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Choices of Modulation Profiles for EPoC

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IEEE 802.3 Plenary Meeting
Nov 12th to 16th, 2012
San Antonio

Supporters

Bill Powell	Alcatel-Lucent
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Acronyms and definitions

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

Outline

- Interpretation of cable SNR measurement results
- in-home-network topologies for EPoC
- Impacts of MMP on MAC & PHY complexity
- Impacts of MMP on system complexity
- Conclusions and proposals

SNR measurement in US and China (I)

- **SNR measurement of HFC in US shows distributions from 32dB to 41dB(*)**
  - Based on SC QAM 256
  - Active coax cable; > N+1
- **SNR measurement of HFC in China shows higher SNR >= 41dB(**); SNR distribution is unknown**
  - Passive coax cable; SC QAM 256
- **General interpretation of SNR measurement results**
  - SNR measurements are at particular frequencies on SC, the results may not be directly extended to OFDM
    - Specific cable impairments may impact certain frequencies
    - A CM with higher SNR may not automatically qualify for a higher OFDM modulation profile, and vice versa
      - CM SNR measurement is based on SC
      - OFDM profile is based on SNR of a given frequency band

*** Data from Comcast production networks**

**** Data from Chinese MSO presentations in Hangzhou meeting, measurement conditions are unknown**

SNR measurement in US and China (II)

- **General interpretation of SNR measurement results (cont'd)**
  - SNR distribution is related to specific HFC outside plant configuration and in-home-network topologies; the results can not be generalized
  - The value of SNR measurements includes noise from AM fiber
  - The optical portion of EPoC is digital, it will not contribute to SNR as that of AM fiber
  - Detailed channel model is needed to correctly interpret the SNR data

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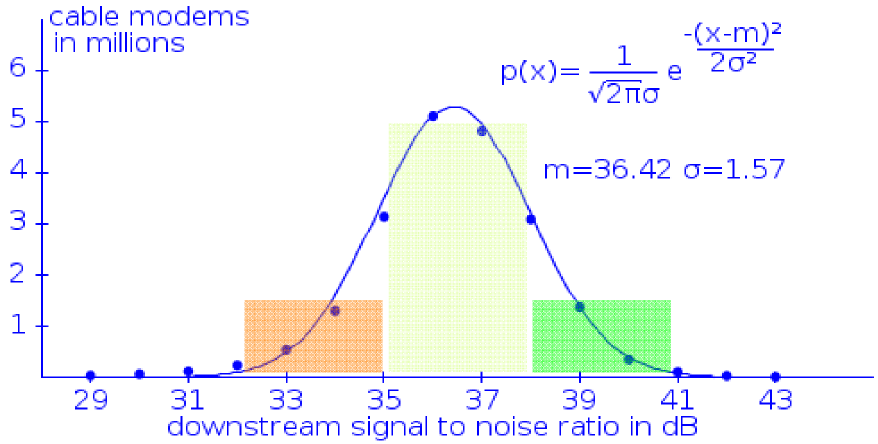
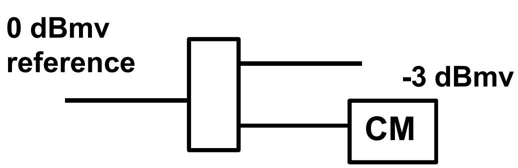
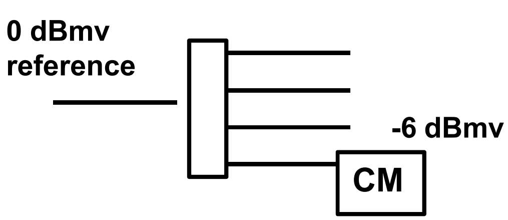
SNR distributions



Data from Comcast
SNR includes impairments from AM fiber
SNR distribution based on given HFC topology

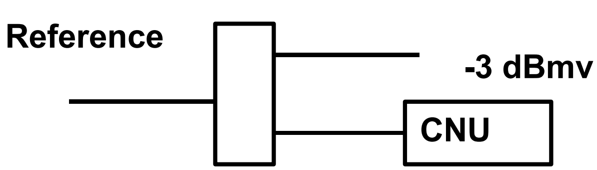




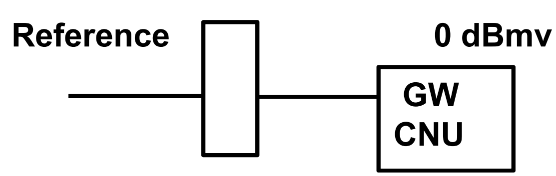
- **SNR data are based on certain HFC topology and in-home-network configuration**
  - Outside plant: active (N+X) or passive (N+0)
  - in-home-network: splitting and tap
- **Various in-home-network topology**
  - A CM may behind a 1x2 splitter
  - A CM may behind a 1x4 splitter
  - Extension amplifier may used in some homes
  - Tap may used in some homes
  - RF input power variation to CM could vary 0 - 9 dBmV due to in-home-network configuration variations
- **If we mandate the use of 1x2 splitter with CM, the sharp SNR distribution curve will change (generally shift to the right)**
- **Remove impairments from AM fiber will also improve SNR**

in-home-network for EPoC

- **Regardless of active or passive outside plant, in-home-network needs to be regulated for EPoC**
  - In order to have a definite channel model
  - Predictable SNR distribution
  - Provide reference for PHY OFDM specifications
- **Although EPoC is a PHY standard, a network reference model is needed**
  - Including outside plant and in-home-networks
  - The range of CNU RF receiving power
    - Dynamic range of both DS and US receivers



Home RF network topology 1
Mixed QAM and IP video



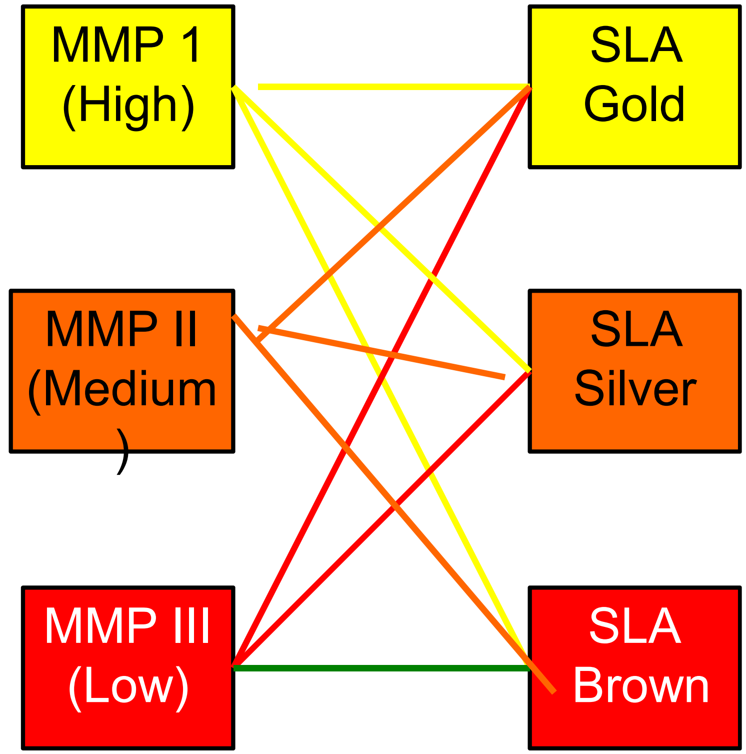
Home RF network topology 2
All IP video

Choices of modulation profiles (I)

- **Recall from MP discussions at Hangzhou meeting**
  - **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
  - **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.

Choices of modulation profiles (II)

- **Recall from MMP and SLA discussions at Hangzhou meeting**
  - End-users have no choice nor visibility on physical layer MP
  - End-users are bounded to service providers by SLA not by the PHY MP
  - There is no direct relation between SLA and PHY MP
  - **Higher MMP has no notable impact on a end-user SLA comparing with that of lower MMP because of fairness in downstream interleaving**



- **Recall from Hangzhou meeting on the complexity of MMP**
  - MAC & PHY layer complexity needs further study
  - System level complexity needs further study

Choices of modulation profiles (III)

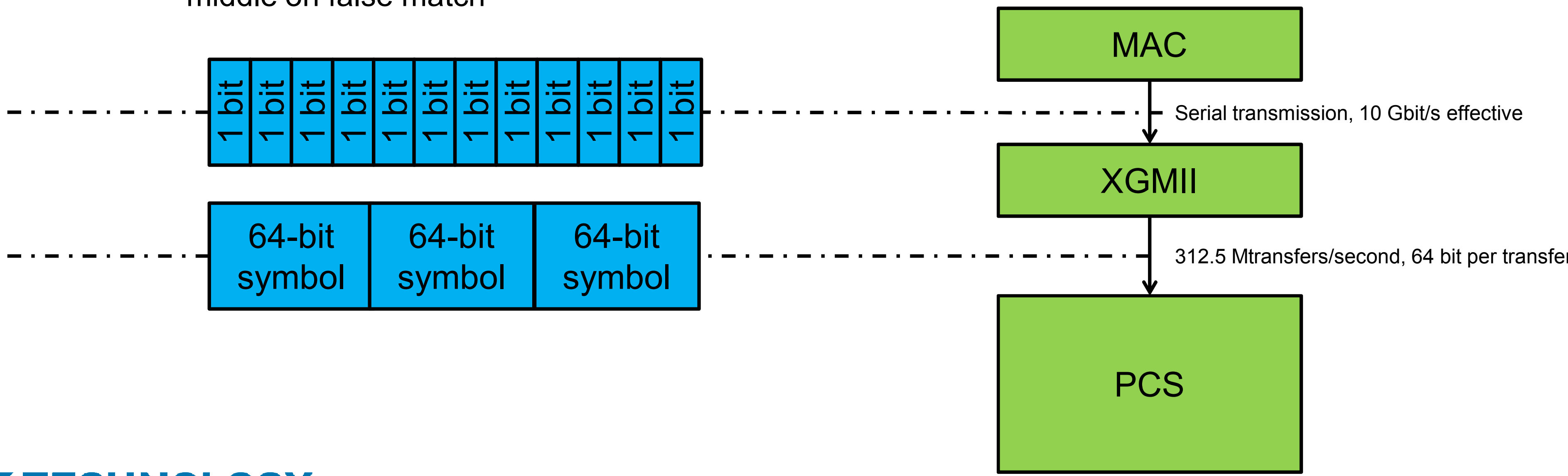
- Multiple Modulation Profiles substantially increase PHY, MAC and system complexity
- The gain of MMP is eroded by lower multicast efficiency, total gain could be negative and it is unpredictable
- Weight between coding rate, SNR and efficiency
  - 1024 QAM at coding rate 9/10 requires 29.5dB SNR(BER 10^-6) with spectra efficiency at 8.89 bit/Hz
  - 1024 QAM at coding rate 5/6 requires 27dB SNR(BER 10^-6) with spectra efficiency at 8.31 bit/Hz
  - 256 QAM at coding rate 9/10 require 24.02dB SNR(BER 10^-6) with spectra efficiency at 7.18 bit/Hz
- Use stronger FEC for subcarriers that have higher modulation orders in SMP may be a balanced solution
  - Balance between spectrum efficiency and SNR
  - Still have relatively higher spectrum efficiency
  - Handles the concern of SNR headroom
  - Keeps PHY, MAC and system simple

MAC and PHY complexity (I)

- **To enable support for MMP in 802.3, changes are needed to MAC and PHY design:**
  - Rate adaption for EPoC for SMP can be readily designed based on 10G-EPON with minor changes needed for dynamic changes of PHY channel capacity
  - For MMP, MAC Control has to change data rate to match destination station data rate profile, and deliver this information to PCS (somehow) across XGMII.
- **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. Result: all PHY layer signaling needs to be generated locally in PHY, if needed at all. This is how data detector in 1G-EPON was born,
  - MAC can only send data at full rate of 10Gbit/s, with no intermediate speed steps (no 5G, 2G, etc. operation is possible)
  - Padding lower data rate to the full MAC data rate with IDLEs is the only mechanism available for EPoC to support dynamic data rate changes needed to adapt to PHY conditions.

MAC and PHY complexity (II)

- **PCS changes**
  - To work correctly, 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 SMP, where all frames are treated the same way and calculations of IDLE symbol count are simpler
    - In MMP, PCS has to become much more complex:
      - Need to identify the start and end symbols for the given frame, sifting through a continuous stream of 64 bit symbols from XGMII
      - Match to Start-Of-Frame delimiter could work, but gives non-zero possibility of a false match
      - Complex hunting process and addition delay, with non-zero probability of error and sending a frame with wrong modulation profile to a wrong ONU, or missing a frame altogether, or fragmenting a frame in the middle on false match



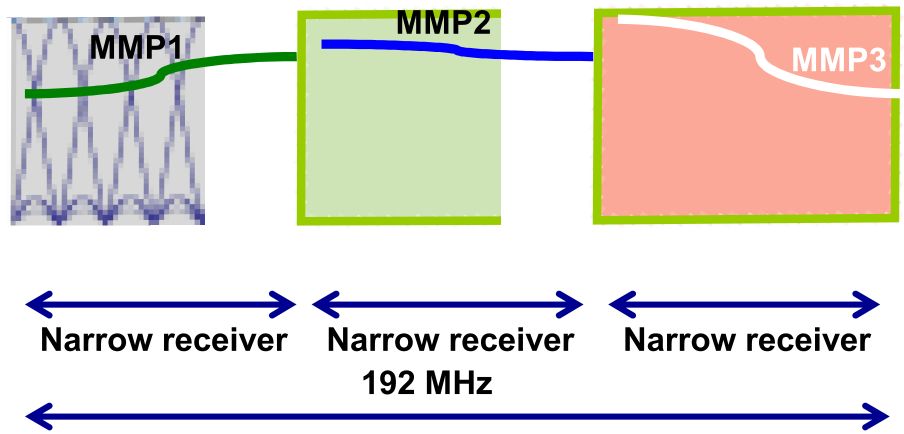
MAC and PHY complexity (III)

- **PCS changes (cont'd)**
  - Once a frame is located, Idle Deletion must know how many IDLE symbols to delete
  - This operation is destination dependent and requires a look-up table with LLID / DA-MAC information available at PCS level.
  - It is not clear right now how this information gets propagated into PCS and used for real time transactions at the full line rate.
- **Clocks and data rates**
  - In MMP approach, in different locations within the EPoC PHY stack, different data rates are likely to exist:
    - Fixed data rate at MAC, RS and XGMII interfaces
    - Dynamic (frame-oriented) interface of MAC Control
    - Bursty interfaces within PCS
    - Unclear at this time what happens to PMA in MMP approach
  - Each new data rate represents implementation challenge for chipset manufacturers
    - For each new data rate, clock synthesis needs to take place
    - This is especially problematic when clock rates are uneven multiples of each other and implementation requires multiple clock sources, of complex scaling mechanisms

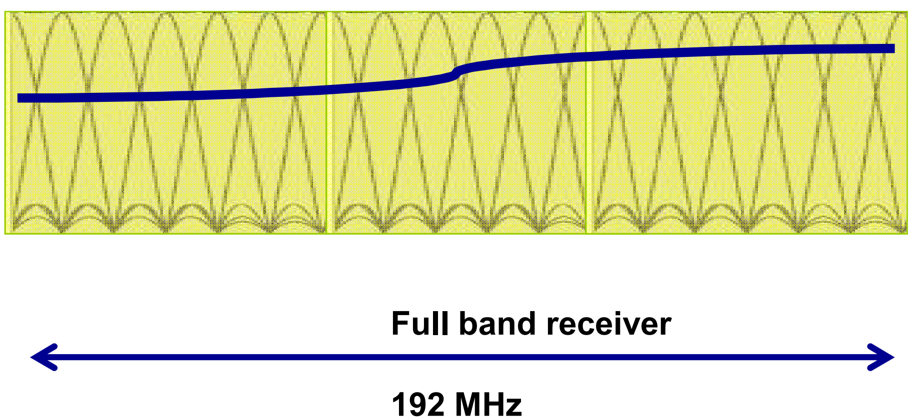
MAC and PHY complexity (IV)

- **Clocks and data rates (cont'd)**
  - In the past, Ethernet PHYs avoided multiple data rates and clock synthesis problem by limiting number of data rate conversions within the stack
  - In MMP approach, each frame leaving the Idle Deletion function might require a different clock rate to fit into the target time slice allocated to the given CNU. This will cause an implementation nightmare.
- **Observations**
  - MMP seems to be more suited for TDD approach, where each downstream burst could be allocated to the given MMP profile in a fixed fashion, helping with transition between target data rates without the use of real-time control from the MAC
  - In FDD, with a continuous downstream transmission, implementation of the MMP will be much more challenging, both hardware and protocol wise, providing little, or no benefit over the SMP solution.
- **Proposal**
  - Examine the option of MMP within TDD mode of operation
  - Select SMP for FDD mode of operation

How to define MMP ?



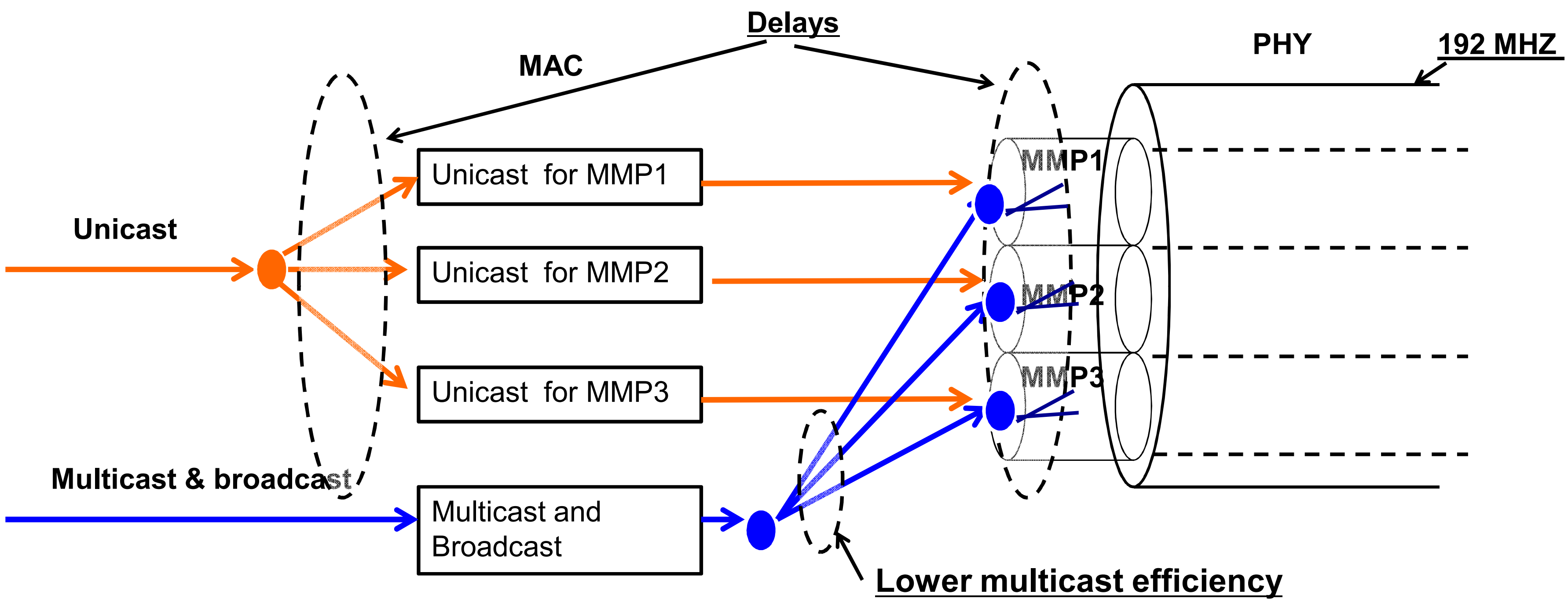
- Narrow band receiver
  - MMP could be defined by receiver bandwidth



- MMP is not a well defined concept for full band receiver
  - SMP covers full 192 MHz bandwidth
  - Or, to introduce PHY and MAC layers signaling with a CNU cover a given set of subcarriers

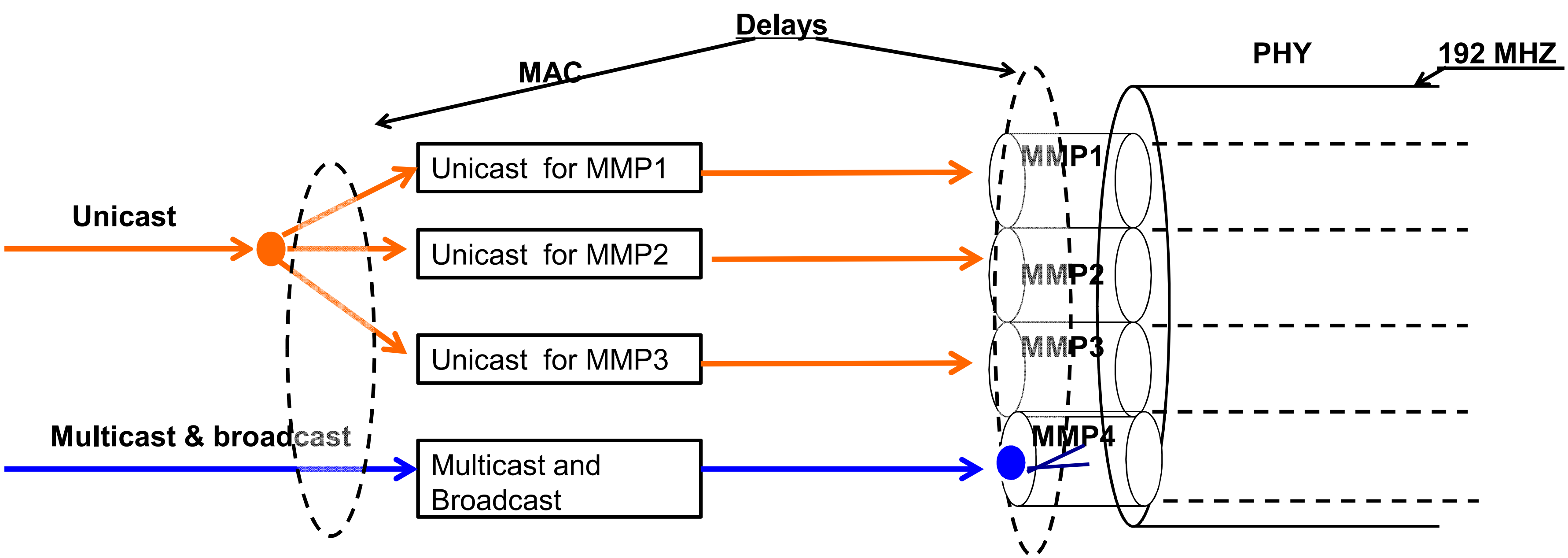
Impacts of MMP on EPoC system (I)

- Need extra buffer for DS traffic MMP classification
- Classify DS unicast traffic into MMP introduce extra delay
- PHY and MAC singling for MMP introduce extra delay
- In case of one MP per CNU, MMP has lower multicast efficiency due to extra duplication of multicast packets
    - MMP gain is eroded by lower multicast efficiency



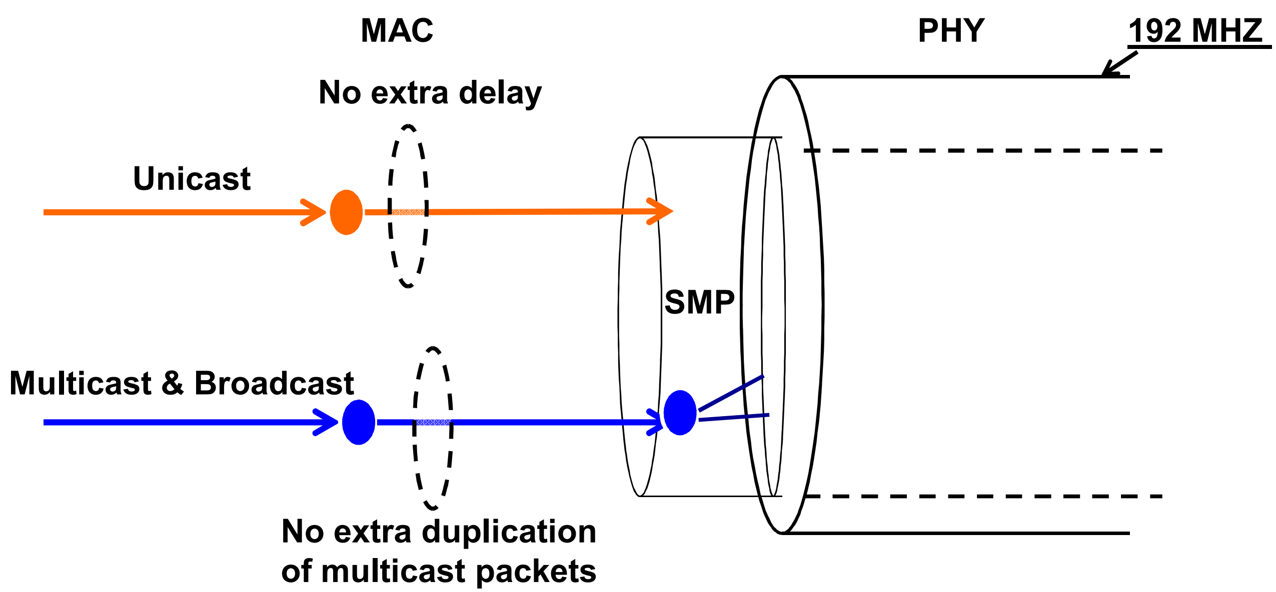
Impacts of MMP on EPoC system (II)

- In case of two MPs per CNU – one unicast MMP and one multicast MMP, extra duplication of multicast packets is avoided, but
  - Scale of multicast traffics needs rescale of multicast MMP, which affects unicast MMPs as well
- Multiple unfilled MMPs, in contrast with one unfilled SMP, have lower bandwidth efficiency
  - Statistics Max effect



Benefits of SMP

- No extra delay caused by MMP classification; no extra buffers are needed
- Keep one multicast tree; no extra duplication of multicast packets
- Simpler PHY and no additional requirement on EPON MAC
- Flexibility against SNR could be achieved by choice of coding rate and adaptive bit loading



Conclusions and Proposals

- End-users do not get notable benefit from MMP
- Service providers do not have direct control of MMP
- There is no direct relationship between MMP and SLA
- MMP introduce significant complexity at PHY, MAC and system levels in FDD mode. How MMP works in TDD mode need further study
- A network reference model is needed that Including outside plant and in-home-networks
  - The dynamic ranges of US and DS CNU RF receiving powers
- We propose using SMP with stronger FEC for OFDM subcarriers that have higher modulation orders to provide a balanced solution between spectrum efficiency and system complexity

Thanks

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