A First Look at Modeling EPoC on Cable

24 January 2012

Andy Boyce, Broadcom

Mark Laubach, Broadcom

"Up To" Speed Requirements

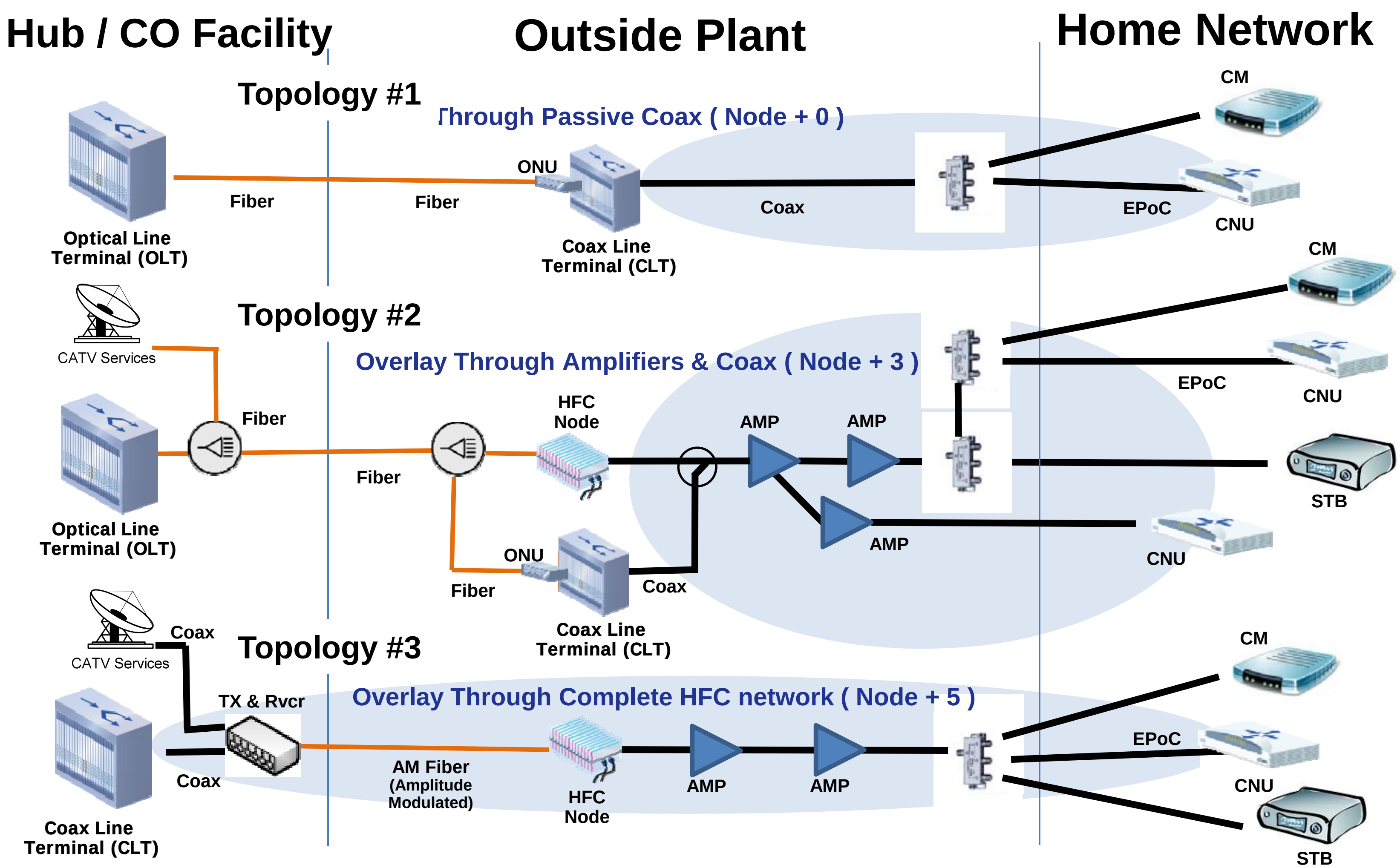
- "Proposed scope of study:

A new PHY for operating the EPON protocol over Coaxial Distribution Networks ("EPoC")

  - Up to 10 Gbps downstream / Up to 10 Gbps upstream
    - Support symmetric and asymmetric full-duplex deployments"
- Study Group Determination should be based on:
  - Cable Operator requirements for the four different topologies:
    1. "Passive", Node + 0
    2. Node + N (where N = 1 to ?)
    3. In amplified band, HFC
    4. In-building MxU
  - Ability to implement
  - Relative cost of CNU (reasonable cost for performance)

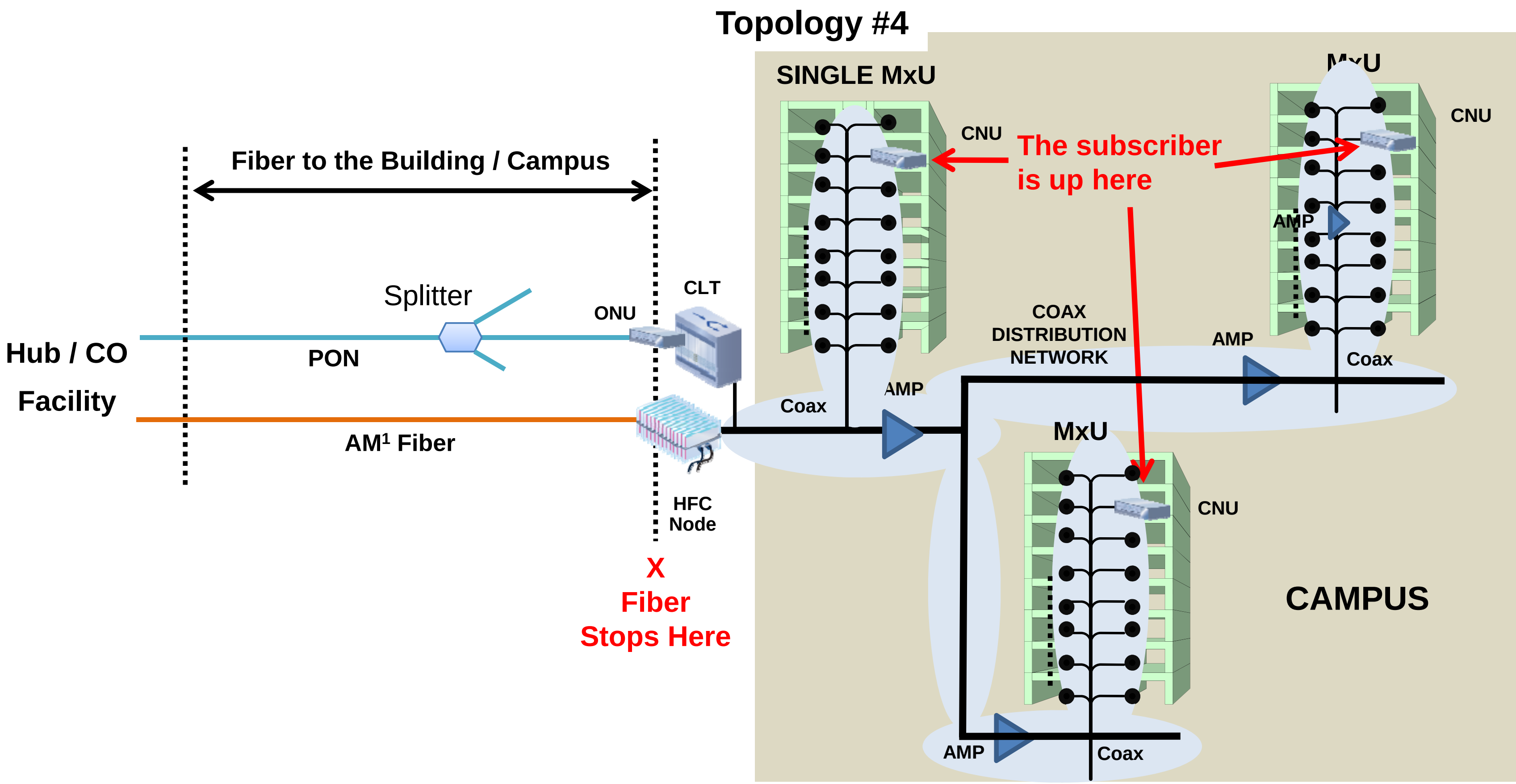
Review: 1. Considering common coaxial cable topologies and architectures

MSO Deployment Options over Coax



Review: The MxU Fiber – Coax Gap

- Fiber stops outside the building / campus, remainder of run is coaxial cable



[1]Amplitude Modulated

“Up To” Speed Requirements

Study Group:

- What “up to” rates are plausible for the Task Force to work on?
  - Our “sandbox” study is up to 10Gbps each direction
  - But what is needed, practical, and implementable?
  - Will there be any options are in the standard?
- Common model for discussing the issues?

Determining "Up To"

	DOWNSTREAM UP to X Gbps										
UPSTREAM UP to X Gbps		1	2	3	4	5	6	7	8	9	10
	1	P									
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	9										
	10										

Working hypothesis: **P** = To be viewed as successful, the EPoC effort produces a draft standard that includes a minimum of least "up to" 1Gbps in downstream and upstream and meets or exceeds worldwide cable industry requirements

A method:

- Examine and fill in the matrix as guidance to the Task Force:
  - – Indicate which downstream and upstream combinations are plausible = P
- Review / examine / consider for each topology:
  - Stated requirements from industry
  - At some min and max distance for each topology
  - Ability to implement
  - At what reasonable relative CNU cost
    - Relative to
      - – EPON ONU
      - – DOCSIS CM

Study Group Contributions

- While we don't know the specific mathematics that will be selected by the Task Force, we can generalize
- Digital modulations approximately share the same characteristics:
  - Power spectral density (spectrum used and power)
  - Signal-to-Noise-Room (SNR)
  - Modulation rate (bits per second per Hz)
- Permits plausibility studies

NOTE: this presentation is an informal study – it is not proposing a formal model, but an illustrative example and call for contribution

An informal look at all Plain Coax

STUDY 1

Study Exercise

- At different lengths of industry standard drop cable in an all passive configuration:
  - Example: passive cabling past last amplifier
  - Cable distance loss only, no tap or splitter losses considered
  - CommScope Series 59, 6, and 11
- Include analog TV and digital channel noise floor contribution
- Describe setup assumptions and configuration
- Per drop cable type and for 100m, 200m, and 300m distances:
  - Compare 1Gbps plausibility based on signal to noise budget for the downstream and upstream
    - Examine bottom and top edges of spectral bandwidth
  - Enumerate impact on different modulation rates

Why All Passive Drop Cable?

- Initial look at “one cable type” all passive scenario
- Drop Cable is commonly used in two places
  - Cable operator network: between tap and subscriber
  - In MxU wiring
- Other cable types (e.g. trunk, feeder) just get better performance

- Future All Passive Studies
  - Mixtures of trunk/feeder and drop cables
  - Include tap and splitter losses, etc.

Modulation SNR

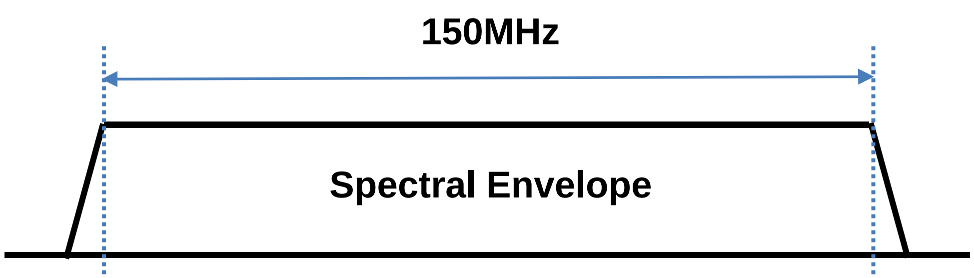
- Assumption:
  - QAM, OFDM, and PAM based modulation required approximately the same minimum SNR to achieve the same modulation rate
    - e.g. for 10^{-10} BER (no FEC)

Type	QPSK	16 QAM	64 QAM	256 QAM	1024 QAM	4096 QAM
Modulation Rate bits / sec / Hz	2	4	6	8	10	12
Typical SNR dB	17	23	20	35	41	47

Spectral Bandwidth Base Model

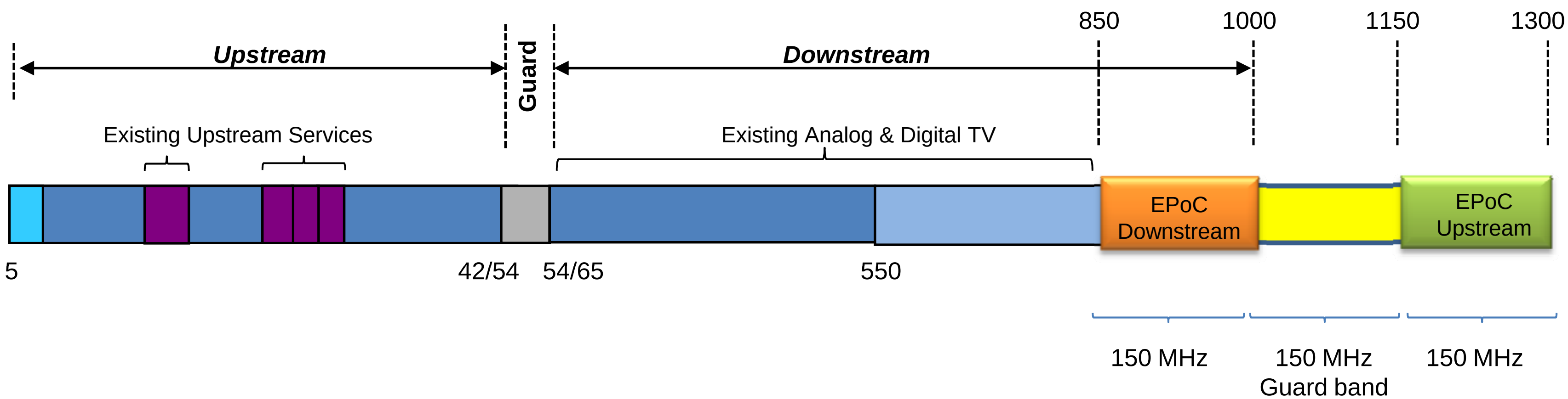
Spectrum Use Assumptions:

- All QAM, OFDM, SDM, etc all are sufficiently similar for this study in spectral envelope and in peak-to-average operation
- EPON 1 Gbps MAC data rate with 20% overhead (FCS, framing, etc.)
- Average 8 bits / second / Hz modulation density (same as 256 QAM)
- 1,200,000,000 bps / (8 bps/Hz) = 150MHz



EPoC Provisioning

- Downstream 850 MHz to 1000 MHz
  - Other cable operator services are below 850MHz
- Upstream 1150 MHz to 1300 MHz
- Guard band from 1000 MHz to 1150 MHz



Electrical Assumptions

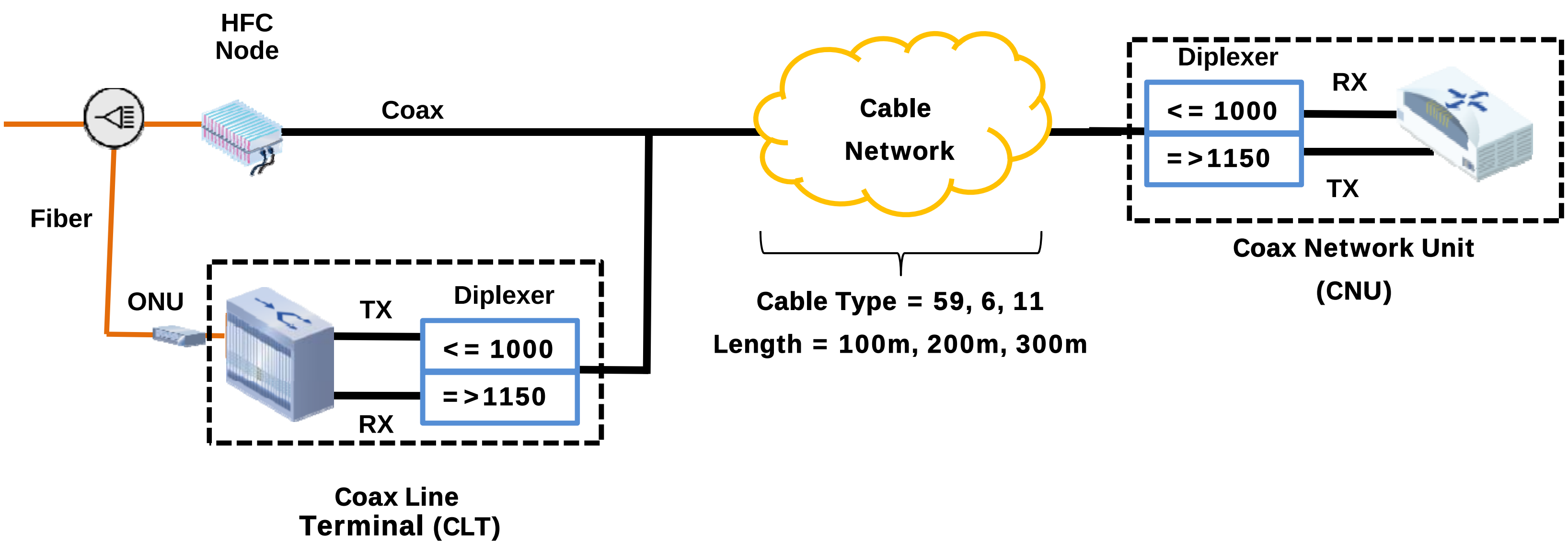
- Interested in transmitter power downstream and upstream
  - CLT TX / RX (example, similar ranges for DOCSIS)
    - Transmitter power max : +61 dBmV / 150 MHz
    - Receiver range 30 dB; e.g. -13 dBmV to +17 dBmV
  - CNU TX / RX (example, similar ranges for DOCSIS)
    - Transmitter power: from ~17 dBmV to ~61 dBmV / 150 MHz
    - Receiver range 30 dB; e.g. -15 dBmV to +15 dBmV
- Operating Assumptions
  - Thermal noise floor in coaxial cable plant: -174 dBm / Hz
  - Typical receiver noise 4 dBm / Hz

Noise Sources

- Downstream Receiver “sees”
  - Analog TV channels
  - Digital channels
  - EPoC TX signal
  - EPoC TX noise
- Upstream Receiver “sees”
  - EPoC TX signal
  - EPoC TX noise

Downstream vs Upstream Positioning

- Downstream is in the amplified pass band under 1000 MHz
  - EPoC + Analog TV channels + Digital channel
- Diplexer separates downstream and upstream
  - Assumed internal to CLT and CNU, not considering losses
- Assume EPoC only service in upstream direction



CommScope®[1] 59, 6 and 11 Drop Cable

Frequency (MHz)	Maximum Attenuation db/100m 20°C		
	59 Series	6 series	11 series
5	2.82	1.90	1.25
55	6.73	5.25	3.15
83	8.04	6.40	3.87
187	11.81	9.35	5.74
211	12.47	10.00	6.23
250	13.45	10.82	6.72
300	14.60	11.64	7.38
350	15.75	12.63	7.94
400	16.73	13.61	8.53
450	17.72	14.43	9.02
500	18.70	15.29	9.51
550	19.52	16.08	9.97
600	20.34	16.73	10.43
750	22.87	18.54	11.97
865	24.67	20.01	13.05
1000	26.64	21.49	14.27

[1] www.commscope.com Drop Cable Products Product Catalog

CommScope® 59, 6 and 11 Drop Cable

- Approximating beyond 1000MHz
  - Table stops at 1000MHz, approximate loss using formulae based on 1000MHz

6.4 Cable Loss vs. Frequency

If you know the cable loss at a given frequency, you can calculate the loss at a desired frequency using the following formula:

$$L_{F_2} = L_{F_1}\sqrt{\frac{F_2}{F_1}}$$

where:

L_{F_2} = Loss at the desired frequency (dB)

L_{F_1} = Loss at the known frequency (dB)

F_2 = Desired frequency (MHz)

F_1 = Known frequency (MHz)

Frequency (MHz)	Maximum Attenuation db/100m 20^{o}C		
	59 Series	6 series	11 series
850	24.3	19.7	12.7
1000	26.64	21.49	14.27
1150	28.6	23.0	15.3
1300	30.4	24.5	16.3
1400	31.5	25.4	16.9
1600	33.7	27.2	18.1
2400	41.3	33.3	22.1
2800	44.6	36.0	23.9
3000	46.1	37.2	24.7

General Cable Plant Noise Formula

	Parameter	Value	Units	
Out Of Channel Noise In a Cable Network	QAM 6MHz Channel Power	56	dBmV	
	QAM Broadband Noise Ratio	73	dBc	
	QAM Noise Power 6 MHz	2.7E-07	mW	
	Analog 6MHz Channel Power	61	dBmV	
	Analog Noise Radio	73	dBc	
	Analog Noise Power 6 MHz	8.4E-07	mW	
In Channel Noise	EPoC Signal Level	61	dBmV	
	EPoC SNR	60	dBc	
	EPoC BW MHz	150	MHz	
	EPoC inband Noise Power	1.7E-05	mW	
	QAM Channels	52	channels	
	Analog TV Channels	72	channels	
	Total Noise	-40.4	dBm/6MHz	$10*Log_{10}$(Sum of mW)
	Total Noise Hz	-108.2	dBm/Hz	
	Thermal Noise Floor (with 4dB receiver noise)	-170.0	dBm/Hz	
	Cable Plant Noise above Thermal Noise Floor	65.8	dB	

General Margin Survey based on dBm / Hz

Step	Value
Transmitter Output over 150MHz bandwidth	61 dBmV
Convert to dBm	-48.75 dB
Convert to dBm / Hz (10*LOG_{10} (150MHz)	-81.76 dB
Subtotal	-69.51 dBm / Hz
Subtract cable loss at survey frequency for cable type for distance	-L.L dB
Compare to Noise Floor or Thermal Floor, whichever is greater	± N.N dBm / Hz
EPoC SNR	± M.M dBm / Hz
For each modulation type, is EPoC SNR – Modulation SNR > 6dB	Plausible
For each modulation type, is 6dB > EPoC SNR – Modulation SNR > 0	Marginal
For each modulation type, is EPoC SNR – Modulation SNR < 0	No

Study 1 Question #1

- Can EPoC deliver 1Gbps symmetric EPON MAC data rate over common types of all passive drop cable up to 300m?
  - Assume the following cable operator provisioning:
    - EPoC downstream 850 MHz to 1000 MHz
    - EPoC upstream 1150 MHz to 1300 MHz
    - Fully loaded mix of analog TV and digital programming
    - EPoC TX electrical outputs “similar” to DOCSIS

Study 1 Q1: 850 MHz and 1000 MHz

	(EPoC SNR – Modulation Rate SNR) @ 850 MHz																	
	Series 59						Series 6						Series 11					
Rate (bps/Hz)	2	4	6	8	10	12	2	4	6	8	10	12	2	4	6	8	10	12
100m	21.7	15.7	9.7	3.7	-2.3	-8.3	21.7	15.7	9.7	3.7	-2.3	-8.3	21.7	15.7	9.7	3.7	-2.3	-8.3
200m	21.5	15.5	9.5	3.5	-2.5	-8.5	21.6	15.6	9.6	3.6	-2.4	-8.4	21.7	15.7	9.7	3.7	-2.3	-8.3
300m	10.4	4.4	-1.6	-7.6	-13.6	-19.6	19.8	13.8	7.8	1.8	-4.2	-10.2	21.7	15.7	9.7	3.7	-2.3	-8.3

	(EPoC SNR – Modulation Rate SNR) @ 1000 MHz																	
	Series 59						Series 6						Series 11					
Rate (bps/Hz)	2	4	6	8	10	12	2	4	6	8	10	12	2	4	6	8	10	12
100m	21.7	15.7	9.7	3.7	-2.3	-8.3	21.7	15.7	9.7	3.7	-2.3	-8.3	21.7	15.7	9.7	3.7	-2.3	-8.3
200m	21.1	15.1	9.1	3.1	-2.9	-8.9	21.6	15.6	9.6	3.6	-2.4	-8.4	21.7	15.7	9.7	3.7	-2.3	-8.3
300m	3.6	-2.4	-8.4	-14.4	-20.4	-26.4	17.1	11.1	5.1	-0.9	-6.9	-12.9	21.6	15.6	9.6	3.6	-2.4	-8.4

Color Legend: Plausible >= 6 dB, Marginal (TF FEC) 0 < Margin < 6 dB, NO < 0

Study 1 Q1: 1150 MHz and 1300 MHz

	(EPoC SNR – Modulation Rate SNR) @ 1150 MHz																	
	Series 59						Series 6						Series 11					
Rate (bps/Hz)	2	4	6	8	10	12	2	4	6	8	10	12	2	4	6	8	10	12
100m	42.7	36.7	30.7	24.7	18.7	12.7	42.9	36.9	30.9	24.9	18.9	12.9	43.0	37.0	31.0	25.0	19.0	13.0
200m	26.4	20.4	14.4	8.4	2.4	-3.6	37.4	31.4	25.4	19.4	13.4	7.4	42.6	36.6	30.6	24.6	18.6	12.6
300m	-2.2	-8.2	-14.2	-20.2	-26.2	-32.2	14.4	8.4	2.4	-3.6	-9.6	-15.6	37.6	36.6	25.6	19.6	13.6	7.6

	(EPoC SNR – Modulation Rate SNR) @ 1300 MHz																	
	Series 59						Series 6						Series 11					
Rate (bps/Hz)	2	4	6	8	10	12	2	4	6	8	10	12	2	4	6	8	10	12
100m	42.6	36.6	30.6	24.6	18.6	12.6	42.9	36.9	30.9	24.9	18.9	12.9	42.9	37.0	31.0	25.0	19.0	13.0
200m	22.7	16.7	10.7	4.7	-1.3	-7.3	34.5	28.5	22.5	16.5	10.5	4.5	42.4	36.4	30.4	24.4	18.4	12.4
300m	-7.6	-13.6	-19.6	-25.6	-31.6	-37.6	10.0	4.0	-2.0	-8.0	-14.0	-20.0	34.7	28.7	22.7	16.7	10.7	4.7

Color Legend: Plausible >= 6 dB, Marginal (TF FEC) 0 < Margin < 6 dB, NO < 0

Study 1 Question #1: Analysis

- Cable distance summary for 1Gbps
  - Downstream
    - Series 59, 300m no, < 200m and dependent on FEC
    - Series 6, problems at 1000 MHz and 300m, FEC might provide sufficient headroom
    - Series 11, ok but dependent on FEC
  - Upstream
    - Series 59, 300m no, < 200m and dependent on FEC
    - Series 6, < 200m and dependent on FEC
    - Series 11, ok
- Comments
  - Downstream could be improved by different mix of analog and digital services, different mixing of RF outputs, and/or tilting channel top end power by +4dB would help Series 6
  - Upstream, total power +8dB with additional +4dB tilt at top end would help Series 6

Study 1 Question #1: Comments

- NOTE: Raising upstream power effects CNU relative cost
  - Higher in frequency will require more power to overcome losses
- Analog TV channel deprecation will improve by 2.6 dB
  - 72 A + 52 D => 124 D
- Other signal combining techniques should improve SNR

- NOTE: realizing this study into an operational model would require additional work for specifying how the 1150 MHz to 1300 MHz upstream is achieved in the passive cable network
  - Presence of taps, bypasses, splitters, combiners etc. are for future study work

Study 1 Question 2: Taps and Splitters

- What general impact do Taps and Splitters have on losses?
  - Taps
    - Insertion loss dependent primarily on Tap Value then Size
    - In 750 MHz to 1000 MHz range (quick sampling of SA and Arris)
      - Two-way taps: 1.7 dB to 5.0 dB
      - Four-way taps: 2.0 dB to 4.0 dB
      - Eight-way taps: 1.7 dB to 5.4 dB
  - Splitters/combiners (quality splitters!)
    - Insertion loss dependent primarily on the number of ports
    - In 750 MHz to 1000 MHz range (quick sampling)
      - Two-way: 3.9 dB to 4.5 dB
      - Four-way: 7.8 dB to 8.4 dB
      - Eight-way: 11.9 dB to 12.8 dB

Study 1 Question 2: Summary

- Effect of taps in splitters in downstream of 850MHz to 1000MHz insert loss for both signal and noise
  - Until the plant noise is at/below thermal noise floor, then the (EPoC SNR – Modulation SNR) value is "squeezed"
- The industry is generally unspecified over 1000 MHz
  - Effect of cable equipment "passives" on Upstream 1150 MHz to 1300 MHz is undetermined in this study
  - As well as bypassing/replacing existing 1000 MHz taps
- Future study work is needed to more accurately model beyond all passive coaxial cable

Summary

- This is an informal look at creating models to answer the general question on plausibility of providing Gbps EPON services over different types of coaxial cable
  - Notion to start at “Up To 1 Gbps” and study “Up To 10 Gbps”
- More contribution and formal work is needed to address:
  - The different cable network and MxU topologies
    - Including taps, splitters/combiners, bypasses, etc.
  - The range of provisioning options
  - Expected service data rate options; e.g. capacity versus spectrum, etc.
- Studies also need to review/compare relative cost of CNU