Example: Multiple OFDM Downstream Channels and Examining Backwards Compatibility

Mark Laubach, Avi Kliger

Broadcom

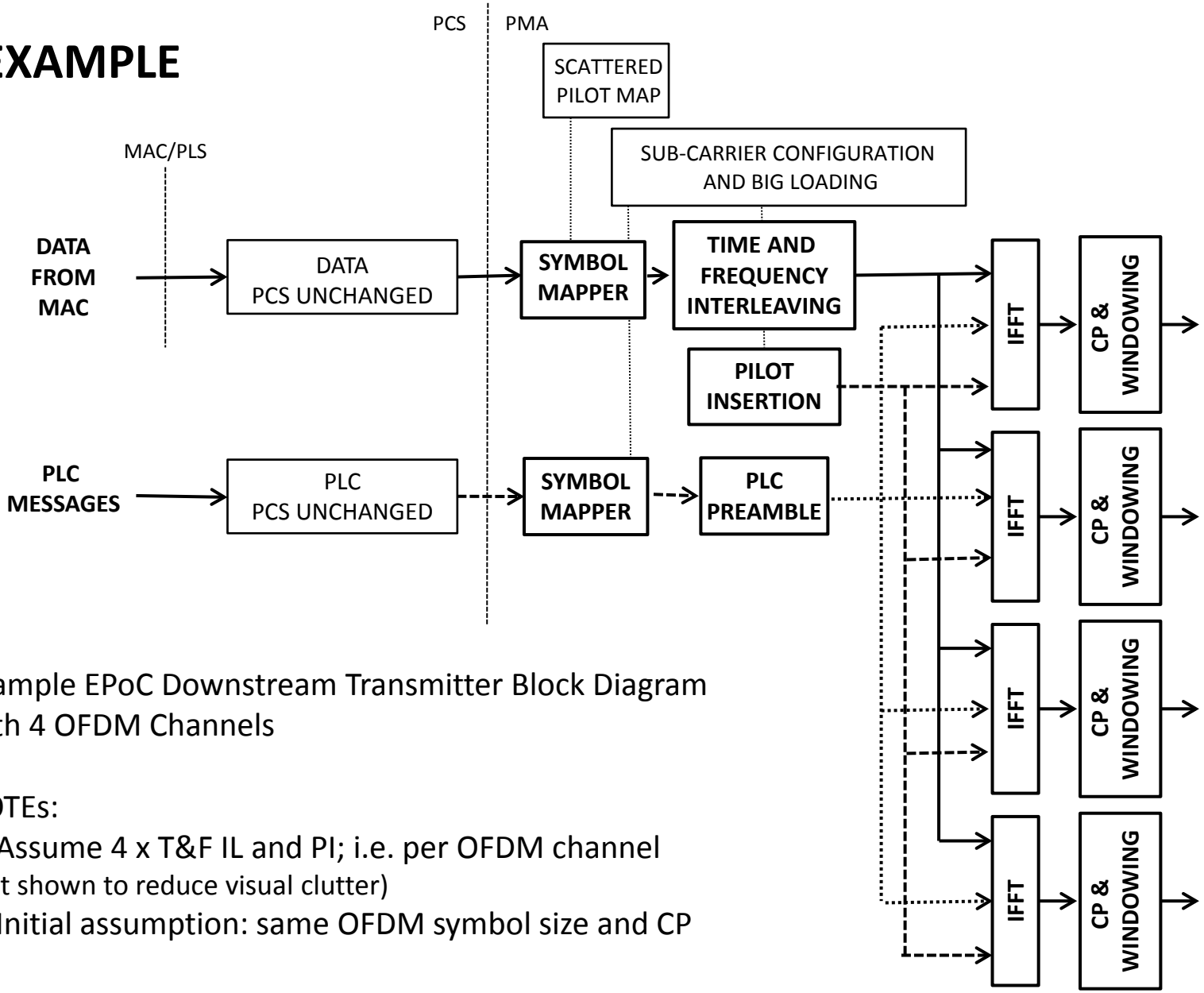
Big Fat Downstream Pipe

MULTIPLE DOWNSTREAM OFDM CHANNELS

Intent of this Presentation

- Socialize an example approach for supporting multiple downstream OFDM channels for EPoC following the “big fat pipe” notion.
- Overview:
  - Expand PMA functions to map / configure 4 OFDM Channels
    - Symbol Mapper
    - Interleaving
    - Pilot Insertion
    - Etc.
  - MAC and PCS remain the same
    - Just a higher data rate across PCS -> PMA interface

EXAMPLE



Example EPoC Downstream Transmitter Block Diagram with 4 OFDM Channels

NOTEs:

1) Assume 4 x T&F IL and PI; i.e. per OFDM channel
(not shown to reduce visual clutter)
2) Initial assumption: same OFDM symbol size and CP

Implementation Impact

Both CLT and CNU downstream:

- 4 x Interleaving, pilot insertion, OFDM IFFT, CP, Windowing
- Expanded Symbol Mapper
  - Added memory for tables
- PCS and PMA at 10Gbps processing

Note:

- Ethernet knows 10Gbps and LDPC:
  - 10GBase-T (Clause 55)

PLC / eOAM Impact

- Messages and mechanisms will need to support CNU signaling and configuring up to 4 OFDM downstream channels
  - Needs to be included in the initial specification
- Question:
  - Number of PLCs?

Channel Bonding Summary

- Creating a single wide downstream channel by an expanded symbol mapper across 4 separate OFDM channels in the PMA is straightforward
  - 10Gbps PCS processing is known in Ethernet
    - E.g. 10GBase-T uses LDPC
  - Initial treatment in PLC and eOAM for 4 DS channels is straightforward

Reality Questions for Task Force

- Will vendors / operators want to burden initial CNUs with multiple OFDM channels?
  - Where and when is the RF spectrum?
    - Observation: question also applies to upstream….
  - Will industry want to get some experience first?
  - Most likely: start with one channel for DS and one for US
- Questions considered in this presentation:
  - How to support one (1) channel and four (4) channel CNUs in the future?
  - What are the backwards compatibility issues?
  - What is impact on CNUs?

MIXING GENERATIONS OF CNUS IN THE DOWNSTREAM

Example Assumptions

- Two generations of CNUs:
  - 1 DS channel (1DSxCNU)
  - 4 DS channels (4DSxCNU)

- Focus is on downstream in this presentation:
  - Separate and Shared (mixed) RF spectrum scenarios

Upstream generation differences should not be an issue:

- Channel differences can be handled via TDMA and 1D-to-2D Gate assignment awareness
- Plan for it in standard
  - CNU upstream capability detection in a must in the PLC

Scenario: Separate RF Spectrum

- Separate DS RF spectrum – “1” and “4”
  - Similar to 1G-EPON and 10G-EPON
    - Difference is that cable operators can (re)provision amount of RF spectrum as needed
  - Cable operator can adjust allocation of RF spectrum as needed as population of CNUs shifts from models 1DSxCNU to 4DSxCNU
  - Single CLT can handle both DS channels to keep under a single MAC domain
    - Upstream still TDMA shared

Scenario: Shared DS RF Spectrum “mixed”

- Existing 1DSxCNUs use original OFDM channel
- Added 4DSxCNUs share same original channel with 1DSxCNUs and use any additional RF spectrum allocated as a second sub-channel for 4DSxCNUs only.
  - This example will use a “sub-channel” term to distinguish the two channels
- Packet ordering and jitter preservation impact:
  - 4DSxCNUs will require two FEC paths requiring additional complexity: packet overhead, implementation, receiver buffer memory, and latency for maintaining packet order and timing

Backwards Compatibility Summary

Deployment	Mode	Comments
1DSxCNU	1	RF DS spectrum just for 1DSxCNU
4DSxCNU	4	RF DS spectrum just for 4DSxCNU
1DSxCNU and 4DSxCNU	1 and 4	RF DS spectrum for 1DSxCNUs separate from 4DSxCNUs, no sharing of same DS spectrum. CLT handles both in the same MAC domain.
1DSxCNU and 4DSxCNU	Mixed	RF DS spectrum for 1DSxCNU channel now shared with 4DSxCNUs, added spectrum for 4DSxCNUs only, impacts with added implementation relative cost and latency. Burdens 4DSxCNUs with extra relative cost when operating in mixed mode.

Note: In all cases, cable operators will need to initially provision RF spectrum and then later adjust as they require.

Impact of Mixed Mode

- +1 FEC path: one for each subchannel
- Playout buffer for packet ordering and timing
  - Buffer memory for 10Gbps * P symbols @ Tsym
    - Example: for 20 usec, 25K bytes (200000 bits) per Tsym
  - Table memory
    - Example: for 25KB and 72B packet, 348 packets * 42 bits = 16.1K bits per Tsym
  - Latency = P * Tsym.
    - P = number of symbols (depth) of playout buffer.
    - Tsym = 20 usec or 40 usec (approximately!! factor 0.9756 with CP of 5 usec)
  - How large is P? Dependent on speed of lower bit rate subchannel: codeword bps
- Added implementation relative cost
  - De-skew / playout algorithm, with timeouts, recovery from codeword loss, etc.
  - Required for 4DSxCNUs (only):

Question for Task Force

- Are the needs for mixed mode operation sufficient to justify the added complexity, relative cost, and latency?
  - Note: this is only required in mixed mode when multiple parallel FEC paths are in use.
  - Not needed when only one FEC path is in use – mode 1 or 4; i.e., the added complexity is only needed during model deployment overlap.
    - When operating with two subchannels, otherwise not needed

EXAMPLE OF MIXED MODE ARCHITECTURE AND REQUIREMENTS

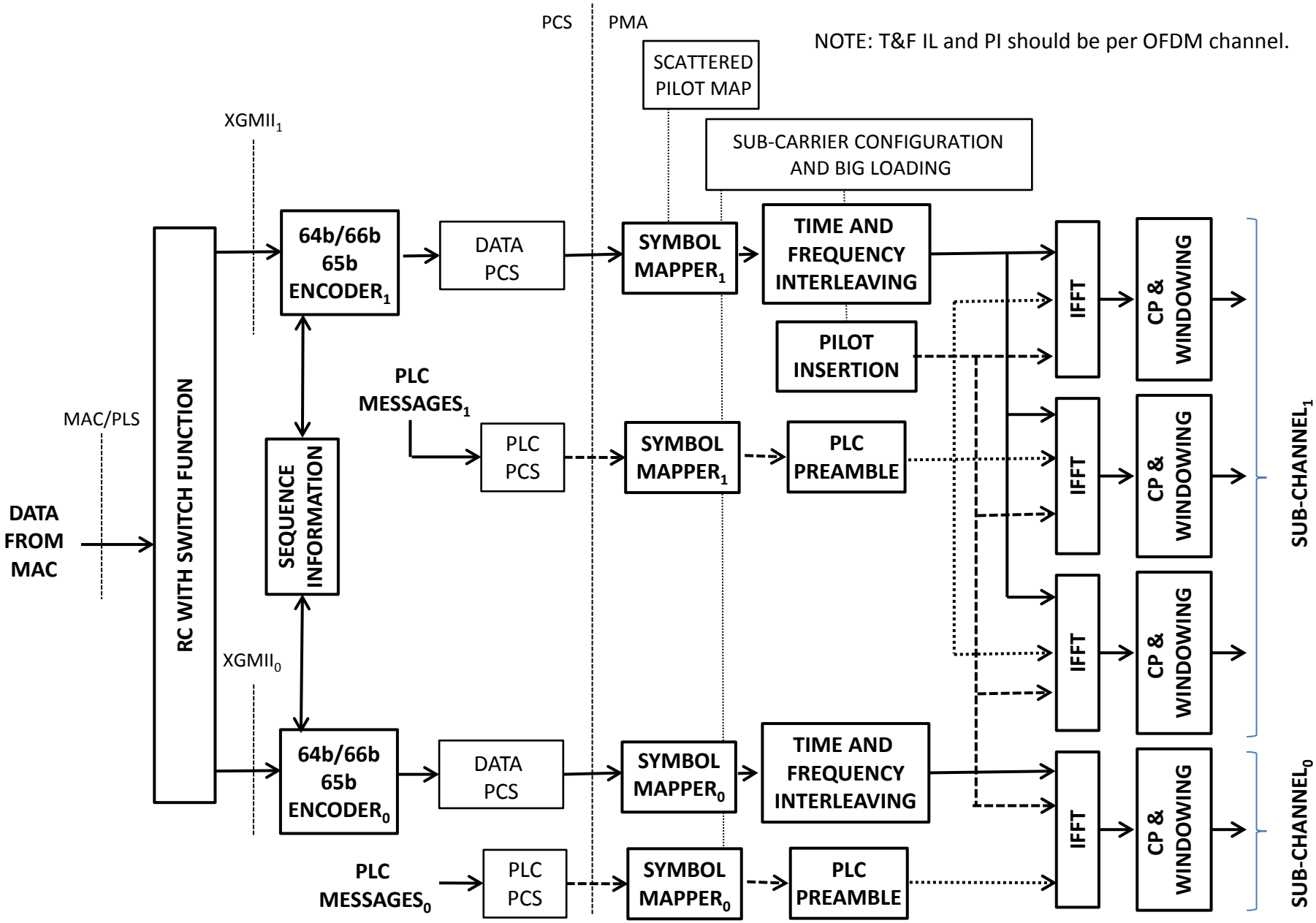
Example: A Possible Solution

- Introduce the concept of two downstream sub-channels, e.g. Sub-Channel$_0$ and Sub-Channel$_1$
  - Sub-Channel0 is only for 1DSxCNUs
  - Both sub-channels are processed by 4DSxCNUs

- Note: focus of this example is on impact on the CNU

Some Up-Front considerations

- PLC architecture must support both sub-channels
  - 1DSxCNUs would be required to only process Sub-channel$_0$ relevant information and ignore Sub-channel$_1$ information
- Burden is placed on 4DSxCNUs and two-channel CLT transmitter
  - Need to maintain packet ordering
  - Need to process both sub-channels if present
- Example defines XGMII$_0$ and XGMII$_1$ in the CLT transmit direction to support use of the two sub-channels


PCS
PMA
NOTE: T&F IL and PI should be per OFDM channel.
SCATTERED PILOT MAP
SUB-CARRIER CONFIGURATION AND BIG LOADING
XGMII1
64b/66b 65b ENCODER1
DATA PCS
SYMBOL MAPPER1
TIME AND FREQUENCY INTERLEAVING
PILOT INSERTION
IFFT
CP & WINDOWING
PLC MESSAGES1
PLC PCS
SYMBOL MAPPER1
PLC PREAMBLE
IFFT
CP & WINDOWING
SUB-CHANNEL1
MAC/PLS
DATA FROM MAC
RC WITH SWITCH FUNCTION
SEQUENCE INFORMATION
IFFT
CP & WINDOWING
XGMII0
64b/66b 65b ENCODER0
DATA PCS
SYMBOL MAPPER0
TIME AND FREQUENCY INTERLEAVING
IFFT
CP & WINDOWING
SUB-CHANNEL0
PLC MESSAGES0
PLC PCS
SYMBOL MAPPER0
PLC PREAMBLE

PCS/PMA Implementation Impact

In both CLT and CNU downstream:

- 2 x Encoder, FEC, Scrambler footprint
  - In 4DSxCNU only
  - Example shows Reconciliation Sublayer switch, can be done elsewhere
- In PMA, Mapper, etc. could support both sub-channels with partition understanding
- Added table and functions in RC, algorithm for switching, idling, codeword filling, etc.
  - May not be the most efficient as MAC packet stream is serialized

TX: A few rules for Switching

- Downstream RS must select which sub-XGMII interfaces to use
  - LLID decision based – need to add a table
- Rule 1: MAC Frames and codewords are never split across sub-channels
- Rule 2: Broadcasts are placed on Sub-Channel$_0$
- Rule 3: MAC Frames on LLIDs for single-channel CNUs are only placed on Sub-Channel$_0$
- All other placement (switching) rules are up to the implementer and/or cable operator

Frame Sequence Ordering indication

- An 4DSxCNU will receive frames simultaneous on each sub-channel
  - Playout ordering and de-jittering required
  - Timestamp based
- Timestamp insertion in CLT TX
  - Include optional frame sequence timestamp in line encoded along with the Frame Start /S/ encoding.
    - Create new “/S/ with ordering” control
  - Common timestamp generator for both sub-channels that the CLT assigns upon receiving a frame across the XGMII
  - When feature is “on”, presented to all CNUs on both sub-channels

Frame Ordering Indication

- CNU RX method: if “/S/ with ordering” is present
  - A 1DSxCNU identifies the “/S/ with ordering” and ignores the timestamp value, and skips over the octets and processes the frame normally
  - An 4DSxCNU must process the timestamp :
    - Playout in time order to maintain frame ordering and delivery timing to the CNU upper layer processing (e.g. MAC)
    - Impose a fixed delay on play-out processing, with no more than *P* symbol time delay (what is *P*?)
      - This permit vendors implementation choice, use of timers, etc.

Frame Ordering Indication

- RX-side line-encoding processing
  - For either 1DSxCNU or 4DSxCNU, upon reception of a frame with an “/S/ with ordering”
    - The “/S/ with ordering” must be converted back to a normal “/S/” and the timestamp removed before being passed “back up” the Rx XGMII to the MAC

Modifications to support /S/ with Ordering

- Table 46-3 and Table 46-4
  - Re-claim reserved value, with 0xFC to mean
    - Start, same semantics as 0xFB for EPoC use
  - This is to reserve value for use in satisfying Section 49.2.4.6 and adding to Table 49-1
- Figure 49-7
  - Add new Control block format for 0xfc
    - $Q_0Q_1Q_2D_0D_1D_2D_3$
    - Where Q code is an octet, three octets for a timestamp
    - Intent is for 64b/66b line encoding to signal that for a Start, data is preceded by a 24-bit timestamp

Modifications Continued

- Table 49-1
  - Add new row
    - “start with ordering”, /S/, 0xfc, Start followed by 24-bit timestamp value
- Add new section 49.2.4.12 [?]
  - Start (/S/) with ordering
    - Reserved for EPoC PHY use. In the CLT transmitter only (downstream), upon receiving a valid start control character (/S/) as per Section 49.2.4.8, if EPoC_PHY_CLT_Ordering_Enabled is True, the EPoC 65b encoder will change the block type value from 0xfb to 0xfc, insert the timestamp value and construct the block payload as per Figure 49-7. In the CNU receiver, if a block type value of 0xfc is received, the EPoC 65b decoder will treat this as equivalent to 0xfb (/S/) and will not include the timestamp octets in the decoded MAC frame.

Timestamp Details

- 10.24 nSec clock
- 24 bits
- Wrap around

Note:

- Max symbol size of 45 uSec and 128 symbols/frame. If PLC frame duration is 5.76 mSec, 20 bits is sufficient rounded up to 24 to permit octet alignment in line encoding

When to Enable?

- For CLT operating in mode 1 or mode 4: (no sub-channel operation), set EPoC_PHY_CLT_Ordering_Enabled to False
  - Feature not needed for these modes
- For CLT operating in mixed mode set EPoC_PHY_CLT_Ordering_Enabled to True

PLC Implications

- Either one-only or one-per sub-channel PLC can be supported
  - One-only
    - Downstream provisioning must be qualified by sub-channel
    - 1DSxCNU only uses Sub-channel$_0$
    - 4DSxCNU must process both
  - One (at least one) per sub-channel
    - Downstream provisioning applies to that sub-channel
    - 1DSxCNU must be re-directed to Sub-Channel$_0$ PLC if its PLC hunt lands on the 4DSxCNU PLC

Impact on MPCP/DBA

- When EPoC_PHY_CLT_Ordering is True, MPCP/DBA must add 4 octets to every frame size for downstream calculations
  - Control Block Type octet + 3 timestamp octets

Deployment and Provisioning Impact

- Same as with bonded OFDM channels, cable operators will need to:
  - Enable OFDM channels
  - Provision frequency allocation for each channel
  - Configure sub-carriers as needed
  - Change provisioning as RF spectrum availability changes
  - Balance / change provisioned allocation of RF spectrum for Sub-Channel$_0$ vs Sub-Channel$_1$
    - Will change over time as 1DSxCNU service load diminishes with respect to 4DSxCNU service load

Backwards Compatibility Summary

- Mixed “shared” mode burdens CNU complexity and relative cost over keep RF DS spectrum separate
- For mixed:
  - Two sub-channel CLT downstream transmitter is feasible
  - Implementation burden on second-generation CLT and 4DSxCNUs
    - Packet memory, tables, algorithms, and latency when in mixed mode
  - Impact on DBA management may not be elegant
  - With this example, adding support for sub-channel IDs for channel provisioning, PLC CNU redirect command, and “/S/ with ordering” processing would be needed initially for 1DSxCNU requirements.

Summary

- Examples have been presented for:
  - Expanding PMA to 4-OFDM channels for creating a ~10Gbps downstream
  - Providing backwards compatibility for 1-channel and 4-channel CNUs
    - Added relative cost and complexity burden for 4-channel CNUs - only when operating in mixed mode
- Contributions are needed to propose course for P802.3bn
  - If supporting “mixed” (shared downstream RF spectrum), need to go into more specification and impact details than this presentation

THANK YOU