EPON over Coax

Limitations of EPON Protocol for EPOC

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Introduction

- This presentation illustrates some of the limitations of the EPON protocol as it applies to EPOC
  - Overview of EPON PHY-layer frame structure
  - Comparison of optical and coax time dispersion
  - OFDM PHY Example
  - Implications to EPOC PHY layer
  - Limitations of EPON Protocol for EPOC
  - Type of EPON Protocol enhancements for EPOC
  - Unified DPoE Management of ONUs and CNUs

Ethernet Frame Structure

8 octets	6 octets	6 octets	2 octets	N octets	4 octets	12 octets
Preamble	DA	SA	Ethertype/ Length	Payload	FCS	IFG

- Payload sizes vary from 46 to 1500 bytes
- Ethernet Frame (DA, SA, ET, PL and FCS) sizes vary from 64 to 1522 bytes
- Total overhead is 38 bytes (including IFG)
- In EPON the logical link ID (LLID) is encoded in the preamble

Ethernet Frame Transmission

- Downstream
  - The OLT sends a sequence of Ethernet Frames
  - Each Ethernet Frame contains an LLID which is used by the ONUs to determine if the Ethernet Frame is for that ONU
  - At the PHY layer each packet contains one payload from the OLT to one ONU
- Upstream
  - The OLT schedules transmission times for each ONU
  - During a transmission time the ONU sends one or more Ethernet Frames, in sequence, to the OLT
  - At the PHY layer each packet contains one payload from one ONU to the OLT

Optical Time Dispersion

- In optical fiber pulses tend to widen as they travel along the fiber. This phenomenon is referred to as time dispersion
- There are a number of types of time dispersion
- This pulse widening limits transmission speeds
- The pulse widening should be limited to half a bit period to avoid significant inter-symbol interference [1]
  - At 1 Gb/s this implies that the time dispersion is less than 0.5 ns in 1 Gb/s EPON
  - It may be even less since there is a 10/8 line-code in EPON

Coaxial Cable Micro-reflections

- In a coax cable plant there are micro-reflections from elements in the cable plant (e.g. taps)
- These micro-reflections cause time dispersion due to the superposition of the original signal and the delayed micro-reflections
- Like in the optical fiber this time dispersion can lead to inter-symbol interference
- In a coaxial cable plant it is expected that the time dispersion is around 1~4 μs
- This is 2000 to 8000 times longer than the time dispersion in EPON optical fiber
- The EPOC PHY will need to handle this large time dispersion

OFDM – Example

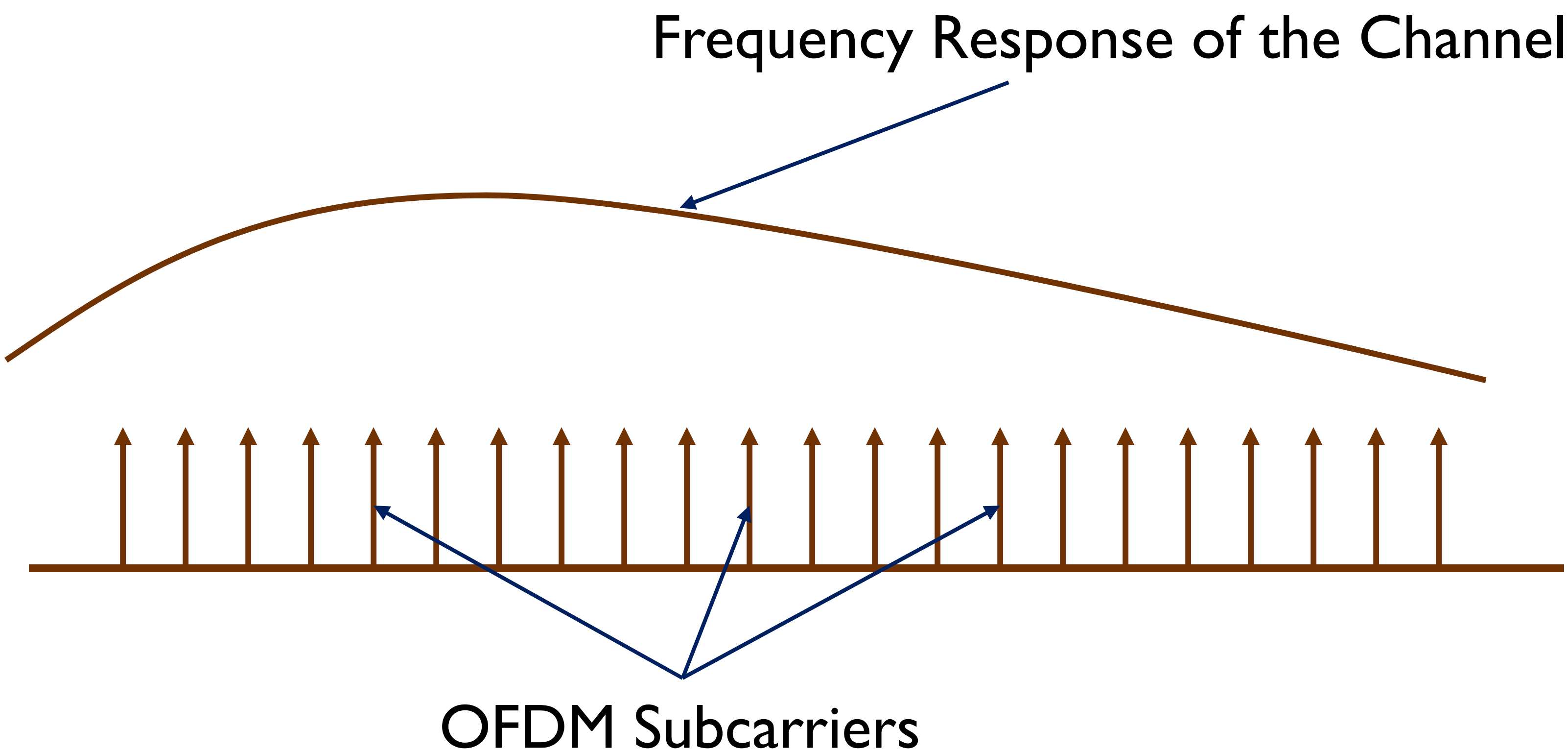
- One method to address the long time dispersion of the channel is to use orthogonal frequency division multiplexing (OFDM)
  - In the literature time dispersion is often referred to as the delay spread of the channel (common wireless terminology)
- We will illustrate how OFDM is designed to handle large delay spreads
- OFDM is not the only possible PHY design, but any PHY that is proposed will have to handle the large delay spread

EPON over Coax

OFDM – Overview

- OFDM consists of a number of subcarriers (or tones) that are spread across the signal bandwidth
- If the total bandwidth of the channel is large the frequency response of the channel may vary within the channel bandwidth
- Each of the subcarriers is modulated, typically using quadrature amplitude modulation (QAM)
- The spacing between the OFDM subcarriers is selected so that each modulated tone passes through a flat channel
- Hence a simple single tap equalizer can be used on each subcarrier

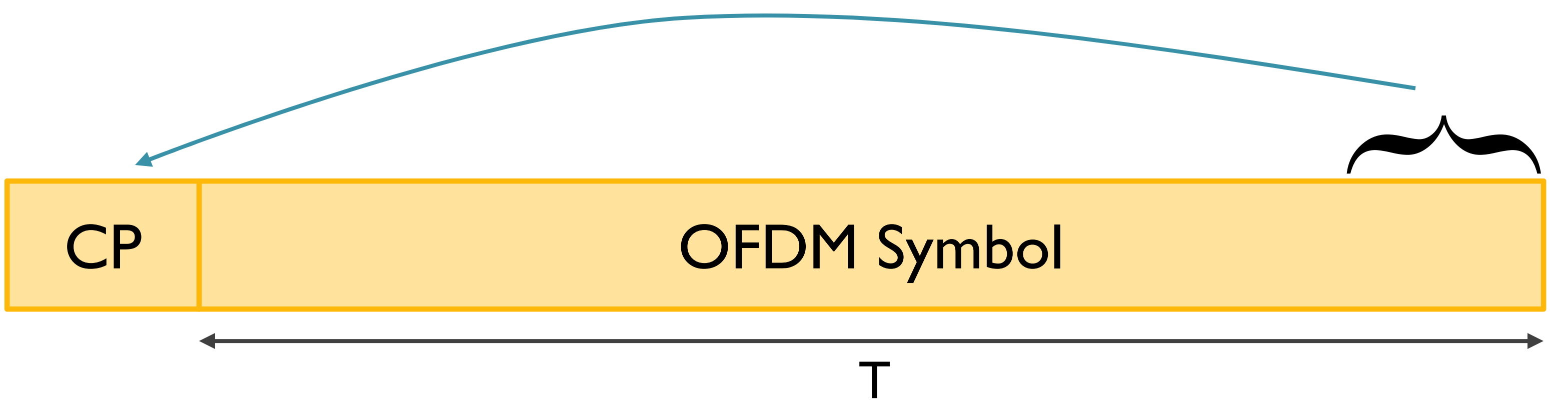
OFDM – Overview



- Each subcarrier passes through a flat channel

OFDM – Overview

- The OFDM tone spacing is Δf
- The OFDM symbol duration (not including the cyclic prefix) is the inverse of the tone spacing: $T = 1/\Delta f$
- To avoid inter-symbol interference OFDM adds a cyclic prefix before the OFDM symbol
- The cyclic prefix is a copy of a portion of the OFDM symbol
- The length of the cyclic prefix is a fraction of the OFDM symbol (e.g. 1/4 1/8, 1/16)



OFDM – Implications

- The micro-reflections of the channel can be modeled as the impulse response a linear time invariant system h(t)
- To avoid inter-symbol interference the duration of the cyclic prefix must be longer than the duration of the impulse response of the channel
  - Other PHY designs will also have some form of overhead associated with delay spread tolerance
- With a channel impulse response duration of around 1 to 4 μs the cyclic prefix needs to be at least that long
- Since the cyclic prefix contributes to the PHY-layer overhead the OFDM symbol should be much larger than the cyclic prefix duration

OFDM – Implications

Cyclic Prefix Duration	CP Fraction of Symbol	OFDM Symbol Duration	CP Plus OFDM Symbol	Information bits in an OFDM symbol @ 1Gb/s	Bytes in an OFDM Symbol @ 1 Gb/s
2 μs	1/4	8 μs	10 μs	10,000	1250
2 μs	1/16	32 μs	34 μs	34,000	4250
4 μs	1/16	64 μs	68 μs	68,000	8500
4 μs	1/32	128 μs	132 μs	132,000	16,500

- The combination of the coax cable channel (micro-reflections) and the need to have low PHY-layer overhead result in a PHY that transports large payloads
- Since RF spectrum is scarce the CP overhead in EPOC should be low

Robustness of Long Packets

- In addition to delay spread tolerance, longer PHY packets have additional benefits
- Cable channels often have burst noise
- A short RF packet can be corrupted by the burst noise due to the limitations of the forward error correction (FEC) block size
  - An interleaver, though useful for dealing with burst noise, is limited by the RF packet duration
- A longer RF packet can utilize a longer FEC block which can correct for longer burst errors
  - The number of correctable burst errors grows linearly with the FEC block length
- Robustness is critical in EPOC where very low BER is required

EPON Protocol Limitations for EPOC

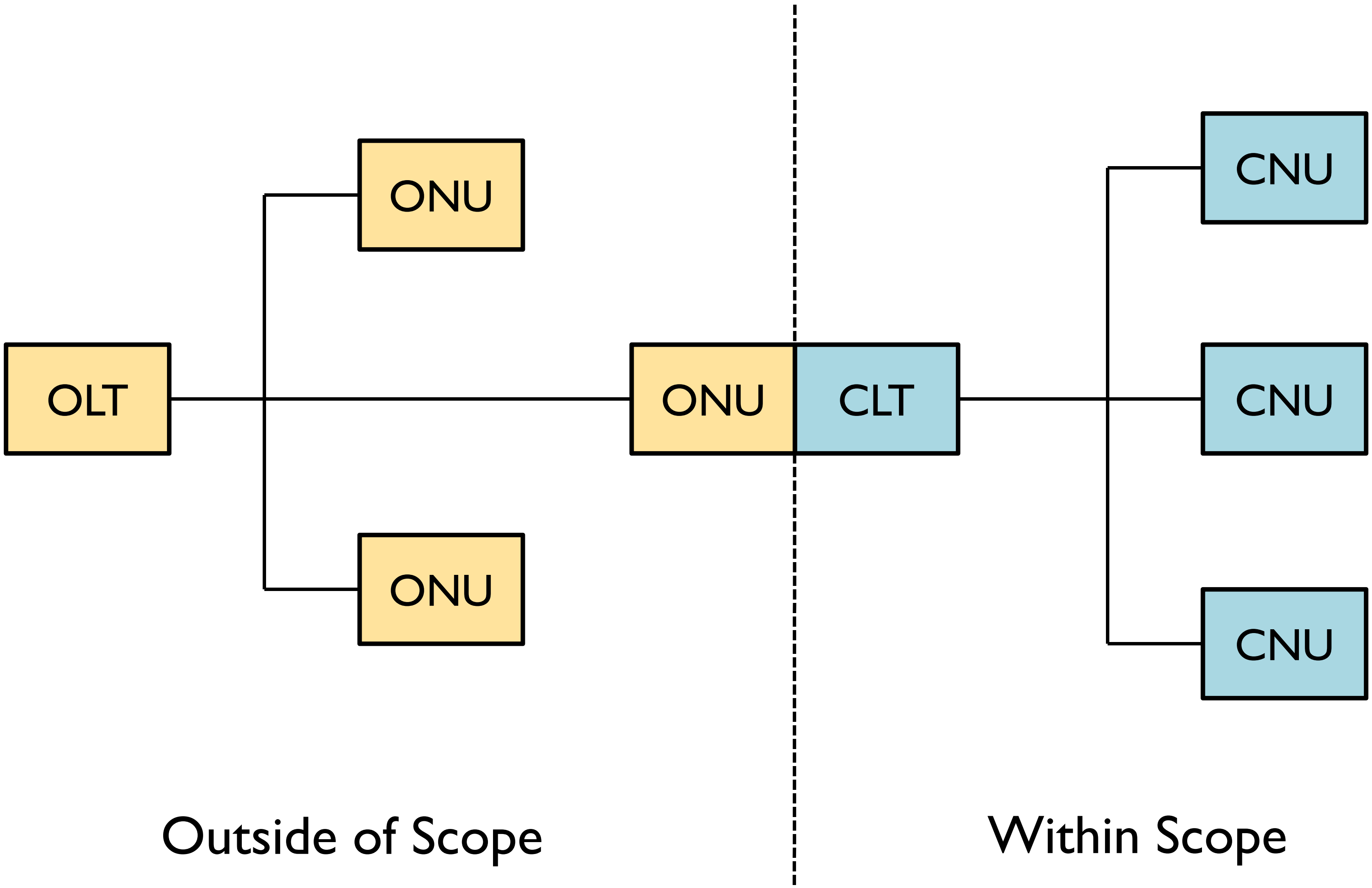
- The current EPON protocol sends packets carrying individual Ethernet Frames of 64-1522 bytes
- The EPOC PHY is likely to have a minimum payload size that is much larger than that
- Without any changes to the EPON Protocol this will lead to low efficiency
  - High PHY rate but low MAC throughput

- Hence, we believe the Task Force should not rule out enhancements to the EPON Protocol for EPOC

Type of EPON Protocol Extensions

- This presentation does not propose specific EPON Protocol extensions for EPOC
- It does provide a description of the type of the changes that we believe should be considered
- Any extensions to EPON protocol would be limited to the EPOC amendment and would not affect the current EPON standard

Scope of EPON Protocol Extensions for EPOC



Type of EPON Protocol Extensions for EPOC

- Current EPOC Packet Structure

8 octets	6 octets	6 octets	2 octets	N octets	4 octets	12 octets
Preamble	DA	SA	Ethertype/ Length	Payload	FCS	IFG
LLID						

- Type of Downstream Packet Enhancements
  - Let us label the set of fields {DA, SA, ET, Payload, FCS} the "MAC Protocol Data Unit (MPDU)"
  - Design the EPOC PHY protocol data unit (PPDU) so it can carry multiple LLIDs and multiple MPDUs for each of the LLIDs

Type of EPON Protocol Extensions for EPOC

- Type of the Upstream Packet Enhancements
  - Design the EPOC PPDU so that it can carry multiple MPDUs
  - Option 1
    - The PPDU encapsulates MPDUs all from the same CNU
    - Only one CNU transmits during a given transmission window
  - Option 2
    - The PPDU encapsulates MPDUs from different CNUs
    - Multiple CNUs transmit during the same transmission window (both time and frequency multiplexing)

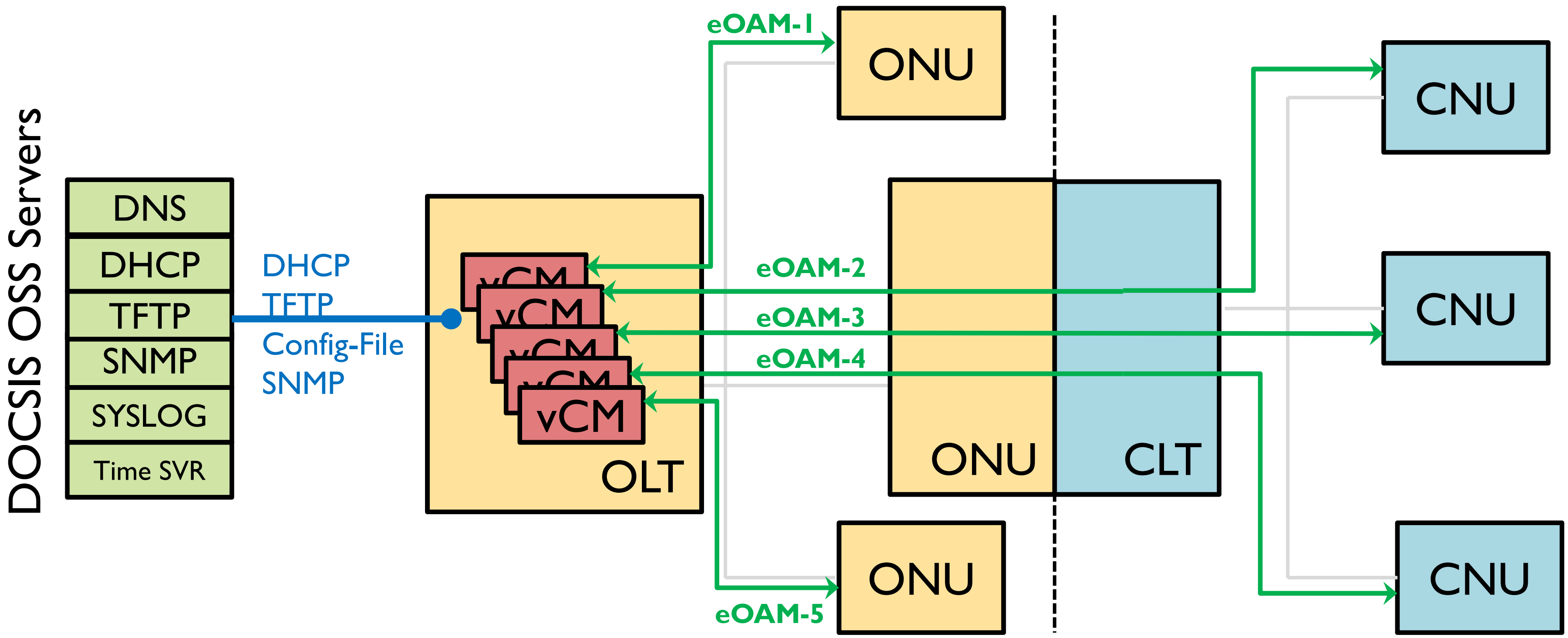
Two Upstream Options

- Option 1
  - This does not require simultaneous upstream CNU transmission so the current Gate message is sufficient for upstream scheduling
  - With multiple CNUs the total dynamic bandwidth allocation (DBA) cycle could be long since only one CNU may transmit at a time. This would lead to longer network latency
- Option 2
  - A new MPCP message (extension of current Gate message) would be required to schedule simultaneous upstream transmissions
  - Lower DBA cycles and hence lower network latency
- Option 2 is preferred in our opinion

Type of EPON Protocol Extensions for EPOC

- Type of MPCP extensions
  - No MPCP changes required to support EPOC PPDU encapsulating multiple LLIDs/MPDUs
  - If simultaneous upstream CNU transmission is to be supported then a new MPCP message (extension of the current Gate message) would be needed in order to schedule simultaneous upstream transmissions

Unified DPoE Management of ONUs and CNUs



- For each registered ONU or CNU, a corresponding vCM entity will be instantiated on the OLT (or DPoE System).
- The vCMs will interact with back-office OSS Servers on behalf of the ONUs and CNUs.
- The vCM will get CM configuration from the TFTP server; decode configuration file content; configure ONU or CNU through DPoE OAM (or eOAM, extended OAM)

Conclusions

- We believe the EPOC project should include extensions to MPCP and OAM to support the new RF PHY

References

[1] Glen Kramer, *Ethernet Passive Optical Networks*, McGraw-Hill, 2005

[2] Geoffrey Li and Gordon Stuber, *Orthogonal Frequency Division Multiplexing for Wireless Communications*, Springer, 2006