IEEE P802.3bn Tutorial Part 2 (Teil 2)

EPON Protocol Over Coax “EPoC”

Monday, 9 March 2015

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Agenda – Review of Part 1 from November 2014

- Introduction
  - Motivation for EPoC
  - P802.3bn overview
  - EPoC Application
  - Overview of Challenges
- Cable Network Requirements
  - Terms
  - EPoC Topologies
  - RF Spectrum availability and flexibility
  - Common component architecture elements
- PHY Link Channel
  - What it is, why we need it
  - DS PHY Link
  - US PHY Link
  - CNU bring up
  - PHY Link Tasks
- Summary
- Q&A

Part 1 tutorial presentation from November 2014:
http://www.ieee802.org/802_tutorials/2014-11/P802d3bn_tutorial1_v01.pdf
Paper from NCTA 2014: IEEE P802.3bn EPoC Status Overview

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Agenda –Part 2

- **Introduction**
  - P802.3bn status
  - Review of objectives and project focus
  - PHY Overview
- **Harnessing OFDM**
  - Refresher on PHY Link
    - CNU Bring up
  - Idiosyncrasies of using OFDM
  - Downstream OFDM framing
  - Downstream subcarrier use
  - Scattered Pilot example
  - Downstream PMA data rate
  - Mapping PCS data bits to symbols
  - Upstream OFDMA framing
  - A word about US pilots
  - What is different in EPoC
  - RBsize = 8 burst markers
  - Symbol mapper two processes
  - Filling overview example
- **Summary**
- **Q&A**

Task Force Status

- Draft 1.3 comment resolution this meeting
  - Expect Draft 1.4 to be authorized
- Task Force Status: www.ieee802.org/3/bn/
  - – 151 Technical Decisions (updated 1/15/15)
  - – Task Force Timeline (updated 7/16/14)
    - – Expect update to July 2014 for Working Group ballot
  - – Current Work Items list

Objectives Overview

- Detailed objectives at http://www.ieee802.org/3/bn/
- Major points:
  - Compatibility with 10G-EPON
  - High modulation rate on coaxial cable networks
    - Downstream: to 12 bits / sec / Hz: 4096-QAM
    - Upstream: to 10 bits / sec / Hz: 1024-QAM
  - Up to 10 Gbps (downstream)
  - Symmetric and asymmetric configurations
  - Efficiency and error performance goals for cable high speed data (HSD) services
  - Operation without causing harmful interference to any signals or services carried in the remainder of the cable spectrum.
- Other
  - Minimal augmentation to EPON MPCP and OAM
  - Consideration for common component architecture with DOCSIS 3.1 (D3.1) PHY where it makes sense; CableLabs copyright permission for P802.3bn

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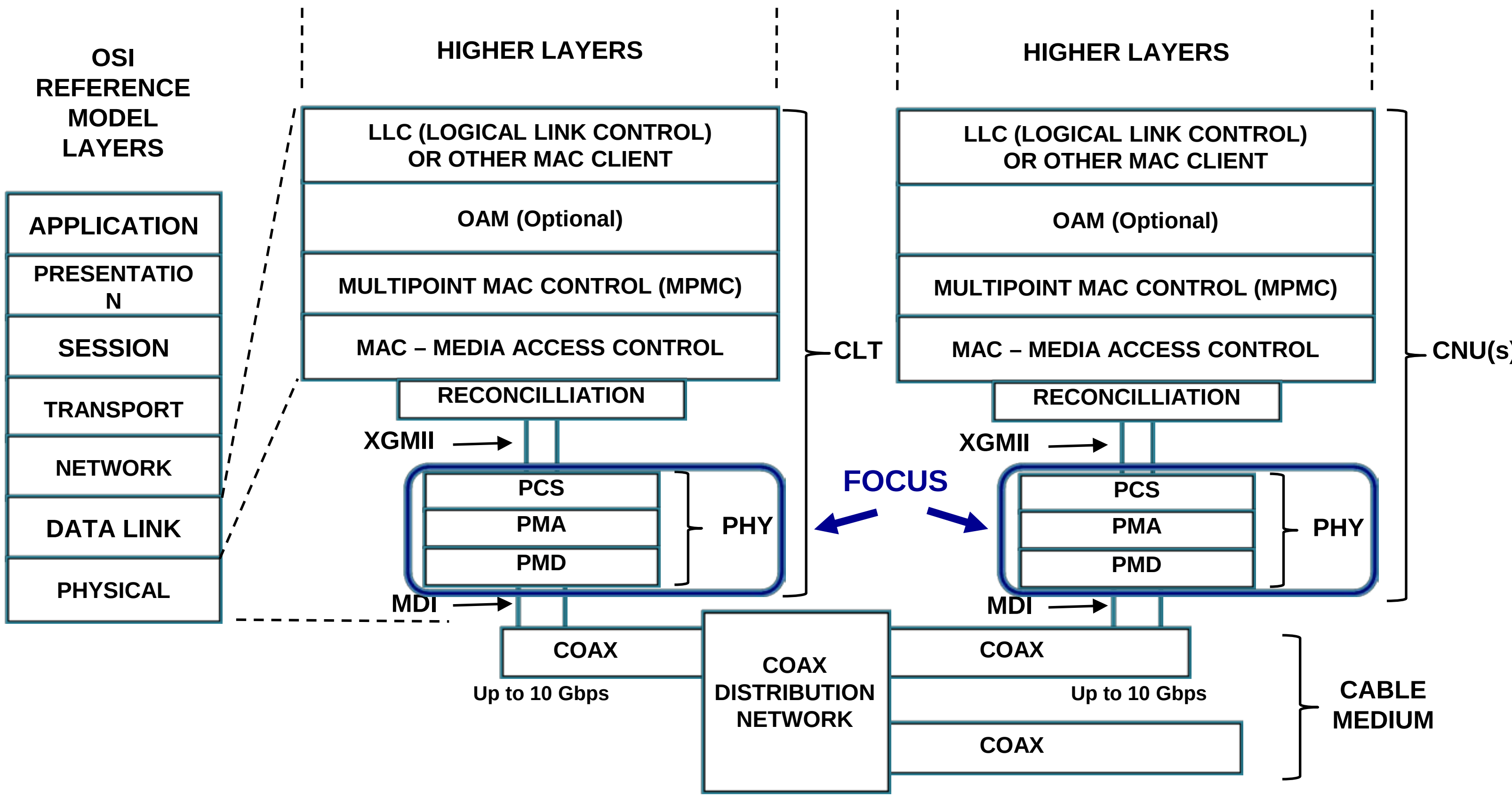
Project Focus



CLT – COAX LINE TERMINAL
CNU – COAX NETWORK UNIT
MDI – MEDIUM DEPENDENT INTERFACE
OAM – OPERATIONS, ADMINISTRATION, & MAINTENANCE

PCS – PHYSICAL CODING SUBLAYER
PHY – PHYSICAL LAYER DEVICE
PMA – PHYSICAL MEDIUM ATTACHMENT
PMD – PHYSICAL MEDIUM DEPENDENT
XGMII – GIGABIT MEDIA INDEPENDENT INTERFACE

Overview of PHY

- Cable industry has focused on gigabit services over existing coax cable networks that includes:
  - Orthogonal Frequency Division Multiplexing (OFDM)
  - “Next generation” Forward Error Correction
    - Low Density Parity Coding (LDPC)
  - Denser modulation rates
    - 4096 QAM (12 bits/second/Hz) in the downstream
  - Multiple RF channel multiplexing (e.g. “bonding”)
  - Flexible configuration for matching to available RF spectrum, channel conditions, and well known interference
    - PHY layer data rate follows cable operator configuration

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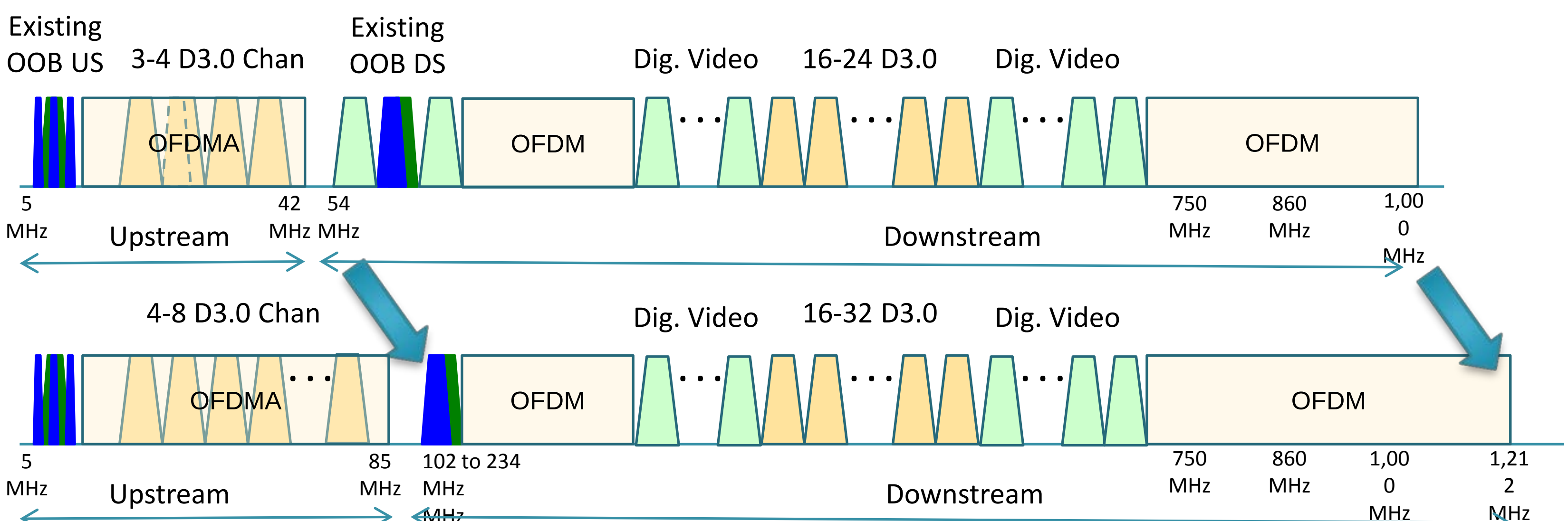
Spectrum Allocation Overview

- Downstream - Deploy EPoC in available spectrum
  - Other services: Digital video channels, DOCSIS 3.0 and 3.1 (N * 6 MHz + OFDM)
- Upstream – Deploy EPoC in available spectrum
  - Other services: DOCSIS 3.0 and 3.1
  - Note: DOCSIS 3.1 can TDMA share with DOCSIS 3.0 channels, EPoC cannot
- Cable operators will provision RF spectrum for EPoC allocation versus other services. Flexibility for adjusting allocations is a must.
- Upstream / downstream frequency split will likely change:
  - e.g., 5 to 42 MHz moving to 5 to 85 MHz (5 to 234 MHz is EPoC maximum)
- Top end downstream passband will change from 1000 MHz to 1200+ MHz



EPoC Downstream Decisions

<u>Decisions to date:</u>

- LDPC FEC, single rate 14400/16200 (soft decision)
- 40-bit CRC per information word to meet 802.3 MTTFPA
- OFDM 192 MHz, 4K FFT, 3800 50 KHz subcarriers per channel
  - Subcarrier use types: excluded, data, PHY Link, continuous pilots
  - 5 OFDM downstream channels
- 24 MHz minimum RF spectrum
- PHY Link channel
  - Well known configuration and placement in RF spectrum;
    - easily discoverable
  - Used for PHY discovery, initialization, ranging, and maintenance
  - Performs Ethernet “link negotiation”
- Repeating 128 symbol cycle Superframe

<u>Downstream (and Upstream) Challenges:</u>

- Rate matching to match 10 Gbps EPON XGMII

EPoC Upstream Decisions

Decisions:

- LDPC FEC, 3 code word rates/sizes (similar to DOCSIS® 3.1 PHY)
- 40-bit CRC per information word to meet 802.3 MTTFPA
- OFDMA 192 MHz, 4K FFT, 3800 50 KHz subcarriers
- Single channel. RF spectrum: 10 MHz minimum to 192 MHz
- Resource Block "Super Frame" concept to organize various signal types:
  - Frame size: 6 probe symbols + 256 symbols, repeating
  - Probes: OFDM timing, synchronization, channel estimation
  - PHY Link channel
    - PHY sublayer management
  - Resource Blocks for MAC data, pilots,
- Resource Blocks (RBs): 8 or 16 symbols in time, 1 subcarrier in frequency. Contain: data, pilots, start / end burst marker

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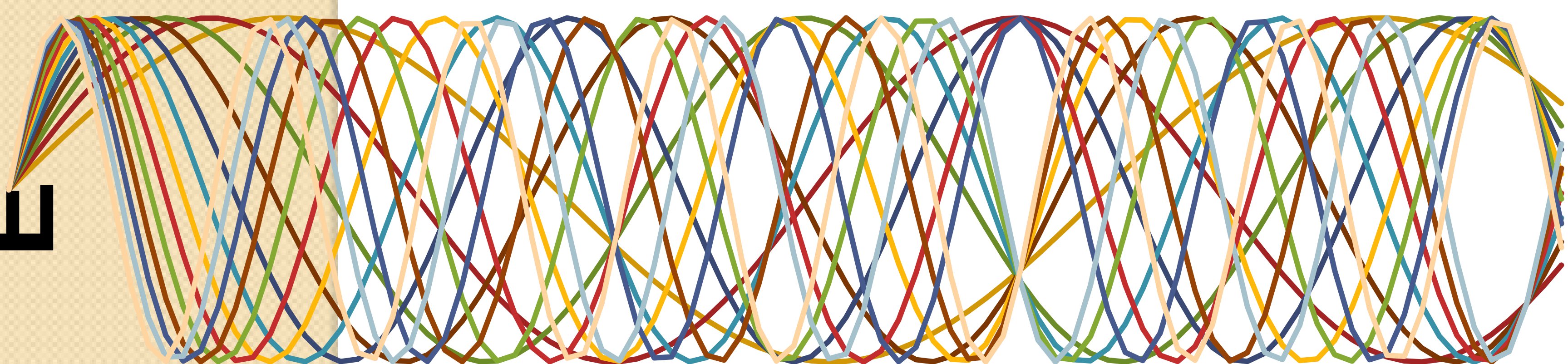
HARNESSING OFDM



Refresher on PHY Link

What is it & Why do we need it

- Separate link used to establish OFDM & OFDMA channel parameters:
  - DS Number of OFDM channels
  - US & DS channel frequency bounds; upper extreme, lower extreme, internal exclusion bands
  - US & DS channel profile; modulation rate (bit loading) for each of the 4096 subcarriers
  - DS & US Cyclic Prefix, Windowing & Time interleaving parameters
  - US PHY Link frequency and OFDMA frame parameters: resource block size (RBsize) of 8 or 16 symbols and Pilot pattern

CNU bring up using PHY Link

- CNU acquires the DS PHY Link
- CNU gathers DS & US OFDM/A channel parameters
  - CLT broadcasts OFDM/A channel parameters
- CLT opens a PHY Discovery opportunity
  - Special use of the 6 symbol Probe Period
- CNU responds to PHY Discovery with MAC Address
- CLT assigns a CNU_ID, performs Fine Ranging, sets pre-equalizer settings, etc.
- CLT declares auto-negotiation has complete and CNU to be “Link-UP” and informs upper layers a new CNU has been found.

Idiosyncrasies of using OFDM

- The FFT size 4096 bins
  - 3800 maximum useable subcarriers per 192 MHz channel (includes 2 * 1 MHz guardbands)
  - 50 KHz subcarrier spacing
  - Individually configured
  - DS: 5 * 4096, US: 1 * 4096
- OFDM receiver processing requires pilots for symbol synchronization to minimize ISI: known patterns in known places
  - Downstream (single transmitter)
    - Constant pilots (dedicated subcarriers)
    - Scattered pilots (algorithmically sequenced through data carrying subcarriers)
  - Upstream
    - Resource Block types containing pilot patterns

Idiosyncrasies, continued

- A cyclic prefix (CP) is added to the IDFT useful symbol, this defines the extended symbol time
  - Mitigation of micro-reflections and similar impairments.
- Downstream: N + DSNcp
- Upstream: N + USNcp

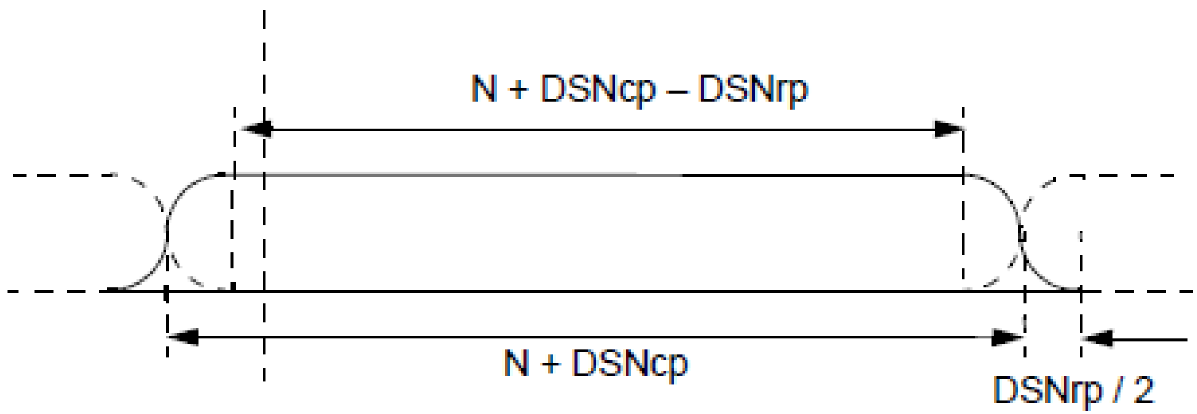
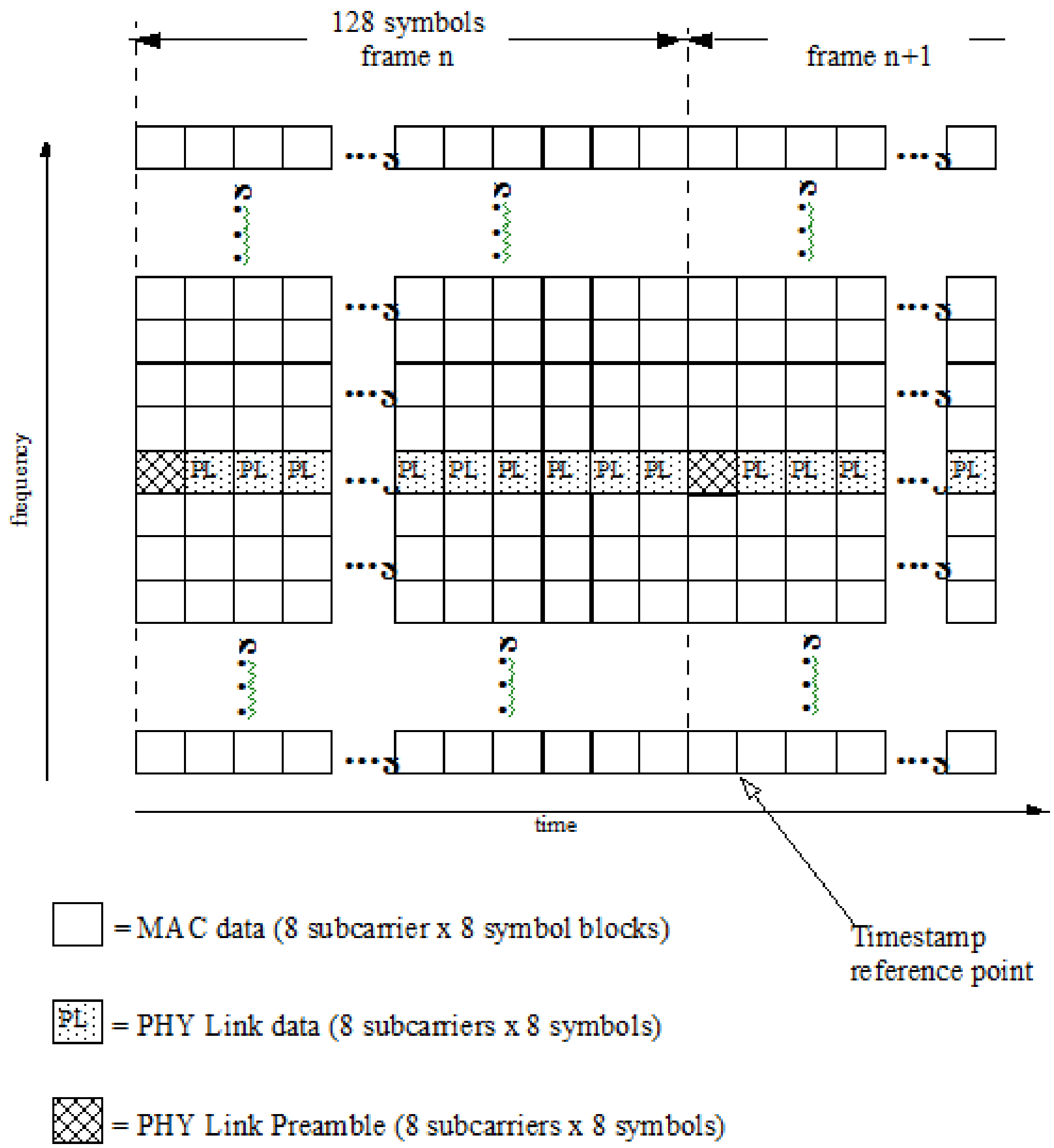


Figure 101–25—Cyclic prefix and windowing algorithm

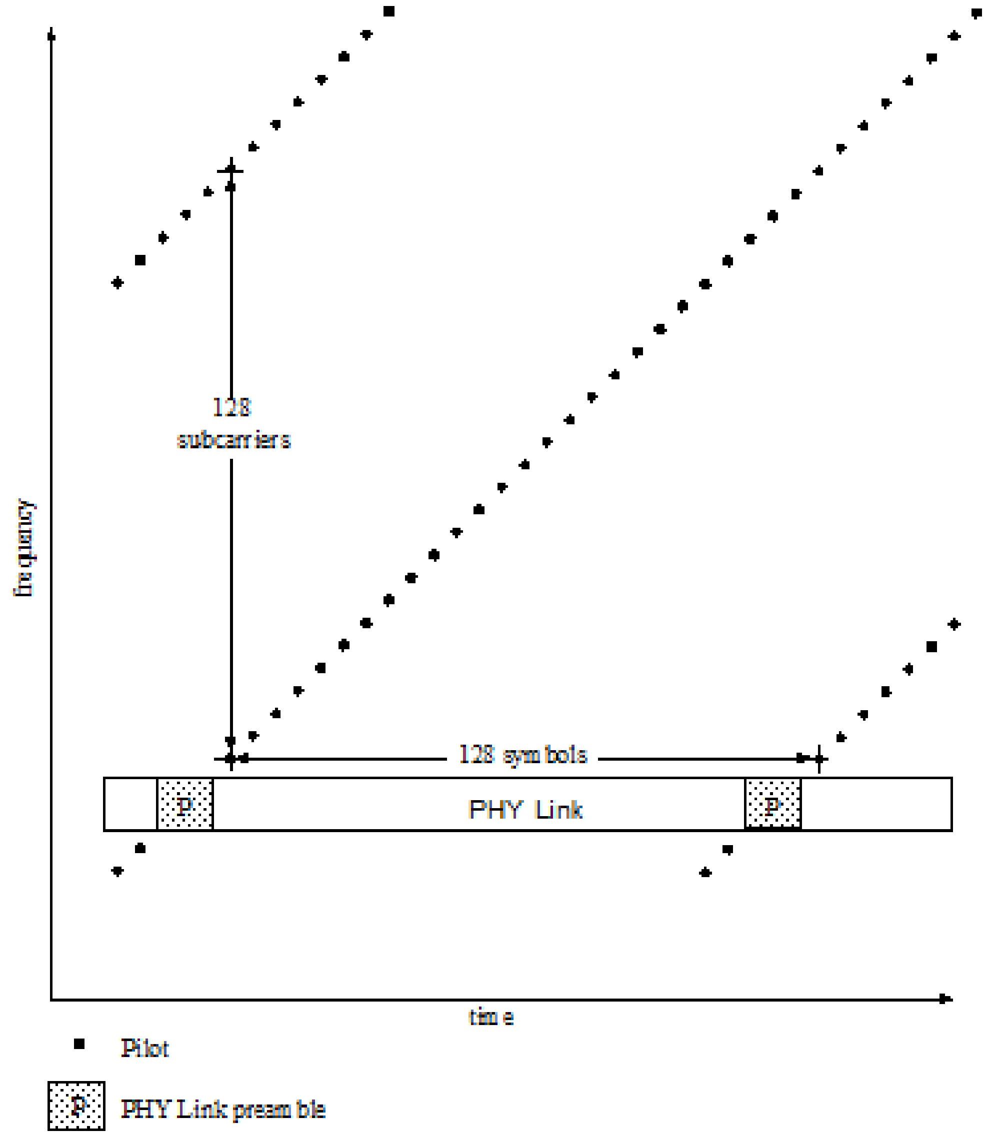
Downstream OFDM Framing



Downstream Subcarrier Use

- Individually configured:
  - Excluded (off, no energy)
  - Data carrying specific bits per symbol loading
  - PHY Link (8 subcarriers out of total)
- Pilot placement is algorithmic
  - Continuous Pilots are configured after number of active subcarriers is configured. Remains fixed until downstream profile is changed
  - Scattered pilots follow placement algorithm that repeats exactly for each 128 symbol downstream frame – not placed in PHY Link
- Pilots are BPSK and modulated using a PRBS

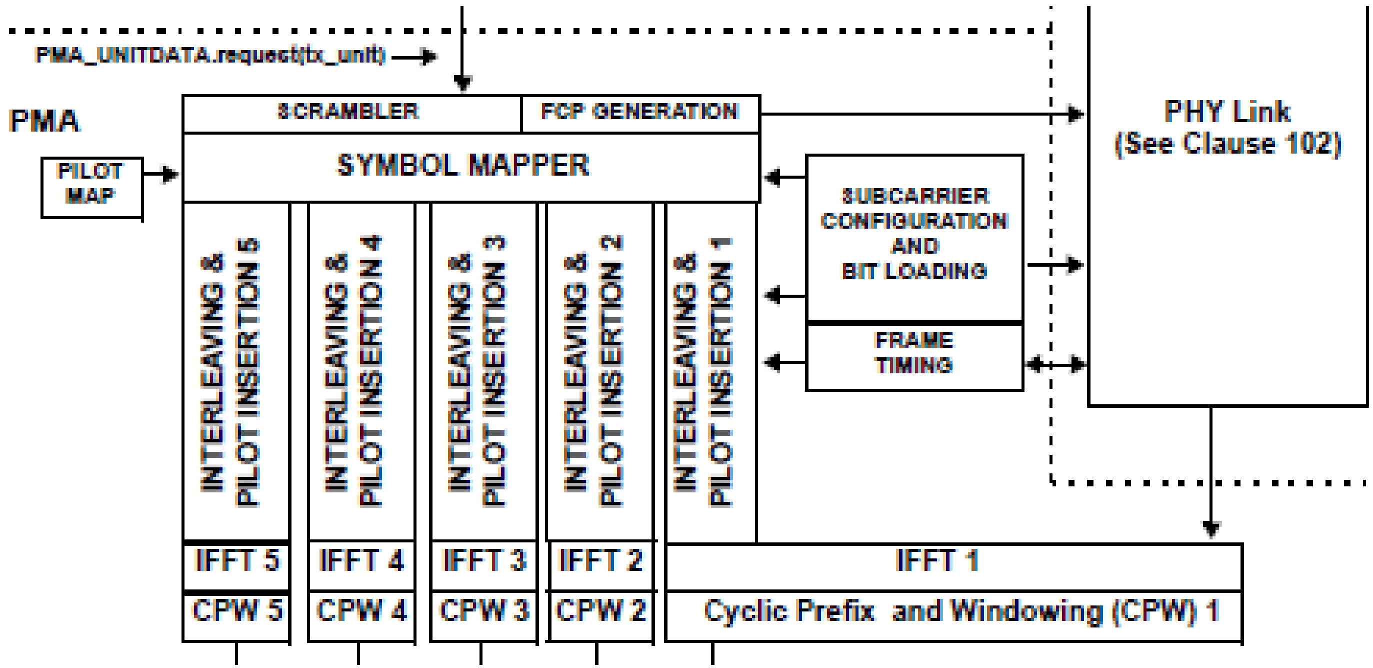
Scattered Pilot Example



Downstream PMA Data Rate

- With a given profile configuration:
  - Subcarriers configured by cable operator
  - Pilot patterns are set
  - Data load is constant per 128 symbol frame
- Symbol time = useful symbol (20 µsec) + configured cyclic prefix size: e.g. 0.5 µsec
- DS_DataRate = data load / frame time
- In EPoC, the PMA_UNITDATA.request is a bit-wise interface, with a nominal data rate of DS_DataRate (US_DataRate)

Mapping PCS Data bits to Symbols



The DS symbol mapper takes one bit at a time across the PMA_UNITDATA.request() and maps the bits into subcarriers, for all data-carrying subcarriers in a symbol, beginning at lowest frequency subcarrier, then moves to the next symbol. Since codewords can straddle frames, the first bit of the start of the first codeword following start of the next frame is sent in the current PHY Link (sounds complicated, but is straightforward).

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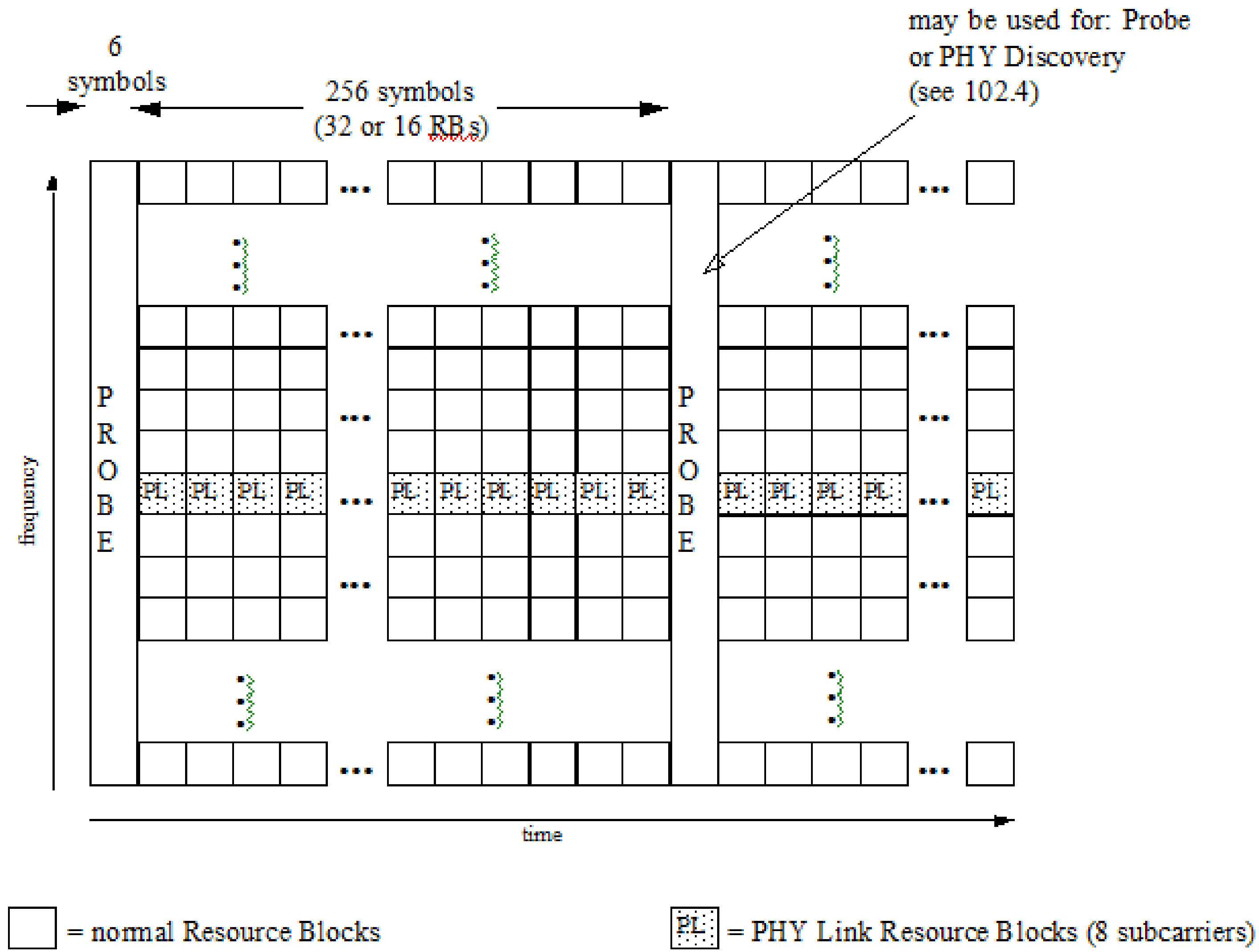
Upstream OFDMA Framing

- US cable receiver require that individual CNU transmitters be pre-equalized to compensate for varying coaxial cable plant conditions.
  - OFDM channel estimation is performed using Probes
  - CLT sets each individual CNU’s pre-equalization
  - A Probe region is part of the upstream Superframe
- To facilitate both better symbol utilization, time-based interleaving protection, and 1D to 2D mapping, the US uses a resource block (RB) to “build” the US RB Superframe. RB length is either 8 or 16 symbols (resource elements)

US RB Superframe



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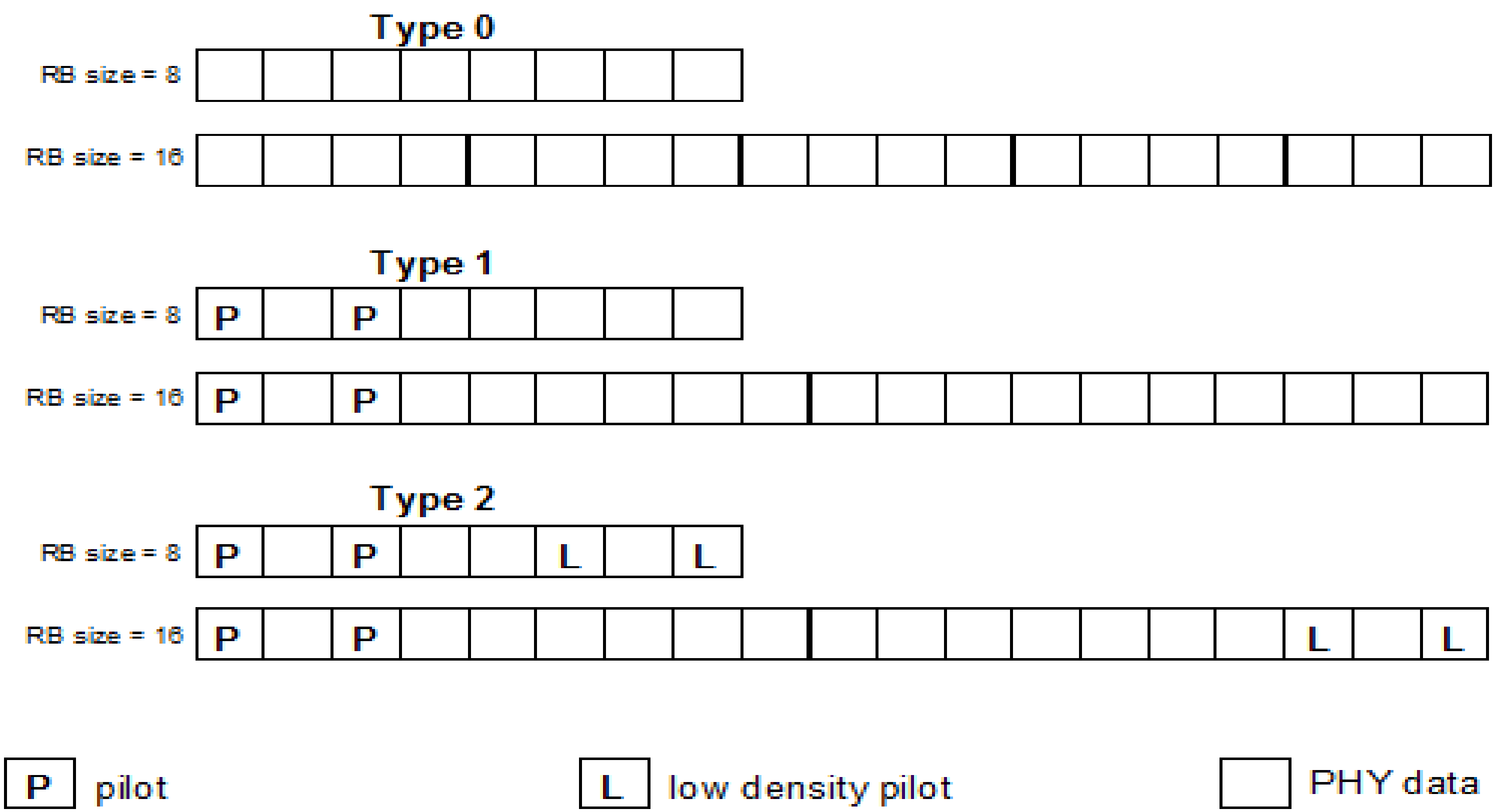
A Word about US Pilots

- There are three (3) RB types.
  - Type 1 and Type 2 placement algorithm is configure by CLT
- P pilot: BPSK modulation pseud-random sequence aligned to subcarrier 0
- L pilot: modulated using the higher modulation order of either BPSK or 4 bits lower than the bit loading specified in the ModTypeSC(n) variable for that subcarrier.



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What is different in EPoC

- OFDM/A framing is not visible to the MAC or MPCP
- In 1G/10G EPON, the MAC specifies the “time on the wire”, in EPoC, the MAC specifies the time within in the DS or US frame.
- EPoC US does not use SP, Burst Delimiter, or End Burst Delimiter (see CL 76), instead uses highly reliable OFDM constructs for start burst marker and end burst marker.
- The job of the US symbol mapper is to determine the starting RB, based on arrival time from the PCS, and then to place the start marker, burst data bits, and end burst marker.

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RBsize = 8 Burst Markers

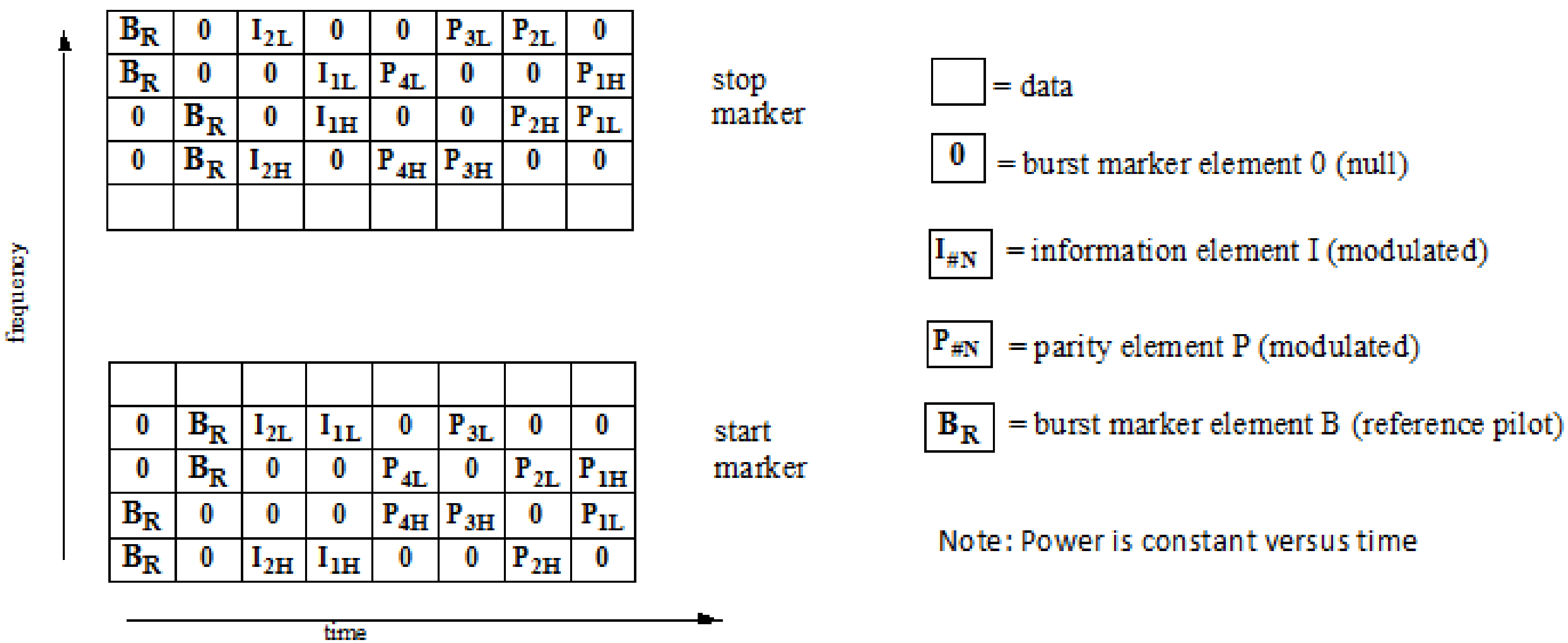

Figure 101–30—Burst marker encoding in 8 symbol resource block

US Symbol Mapper Two Processes

- Idle – "walking" through the data carrying Resource Elements, bit by bit, at the rate specified by *US_DataRate*. Unused RB's (subcarriers) are transferred by column to the IDFT; i.e., become same as excluded subcarriers -> no energy
  - All CNUs are synchronized for Superframe alignment, therefore all CNUs will "walk" the Superframe identically. See *100.2.6.2 US_DataRate.*
- Fill – upon arrival of a burst at the PMA Service Interface, the Symbol Mapper will begin the filling process at the current "walk point" and will being insertions: start/end markers, and burst data bits mapped to QAM symbols, Type 2 L pilots.
  - Pilot placement is determined by the pilot map and Type 1 and Type 2 P pilots are inserted only when the RB is in use and prior to passing to IDFT
  - This process first fills a resource block (row) and then moves to the next resource block (column) and therefore also provides row-column time based interleaving.

Filling overview example, RB length = 8

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This is only an example to illustrate key items. Pilot Map / placement assumed.

New Burst Arrives:

- Idle Walk Point was in RB Frame 1, Sub + 7
- Start Burst Marker **S** placed in Sub + 7
- Data fill D starts at Sub + 10, RE 1 **F**
  - Continues across Exclusion Band(s) and wraps to next RB Frame
- End of burst was detected while filling RB Frame 2, Sub +1, RE 4, with bit position in QAM symbol known
  - Last RE **L** and Last Biit position recorded
  - Padding **P** (0's through scrambler) in all remaining data bits to end of RB
- End Burst Maker **E** placed with encoded Last RE and Last Bit
- Wait for start of next burst

Subcarriers	<- RB Frame 1							->	<- RB Frame 2							->
Sub + X +6	D	D	D	D	D	D	D	D								
Sub + X +5	D	D	D	D	D	D	D	D								
Sub + X +4	D	D	D	D	D	D	D	D								
Sub + X +3	D	D	D	D	D	D	D	D								
Sub + X +2	D	D	D	D	D	D	D	D								
Sub + X +1	D	D	D	D	D	D	D	D								
	Exclusion Band (Width X subcarriers)															
Sub +11	F	D	D	D	D	D	D	D								
Sub +10	S	S	S	S	S	S	S	S								
Sub +9	S	S	S	S	S	S	S	S								
Sub +8	S	S	S	S	S	S	S	S								
Sub +7	S	S	S	S	S	S	S	S								
Sub +6																
Sub +5									E	E	E	E	E	E	E	E
Sub +4									E	E	E	E	E	E	E	E
Sub +3									E	E	E	E	E	E	E	E
Sub +2									E	E	E	E	E	E	E	E
Sub +1									D	D	D	L	P	P	P	P
Sub									D	D	D	D	D	D	D	D
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8

Time ->

Summary

- P802.3bn represents the application of OFDM / OFDMA to extend EPON over Coax
- The Task Force is in the process of completing its main technical decisions and will focus on technical completeness.
- Target will be July 802.3 Plenary to request to go to working group ballot

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Q&A

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THANK YOU!!