PHY Link Channel

Resource Allocation, Overhead, Impact on Procedures

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Summary

- A PHY Control Channel (PLC) is needed for
  - Aiding PHY initialization and CNU bring-up
  - Broadcasting information strictly necessary to enable the operation of the PHY layer (e.g., proper demodulation and decoding of data)
  - Collecting CNU-specific information (e.g., supported MCS in DS)
  - It does **not** convey MAC Control information (GATE/REPORT messages)
- This presentation aims at providing more details on the PLC proposal presented in San Antonio
  - Information carried on the PLC (DS/US)
  - Amount of required resources and proposal for resource allocation
  - Implications on buffering requirements and impact on upper layers
- Assumptions:
  - MMP with MCS per profile (**no** bit-loading)
  - In order to ensure **scalability**, each PHY channel (192MHz) has its own, dedicated PLC

Downstream PLC

Purpose of PLC - Downstream

- PLC Reference Signal: Aids PHY acquisition
  - Carrier frequency recovery
  - PHY frame synchronization

- PLC Data: Broadcasts network information + **CNU-specific information**
  - OFDM channel ID
  - DS Bandwidth (Number of available sub-carriers in this OFDM channel)
  - Exclusion bands, e.g.,
    - Start frequency of each EB
    - Bandwidth of each EB
  - Info regarding PHY frame structure
    - TDD split in terms of US/DS OFDM symbols and guard interval
    - FDD US information: carrier frequency, number of available subcarriers
  - Frequency Interleaving pattern (logical to physical subcarrier mapping)
  - Time Interleaving depth for DS
  - Active profiles (active MCS's)
  - **Timing advance information for specific CNU(s)**
  - **Assignment of specific CNU(s) to a given DS/US profile**
  - **Power control information for specific CNU(s)**

Needs definition of a PHY address

Evaluation of Necessary Resources (Upper Bound)

Feature	Item	Value
MMP	Number of profiles	2 bits (max 4 profiles)
	MCS index	4 bits (max 16 MCS)
Exclusion Bands (6MHz)	Number of EBs DS	4 bits (max 16 EBs)
	Index of EB DS	7 bits (2MHz grid)
	Number of EBs US	4 bits (max 16 EBs)
	Index of EB US	7 bits (2MHz grid)
Channel Structure	DS channel width	13 bits (8k FFT)
	US carrier frequency	10 bits (2MHz grid)
	US channel width	13 bits (8k FFT)
	TDD Frame Structure	4 bits (16 possible splits)
Interleaving	DS Interleaving depth	4 bits (16 possible values)
CNU-specific message	CNU ID	48 bits (full Eth. address)
	Timing advance	16 bits (1.2 ns resolution with 80us symbol duration)
	Power control	4 bits
	DS profile assigned	2 bits
	US profile assigned	2 bits
Error Control	CRC	16 bits

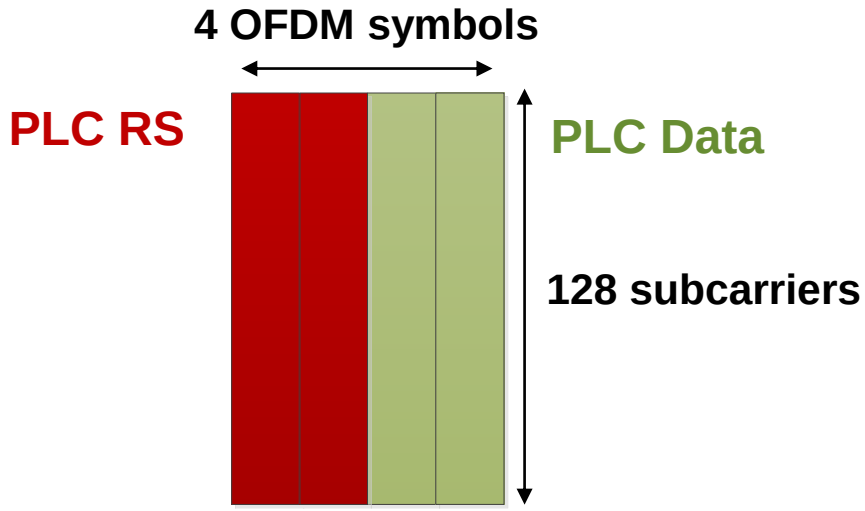
Total: <50 Bytes
(accounting also for an additional PLC header field)

Resources needed:

- **648 bits (802.11n code rate 3/4)**
- **162 QAM symbols (16QAM modulation)**

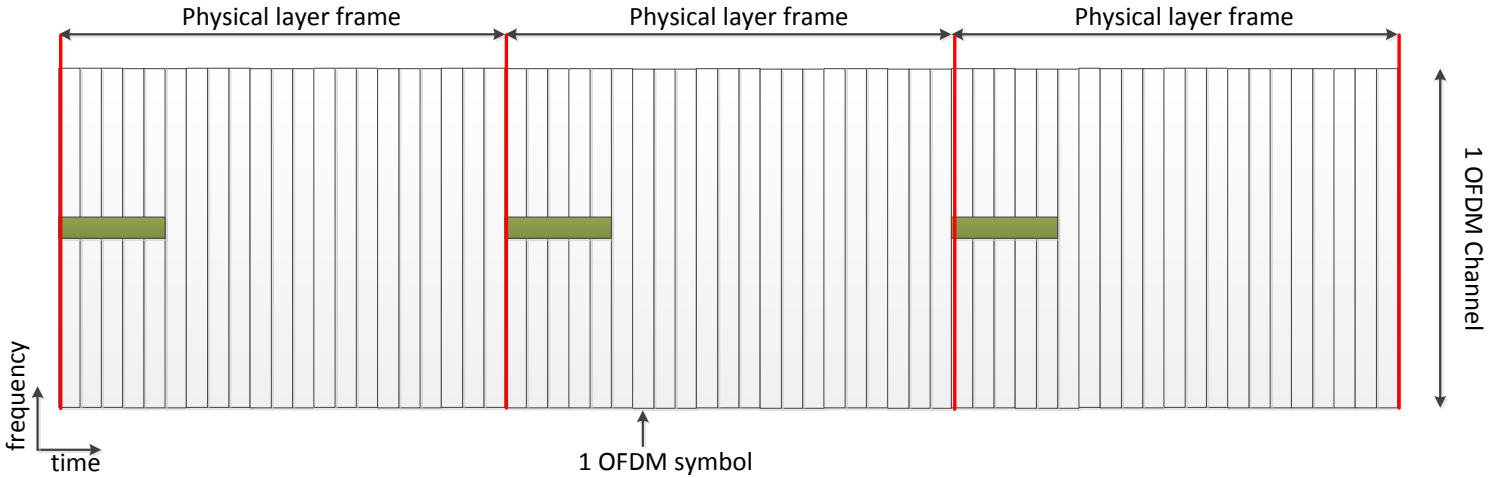
A First Proposal for DS PHY Link

- We propose to allocate a **limited** number of symbols for PLC Data in order to perform
  - Time interleaving
  - Repetition of PLC Data
- PLC includes reference signals (RS) for PHY acquisition (“preamble”)
- Example configuration (8k FFT – would scale accordingly for a different FFT size):



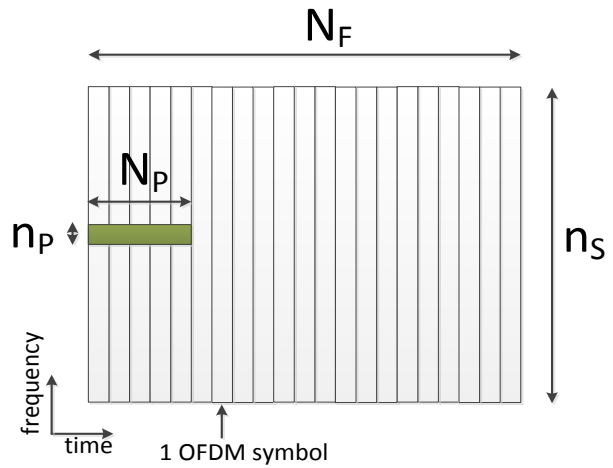
- Why it is good to have a wide-band preamble:
  - Pre-FFT detection (**time-domain processing**)
  - Resilient to:
    - Residual Timing Offset (FFT window placement)
    - **Residual Carrier Frequency Offset (causes inter-carrier-interference)**
    - **Channel delay spread (non-coherent detection)**

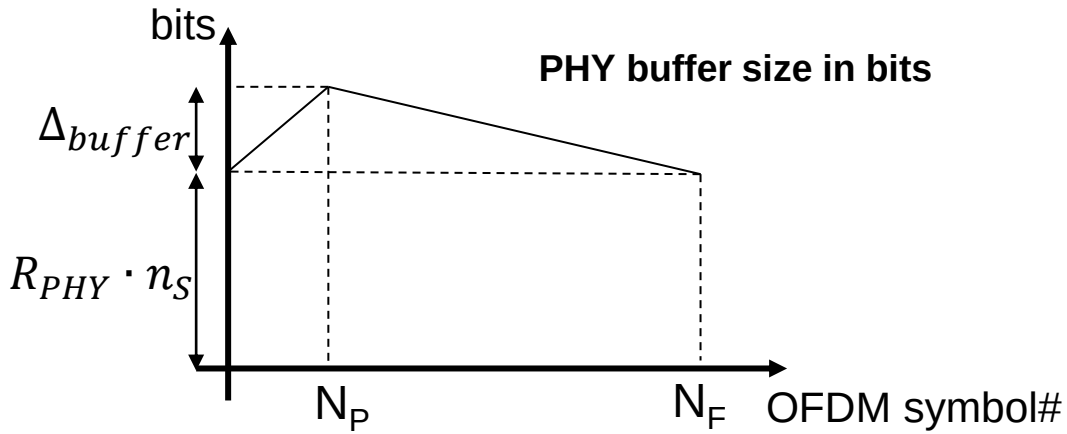
Resources Reserved for PLC - Downstream



- *Frequency* location:
  - We propose to locate the PLC around the center frequency of the OFDM channel
    - *Does it really make sense to center an OFDM channel right on top of an Exclusion Band ?*
    - Alternatively, we may define a *small* set of pre-defined center frequencies on the 2MHz grid.
- *Time* location:
  - A fixed number of subcarriers within the first few symbols of a PHY frame
    - Incurred overhead is the bare minimum
    - Rate adaptation is performed according to the net PHY rate (accounting for all overheads)
      - » MAC is aware of the net PHY rate (accounting for all overheads).
    - Moderate increase of buffering requirements at the PHY (see next slide)

Buffering Requirements





- No interleaving (worst case): proportional to the PLC overhead and PHY frame duration in symbols (N_{FRAME})
  - R_{PHY} is the maximum possible PHY rate in bps/Hz (accounting for all overheads)
  - Buffer increase can be quantified as

$$\Delta_{buffer} = R_{PHY} \cdot n_P \cdot N_P \text{ [bits]}$$

  - The *relative* buffer increase can be computed as

$$\Delta_{buffer\%} = \frac{R_{PHY} \cdot n_P \cdot N_P}{R_{PHY} \cdot n_S} \times 100$$

Nominal Buffering requirements for a single OFDM symbol

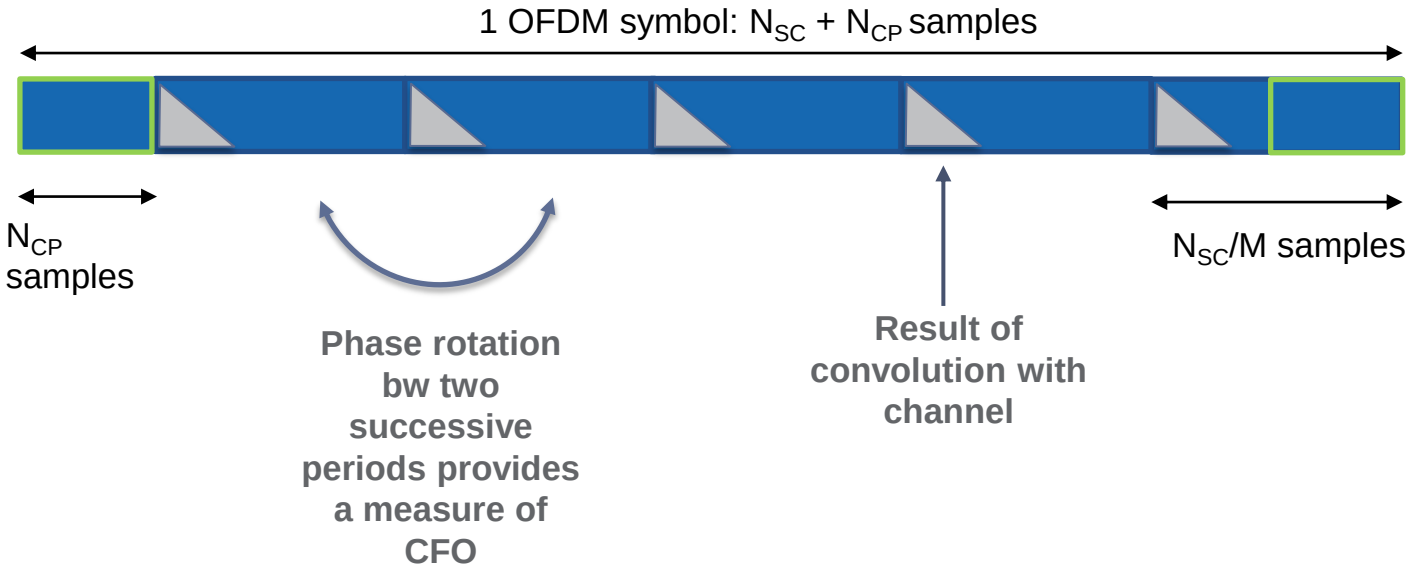
$$= \frac{n_P \cdot N_P}{n_S \cdot N_F} \cdot N_F \times 100$$

Buffer increase % = OH_{PLC} x N_F x 100

  - Same buffering requirements apply at both TX and RX side

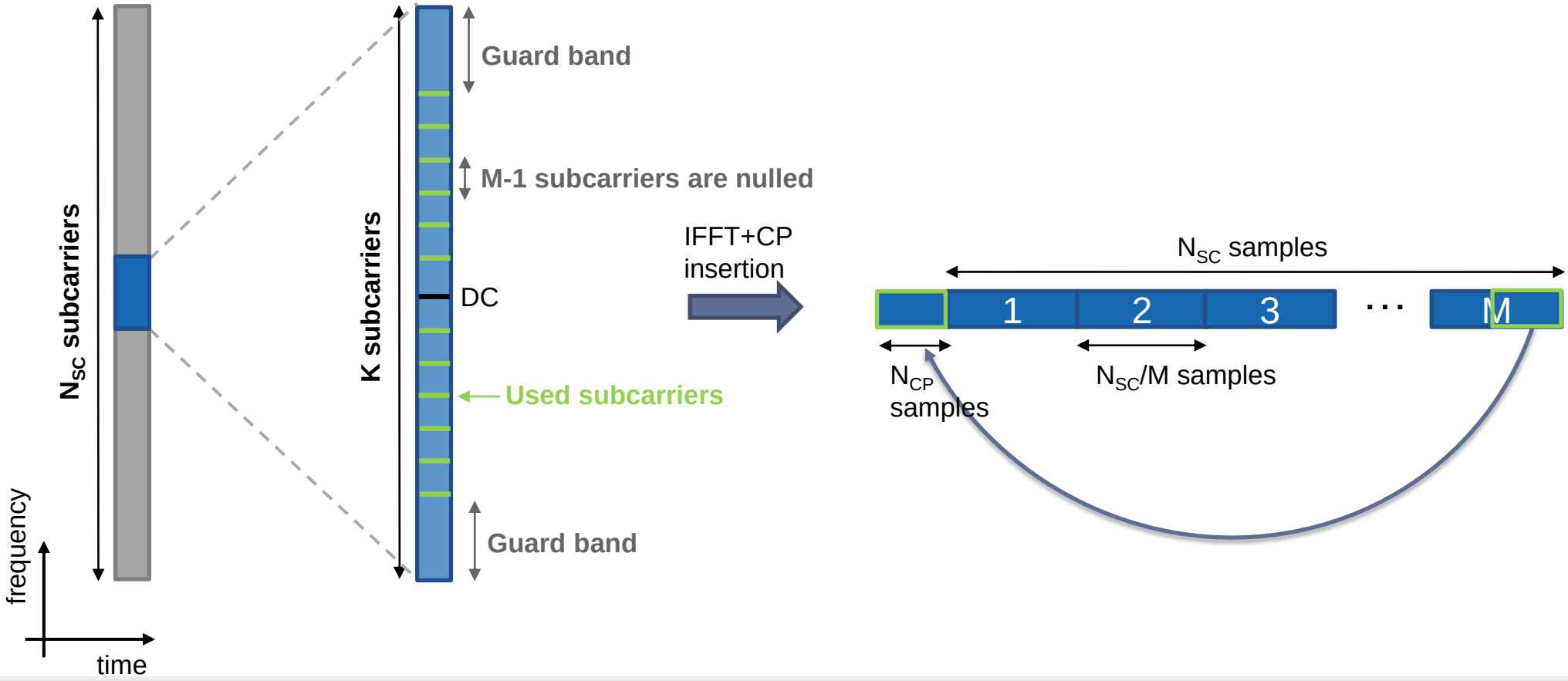
Preamble Structure in Time

- The preamble signal is designed so that in the time domain (after band-pass filtering) it appears as a periodic/repeating sequence
  - Periodic structure is not affected by convolution with channel
  - Periodic structure facilitates CFO and Rx I/Q imbalance estimation
  - Also, the resulting estimate already makes use of all the energy coming from the channel, without the need for a multi-finger correlation

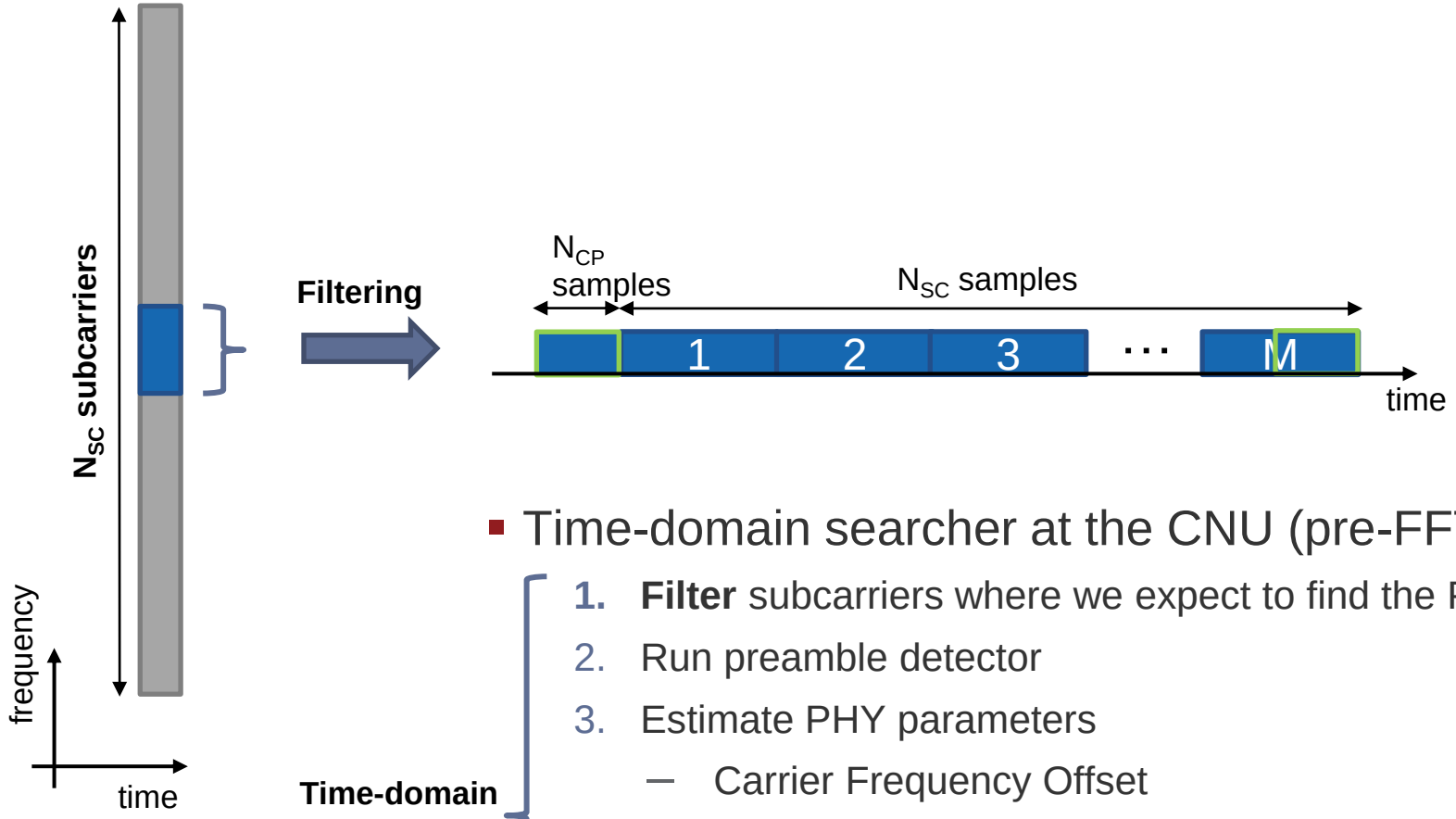


Preamble Structure in Frequency and Time

- Time-periodic structure with M repetitions is induced by employing only 1 subcarrier out of M in the frequency domain
- Energy loss due to subcarrier nulling can be partially or entirely recovered by boosting the power of preamble QAM symbols
  - E.g., M=2 leads to an energy loss of 3dB. This can be compensated by a 3dB power boost of the Preamble subcarriers.



Initial PHY Acquisition Procedure



- Time-domain searcher at the CNU (pre-FFT)

Time-domain processing

1. **Filter** subcarriers where we expect to find the PLC
2. Run preamble detector
3. Estimate PHY parameters
   - Carrier Frequency Offset
   - Raw symbol timing synchronization
   - Gain control
   - Others as needed
4. Find FFT boundaries (fine symbol timing synchronization)
5. **Perform IFFT** and decode PLC information only

Upstream PLC

Purpose of PLC - Upstream

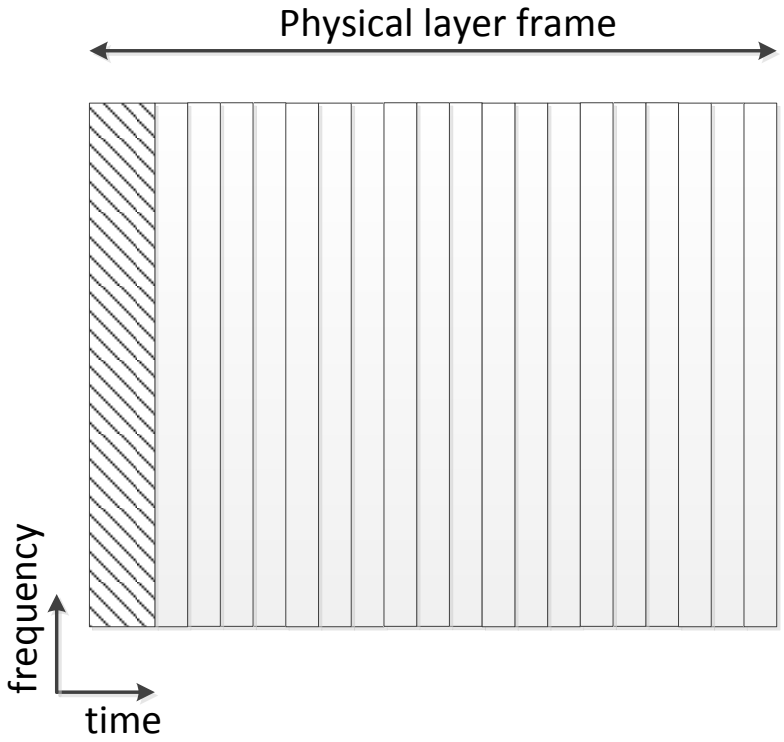
- PLC Reference Signal: Aids PHY procedures
  - Timing advance estimation for the CNU which is transmitting
  - Assignment of the CNU to a specific US profile (evaluation of US MCS)

- PLC Data: CNU-specific information
  - PHY address identifying this CNU
  - Supported MCS for DS for this CNU (needed to assign CNU to a specific DS profile)
  - Unusable sub-carriers in DS for this CNU (needed by CLT to determine Exclusion Bands in DS)
  - Protected with a strong FEC code

Feature	Item	Value
CNU-specific	CNU ID	48 bits (full Eth. address)
	DS profile supported	2 bits
	Number of EBs DS	4 bits (max 16 EBs)
	Index of EB DS	7 bits (2MHz grid)
Error Control	CRC	16 bits

Resources Reserved for PLC - Upstream

- The upstream PLC is accessed with a **contention-based protocol**
- Resources need to be reserved for the PLC in upstream
  - Reserve a fixed number of OFDM symbols within a PHY frame

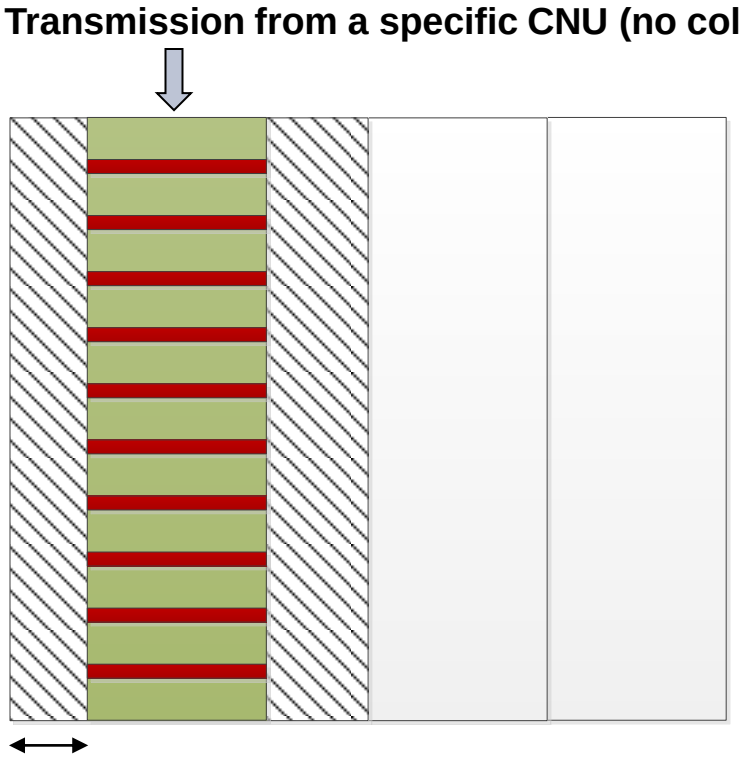


Resources Reserved for PLC - Upstream

- The upstream PLC is accessed with a **contention-based protocol**
- Resources need to be reserved for the PLC in upstream
  - Reserve a fixed number of OFDM symbols within a PHY frame

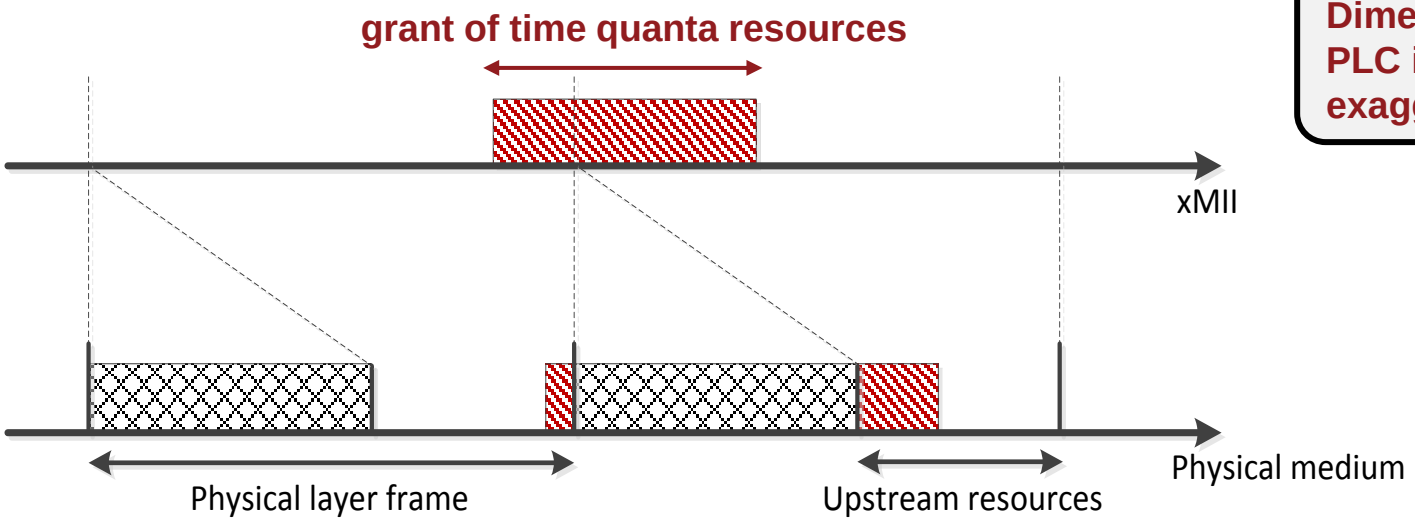
Features:

- CLT estimates **full channel** for the user and assigns US profile
- CLT estimates timing advance (to compensate propagation delay)
- CLT estimates optimal power control settings
- CNU is identified after decoding PLC Data



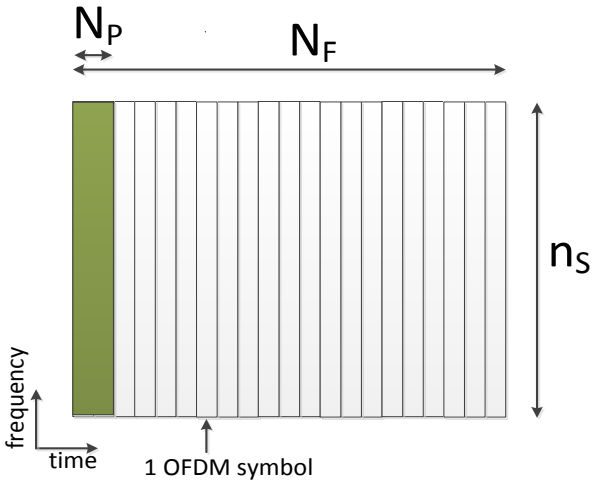
Resource Mapping

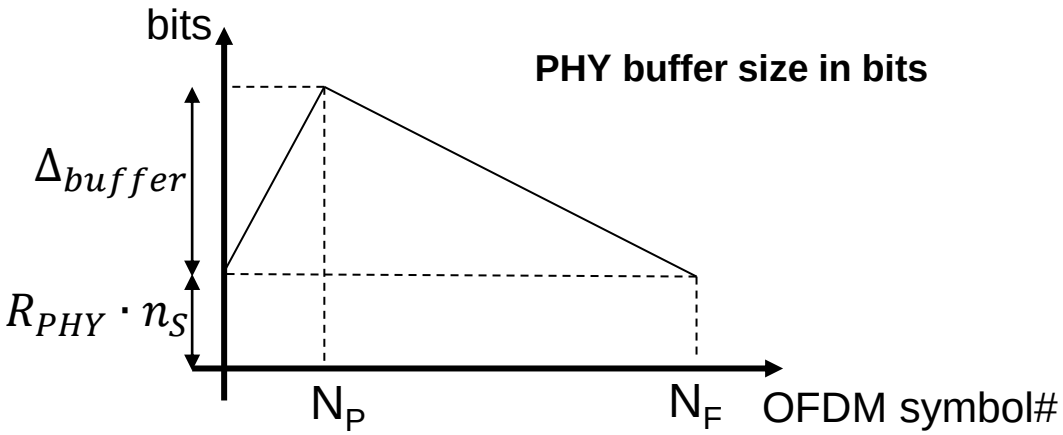
- With the proposed frame structure for upstream, data transmission is not allowed in the two (or more) OFDM symbols dedicated for the US PLC.
- However, at the xMII interface, we require a full-duplex, continuous transmission
- This can be enforced by a proper **mapping** between the xMII time scale and the PHY time scale
  - One-to-one map of time intervals (see figure)
  - An additional 1D-to-2D map may be needed to map time intervals to time/frequency resources
  - Increased buffering requirements (see next slide)



Dimension of US PLC is here exaggerated

Buffering Requirements





- Analysis is analogous to DS case:
  - R_{PHY} is the maximum possible PHY rate in bps/Hz (accounting for all overheads)
  - Buffer increase can be quantified as

$$\Delta_{buffer} = R_{PHY} \cdot n_S \cdot N_P \text{ [bits]}$$

  - The *relative* buffer increase can be computed as

$$\Delta_{buffer\%} = \frac{R_{PHY} \cdot n_S \cdot N_P}{R_{PHY} \cdot n_S} \times 100 = \frac{N_P}{N_F} \cdot N_F \times 100$$

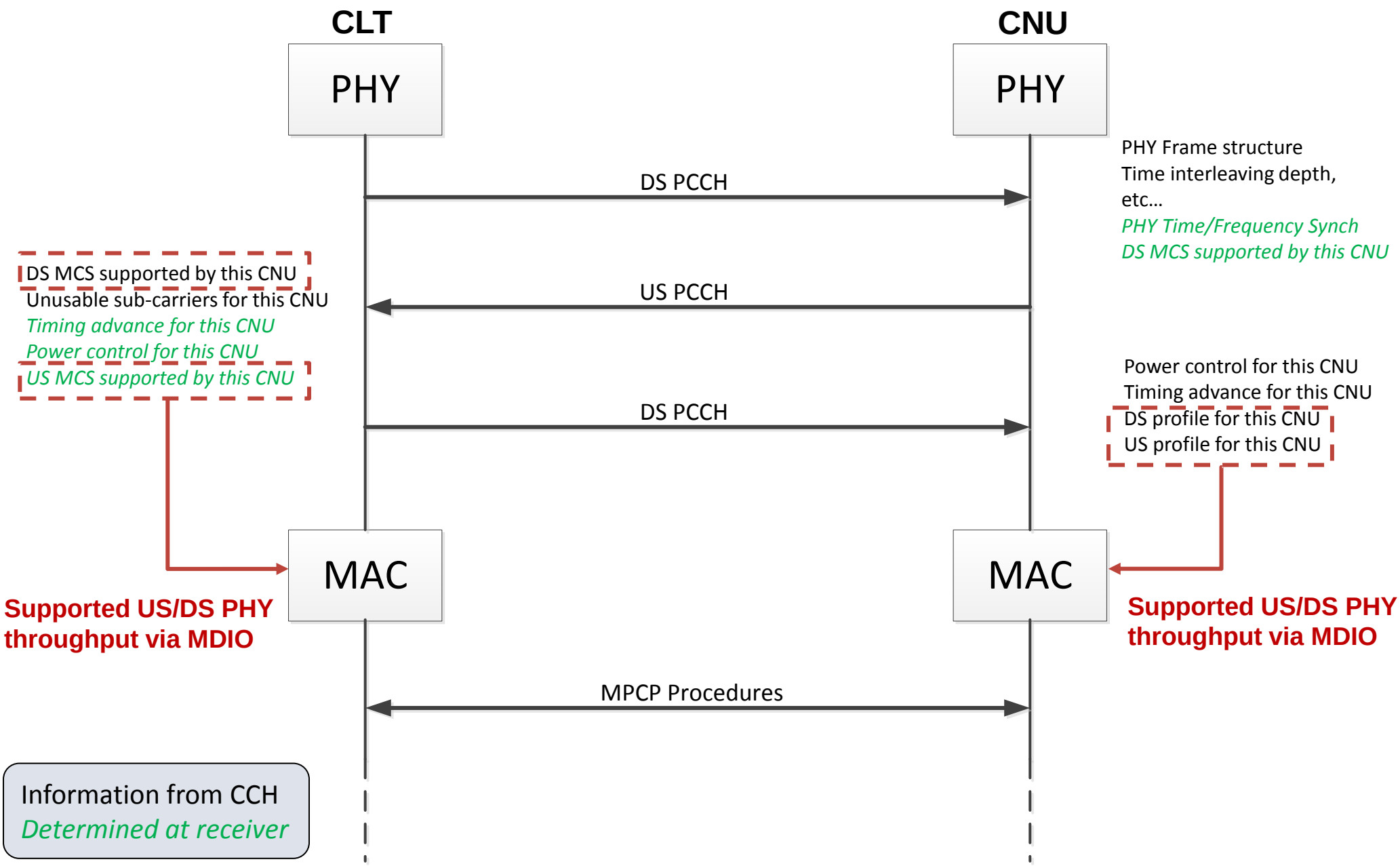
Nominal Buffering requirements for a single OFDM symbol

Buffer increase % = OH_{PLC} x N_F x 100

  - This requirement (and the related delay) applies at both TX and RX side

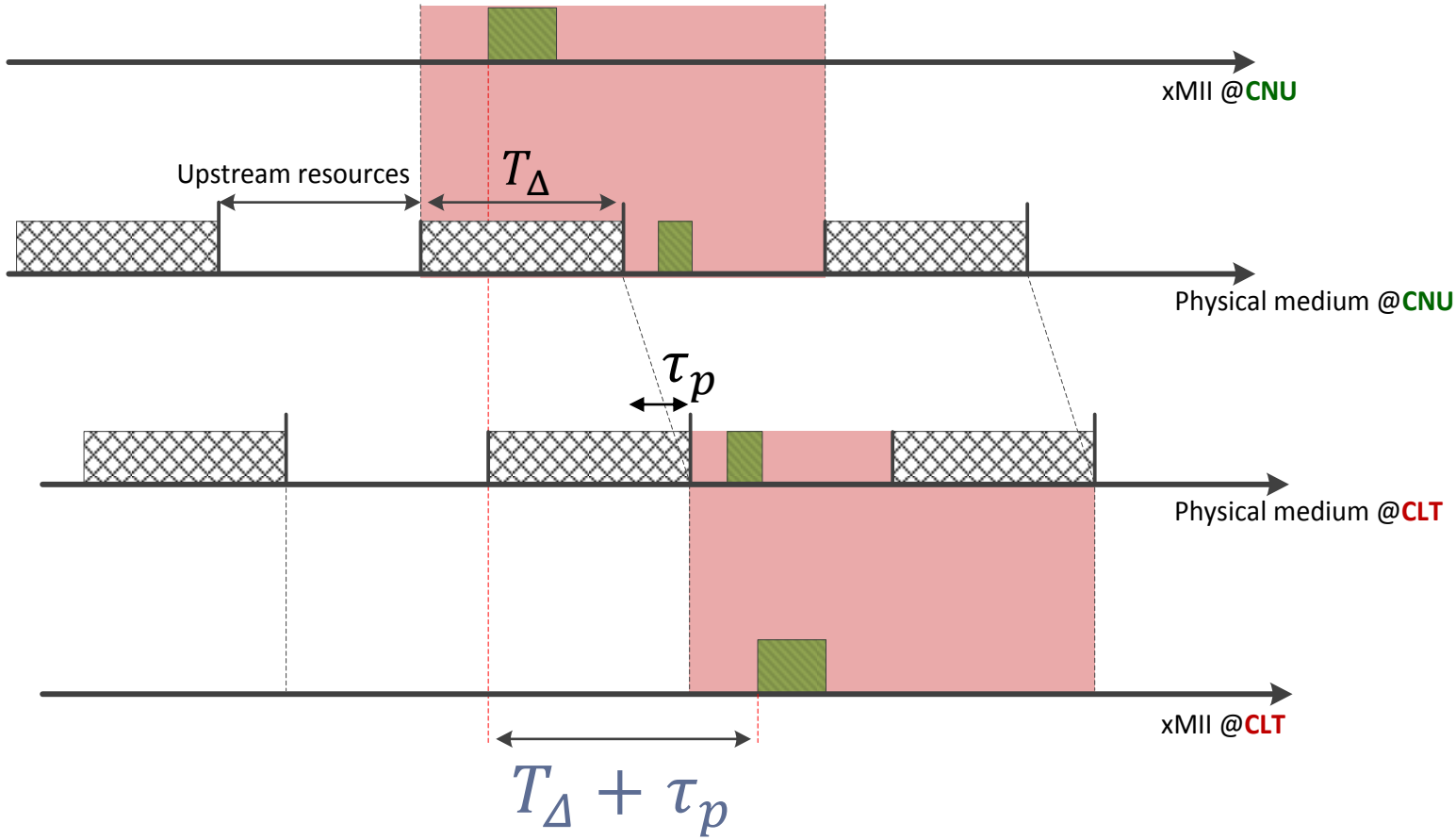
Initialization Procedure

Timeline of PHY Initialization Procedure

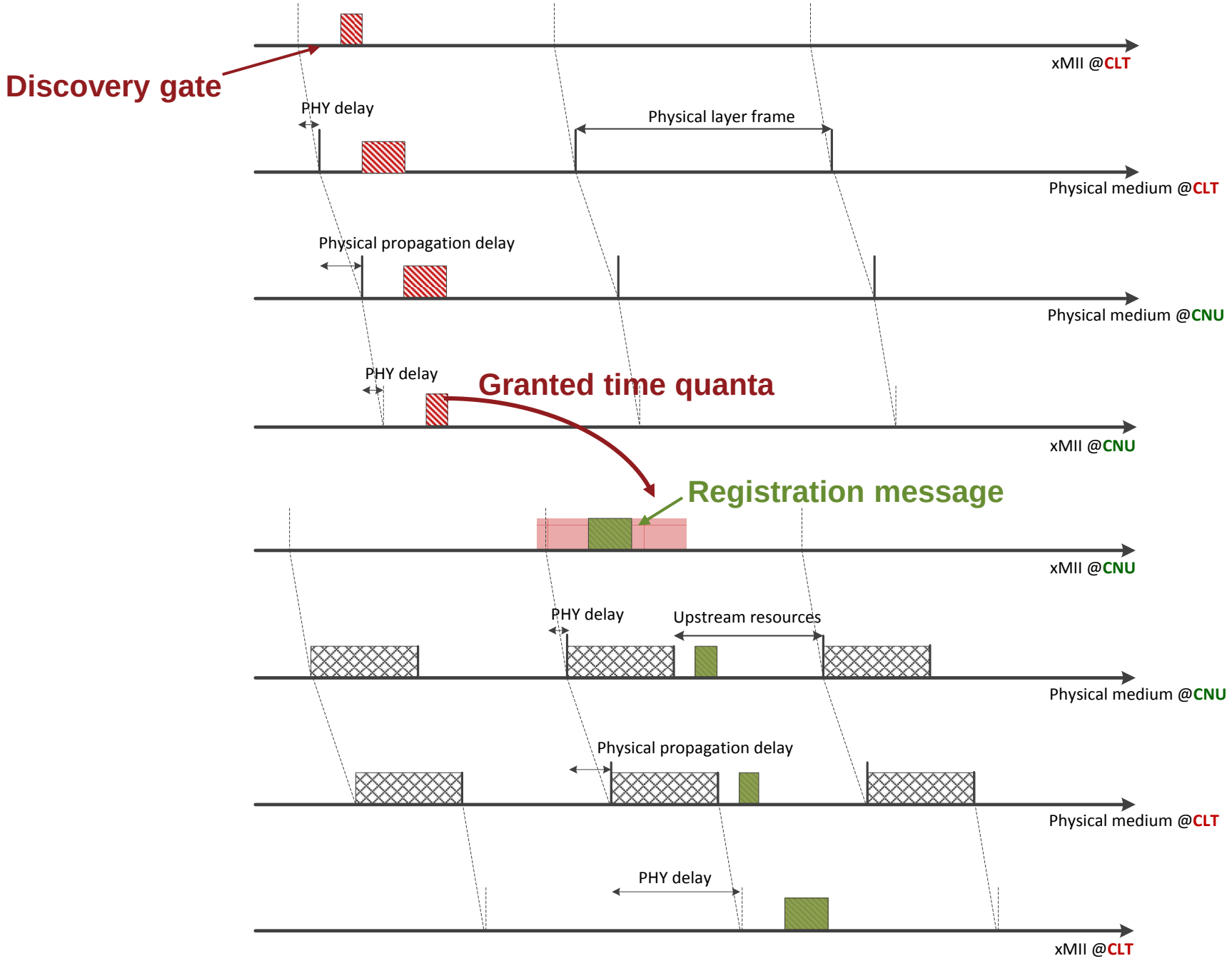


Overall Delay for Upstream Transmission

- Let's assume that we have **no** PHY processing delays and we have only propagation delays
- Let's assume that PHY initialization has been successful
  - Proper timing advance is performed at the PHY layer
- We can evaluate the **overall upstream delay** at the xMII interface:



RTT Measurement (including PHY processing delays)



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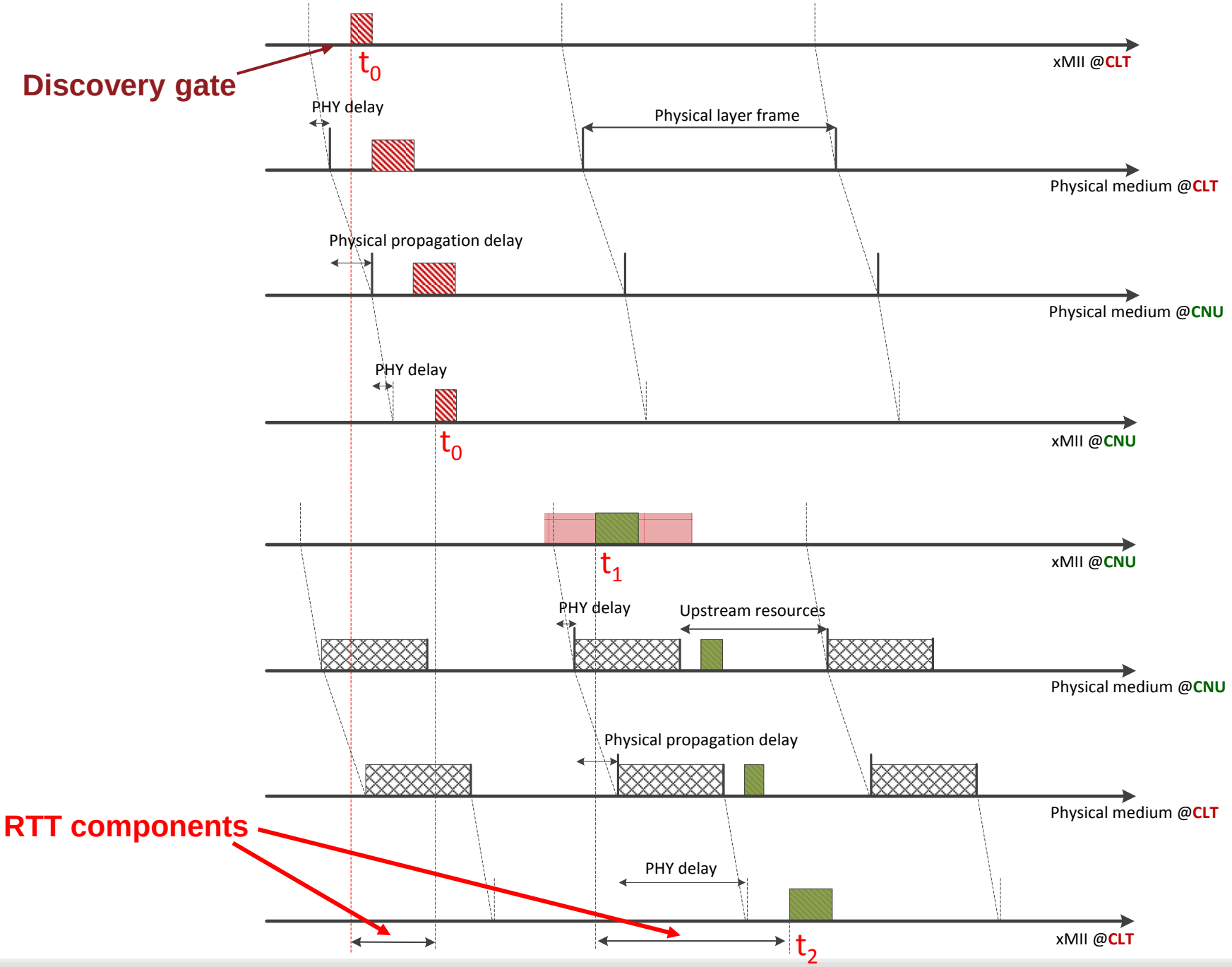

RTT Measurement

- The sum of the two RTT components is (assuming symmetric PHY processing delays for simplicity)

$$RTT = \left(2\tau_{PHY\ delay} + \tau_p\right) + \left(2\tau_{PHY\ delay} + \tau_p + T_\Delta\right)$$

$$= 4\tau_{PHY\ delay} + 2\tau_p + T_\Delta$$

- Increase in RTT is limited to the time interval when transmission is not allowed (T_Δ)
  - 2 OFDM symbols in our case

- RTT measurement can be carried out at the xMII level using the same procedures employed in EPON.

Notes on PHY Initialization Procedures

- There is no need for a complex protocol for exchanging information over the PLC
  - Simple three-way exchange
- DS PLC is a broadcast channel
  - i.e., information on the PLC can be decoded by all CNUs
  - It contains both broadcast (network info) and unicast (CNU-specific) information
- US PLC carries only CNU-specific information
- RTT measurement and upper-layer procedures are not affected by the amount of resources occupied by PLC
  - Buffering requirements have been quantified

Proposals

- For Downstream, PLC is carried only in selected few OFDM symbols within a PHY frame

- Simple PHY initialization procedure (Slide 19)