# EPOC Upstream PHY Link Channel and Channel Probing

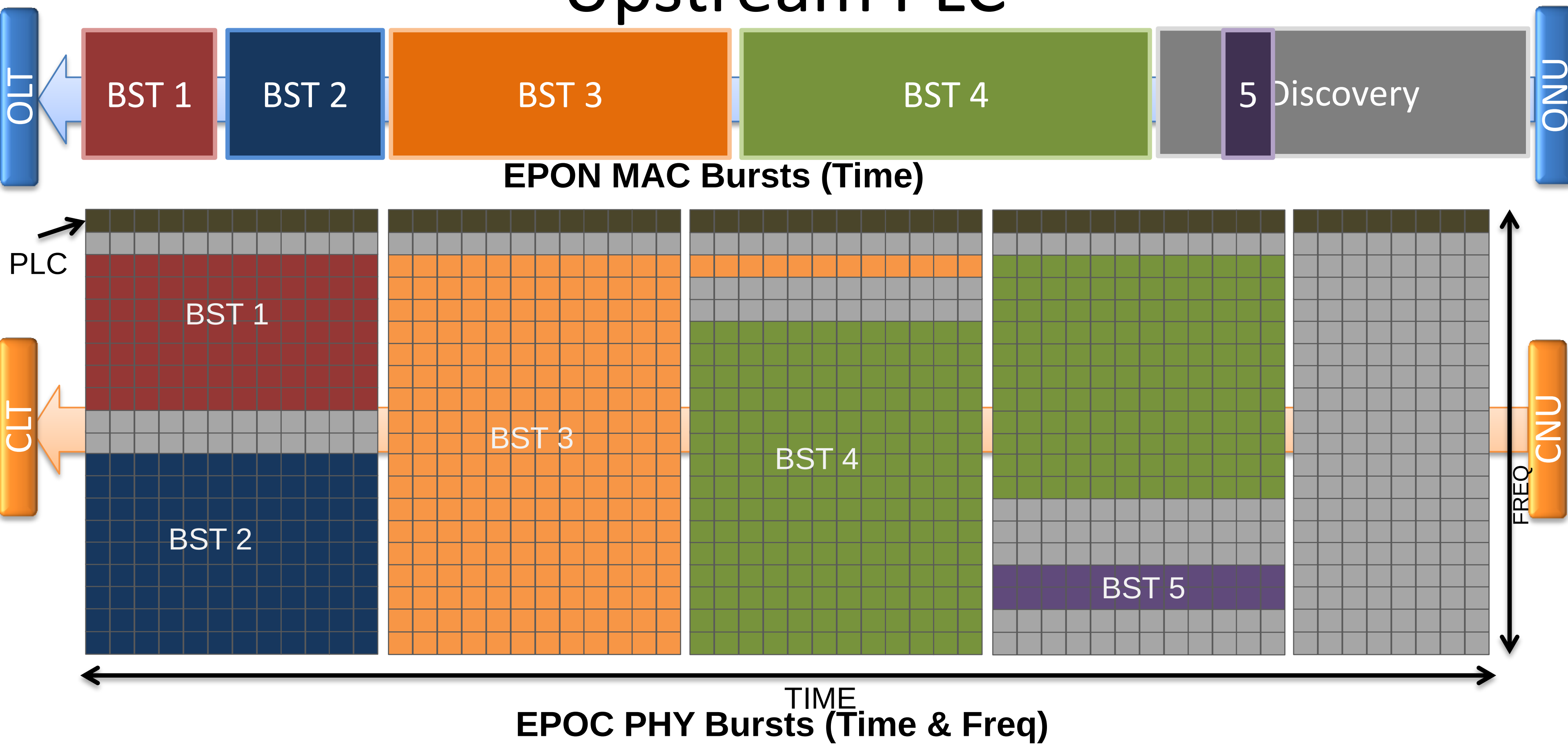
Ed Boyd, Broadcom

Avi Kliger, Broadcom

Nicola Varanese, Qualcomm

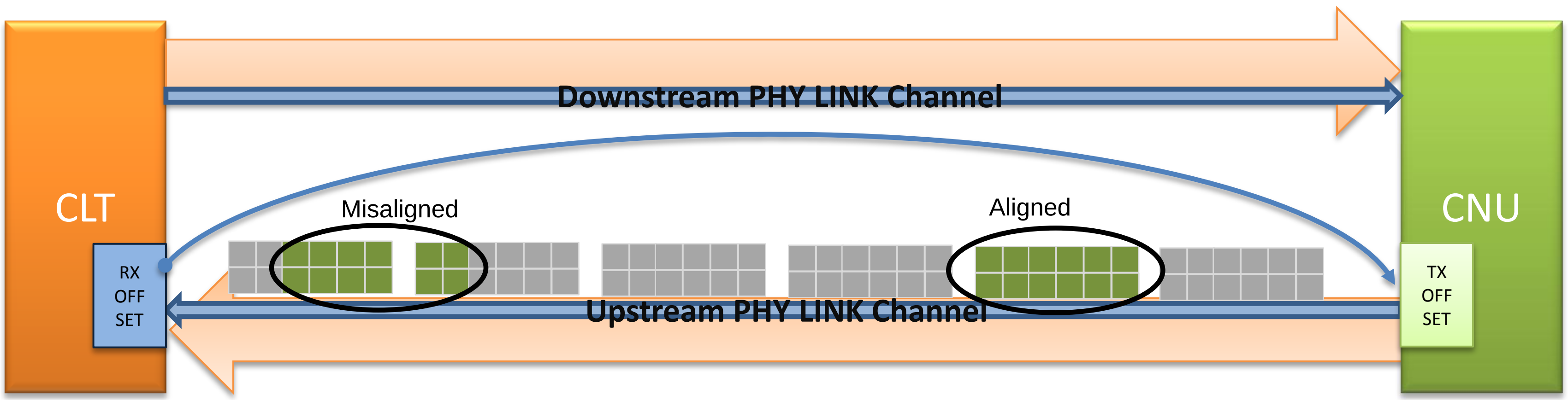
# UPSTREAM PLC

# Upstream PLC




- The Upstream PLC is an isolated in frequency.
- The Upstream PLC can be enabled or disabled in the PHY.
- CLT PHY directs CNU PHY to generate PLC bursts independent of MAC bursts.

# Upstream PLC for Discovery




- The Upstream PLC provides isolated carriers for initial timing and power adjustment.
- The isolation prevents initial messages from disrupting MAC messages.
- The Upstream PLC provides the PHY or MAC address for the CNU so the Downstream PLC messages can be addressed to a CNU.
- The Upstream PLC bursts are triggered by the Downstream PLC channel.

# Other Upstream PLC Functions

- The Upstream PLC allows for “write verify” and “read” commands from the downstream PLC.
  - Verify configuration changes
  - Read MAC Address of CNU PHY

- The Upstream PLC will be used to gather statistics and status indicators from the CNU PHY.
  - To Determine MAC data channel performance to select bit loading , null carriers, or profile in downstream.
  - To retrieve other downstream characteristics to adjust the downstream transmitter.

# Upstream PLC Requirements

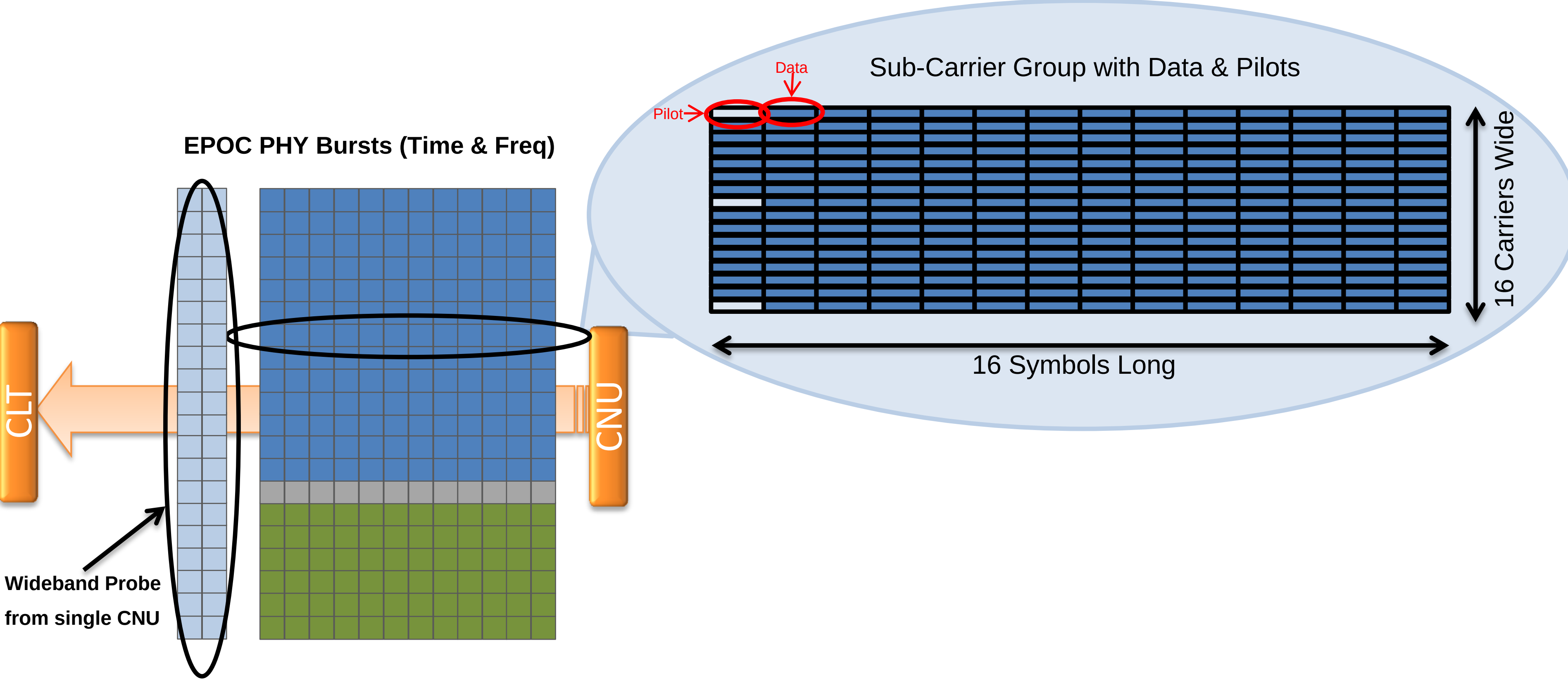
- Preamble, Data, CRC, and FEC
- Low modulation order (QAM16?)
- Random transmit offset for initial discovery
- Fixed Length for easy reception

# UPSTREAM CHANNEL PROBES

# Upstream Probe Options

- PLC does not provide means to the CLT to estimate the channel for a specific CNU over the entire US channel bandwidth
  - Rotating the PLC would be slow
  - Full channel knowledge is a key enabler for US pre-equalization
- Some means for Wide Band Probing are necessary
  - MAC Controlled Method
    - MAC Schedules space for PHY to insert probes.
  - PHY Controlled Method
    - MAC decreases data rate and PHY opens up space for Probes.

# Wideband Probe Overview

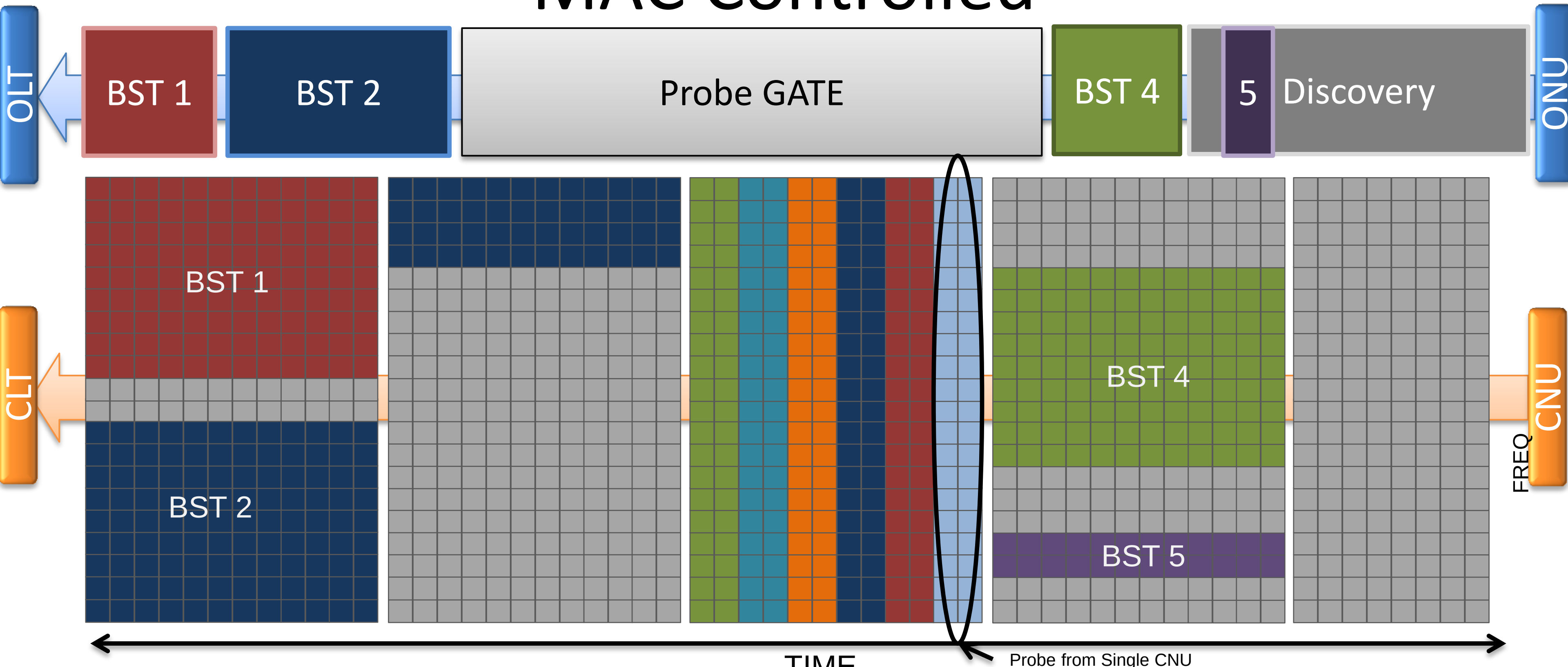



- By allowing a CNU to transmit a probe across all carriers, the number of pilots in a sub-carrier group can be reduced thanks to pre-equalization.
- 2 Pilots of overhead would be required in a 256 sub-carrier group. (.78%)
- A CNU should transmit a probe once per second.
- A Probe across all carriers will disrupt the upstream.
- Space for probes could be controlled by the MAC or PHY.

# MAC Controlled

- Use discovery slot size grants from CLT MAC to trigger Probe bursts from CNU PHY.
- Multiple CNU PHYs could use single slot.
- Could require the introduction of a new type of GATE message (Probe GATE)
  - Alternative would be to mix PHY probes and MAC REGISTRATION messages within the DISCOVERY window
- Slot size must be almost 2 times large as necessary so disruption is huge if OLT scheduler is completely blind to boundaries.
- Constant delay in loop but adds significant upstream burst disruption (500us?) and jitter.

# MAC Controlled

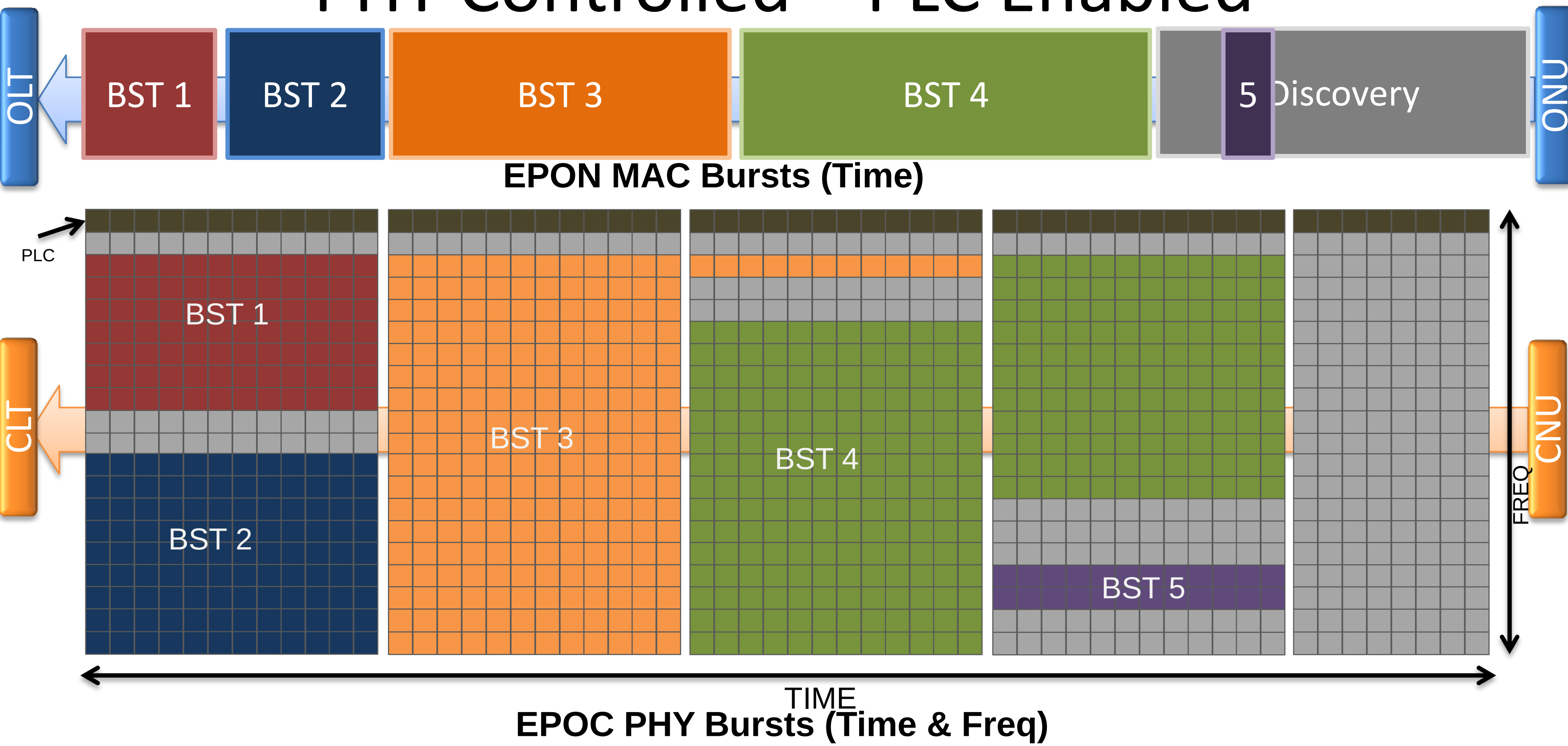



**EPOC PHY Bursts (Time & Freq)**

- CLT PHY configures specific CNU PHYs to respond in specific offsets in symbol boundary.
- CLT PHY starts Probe transmission at burst block boundary for one burst block.
- Multiple PHYs should be handled at once. (Six are shown in the drawing but number depends on block interleaver size)

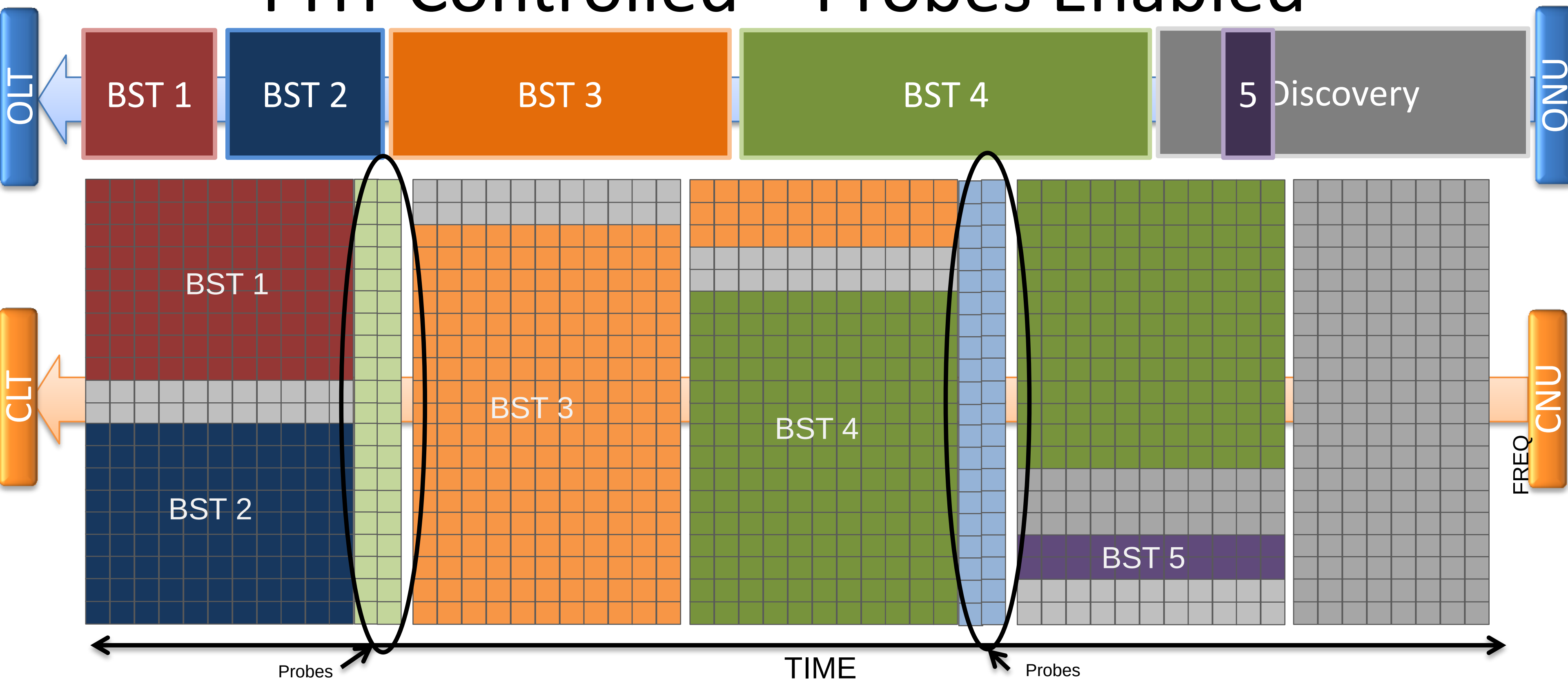
# WIDEBAND PROBE
# PHY CONTROLLED

# PHY Controlled – PLC Enabled




- CLT PHY configures CNU PHY to use a number of carriers for PLC. – Reduced MAC data rate, constant overhead.
- CLT PHY directs CNU PHY to generate PLC bursts independent of MAC bursts.

# PHY Controlled – Probes Enabled




**EPOC PHY Bursts (Time & Freq)**

- Take one symbol from each burst block for Probes (constant overhead)
- CNU PHY generates pilots as directed by PHY Link Channel independent of MAC bursts.
- CLT PHY rotates probe reservation through all CNUs.
- Two symbols allocated for the probe to enable fine timing advance adjustments

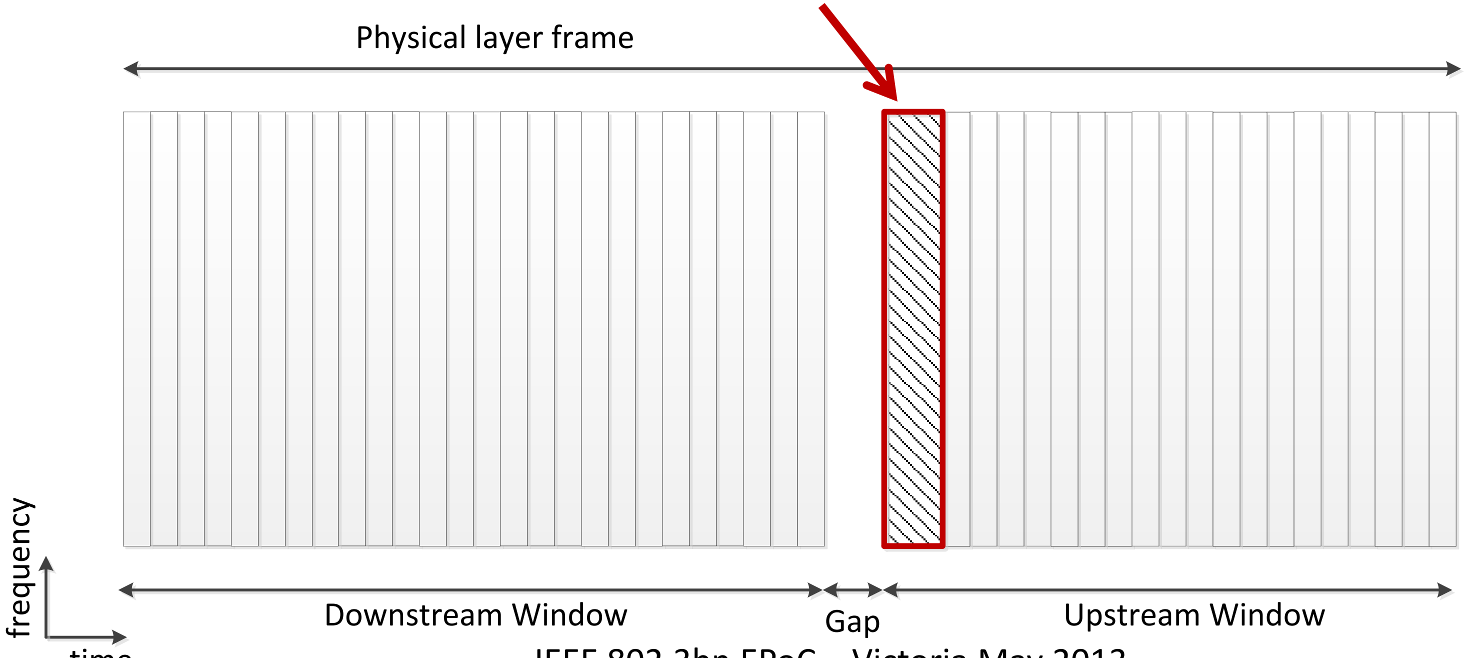
# PHY Controlled

- MAC Data Rate is periodically changed to open space for PHY operation.
- If PLC and Probe are roughly the same overhead, constant rate could be assumed for MAC (pick worst case).
- Requires increasing block interleaver size (and US delay) by 1 symbol.
- Block size is constant with or without probe so PHY delay is constant in both modes.
- Overhead is dependent on interleaver size.

# WIDEBAND PROBE
# PHY CONTROLLED – TDD-SPECIFIC ASPECTS

# TDD US Probing

- If Time-interleaving is applied for US transmissions, the same mechanism could be applied without specific differences between FDD and TDD modes, except:
  - US PLC (when enabled) would be present only in OFDM symbols belonging to the Upstream Window
- However, when TDD is operated in the High Band, there may be no need for time interleaving (analogously to FDD DS)
  - What would then be the implications of US probing for the case where no time-interleaving is performed ?
- We propose to reserve the first two OFDM symbols of the US window of a PHY frame (Probing Slot) for probing purposes (when US PLC is disabled)

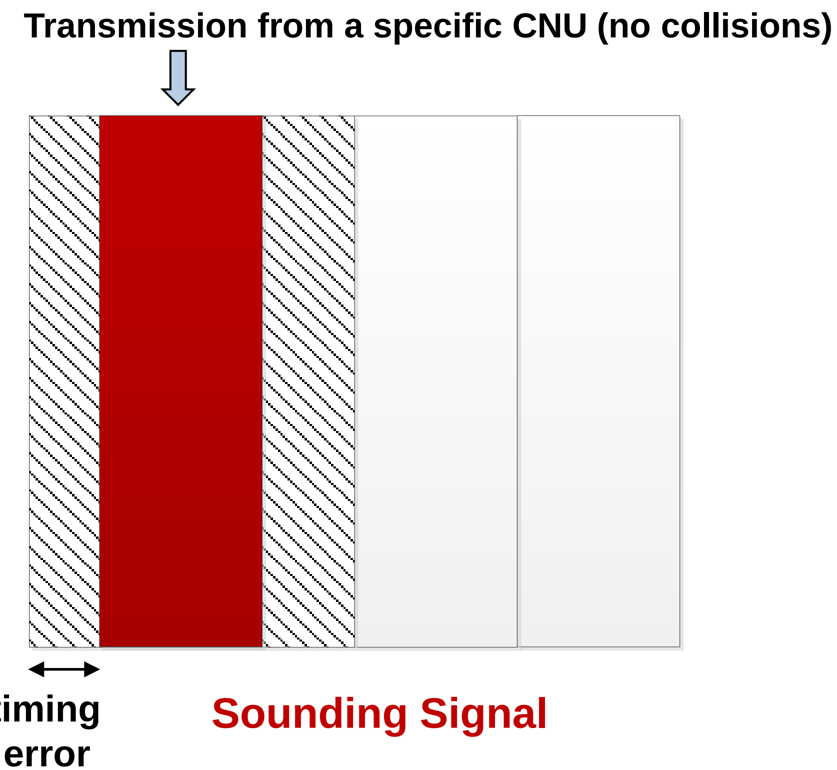


# TDD US Probing

- The DS PLC turns probing mode on and off and may additionally signal possible changes in terms of MAC data rates. Options for MAC rate adaption:
  1. MAC conveys data at worst-case rate (no rate adaption, always assume highest overhead)
  2. CNU MAC is informed of the effective PHY rate via MDIO
  3. Alternatively, PHY probing state and MAC rate change with a pre-definite (known) pattern
- The DS PLC regulates the access to the Probing Slot deciding which CNU should transmit
  – Very similar to TDD DS pilot pattern (for DS we have only a single transmitter and access arbitration is not necessary)

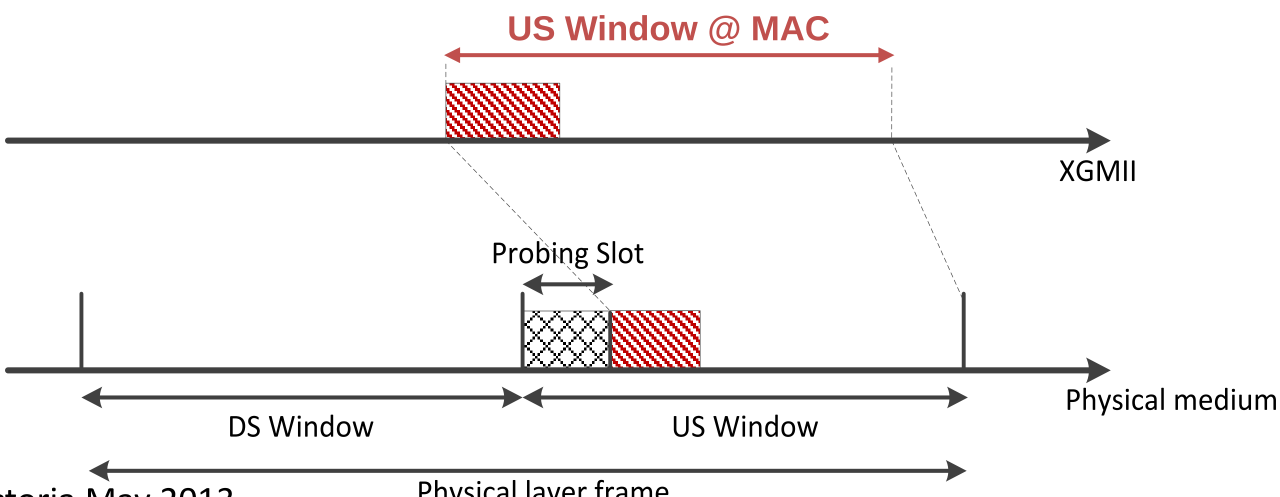
**Features:**

- CLT estimates **full channel** for the CNU and <u>assigns US profile</u>
- CLT <u>refines timing advance adjustment</u> (to compensate propagation delay)
- CLT <u>refines optimal power control settings</u>



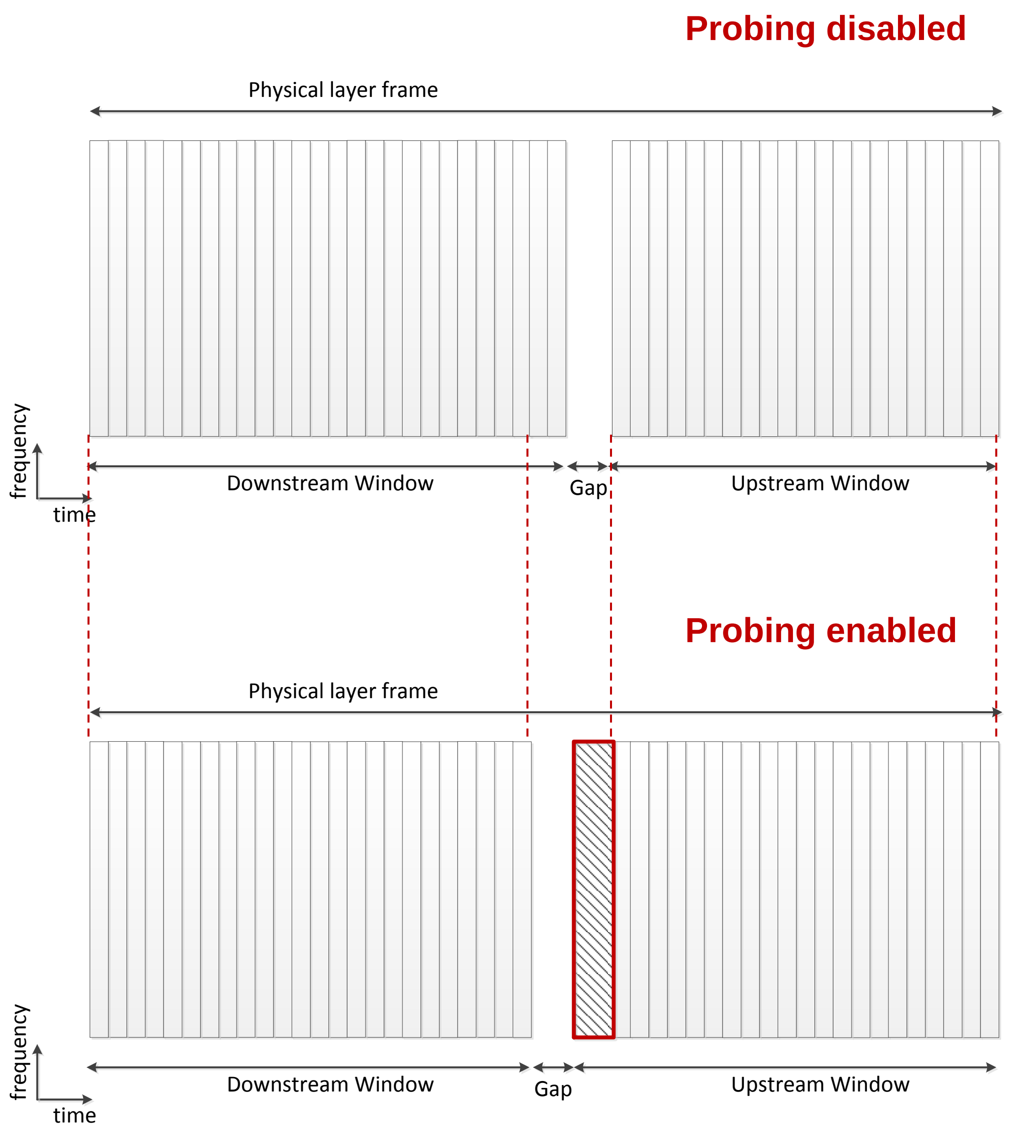
# Impact on CNU MAC Layer

- With the proposed US frame structure, data transmission is not possible in the first two OFDM symbols of a PHY US window when probing is enabled.
- However, MAC is aware of TDD operation. We have two options for MAC operation when US probing is enabled:
    1. MAC performs TDD timing adaption: the start of the MAC US window is moved at the end of the Probing Slot (i.e., MAC US window does not include the Probing Slot). The MAC needs to be aware of the change in size of the MAC US window (and corresponding time delay) in addition to the change of supported rate (see previous slide)
    2. MAC does not perform TDD timing adaption: MAC US window includes the Probing Slot. In this case the MAC is only aware of the change in terms of supported rate (see previous slide). However, this way of operation implies:
        - A change in the mapping between time and time/frequency resources performed by the CNU PHY (see figure below)
        - Additional buffering at the CNU and CLT PHY layer (see next slide)



# Alternative PHY Frame Structure

- In order to avoid increasing the US delay when it is unnecessary (namely even when probing is disabled), an alternative frame structure could be adopted
- Differently from the previous slides, the number of OFDM data symbol in the US window is kept constant, while the number of OFDM data symbol in the DS window is changed to accommodate space for the Probing Slot
- This solution eliminates additional buffering and US delays, at the price of changing the TDD split and DS effective rate (CLT MAC needs to be informed of change in DS window size)



Upstream Probe Options

# COMPARISON & SUMMARY

# Comparison: MAC VS PHY Controlled

- For Analysis – assume 240us block size (12x20us symbols)
- Delay
  - MAC Controlled = 12x20usx2=480us
  - PHY Controlled = 13x20usx2=520us
- Disruption
  - MAC Controlled = 480us
  - PHY Controlled = No additional (Discovery time is largest disruption)
- Bandwidth
  - MAC Controlled [256 CNUs every second]
    - 256/6=42 slots per second. 42 slots*480us/1second=2%
    - 2 pilots/(12 symbols x16 sub-carriers)= 1%
    - Total = 2% + 1% = 3%
  - PHY Controlled [256 CNUs every second]
    - 500us for each CNU so 128ms for all CNUs
    - Assume 10ms to switch ON & OFF channel so 148ms out of 1 second with overhead.
    - (1/12)*(148ms/1000ms) = 1.2% + 1% = 2.2%

# THANK YOU