Multiple Modulation Profiles for EPoC

- Potential benefits, issues and solutions

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Acronyms and definitions

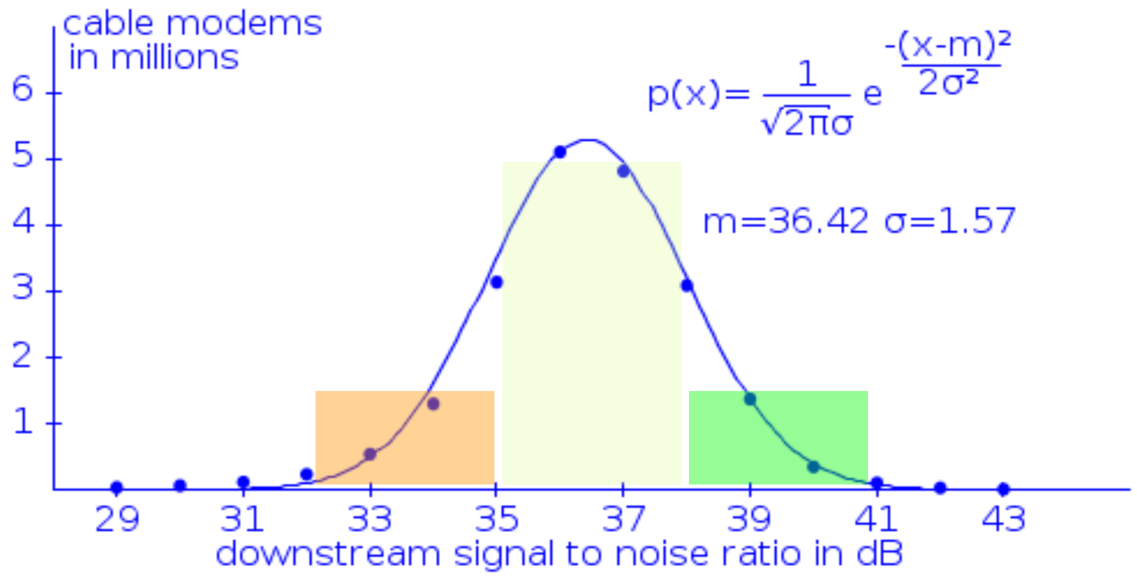
IMP - Individual Modulation Profile
MMP - Multiple Modulation Profiles
SMP - Single Modulation Profile
UMP - Universal Modulation profile
SLA - Service Level Agreement
ORU – Optical RF Unit
Cable segment – A section of coax cable connects to a ORU

Outline

- Motivation for Multiple Modulation Profiles (MMP) for EPoC
- SLA or MMP ?
- What are the benefits of MMP for end-users?
- Impacts of MMP on total Downstream spectrum efficiency
- Conclusions

Motivation

- **DOCSIS 3.0 cable modem SNR measurement on QAM 256 shows distributions**
  - A large percentage of CM may have sufficient SNR to support 1024 QAM modulation
  - A small percentage of CM may have SNR higher enough to support 4096 QAM modulation
  - Another small percentage of CM may only support 256 QAM modulation
  - Assuming the SNR measurement results on QAM 256 can be expended directly to QAM 1024 and QAM 4096



Data form Comcast
SNR including impairments from AM fiber

- **Can an EPOC PHY adapt to the plant condition with Flexible Modulation Orders?**
- **How much flexibility is needed?**
- **Individual Modulation Profile (IMP) for each CNU ?**
- **Multiple Modulation Profiles (MMP) for a groups of CNUs ?**

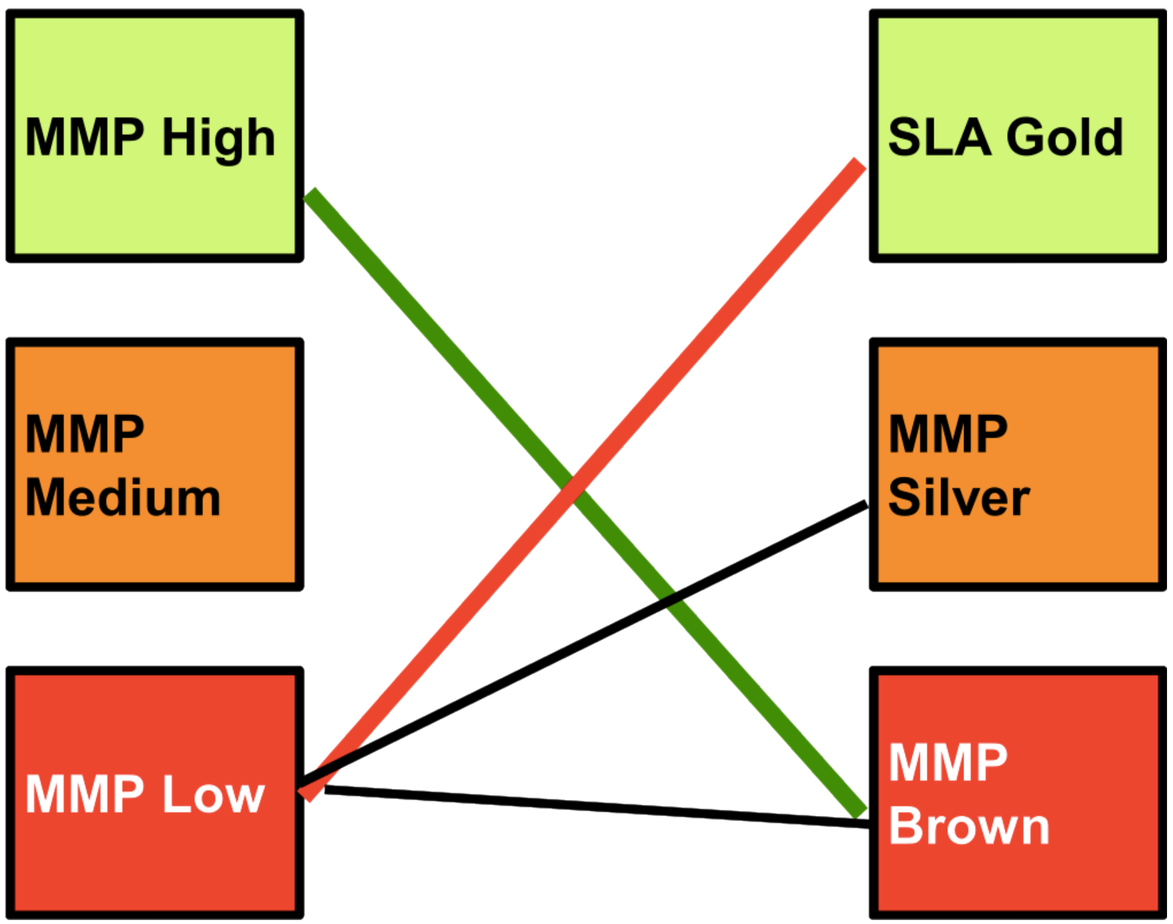
- What are the benefits for end-users?
- What are the benefits for network?

Many Choices ...

- **Individual Modulation Profile per CNU**
  - Definition: Each CNU has its own modulation profile although 2 or more CNUs could have identical modulation profile
  - EPoC downstream is then effectively a bundle of P2P physical connections
  - This option was ruled out at the early stage of discussion
- **Multiple Modulation Profiles**
  - Definition: A common modulation profile is assigned to a group of CNUs according to their SNR range. A different group of CNUs on the same cable segment could be assigned with another common modulation profile.
  - Only need a few MMPs, for example 2 - 4 MMPs may be enough.
- **Single Modulation Profiles**
  - Definition: A common modulation profile is assigned to all CNUs on one cable segment; all CNUs on different cable segment could be assigned with different SMP.
- **Universal Modulation Profile**
  - One MP is assigned to all CNUs on cable segments connect to an EPON OLT port (or EPoC CLT); CNUs connect to different OLT port could have different UMP.

SLA or MMP, which one matters?

- **End-users have no choice nor visibility into physical layer MMP**
  - MMP is determined by network properties such as CNU SNR
  - A service provider does not assign a specific MMP to an end-user
- **End-users are bounded to service providers by SLA**
  - SLA is a service contract between an end-user and a service provider; a modulation profile is not.
- **There is no direct relation between SLA and modulation profiles**
  - An end-user with low MMP may request premium SLA
  - An end-user with higher MMP may subscribe only basic SLA



Net bandwidth benefits

- **Current MSO outside plant supports 256 QAM for downstream**
  - All DOCSIS 3.0 modems support QAM 256 in DS
  - Some cable with higher SNR may support QAM 1024
- **With fiber nodes going deeper into network, outside plant condition is expected to improve continuously**
- **QAM 1024 has 10 bit/Hz spectrum efficiency; 2 bit/Hz higher than that of QAM 256**
  - However, FEC needs to be taken into account for efficiency comparisons
  - Net spectrum efficiency of QAM 1024 with 9/10 coding rate is 8.89 bit/Hz
  - Net spectrum efficiency of QAM 1024 with 3/4 coding rate is only 7.47 bit/Hz

Modulation (QAM)	FEC Code Rate	Spectrum Efficiency (Bit/s/Hz)	SNR @ BER 10^{-6} (dB)
4096	9/10	10.78	34.97
4096	5/6	9.97	32.36
1024	9/10	8.89	29.5
1024	5/6	8.31	27.15
1024	3/4	7.47	24.81
256	9/10	7.18	24.02
256	5/6	6.65	21.96
256	3/4	5.98	19.97
64	9/10	5.39	18.4
64	4/5	4.78	16.05
64	2/3	3.99	13.47
16	9/10	3.59	12.8
16	4/5	3.19	10.72

DVB C2, LDPC 64800

MAC and PHY complexity (I)

- **To enable support for MMP in 802.3, substantial changes are needed to MAC and PHY design:**
  - Rate adaption is already for EPoC with SMP
  - For MMP, MAC Control has to include multiple data rate adaptation functions, one for each MMP profile
  - A new aggregation sub-layer connected to MAC may needed to collect data from multiple data rate adaptation functions and pass resulting frames towards MAC
    - MAC has a single interface to MAC Control
  - **No Changes to XGMII to adapt MMP are feasible, no new signaling lanes, etc.**
    - There is no real-time control signaling in 802.3 PHY, which would drive the behavior of PHY from MAC Control layer
    - Recall the laser control signal discussion in EFM for 1G-EPON
    - All PHY layer signaling needs to be generated locally in PHY
    - MAC can only send data at full rate of 10Gbit/s, with no intermediate speed steps (no 5G, 2G, etc. operation is possible)

MAC and PHY complexity (II)

- Con’t:
  - Idle Deletion function in PCS has to know how many IDLEs to delete from **i**ncoming data stream to match it to target PHY data rate
    - Not a problem at high load, but consider what happens in light load conditions when majority of data stream is composed of IDLE characters
    - In MMP approach, PCS needs to identify individual frames (start/stop) and be able to figure out what target data rate the frame will be transmitted at, to know how many IDLEs to delete after the frame.
    - This requires data rate information (on per-frame basis) available at PCS level. The only place where it is available is MAC Control.
    - Recall from XGMII discussion that there is no way to deliver such information in real-time to PCS. MDIO is too slow and bandwidth limited for such exchange.
  - **Clock synthesis for PMDs**
    - Effective clock rate at PMD in MMP approach has to change from frame to frame, to accommodate different modulation depths. It is doable at 1G, but may represent substantial challenge above 2.5/3G.
    - Miracles come at the cost of increased space, power consumption and complexity. Is this really worth the trouble?

Impacts of MMP on SLA, how big?

- Assuming an EPoC with 192 MHz spectra for downstream
  - High MMP with 1024 QAM provides 889 Mbit/s PHY rate with 9/10 coding rate
  - Low MMP with 256 QAM provides 718 Mbit/s PHY rate with 9/10 coding rate
- Assuming 64 CNUs attached to the EPOC system
  - Average bandwidth per CNU with High MMP is 13.9 Mbit/s
  - Average bandwidth per CNU with Low MMP is 11.2 Mbit/s

MMP Class	Data Rate (192 MHz)	SLA	Average Bandwidth	Multicast bandwidth (%)	Max rate/(Ave available unicast Bandwidth)
High, 1024 QAM (9/10)	1706 Mbit/s	Gold (100 Mbit/s)	26.6 Mbit/s	30	91.5
Low, 256 QAM (9/10)	1378 Mbit/s	Gold (100 Mbit/s)	21.5 Mbit/s	30	91.5

- **In both case a CNU can receive downstream burst at rate 90 times higher than average rate**
- **Both meet SLA with large margins**
- **Consider fairness of DS interleaving, high MMP has no notable impacts on a end-user comparing with that of low MMP**

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My loss is your gain...

- Assuming MMP is there (In spite of PHY, MAC and system level complexities)
  - The potential benefit depends on various outside plant conditions
- The table below based on assumption:
  - High MMP (4096 QAM) 10%, Medium MMP (1024) 45%, Low MMP (256 QAM) 45%. Total numbers of CNU = 64
  - Strong FEC = 5/6 coding rate, the rest coding rate = 9/10 (5/6 coding rate assumed for 4096 QAM)

MMP Class	Data Rate (192 MHz)	Max IP Video Streams	MMP Gain	Multicast Gain *	Total Gain
High 10%, Medium 45%, Low 45%	1580 Mbit/s	128	202 Mbit/s	0 to (- 560) Mbit/s	202 to (-254) Mbit/s
Low 100%	1378 Mbit/s	128	0	Reference	Reference
Medium 100% with strong FEC	1595.5 Mbit/s	128	217.5 Mbit/s	0	217 Mbit/s

* Multicast gain is under the assumption of 64 CNUs 2 video streams per CNU

- **MMP gain is at the cost Multicast lost**
- **SMP (equivalent to 100% Medium MMP with strong FEC) shows hightest total gain**

More than one way to skin that cat ...

- **Multiple Modulation Profiles greatly increase PHY, MAC and system complexity**
  - PHY layer complexity needs further study
  - Multi-rate adaption needs further study
  - System level complexity needs further study
- **The gain of MMP is eroded by multicast loss, total gain could be negative**
  - The total gain or loss is unpredictable
- **UMP is equivalent to SMP when all ORUs connect to an OLT have common SMP**
- **Weight between coding rate, SNR and efficiency**
  - 1024 QAM at coding rate 9/10 requires 29.5dB SNR at BER 10^-6 with spectra efficiency at 8.89 bit/Hz
  - 1024 QAM at coding rate 5/6 requires 27dB SNR at BER 10^-6 with spectra efficiency at 8.31 bit/Hz
  - 256 QAM at coding rate 9/10 require 24.02dB SNR at BER 10^-6 with spectra efficiency at 7.18 bit/Hz
- **Use stronger FEC for higher order modulation with SMP may be a balanced solution**
  - Balance between spectrum efficiency and SNR
  - Still have relatively higher spectrum efficiency
  - Keeps PHY, MAC and system simple

Conclusions

- End-users are bounded to service providers by SLA not by PHY modulation profiles
- MMPs do not have direct link with SLA
- Considering fairness of downstream interleaving, higher MMP has no notable impact on a end-user SLA comparing with that of lower MMP
- The complexities of MMP at PHY, MAC and system levels and the impacts need further study
- Use SMP with higher order modulation with stronger FEC may provide a balanced solution between spectrum efficiency and complexity

Thanks