase capacity as well. An example is called DSL Phantom Mode by Alcatel-Lucent and Phantom DSL by Nokia Siemens, combing several technologies in bonding several copper pairs along with noise cancelling techniques that can increase data rates of VDSL [14].

The capacity data from system and sub-system suppliers may develop and configure systems in ways beyond the published standards transmission data rates of the ITU-T [11]. In a press release from the ITU-T, G.993.2 is stated to support the transmission at a bidirectional net data rate (the sum of upstream and downstream rates) up to 200 Mbit/s on twisted pairs [11].

The analysis will take a more conservative approach in assessing the capacity of VDSL2. We will assume a single twisted pair to each unit and assume that the copper cabling distance between network elements will be not exceed 300-400 meters. We will further assume that the full frequency spectrum of up to 30 MHz is possible. There are several published findings that claim support for 100 Mbps symmetrical over similar distances and assume a single pair of copper wires [10,11,12,13,14].

The MDU designers will need to understand these critically important factors when assessing technologies, including the physical conditions of the network, distances, and the number of twisted pairs to each unit.

VDSL2 Capacity Increase [17]

VDSL2 technology supports several methods to increase capacity. These include:

1. Reducing the local loop (push fiber and the DSL access multiplexer DSLAM closer to the subscribers)
2. Expanding the frequency band
3. Bonding (the use of multiple copper pairs nearly doubling the capacity)
4. VDSL2 vectoring
    a. This is the use of silent suppression or noise cancelling technology using anti-phase signals that are applied to each pair of copper lines in a bundle to remove crosstalk interferers, which reduce capacity.
    b. VDSL2 vectoring enables the bundle of cables nearly a 3X increase in capacity for 24 cables and 400 meters, worst cases studied by Alcatel-Lucent show the low rate of mid-30s Mbps without vectoring and with the low line yielding mid-90 Mbps.

VDSL2 Summary Features Set:

- Spectrum band plan: upstream and downstream band up to 17 & 30 MHz

- Modulation: DMT (up to 15 bits per carrier)
- FEC: Trellis code + Reed Solomon
- Frequency division duplexing (FDD)
- Techniques to increase capacity:
  - Deploy fiber deeper (<2500 often less)
  - Reduce distance from DSLAM and home
  - Enable all spectrum
  - Enable vectoring (noise cancellation) data rate increase ~150%
  - Enable bonding + vectoring data rate increase 100% down & 25% up
- Typical Architecture:
  - Fiber to the node / cabinet (FTTN/C)
  - Serving 300 HHP
  - Ground mounted and plant powered
  - <2500 Meters most often <1000 Meters
  - Distributed access architecture (DAA) only called remote mini-DSLAM

In Figure 1, we assess a possible deployment case of VDSL2 with vectoring and Figure 2 adding pair bonding. The important takeaway is that the max capacity is estimated at 100 Mbps to 200 Mbps downstream and up to 40 Mbps to 50 Mbps upstream at 400 meters in this example [8]. This capacity limit will need to support IPTV and VHSI services.

Network Technology Name	**VDSL2 Vectoring [8]**
Type of Wire/Cabling to the Unit	One Twisted Pair (phone line)
Access Technology	VDSL2 with Vectoring
Duplexing Technology (FDD or TDD)	Frequency Division Duplexing (FDD)
Telephone Service Support	Yes, Voice over IP
Broadcast Analog Video Service Support	No, but supports coexistence
Broadcast Digital Video Service Support	No, but supports coexistence
IPTV Broadcast Digital Video Service Support	Yes, Video over IP
Video On Demand Service Support	Yes, Video over IP
Very High-Speed Data Service Support	Yes
Max Data Network Capacity Downstream rate	100 Mbps (1 Pair)
Max Data Network Capacity Upstream rate	40 Mbps (1 Pair)`
Sum of Downstream and Upstream rates	140 Mbps
In-Building Wiring Coverage Distance:	300 – 400 Meters
Max Number of Customers per Service Group	1 (point to point technology)

Figure 1: VDSL2 Plus Vectoring Estimates for the MDU

Network Technology Name	VDSL2 Bonding and Vectoring [8]
Type of wire/cabling to the unit	Two twisted pair (phone line)
Access technology	VDSL2 with vectoring with pair bonding
Duplexing technology (FDD or TDD)	Frequency division duplexing (FDD)
Telephone service support	Yes, voice over IP
Broadcast analog video service support	No, but supports coexistence
Broadcast digital video service support	No, but supports coexistence
IPTV broadcast digital video service support	Yes, video over IP
Video on demand service support	Yes, video over IP
Very high-speed data service support	Yes
Max data network capacity downstream rate	200 Mbps (2 Pairs)
Max data network capacity upstream rate	50 Mbps (2 Pairs)`
Sum of downstream and upstream rates	250 Mbps
In-building wiring coverage distance:	300 – 400 Meters
Max number of customers per service group	1 (point to point technology)

Figure 2: VDSL2 Bonding Plus Vectoring Estimates for the MDU

G.fast Solution

The latest in copper technology is called G.fast and is intended for deep fiber applications, called fiber-to-the-distribution point (FTTdp) where the distribution point is about 200 meters or less away from the home. The ITU began working on this technology in 2011 and is expected to conclude in 2014. This is an extended frequency approach using 106 MHz and 212 MHz profiles unlike the 30 MHz spectrum limit of VDSL2. G.fast is not intended to replace VDSL2 copper links greater than 250 meters. G.fast speeds promise up to 1 Gbps, but typical speeds may be 150 Mbps for 250 meters [19], 200 Mbps for 200 meters [19] and 500 Mbps for 100 Meters [18, 19]. Capacity will vary on spectrum used and distance.

G.fast Summary Feature Set:

- Spectrum band plan
  - Start frequency: 2.2, 8.5, 17.664, or 30 MHz
  - End frequency: 106 & 2-212 MHz
- Modulation:
  - DMT, 2048 sub-carriers, sub-carrier spacing 51.75 kHz, ≤12 bits/sub-carrier
- FEC: Trellis code + Reed Solomon
- Time division duplexing (TDD)
  - Downstream and upstream capacity shared

- Downstream/upstream asymmetry ratio
  - Mandatory: 90/10 to 50/50
  - Optional: from 50/50 to 10/90
- Delay increased with distance between FTTdp and customer

- Backward compatible with VDSL2
- Coexistence with xDSL
- Techniques to increase capacity:
  - Deploy fiber deeper
  - Reduce distance from G.fast dPU and home
  - Enable full spectrum
  - Enable vectoring and bonding
  - Type of gauge of copper wires
  - Capacity is reported as down + up
- Typical architecture:
  - Fiber to the distribution point (FTTdp)
  - Fiber and G.fast serving 8 – 16 homes
  - Pole mounted (often) or pedestal
  - Reverse power feed from the customer home
  - <250 Meters between FTTdp and home
  - Remote G.fast distribution Point Unit (16 ports)

Summary for Copper Solutions:

Telcos will offer VDSL2 and G.fast in the MDUs, with likely the end-state architecture being G.fast systems since they are expected to support a fall back to VDSL2 to support legacy devices. Also, and most importantly, the distance and speed attainable by G.fast will help drive telcos to this technology for MDUs. The figure below estimates the upstream and downstream data rate measured in Mbps for VDSL2 and G.fast.

	Upstream	Downstream
VDSL2 with Vectoring Single Pair ~ 400 Meters	40	100
VDSL2 with Vectoring + Bonding Single Pair ~ 400 Meters	50	200
G.Fast Single Pair ~ 250 Meters (Downstream & Upstream Ratio 90/10)	15	135
G.Fast Single Pair ~ 200 Meters (Downstream & Upstream Ratio 90/10)	20	180
G.Fast Single Pair ~ 100 Meters (Downstream & Upstream Ratio 90/10)	50	450

Figure 3: Key Estimates and Predictions for VDSL2 and G.FAST for the MDU

COAX-TO-THE-UNIT (CTTU) SOLUTIONS

Coaxial cable, also known as simply ‘coax’, is widely prevalent within MDUs. The wiring conditions will vary, but this cable has not been subjected to the harsh weather conditions of an outside plant network and so the use of this cable may be predictable. The coaxial cable network will have less distance to traverse compared to the outside plant network of a typical cable provider. The cable operator that serves an SFU area may have 6 to 7 miles of coaxial cable comprising the serving area of a node. The distance will result more active equipment such as amplifiers and more passives like taps. However at the MDU location, the number of households passed (HHP) or customers in the service area requires less coax, less actives, and fewer passives. This is of critical importance to the MDU owner and their service provider considering very high bit rate network capacity.

The coaxial cable may use more spectrum than currently used. If the spectrum is extended above 1 GHz it is possible to provide even more data capacity, and 10 Gbps of data capacity is not out of the question. In addition, the mix of spectrum usage can be changed, like the allocation of downstream spectrum and upstream spectrum. In fact, the MDU building, since this is really an isolated network, may elect that the spectrum split change to accommodate higher data rate services for Internet. These changes could be made just to the MDU network and an adjacent MDU building or SFU subdivision may use a different spectrum allocation. This is key: the MDU network may select to allocate spectrum in different ways for their property, perhaps selecting more upstream and downstream spectrum and RF/data capacity. Changing the spectrum split for specific MDU locations could enable very high speed Internet services, perhaps several Gbps downstream and 1 Gbps or more upstream.

DOCSIS network capacity is determined by the frequency or spectrum allocated by the service provider. In a demonstration in 2011, the capabilities of DOCSIS throughput reached 4.5 Gbps downstream and a DOCSIS upstream throughput of 575 Mbps [16]. In a recent live network deployment, cable operator UPC Austria achieved a remarkable sustained maximum downstream Internet speed of 1.3 gigabits per second [15]. The capacity for a single subscriber will be defined by the modem used and high-speed service provided. The use of DOCSIS channel bonding allows the cable operator to offer high data capacity services to subscribers, while also pooling groups of customers to share this infrastructure. This enables subscribers to have very high-speed Internet services (VHSI) and also support IPTV. The capacity of the coaxial network is determined by the service provider and may move to larger or smaller pools of subscribers, depending on the capacity, service, and utilization the MDU desires per segment.

Regarding network capacity, distance does not play a role in DOCSIS, unlike VDSL2. The DOCSIS standards define that the distance between the cable modem termination system (CMTS) and the cable modem customers may reach 100 miles or roughly 160 km. There simply is not a question about the distance area of the MDU wiring network to support a defined data rate.

The DOCSIS standard allocates separate spectrum for upstream and downstream usage; this is known as frequency division duplexing (FDD).

Summary of DOCSIS Releases:

DOCSIS 1.0 March 1997
- Beginning of data over cable system interface specification (DOCSIS)
- Defined support for high-speed data over HFC

DOCSIS 1.1 April 1999
- Adds state of the art QoS techniques for priority services (e.g. VoIP)

DOCSIS 2.0 December 2001
- Increased upstream modulation format for more b/s/Hz
- Adds new physical layer (PHY) for the upstream SCDMA
- Defined a state of the art advanced media access layer (MAC) (even to this day)
- Enabled two (2) dimensional upstream bandwidth allocation and/or simultaneous transmission within the same channel for Quality of Service (QoS) and Quality of Experience (QoE)

DOCSIS 3.0 August 2006
- Added IPv6 & multicast QoS
- Expanded 2D upstream scheduling now across multiple channels
- Increases data capacity with channel bonding similar to other technologies
- Kept PHY layer modulation formats & Old Forward Error Correction (FEC) (DOCSIS 3.0 speed limit)

DOCSIS 3.1 October 2013
- Enables backward compatibility (as opposed to coexistence)
    - Avoids spectrum tax (allocating separate spectrum for legacy and new)
    - Leverage DOCSIS MAC across legacy SC PHY & new Orthogonal Frequency Division Multiplexing (OFDM) PHY
    - Enable SC-QAM and OFDM to share a bonding group
- Data rate capacity increases
    - Enables 10+ Gbps downstream capacity
    - Enables 1+ Gbps upstream capacity
    - The maximum is unbounded (10 – 20 Gb/s or ??)
- Modernize the PHY Layer (to increase bits per Hz)
    - Support legacy DOCSIS PHYs plus
    - Downstream & upstream modulation formats (16384 QAM / 4096 QAM)
    - Adds downstream OFDM (Orthogonal frequency-division multiplexing)
    - Adds upstream OFDMA (Orthogonal frequency-division multiple access)
    - Adds error correction technology
    - Outer FEC: Bose-Chaudhuri-Hocquenghem (BCH) codes

- Inner FEC: Low-density parity-check (LDPC) codes
- The changing of the FEC in DOCSIS 3.1 from DOCSIS may result in:
  - Gain could be up to two modulation orders in the same SNR environment for the ATDMA upstream and EuroDOCSIS downstream annex A
  - Gain could be close to a single order for the DOCSIS J.83 annex B downstream
- Defines new cable spectrum band plan
  - Upstream may extend to 200 MHz (D3.0 defines 5-85 MHz)
  - Downstream may extend to 1.2 GHz or 1.7 GHz (D3.0 defines 1 GHz)

DOCSIS 3.0

The digital video and DOCSIS services deployed by cable operators around the world use an RF technology defined in Recommendation ITU-T J.83 and the four Annexes (Annexes A, B, C, and D). This standard defined the physical (PHY) layer technology used for digital video MPEG-TS and DOCSIS downstream specifications through version 3.0.

The main differences between the ITU-T J.83 annexes are the channel coding and modulation specified, as well as the channel width. The highest order modulation in all versions is 256 QAM. A key attribute of the annexes is the selection of error correction technology. Annex A/C/D defines a single error correction technology called Reed-Solomon. The ITU-T J.83 Annex B uses outer FEC called Reed-Solomon (R-S) and an inner FEC called trellis coded modulation (TCM). The use of trellis coding in J.83 annex B is embedded in the modulation process. The use of an inner and outer FEC means that J.83 annex B is more robust than the annex A/C/D versions. The impact of these differences in FEC means that J.83 annex A/C will require about 2 dB better system performance than J.83 annex B to support the same modulation format and assuming about the same code rate for each.

The upstream RF data technologies are based on CableLabs DOCSIS 2.0 standard called advanced time division multiplex access (A-TDMA) and synchronous code division multiple access (S-CDMA).

DOCSIS capacity is driven by the allocation of spectrum, the CMTS bonding support, the selection of the cable modem bonding support, DOCSIS 3.0 versus DOCSIS 3.1, and the highest order modulations, among other factors. In Figure 4, the capabilities of DOCSIS 3.0 with mid-split are examined and immediately below table 5, defines the assumptions used in the capacity estimate calculations.

Network Technology Name	DOCSIS 3.0 Mid-Split
Type of wire/cabling to the unit	Coax
Telephone service support	Yes, voice over IP
Broadcast analog video service support	Yes, supported over coax
Broadcast digital video service support	Yes, supported over coax
IPTV broadcast digital video service support	Yes, video over IP
Video on demand service support	Yes, video over IP
Very high-speed data service support	Yes
Max data network capacity downstream rate	5660 Mbps (Assuming 108 -1002 MHz downstream at 256 QAM)
Max data network capacity upstream rate	285 Mbps (Assuming 5 - 85 MHz upstream at 64 QAM)
Sum of downstream and upstream rates	5945 Mbps
In-building wiring coverage distance:	Entire building
Max number of customers per service group	1000s and migrate down as bandwidth demands increase

Figure 4: Key Estimates and Predictions for DOCSIS 3.0 for the MDU

HFC - DOCSIS 3.0 Upstream 5-85 MHz and Downstream 108 - 1002 MHz	Upstream	Downstream
Top of Spectrum	85	1002
Bottom of Upstream	5	108
Total Possible	80	894
Minus Unusable	-10	0
Total Usable	70	894
Modulation Order Used	64QAM	256QAM
Bit per MHz Raw	6	8
DOCSIS 3.0 PHY Efficiency	0.678	0.791
PHY Rate b/s/Hz shown in Mbps per MHz	4.066	6.331
Total Usable * Mbps per MHz = Mbps	285	5660

Figure 5: Key Assumptions for DOCSIS 3.0 Mid-Split for the MDU

DOCSIS 3.1

DOCSIS 3.1 systems use a better FEC and multiple modulation profiles (MMP), which enable groups of customers to use the highest order modulation possible. The adoption of very higher modulation formats in DOCSIS 3.1 up to 16384 QAM in the downstream and 4096 QAM in the upstream will increase b/s/Hz of DOCSIS 3.1.

We will assume 4096 QAM will be used in the forward and return path in the MDU network. These networks will have few or no amplifiers and will assume that this will be a fiber-to-the-building implementation. In Figure 6, the capabilities of DOCSIS 3.1 with Mid-split are examined and immediately below table 7, defines the assumptions used in the capacity estimate calculations.

Network Technology Name	DOCSIS 3.1 Mid-Split
Type of wire/cabling to the unit	Coax
Telephone service support	Yes, voice over IP
Broadcast analog video service support	Yes, supported over coax
Broadcast digital video service support	Yes, supported over coax
IPTV broadcast digital video service support	Yes, video over IP
Video on demand service support	Yes, video over IP
Very high-speed data service support	Yes
Max data network capacity downstream rate	8576 Mbps (assuming 108 -1002 MHz downstream at 4096 QAM)
Max data network capacity upstream rate	684 Mbps (assuming 5 - 85 MHz upstream at 4096 QAM)
Sum of downstream and upstream rates	9260 Mbps
In-building wiring coverage distance:	Entire building
Max number of customers per service group	1000s and migrate down as bandwidth demands increase

Figure 6: Key Estimates and Predictions for DOCSIS Spectrum for the MDU

HFC - DOCSIS 3.1 Upstream 5-85 MHz and Downstream 108 - 1002 MHz	Upstream	Downstream
Top of Spectrum	85	1002
Bottom of Upstream	5	108
Total Possible	80	894
Minus Unusable	-10	0
Total Usable	70	894
Modulation Order Used	4K QAM	4K QAM
Bit per MHz Raw	12	12
DOCSIS 3.1 PHY Efficiency	0.815	0.799
PHY Rate b/s/Hz shown in Mbps per MHz	9.775	9.593
Total Usable * Mbps per MHz = Mbps	684	8576

Figure 7: Key Assumptions for DOCSIS 3.1 Mid-Split for the MDU

In Figure 8, the capabilities of DOCSIS 3.1 with extended spectrum used with High-split (5 – 200 MHz) and 1.2 GHz are examined. Figure 9 lists the assumptions used in the capacity estimate calculations in Figure 8.

Network Technology Name	DOCSIS 3.1 High-Split and 1.2 GHz
Type of wire/cabling to the unit	Coax
Telephone service support	Yes, voice over IP
Broadcast analog video service support	Yes, supported over coax
Broadcast digital video service support	Yes, supported over coax
IPTV broadcast digital video service support	Yes, video over IP
Video on demand service support	Yes, video over IP
Very high-speed data service support	Yes
Max data network capacity downstream rate	9036 Mbps (assuming 258 -1200 MHz downstream at 4096 QAM)
Max data network capacity upstream rate	1,808 Mbps (assuming 5 - 200 MHz upstream at 4096 QAM)
Sum of downstream and upstream rates	10,845 Mbps
In-building wiring coverage distance:	Entire building
Max number of customers per service group	1000s and migrate down as bandwidth demands increase

Figure 8: Key Estimates and Predictions for DOCSIS Spectrum for the MDU

HFC - DOCSIS 3.1 Upstream 5-200 MHz and Downstream 258 - 1200 MHz	Upstream	Downstream
Top of Spectrum	200	1200
Bottom of Upstream	5	258
Total Possible	195	942
Minus Unusable	-10	0
Total Usable	185	942
Modulation Order Used	4K QAM	4K QAM
Bit per MHz Raw	12	12
DOCSIS 3.1 PHY Efficiency	0.815	0.799
PHY Rate b/s/Hz shown in Mbps per MHz	9.775	9.593
Total Usable * Mbps per MHz = Mbps	1808	9036

Figure 9: Key Assumptions for DOCSIS 3.1 High-Split for the MDU

Summary for Coax / DOCSIS Solutions:

The use of DOCSIS technology for very high bit rate data service could be a way to save the capital investment and address time to market challenges. If MSOs want to use DOCSIS and existing coax to the unit (CTTU) to offer PON downstream speeds they can leverage DOCSIS 3.0 and eventually DOCSIS 3.1. If the MSOs want to offer PON speeds on the upstream they may consider spectrum split just for the MDU, this is a closed or isolated network and the MSO may have liberty to changes spectrum split and take necessary steps to accommodate a spectrum change, all this without re-wiring the building for PON/RFoG to the unit. The spectrum change will allow PON speeds over coax and also HFC supports all of the current CPE devices and operations including labor force, processes and systems. Many telco providers are leveraging the existing wiring (copper phone lines) but the difference is that Coax and DOCSIS has ability to reach PON data rates.

Perhaps MSOs may take high-bit rate DOCSIS to competitive MDUs and offer data services of 1 Gbps downstream and also consider spectrum splits for high-bit rate upstream just for competitive MDUs before competitors come in and challenge the MSO. Recall, that 30% of the U.S. population and higher in other parts of the world live in MDUs and perhaps some of this market may need to be address with high-bit rate services, DOCSIS and existing coax could be choice.

FIBER-TO-THE-USER (FTTU)

If the MDU considers retrofitting the network, the best choice would be fiber-to-the-unit, also referred to as fiber-to-the-user (FTTU). The use of fiber has many technology choices, some of which are examined in the following section. The selection of fiber over the use of Cat5 cabling is preferred because the distance challenges found with Cat5 Ethernet are not an issue. The advances in fiber cabling have added to the possibilities of fiber solutions for the MDU.

A paper “Next Generation Ruggedized Drop Cable” examines 4.8 mm diameter cable utilizing a bend-insensitive fiber that is designed specifically to withstand the stapling and tight bends expected in MDU installations [9]. That paper also states some challenges found in the MDU environments for retrofitting a building for new cabling. The first problem is creating pathways in areas that are confined and obstructed [9]. Another point cited in that paper is that since no MDUs are the same, the installations and retrofitting are unique, requiring different routing of cabling while minding the bend degree radius limitations [9]. The advances in ruggedized drop cables are targeted for MDU applications. The installers of this cabling still need to conform to the bend radius and cabling securing method, (e.g., stapling), in line with the tolerances of the fiber optic cables [9].

The use of fiber optical cabling to retrofit existing MDUs is still costly [4]. The advances in coaxial cable network technology have provided a longer life and viability for the use of coax as the in-building wiring media [7,8,15,16]. Delaying or avoiding the need to retrofit a building with fiber optic cable to each unit saves MDU investors, owners, service providers, and customer’s time and money without sacrificing services.

If fiber to the unit is available or preferred, consideration could be given to IEEE-based Ethernet passive optical networking (EPON). This is a widely deployed PON technology and PON technology generally has better economics than point-to-point optical solutions. This author has assessed only EPON technology in this paper for MDU applications, though other PON technologies exist, such as RFoG and GPON. The reasoning for the examination of EPON is the scalability to reach 10 Gbps symmetrical, backwards compatibility with earlier versions of EPON, multi-vendor service interoperability, and the cable industry efforts in DPoE (DOCSIS Provisioning of EPON).

EPON and 10G EPON

The IEEE 802.3ah was approved and defined as 1 Gbps EPON with symmetrical 1 Gigabit per second upstream and downstream rates. IEEE 802.3av was approved in 2009 and is known as 10G-EPON. The 10G-EPON standard supports 10 Gbps symmetrical, 10 Gbps downstream and 1 Gbps upstream, as well as 1 Gbps symmetrical for backwards compatibility with the previous standard. The downstream wavelength plan support simultaneous operation of 10G-EPON and 1 Gbit/s on a separate wavelength for operation of IEEE 802.3av and IEEE 802.3ah on the same PON interface concurrently. The upstream channel can support simultaneous operation of IEEE 802.3av (10 G) and IEEE 802.3ah (1 G) simultaneously on a single shared receiver. This backwards compatibility is similar to DOCSIS' history of support early versions concurrently with the latest released version of the standard. This has proven to be widely beneficial to the service provider and consumers alike.

802.3ah EPON

- 1.25 Gbps down x 1.25 Gbps up
- After encoding 1 Gbps
- 1.25G US wavelength US 1310nm ±50 (1260nm to 1360nm) known as wideband G.984.2
- 1.25G US wavelength US 1310nm ±20 (1290nm to 1330nm) known as narrowband as defined by ITU-T G.984.5
    - Narrowband is not defined in the IEEE but used worldwide and same optics as GPON

802.3av 10G EPON

- 10 Gbps down x 1 Gbps up
- 10 Gbps down x 10 Gbps up
- After encoding and FEC 8.7 Gbps
- 10G DS wavelength US 1577.5nm ±2.5 (1575nm to 1580nm)
- 10G US wavelength US 1270nm ±10 (1260nm to 1280nm)
- Backward compatible: Yes, 1G EPON and 10G EPON may share the same OLT Port
- Coexistence: Yes, 1G and 10G EPON can share the same fiber and run as independent MAC domains

Figure 10 estimates the capabilities of use a 10G-EPON Optical Line Terminal (OLT) to serve and MDU.

Network Technology Name	EPON or 10G-EPON
Type of wire/cabling to the unit	Fiber to the user/unit (FTTU)
Telephone service support	Yes, voice over IP
Broadcast analog video service support	No, but supports coexistence
Broadcast digital video service support	No, but supports coexistence
IPTV broadcast digital video service support	Yes, video over IP
Video on demand service support	Yes, video over IP
Very high-speed data service support	Yes
Max data network capacity downstream rate	8.7 Gbps after FEC + overhead
Max data network capacity upstream rate	8.6 Gbps after FEC + overhead
Sum of downstream and upstream rates	20 Gbps
In-building wiring coverage distance:	1 – 2 Kilometers @ 128 Split
Max number of customers per service group	128 or less if desired or conditions require less

Figure 10: Key Estimates and Predictions for 10G-EPON for the MDU

CATEGORY 5 (CAT 5) CABLE SOLUTIONS

The use of Category 5 cable (Cat 5) twisted pair cabling or Cat5e is an option for some MDUs. This is dependent on several factors, primarily when the MDU was built, as buildings may have prewired the unit to support data services. The use of Cat5 cable is also possible for buildings not prewired. However, this can be at considerable costs.

There may be some circumstances where running new cable to the units in the MDU is not economically viable. This is a core reason why technologies that utilize the pre-existing in-building wiring are very compelling to the MDU service providers [4].

A key challenge that remains with Cat5 cabling and Ethernet is the distance factor in the MDU; 100 meters (328 feet) to remain within specifications. The other challenge is the cost to run cable from the units to wiring closets on each floor to solve the distance problem and then cabling from wiring closets to the basement. If the distance challenge is resolved, one of the major drivers to use Cat5 cable with Ethernet is speed, such as 100 Mbps with Fast Ethernet (FE) and 1000 Mbps with Gigabit Ethernet (GbE). As described in the Access Technology section below the use of other cabling options, such as the existing phone lines, including installed coaxial cable, are reaching or exceeding the data rates of FE and VDSL2, as well as GbE (DOCSIS 3.0.) These technologies and others are described in the network technology section below.

This cabling is not present in MDU structures unless that structure was built in recent years, although some retrofitting has occurred. The high-rise high density MDU may find challenges with meeting the 100 meters (328 feet) targets of Fast Ethernet or Gigabit Ethernet to remain within specifications. Garden-style high density MDUs may be an opportunity for Ethernet. The use of Ethernet architecture in fiber to the unit remains viable because distance challenges can be solved. The cost to run new cabling will be an additional challenge as stated above, and advances in coaxial cable solutions may avoid running new cabling altogether.

Fast Ethernet (FE)

The uses of Fast Ethernet (FastE or FE) over Cat5 will have a distance challenge because of the 100-meter connection limitation. In addition, the low bit rate compared to current solutions from xDSL, cable, and Gigabit Ethernet is an additional challenge for FE. Finally, FE is in many ways being superseded in the market place by Gigabit Ethernet (GbE), providing 10 times the data rate.

Gigabit Ethernet (GbE)

The IEEE 802.3 Ethernet standard organization created specifications for Gigabit Ethernet (GbE), specifically called IEEE 802.3ab, for 1000BASE-T Gigabit Ethernet over copper wiring. The network segment can be a maximum length of 100 meters (328 feet) and use all four pairs of copper cable found in Cat5 or higher cable, such as Cat5e and Cat6. The 10 times speed increase over FastE will provide sufficient data capacity. The distance challenge remains for Ethernet solutions over copper cabling and if new cable is desired, running fiber optic cabling will avoid the distance challenge. There are additional technical solutions available.

The use of Fast Ethernet or Gigabit Ethernet over copper (if the building has been pre-wired with spans less than 100 meters) remains viable. If retrofitting a MDU is desired, Cat5e and Ethernet should be avoided because of the distance challenges and fiber cabling advances stated earlier in the paper. Again, as stated earlier the advance in coaxial cable technologies are making the consideration for retrofitting a building a much harder business case.

DOCSIS CM or EPON ONU for Cat5 Use Case

- MSOs could leverage the Cat5 to the Unit
- The Cat5 likely terminates in a wiring closet
- MSOs could leverage existing coax or run new to the wiring closet where DOCSIS 3.0/3.1 modems are located (MSOs could run High-split and 1.2 GHz)
- MSOs could run fiber to wiring closet and use xPON ONUs
- Core benefit: entire back office systems leveraged

SUMMARY NETWORK TECHNOLOGY OPTIONS FOR THE MDU

This section examined several of the possible data networking technologies that may be used in MDU environments. The information contained in the section and throughout this paper may not be the performance of specific products today or in the future. The condition of the MDU network and topology will play a role in actual performance data. Every attempt has been made to accurately assess the capabilities of the technologies, and sources have been cited in many areas of the document. As stated in the paper, some of the information varies widely in published reports, specifications, and supplier material. These deltas in performance figures may represent innovations of some suppliers to reach beyond the capabilities of the specification or the results may be under test conditions, which differ from test conditions used to measure other public findings. This document is meant for high-level thought of the needs and capabilities of the technologies; please consider this a forward-looking document and for discussion purposes only.

The current findings of the report show that coaxial cable has extensive capabilities far and above the capabilities of twisted pair. The capabilities of coaxial cable today may have even more capacity than some fiber to the unit solutions considered. The core takeaway for the MDU is that the existing coaxial cable will meet the needs for this decade and well into the next decade, and perhaps beyond. The assessment of the technologies possible over coax may provide justification to avoid retrofitting and rewiring the MDU. In the examination of the network access layer technologies, DOCSIS should meet the needs for the future, providing ample network capacity and supporting all services over coax either through use of analog video, digital video, and DOCSIS delivered IPTV. The DOCSIS technology allows for very high speed Internet (VHSI) as well as support for IPTV.

The Figures 11 through 14 compiles the material found in the previous sections to allow for a side-by-side comparison of the technology choices that could serve an MDU. Located at the top of each figure defines the technology types. An obvious conclusion as seen in the figures below is that HFC and DOCSIS have far greater capacity than the copper twisted pair solutions, where both would compete to leverage existing MDU wiring. Some MDU service providers are re-wiring buildings with fiber to the unit and utilizing various PON technologies identified in Figure 14 and estimates are based on physical layer (PHY layer) after encoding and forward error correction (FEC) overhead if used and no other overhead is assumed. The great thing for a cable operator is that existing HFC and DOCSIS can compete well against these alternatives while leveraging the existing MDU wiring.

Network Technology Name	VDSL2	G.fast	DOCSIS 3.0	DOCSIS 3.1	DOCSIS 3.1 High-Split	EPON or 10G-EPON
Type of Wire/Cabling to the Unit	1 Twisted Pair (phone line)	1 Twisted Pair (phone line)	Coax	Coax	Coax	Fiber-to-the-User/Unit (FTTU)
Telephone Service Support	Yes, Voice over IP	Yes, Voice over IP	Yes, Voice over IP	Yes, Voice over IP	Yes, Voice over IP	Yes, Voice over IP
Broadcast Analog Video Service Support	No, but supports coexistence	No, but supports coexistence	Yes, Supported over Coax	Yes, Supported over Coax	Yes, Supported over Coax	No, but supports coexistence
Broadcast Digital Video Service Support	No, but supports coexistence	No, but supports coexistence	Yes, Supported over Coax	Yes, Supported over Coax	Yes, Supported over Coax	No, but supports coexistence
IPTV Broadcast Digital Video Service Support	Yes, Video over IP	Yes, Video over IP	Yes, Video over IP	Yes, Video over IP	Yes, Video over IP	Yes, Video over IP
Video On Demand Service Support	Yes, Video over IP	Yes, Video over IP	Yes, Video over IP	Yes, Video over IP	Yes, Video over IP	Yes, Video over IP
Very High-Speed Data Service Support	Yes	Yes	Yes	Yes	Yes	Yes
Max Data Network Capacity Downstream rate	100 Mbps	450 Mbps	5660 Mbps (Assuming 108 -1002 MHz Downstream at 256 QAM)	8576 Mbps (108 -1002 MHz at 4096 QAM)	9036 Mbps (258 -1200 MHz at 4096 QAM)	8.7 Gbps Usable
Max Data Network Capacity Upstream rate	40 Mbps	50 Mbps	285 Mbps (5 - 85 MHz at 64 QAM)	684 Mbps (5 - 85 MHz at 4096 QAM)	1,808 Mbps (5 - 200 MHz at 4096 QAM)	8.6 Gbps Usable
Sum of Downstream and Upstream rates	140 Mbps	500 Mbps (Downstream & Upstream Ratio 90/10)	5945 Mbps	9260 Mbps	10,845 Mbps	17.3 Gbps
In-Building Wiring	300 – 400	100	Entire	Entire	Entire	1 – 2 Kilometers @

Coverage Distance:	Meters	Meters	Building	Building	Building	128 Split
Max Number of Customers per Service Group	1 (point to point technology)	1 (point to point technology)	1000s and migrate down as bandwidth demands increase	1000s and migrate down as bandwidth demands increase	1000s and migrate down as bandwidth demands increase	128 or less if desired or conditions require less

Figure 11: Summary Estimates and Predictions for MDU Access Layer Technologies

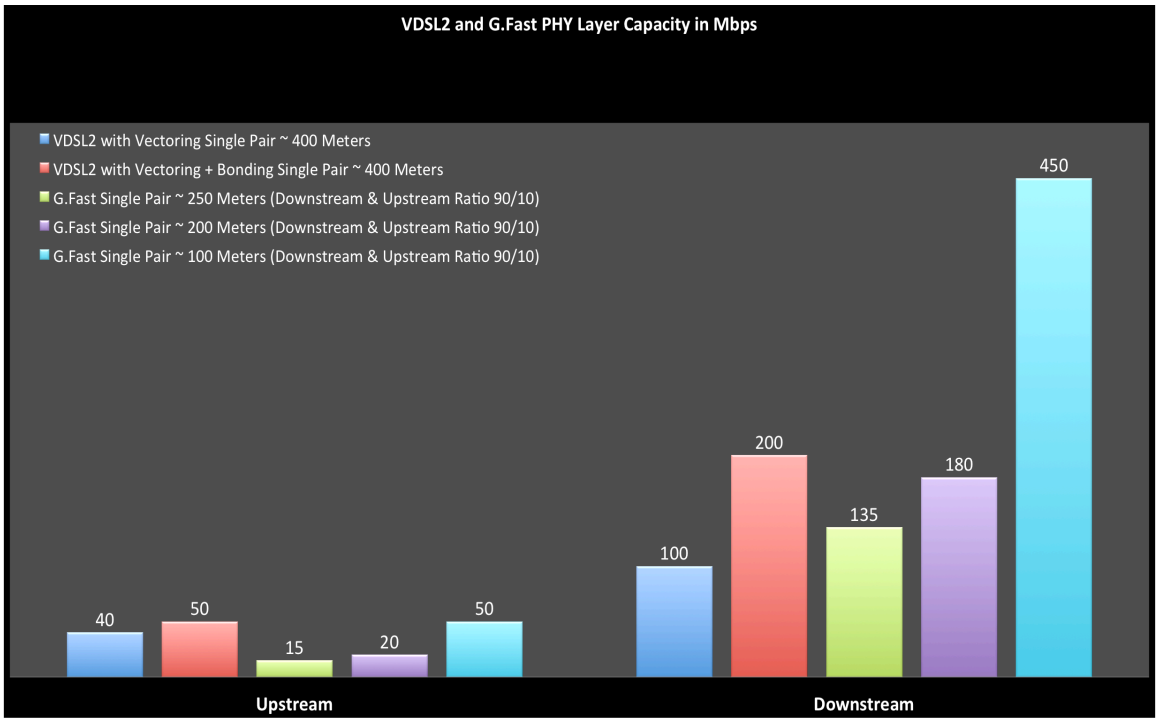

Figure 12: Summary Estimates VDSL2 and G.FAST Access Layer Technologies

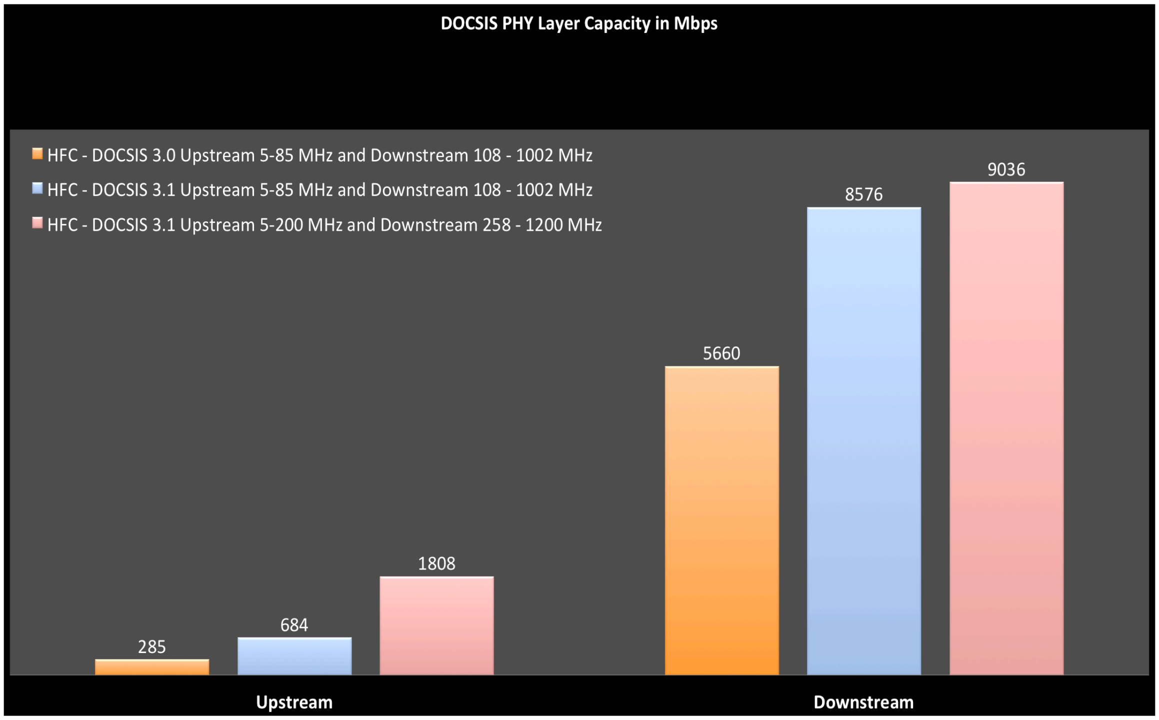

Figure 13: Summary Estimates DOCSIS 3.0 and DOCSIS 3.1 Access Layer Technologies

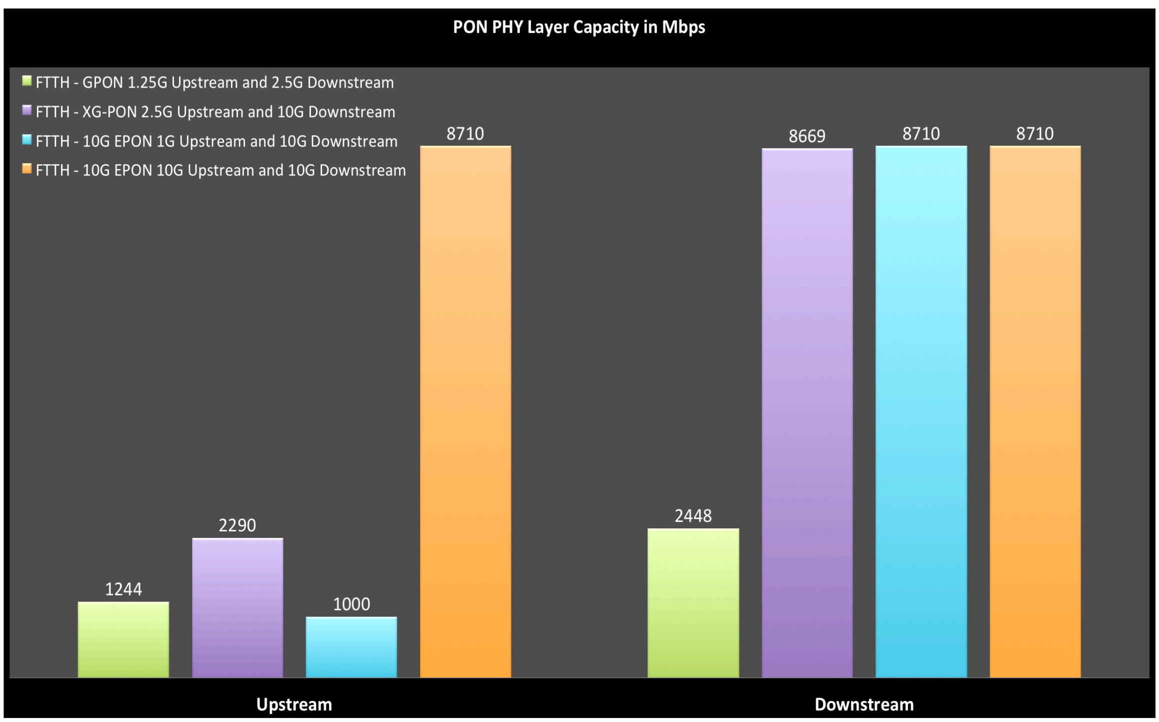

Figure 14: Summary Estimates GPON and EPON Access Layer Technologies

NETWORK ACCESS LAYER ARCHITECTURES OPTIONS (CAA & DAA)

This section compares two (2) types of network access layer architectures, 1) Centralized Access Architecture (CAA) and 2) Distributed Access Architecture (DAA).

Centralized Access Architecture (CAA)
The centralized access layer architecture places the full access layer functions in the headend/hub or the central office facility for the telco. The access layer network element delivers network services to many subscribers and these access layer devices are often intelligent network elements, like DSLAMs, OLTs, CMTS, EQAM, Ethernet switches, etc. In a CAA all of these network elements are located at the service provider facility (headend, hub, CO). In the CAA the outside plant or the MDU location does not contain any intelligent access network elements, until the connection reaches the subscriber location like a home or apartment.

The use of a centralized access architecture is not possible with copper phone line technologies such as VDSL2 and G.fast due to the data rates expected. Thus the telco must place intelligent network access layer systems at the MDU location.

The deployment of fiber-to-the-unit could be served from the CO or headend and the MDUs could be completely passive, but optical budgets and customers served per port will determine if the OLT should be in the CO/headend constituting a CAA or placed at the MDU location constituting a DAA.

As shown in Figure 15, MSOs have a choice for the location of the intelligent access equipment like the CMTS or CCAP. Cable operators may keep all of the intelligence in the CCAP located in the headend and/or primary hub locations as well as the CPEs in the home. These locations would be the sites where complex hardware and software configurable system would be located at the MDU. Figure 15 illustrates three examples of a centralized access architecture using coax-to-the-unit (CTTH) as well as two examples using fiber-to-the-unit (FTTU). In Figure 15, I-CCAP is shown with DOCSIS, Edge QAM, 10G-EPON, and DPoE System functions. Fiber-to-the-building (FTTB) is assumed in this diagram and the terminating device can be placed outside the MDU in a node enclosure or in the basement in a node enclosure, though other form factors are possible. This is shown in a centralized access architecture (CAA) with MAC and PHY functions placed only in the headend and the outside plant and MDU locations are transparent, though two-way monitoring is possible. The CAA enables only the bookends to have complex systems and software for the access layer, thus only at the headend and CPE.

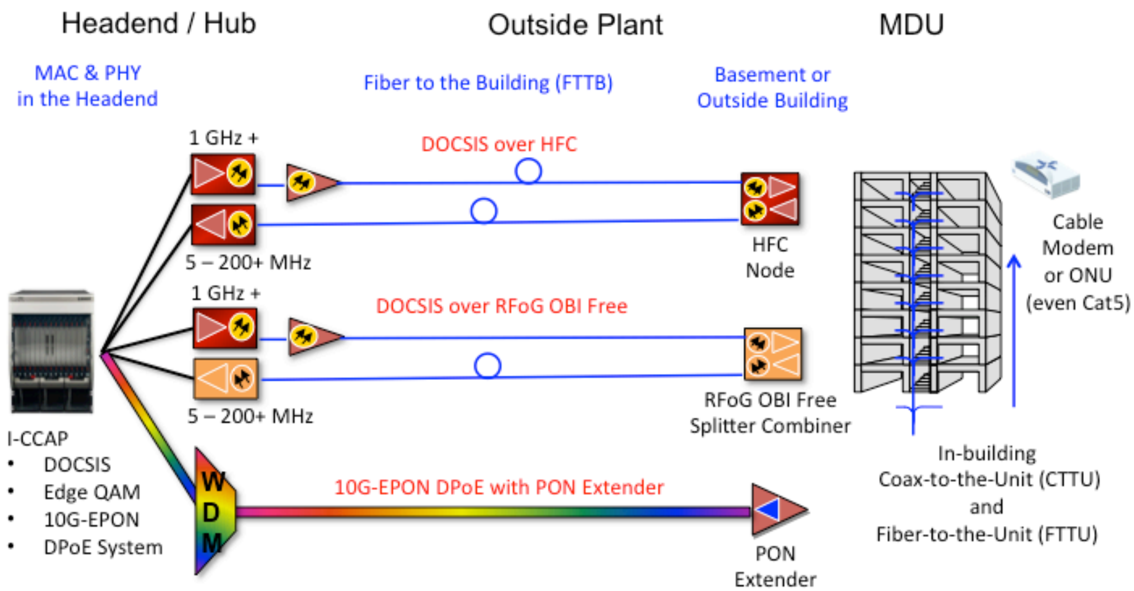

Figure 15: Centralized Access Layer Architecture for MDUS

Distributed Access Architecture (DAA)

Distributed access layer architecture places some, or all, of the access layer functions in locations. Distributed access layer architecture (Figure 16), may be deployed in some MDU and hospitality cases. This places the access layer network element in the node or at the MDU.

The access layer delivers network services to many subscribers, and the access layer devices are often intelligent network elements, like DSLAMs, OLTs, CMTS, EQAM, Ethernet switches, etc. These devices are in the basement or in a wiring closet of the MDU. The telcos, DBS, and MDU service providers that serve the high-density MDUs often use this architecture. It requires fiber-to-the-building and the access layer element in the basement. The main reason is reach. The technologies often selected by telcos and DBS are distance-sensitive, like VDSL2 and G.fast. The telcos, DBS, and MDU service providers must install distributed access architecture whereas the cable operator has a choice of architecture.

In China, some MSOs choose a distributed access architecture placing the CMTS or equivalent functions at the MDU or in a node housing outside of a group of MDUs. In Figure 16 this is referred to as a remote network gateway / node. Distributed access layer architecture may be selected if the two-way HFC plant does not exist or if this is a desire by the MSO to remote the CMTS/CCAP functions to the MDU.

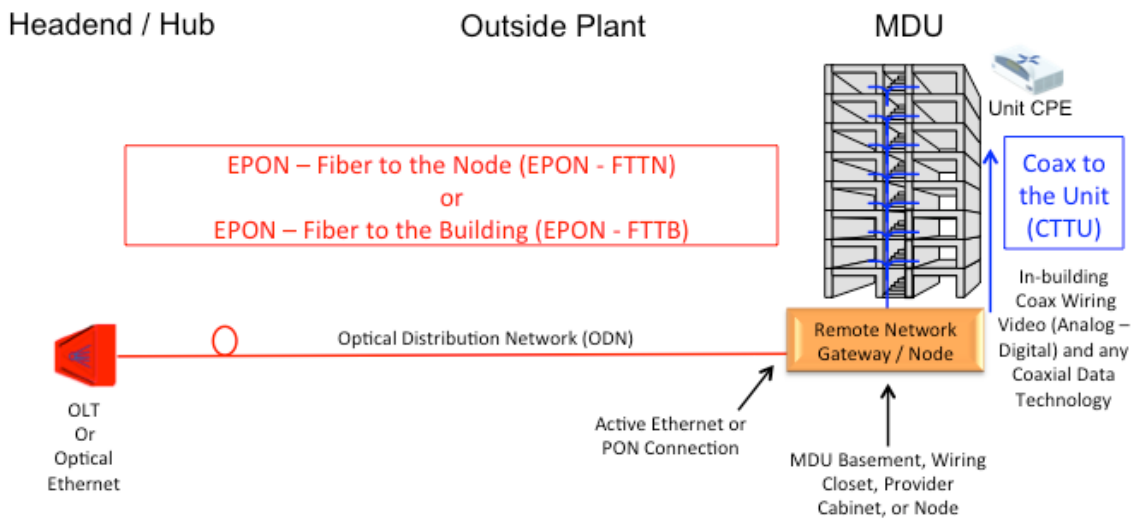

Figure 16: Distributed Access Layer Architecture for MDUS

As stated previously, the telco, DBS, and MDU service provider must deploy a DAA architecture whereas the MSO has a choice. The MSO has an advantage as they may choose either architecture or a mix of both. The MSO may elect to deploy FTTB and keep the access layer elements in the headend. The fiber connection to the building allows isolated capacity to meet future needs and have the flexibility to move access network elements to the MDU, when or if desired.

Summary of Centralized Access Architectures

1. Enabling a centralized access layer increases economies of scale, reliability of systems and just in time investment in capacity
2. Centralized access layer architectures use HFC optical architecture
3. HFC optical transport enables transparency, flexibility, versatility, and simultaneous support of legacy and new MAC/PHY technologies remains a core benefit and value of HFC
4. Centralized access layer requires HFC optical transport to and from the node or MDU location, this means that changes in capacity of the data network could be made only at the headend, with the increase of data spectrum allocation
5. Fiber-to-the-building and few or no amplifiers will likely yield the support of very high order modulation when the MSO deploys DOCSIS 3.1
6. VDSL2 and G.fast cannot use a CAA, they must deploy the access device at the MDU
7. FTTU with RFoG, GPON, or EPON could be deployed using CAA, this may impact the number of subscribers supported per PON and per MDU if the OLT is centralized

8. CTTU using DOCSIS may use a CAA without impacting performance and this architecture has proven valuable to MSOs, with the intelligence devices only at the bookends (headend – CMTS and the home/unit the CM/EMTA/STB)

Summary of Distributed Access Architectures

1. For cable operators, the distributed access layer architectures place the CMTS MAC/PHY or PHY intelligence in the fiber node or MDU location. This may impact reliability of the system in terms of mean time to repair (MTTR) and overall failure rates for systems
2. The telco must deploy a DAA for VDSL2 and G.fast (they have no choice)
3. FTTU use of PON will likely use a DAA in large MDU complex due to the number of subscribers supported per PON port 64 – 128 among other factors

OPERATIONS ADMINISTRATION MAINTENANCE AND PROVISIONING (OAM&P)

The technologies under examination use different platforms for providing OAM&P. The cable industry has built systems using standards for provisioning, network management, network accounting, and the ability to interface with network management system platforms in the MSO's network operations center (NOC). The MDU network requires a carrier class network and OAM&P infrastructure to enable next generation services. The network, as shown in Figure 15, could have addressable devices from the headend CMTS and Edge QAM, MDU node, and the CPE in the MDU while all being remotely monitored. The DOCSIS technology was designed from the beginning as a coaxial-based network access platform over an outside plant network. The use of RFoG with DOCSIS and/or EPON also leverages the MSO existing back office systems.

CONCLUSIONS

Similar to the cable and telco networks that serve single-family residences, the MDU market is making network upgrade investments. A key conclusion is that HFC and DOCSIS have far greater capacity than the copper twisted pair solutions, where both would compete to leverage existing MDU wiring. Some MDU service providers are re-wiring buildings with fiber to the unit and utilizing various PON technologies. The great thing for a cable operator is that existing HFC and DOCSIS can compete well against these alternatives while leveraging the existing MDU wiring. The MDU and hospitality markets may be able to leverage the existing in-building coaxial network to each unit while supporting all the services and network capacity forecasted for the next decade and beyond. The deployment of DOCSIS technology in the MDU will provide several core benefits to MDU service provider and end-users. The MSOs may use DOCSIS as their technology over coax but in some MDU applications fiber-to-the-unit (FTTU) may be required. If MSOs use DOCSIS they may use two network architectures as shown in Figures 15 and 16.

The use of DOCSIS CMTSs at the MSO headend or hub site to an HFC node at the MDU will provide a fiber optic feed to the building providing the network capacity to meet the needs of the future. This is referred to as the centralized DOCSIS architecture over HFC and will enable the MSO facility and the end-user customer location to have the intelligent data equipment. This centralized DOCSIS CMTS architecture over HFC is how the MSO provides services to their customers today.

As described in this paper, distributed access architectures may be used by cable operators as an option and likely used only if they must. Otherwise the MSO may keep all of the intelligence in their facility and the optical and coax network transparent with the only configurable devices being the CPE. Telco, DBS, and MDU service providers must use a distributed access architecture. They simply have no choice.

Conclusions and recommendations

- **1 Gbps Services**
    - Consider using DOCSIS to address competitive markets before your competition
    - DOCSIS can deliverer high-bit rate over existing coax in the building
    - Copper technologies like VDSL2 and G.fast can't reach the DOCSIS data rates
    - Coax can deliver video services using different spectrum
    - Coax has more capacity than copper lines
    - Coax can reach the capacity of PON technologies

- **Achieving Customer Requirements:**
    - If Coax-to-the-unit (CTTU) is acceptable, support triple play services
    - DOCSIS can offer PON like speed and grow to full PON capabilities

- **Keeping Costs Low:** The MDU may avoid the unnecessary spending for new cabling like CAT5 or fiber-to-the-user (FTTU), while not sacrificing capacity or performance. Additionally, DOCSIS CPE may be purchased at retail at competitive prices. The home network does not require a home gateway per unit. DOCSIS is designed for high subscriber counts and every outlet in the MDU could support a DOCSIS cable modem or set-top box.

- **Scalability and Long Term Viability:** MDU owners will have a scalable network that may reach multi-gigabit downstream and gigabit upstream speeds over time; in fact this may offer more capacity than any other coaxial or twisted pair solution. The use of coax and DOCSIS does not have distance challenges as found in other technologies; this can easily serve any MDU. Since DOCSIS can expand the capacity of the network, it may grow higher downstream capacity and 1 Gbps or more of upstream capacity. DOCSIS may be deployed as a pay-as-you-grow architecture, meaning that when additional network capacity is needed it may be deployed. DOCSIS may coexist with existing video services. The MDU market may not require home gateway architecture for service because DOCSIS services may be used at every outlet in the MDU.

- **OAM&P:** The term Operations, Administration, Maintenance, and Provisioning (OAM&P) has been adopted by the cable industry. The DOCSIS standards are more than merely network specifications. The DOCSIS standards define service provisioning, network accounting and network management system requirements. Since DOCSIS is a mature network access technology used to support critical lifeline services, the industry has invested in OAM&P. There are many DOCSIS network elements: provisioning systems, accounting systems, and network management systems that enable service providers' network operations centers to deliver carrier class services to customers. DOCSIS is not a home networking technology that has evolved to serve as an access layer technology; DOCSIS is designed as a carrier class access layer technology over coax designed to support 1000s of subscribers per network domain. DOCSIS provisioning and back office systems scale to support millions of user accounts as well as the provisioning of different service types and profiles.

RELATED READINGS

- PAPER: A Technical Migration Plan for the Evolution to DOCSIS 3.1
- PAPER: Predictions on the Evolution of Access Networks to the Year 2030 & Beyond

MEET ONE OF OUR EXPERTS: Mike Emmendorfer

Mike Emmendorfer serves as Senior Director, Systems Engineering and Architecture, in the Office of the CTO at ARRIS. In this role, he is responsible for forward-looking architecture and strategy to determine the viability of new products and technologies. Projects have included DOCSIS enhancements, EPOC, EPON, Metro Ethernet Forum, Wireless, RFoG, Remote Access Architectures, and IPTV. Recently, Mike was lead author in a series of ARRIS publications, presented at numerous conferences spanning the globe during 2011 and 2012 that defined the next generation of DOCSIS, which later became DOCSIS 3.1. The final release of the “Next Generation – Cable Access Network (NG–CAN)” series of papers and publications in February 2012 defined the core features set for what later become DOCSIS 3.1. Later, in May 2012 for the NCTA – Cable Show, Mike teamed up with technical leaders from Cisco, Intel, and Motorola to co-author “Mission is Possible: An Evolutionary Approach to Gigabit-Class DOCSIS”, and it was this joint paper that launched DOCSIS 3.1. Mike holds a Bachelor of Science degree in Management Information Systems from Saint Louis University.

REFERENCES

1) TMG Legal, Court Upholds FCC Order Prohibiting Cable-MDU Exclusivity Agreements, June 3, 2009 http://tmglegal.com/_pdfs/Client%20Alert%20%20Cable%20MDU%20Exclusivity%20Prohibition.pdf

2) Paul Weiss, Court Affirms FCC Ban On Exclusive MDU Contracts, May 29, 2009 http://www.paulweiss.com/files/Publication/bb37b4df-a267-4904-990a-0a35f25ddb09/Presentation/PublicationAttachment/f296dd72-99c3-495a-b3a0-0d78de7835e8/CTD-5-29-09L.pdf

3) FierceTelecom, DIRECTV, Alcatel-Lucent jointly target the MDU service opportunity April 29, 2010, Sean Buckley http://www.fiercetelecom.com/story/directv-alcatel-lucent-jointly-target-mdu-service-opportunity/2010-04-29#ixzz0mXBNHfUm

4) Connected Planet, OFC: Verizon details plans to bring fiber to larger MDUs, February 27, 2008. http://connectedplanetonline.com/fttp/news/verizon-fiber-mdus-0227/

5) FCC, SIXTH BROADBAND DEPLOYMENT REPORT, July 20, 2010 http://transition.fcc.gov/Daily_Releases/Daily_Business/2010/db0720/FCC-10-129A1.pdf

6) FCC, Federal Communications Commission National Broadband Plan, America's Plan Chapter 2, Goal No 1 http://www.broadband.gov/plan/

7) Communications Technology, "Virgin Media Trials 1.5 Gbps Broadband", April 21, 2011

8) The Magic Number … 100 Mbps? VDSL2 Vectoring Delivers On Its Promise by: S. Vanhastel, J. Verlinden, P. Spruyt, B. Orr, C. Treleaven OSP Magazine http://www.ospmag.com/issue/article/The-Magic-Number-100-Mbps

9) Next Generation Ruggedized Drop Cable International Wire & Cable Symposium, Proceedings of the 56th IWCS http://ecadigitallibrary.com/pdf/IWCS07/10_6fd4.pdf

10) Wikipedia, the free encyclopedia Digital Subscriber Line http://en.wikipedia.org/wiki/Digital_Subscriber_Line

11) ITU-T Rec. G.993.2 (02/2006), Very high speed digital subscriber line transceivers 2 (VDSL2), page 1

12) Infineon, Future Proof Telecommunications Networks with VDSL2; http://www.netsys.com.tw/support/download/VDSL2_WP.pdf

13) Zyxel, Leveraging Copper & Transitioning to Fiber http://www.us.zyxel.com/creative/tailormade/Leveraging_Copper-Transitioning_to_Fiber-ZyXEL_solution-paper.pdf

14) PC Magazine, Vendors closing in on 1Gbps using DSL, 26 October 2010, http://www.pcworld.idg.com.au/article/365686/vendors_closing_1gbps_using_dsl/

15) BTR Broadband Technology Report, "UPC Hits 1.3 Gbps with ARRIS D3 Gear" September 7, 2011; http://broadbandgear.net/2011/09/upc-hits-1-3-gbps-with-arris-d3-gear/

16) Broadband DSL Reports.com, "Cable Broadband at 4.5 Gbps Arris Pushes DOCSIS 3.0 Even Further" June 13, 2011; http://www.dslreports.com/shownews/Cable-Broadband-at-45-Gbps-114677

17) Get to Fast, Faster, Accelerate the existing Copper Plant with VDSL 2 VECTORING and BONDING, Strategic White Paper http://www.alcatel-lucent.com/wps/DocumentStreamerServlet?LMSG_CABINET=Docs_and_Resource_Ctr&LMSG_CONTENT_FILE=White_Papers/Get_to_Fast_Faster_EN_StraWhitePaper.pdf

18) G.fast – Shifting the limits of copper, Bell Labs, Alcatel-Lucent - Jochen Maes 19 January, 2012 @ UKNOF http://www.uknof.org.uk/uknof21/Maes-Gfast.pdf

19) Brown, Les (2012-09-22). "G.fast for FTTdp". Joint ITU/IEEE Workshop on Ethernet - Emerging Applications and Technologies. ITU-T / IEEE. Retrieved 2014-02-14. http://www.itu.int/dms_pub/itu-t/oth/06/5B/T065B0000320009PPTE.ppt

ABBREVIATIONS & ACRONYMS

CAT5	Category 5 cable
CMTS	Cable Modem Termination System
CTTU	Coax-to-the-Unit
DBS	Digital Broadcast System
DOCSIS	Data-Over Cable Service Interface Specifications
DS	Downstream
DTA	Digital Terminal Adapter
EPON	Ethernet Passive Optical Network
FCC	Federal Communications Commission
FTTB	Fiber-to-the-Building/Business
FTTC	Fiber-to-the-Curb
FTTH	Fiber-to-the-Home
FTTN	Fiber-to-the-Node
FTTP	Fiber-to-the-Premise
FTTU	Fiber-to-the-User
Gbps	Gigabits per Second
GPON	Gigabit PON
HFC	Hybrid Fiber Coax
HHP	Households Passed
HSD	High Speed Data
HSI	High-speed Internet
IP	Internet Protocol
IPTV	Internet Protocol TV (video) over IP networks
MAC	Media Access Layer
Mbps	Megabit per Second
MDU	Multiple Dwelling Unit
MoCA	Multimedia over Coax Alliance
MSO	Multiple System Operator
NOC	Network Operations Center
OFDM	Orthogonal Frequency Division Multiplexing
OTT	Over-the-Top
P2P	Peer-to-peer
PHY	Physical Layer
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
RFoG	RF Over Glass
US	Upstream
VHSI	Very High-speed Internet
VDSL	Very High Bitrate DSL

VDSL2	Very High Bitrate DSL2
VoD	Video-on-Demand