EPoC Upstream

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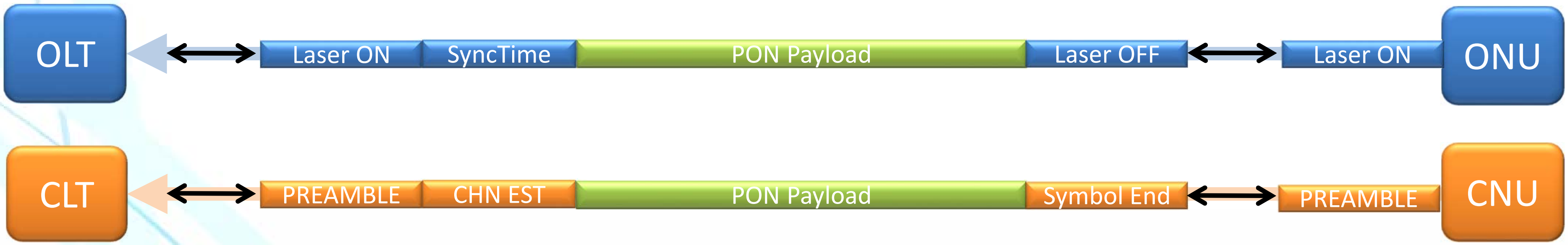
Upstream Burst Options

- This presentation looks at 3 different options for the EPoC upstream and evaluates the overhead.
  - Unaligned TDMA
    - No symbol alignment for transmitter.
    - Single Transmitter per symbol.
  - Aligned TDMA
    - CNU transmitters are all phase aligned to the CLT PHY's FFT boundary.
    - Single Transmitter per symbol.
  - OFDMA with 1D-2D translation
    - CNU transmitters are all phase aligned to the CLT PHY's FFT boundary.
    - Multiple Transmitters per symbol
- A Solution for the OFDMA with 1D-2D translation is presented.

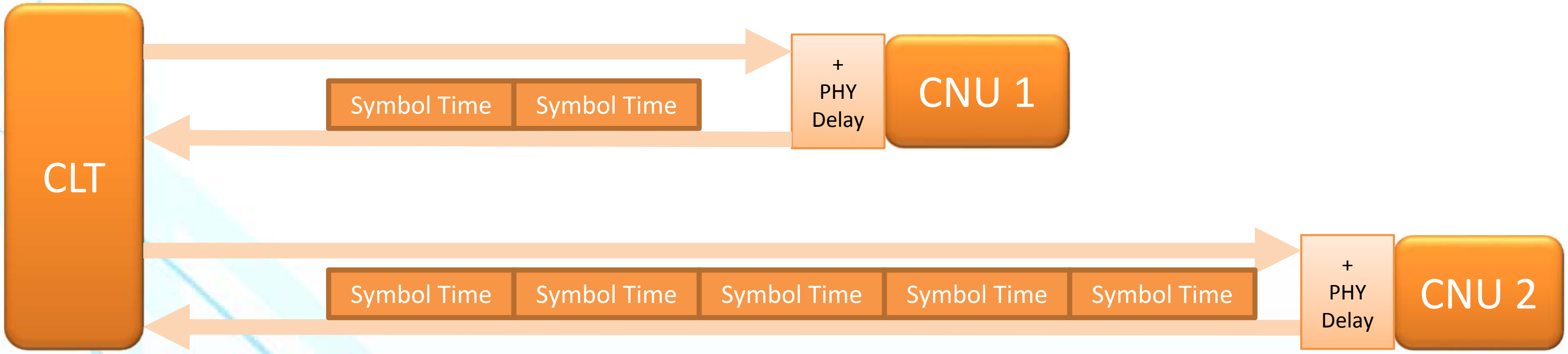
Unaligned TDMA



- Unaligned TDMA would require preamble symbols so the CLT receiver could align to symbol boundaries.
  - In G.Hn coax, it is multiple symbols of overhead.
- Channel Estimation Symbols
  - Channel Estimation Symbols allow for measurement of the channel.
- Symbol End
  - The end of the burst must be on a symbol boundary so the finest granularity for burst size is a single symbol.
- Overhead Costs
  - A low-end estimate is 3 symbols of overhead for preamble/channel estimation.
    - With 20us symbols at 1Gbps; it is 7,500 Bytes of Burst overhead with a granularity of 2,500 Bytes (much high than EPON 192 Bytes of burst overhead and 2 bytes of granularity)
    - With 40us symbols at 1Gbps; it is 15,000 Bytes of Burst overhead with a granularity of 5,000 Bytes (much high than EPON 192 Bytes of burst overhead and 2 bytes of granularity)
  - Time Interleaving would make these numbers much worse and couldn't be supported.

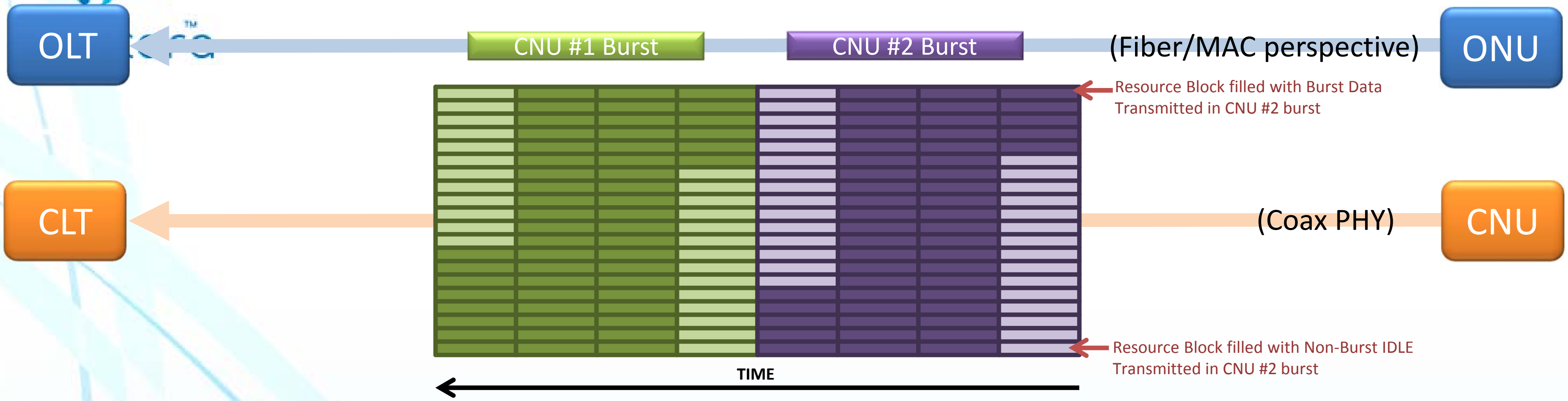
Overhead is very high for unaligned TDMA

Aligning TDMA: PLC Ranging



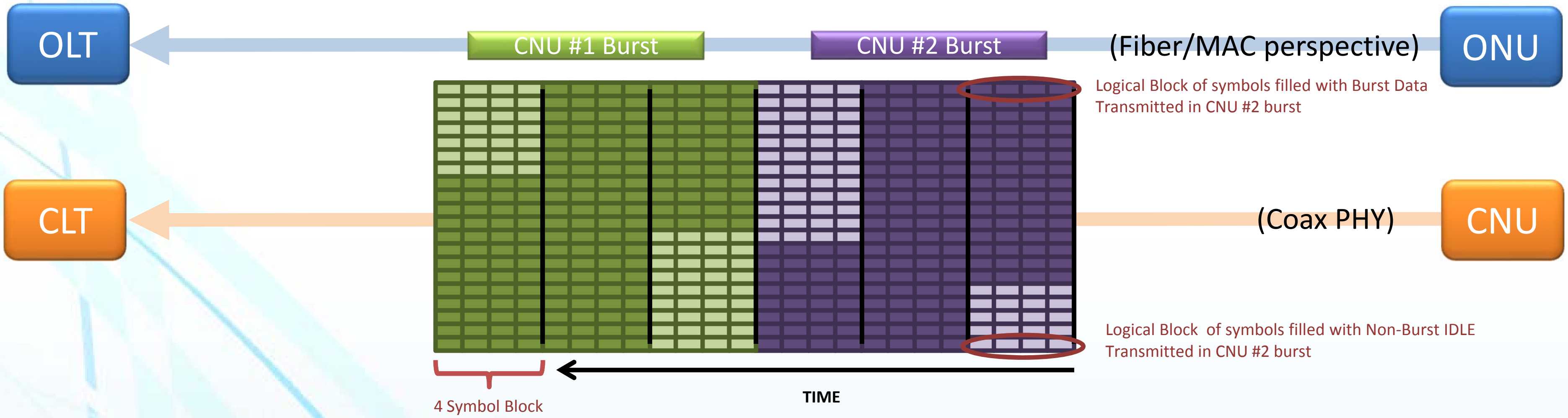
- All CNU receive symbol start reference time from downstream PLC.
- PLC Link Up procedure adds delay per CNU so PHY symbol times are aligned at CLT Receiver.
- With known symbol timing at receiver, the preamble can be eliminated.
- All CNU PHY will start/stop bursts at Symbol Boundaries
  - Ethernet MAC is not aligned to symbol boundaries and will start and stop transmissions without regard to PHY symbol time.

Aligned TDMA: MAC Bursts in PHY Symbols



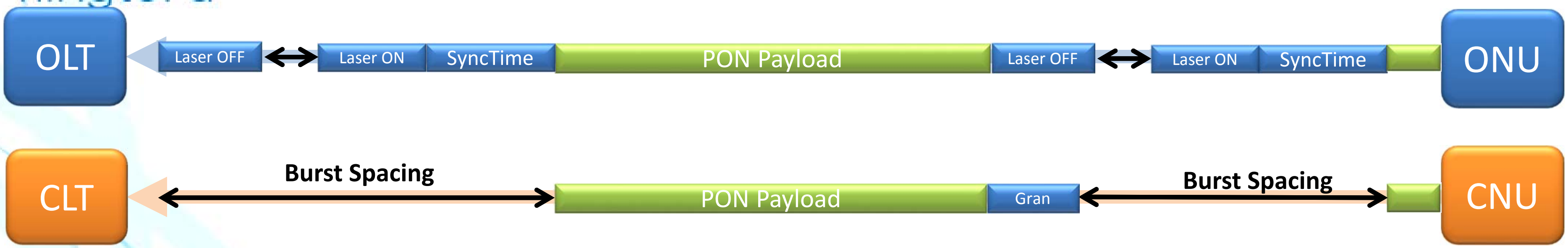
- Spacing Bursts at MAC Layer by more than 1 symbol guarantees that 2 bursts will not share a symbol.
  - Bursts from the MAC are not required to be multiples of symbol times long
  - Bursts from the MAC are not required to start or stop on symbol boundaries.
  - Simple configuration at MAC Layer to accommodate minimum spacing of 1 symbol time
  - Granularity of burst size is based on Resource Block Size (the symbol size is only important for spacing)
- MAC Layer burst timing is preserved across Coax PHY
  - If a CNU burst from the MAC layer starts during a symbol time, the CNU will transmit on all sub-carriers in the symbol.
  - The symbol will contain "Burst Data Symbols" (Preamble, Data, IPG) or a newly defined "Non-Burst IDLE Character".
  - Non-Burst IDLE characters fill in the portion of the symbol NOT occupied by the CNU burst.
  - The start/end position of the burst from the MAC is preserved by the "Burst Data Symbols" position in the data stream.

Aligned TDMA: Adding Interleaving



- Block Interleaving in the upstream adds protection for burst noise
  - In the example above, 4 symbols are grouped so the time interval spanned by a FEC block is 4 times longer. Burst error protection is 4 times longer.
- Blocks of symbols are grouped together to form a logical block of data.
  - PLC upstream ranging aligns the logical block start (symbol start isn't enough)
  - MAC Layer must separate bursts by logical block size.
  - Granularity of burst size is based on resource block size and logical block size.

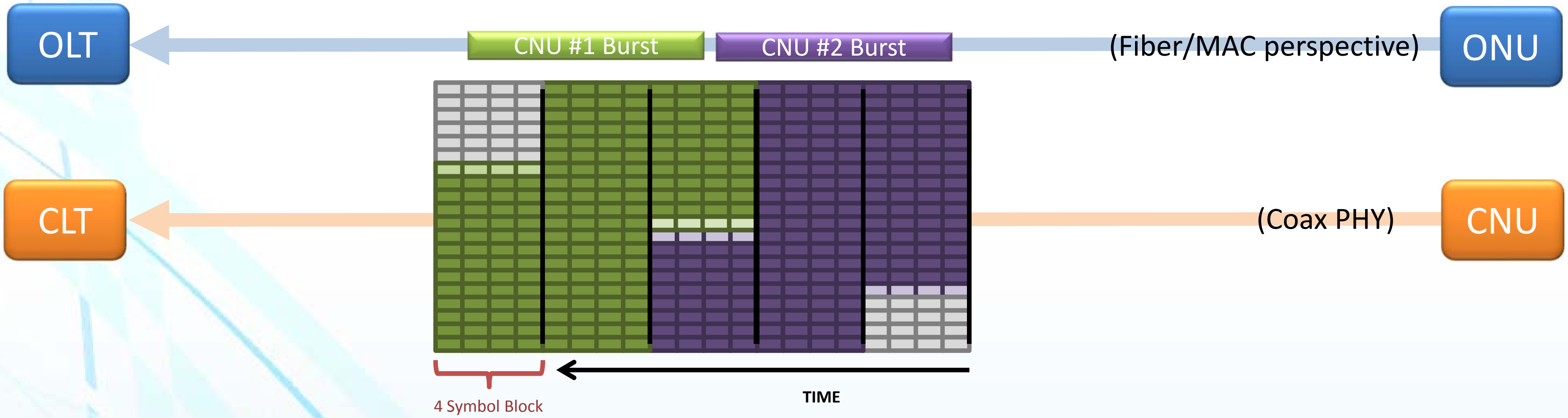
Aligned TDMA Performance



- Burst Spacing (assume 1Gbps upstream)
  - EPON: 100 TQ or 200 Bytes
  - No Interleaving (20us symbols): 2,500 Bytes Spacing
  - 4 Symbols (20us symbols): 10,000 Bytes Spacing
  - 8 Symbols (20us symbols): 20,000 Bytes Spacing
  - 12 Symbols (20us symbols): 30,000 Bytes Spacing
  - No Interleaving (40us symbols): 5,000 Bytes Spacing
  - 4 Symbols (40us symbols): 20,000 Bytes Spacing
  - 8 Symbols (40us symbols): 40,000 Bytes Spacing
  - 12 Symbols (40us symbols): 60,000 Bytes Spacing

Burst Spacing Penalty is very high with time interleaving and long symbols.

OFDMA: Minimize Spacing



- OFDMA allows multiple transmitters in a symbol block.
- The spacing for the interleaved block is dramatically reduced.
  - Start and End Marker along with Resource Block Size
  - Even with 4 or 8 symbols interleavers, it is 100's of bits between bursts versus 10's of thousands.
- MAC Layer Timing is preserved
  - 1D to 2D translation allows for the MAC layer to see a constant flow of data.

Conclusions

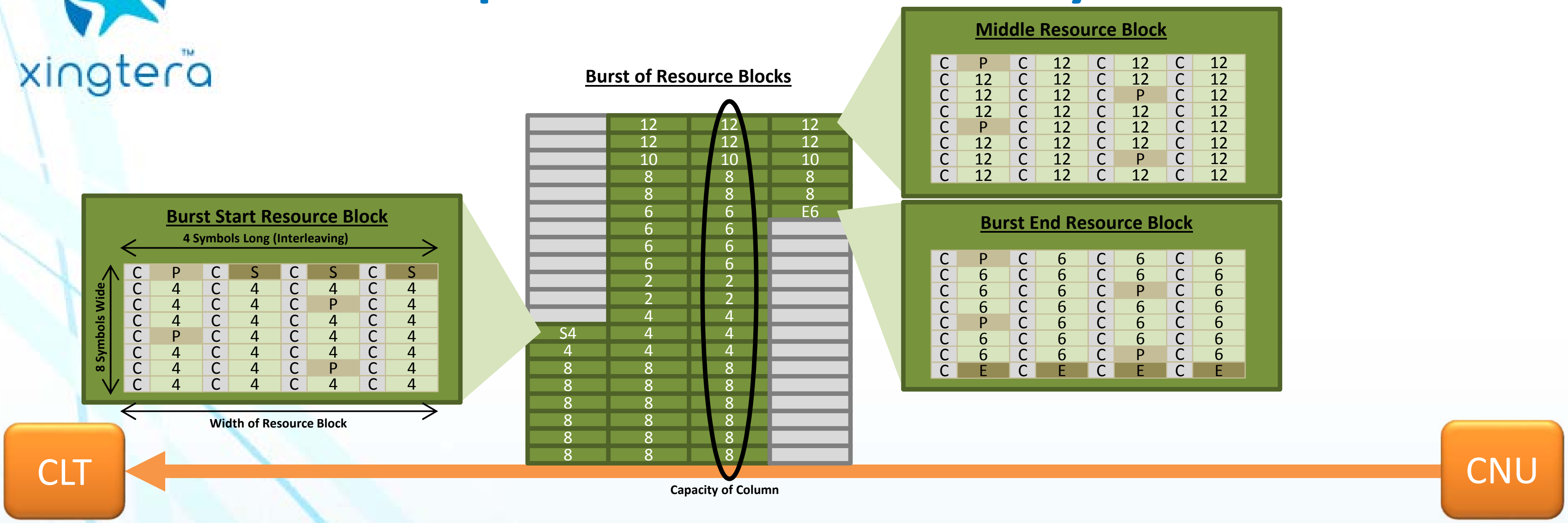
- Unaligned TDMA has too much overhead for a high data rate upstream.
- Aligned TDMA could be used for lower data rate and applications without interleaving.
- OFDMA has significant efficiency improvement for a high data rate upstream or an upstream that requires interleaving.

OFDMA & 1D-2D TRANSLATION

Overview

- This presentation looks at the CNU upstream data path from the XGMII interface to the PMA symbol mapper.
- The requirements for the PCS and PMA to support 1D-to-2D will be shown
- The PCS/PMA interface will be defined to add to support 1D-to-2D upstream bursts.

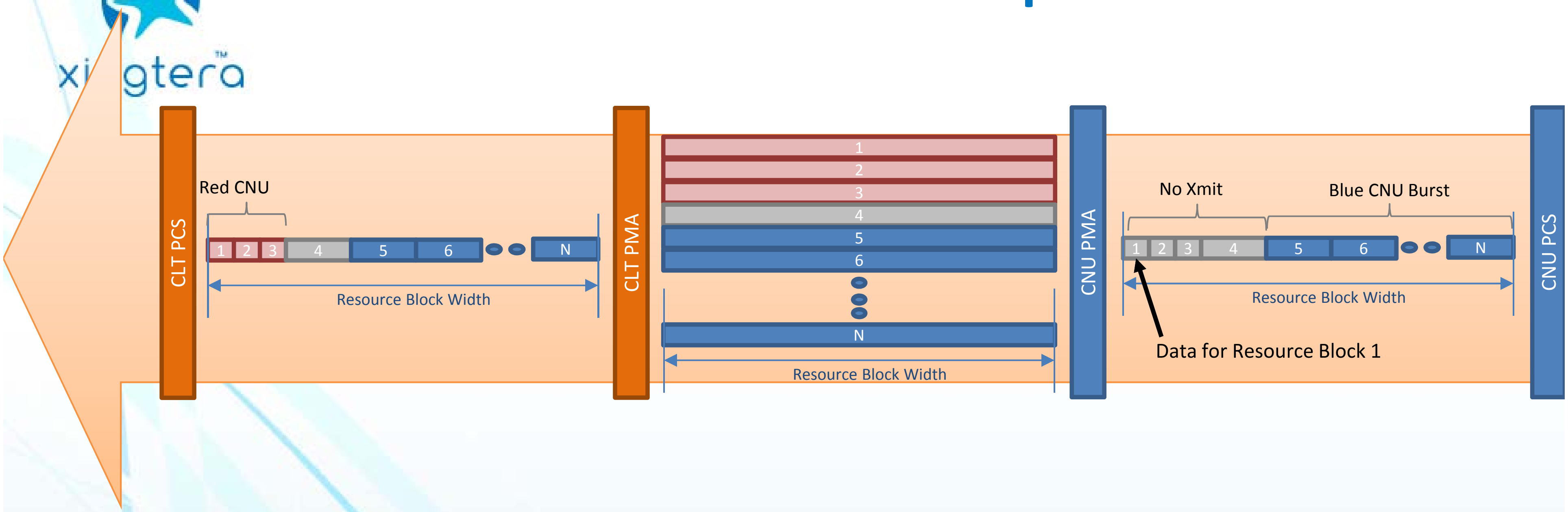
Upstream Burst Anatomy



Disclaimer: This slide illustrates one of many possible resource block definitions that would work with 1D-to-2D translation.

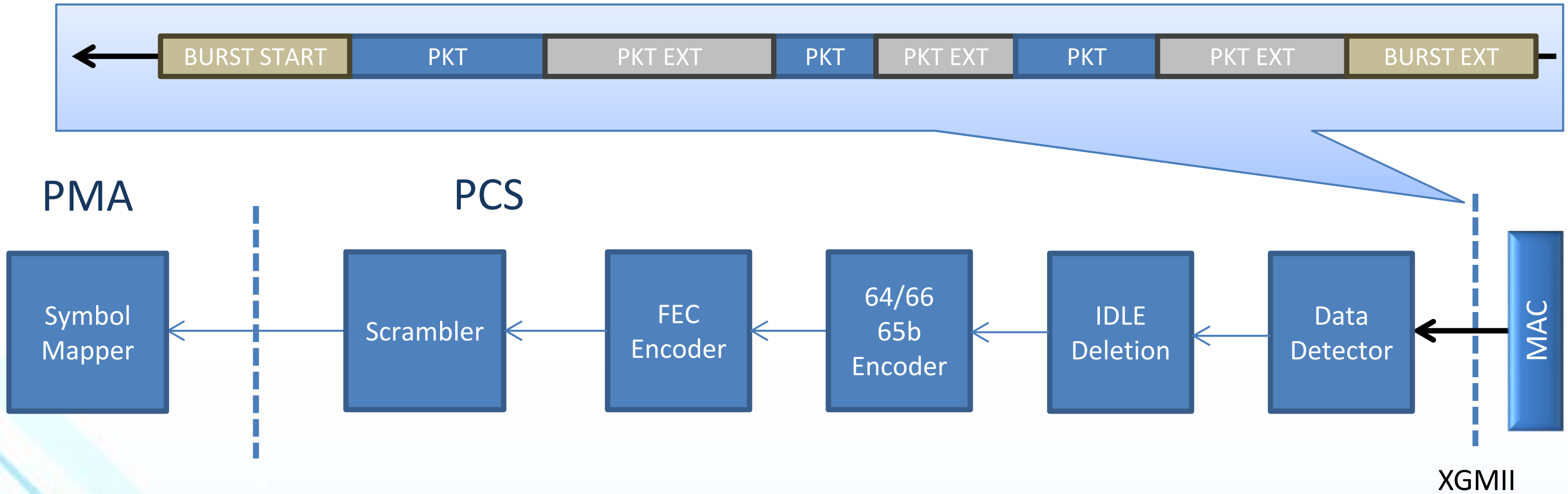
- Bursts are made up of resource blocks
  - Resource Blocks are as long as the interleaver (Example above is 4 symbols).
  - Resource Blocks are a pre-defined or configured set of consecutive sub-carriers (Example above is 8 sub-carriers).
  - Resource Blocks contain pilots and data carrying symbols. They may contain a start or end marker.
  - All Data Carrying Sub-carriers within a resource block carry the same number of bits.
- Resource Blocks Usage
  - Multiple consecutive Resource Blocks make up a burst.
  - There is only a single transmitter in a resource block.
- Calculating Sustained Data Rate (Capacity-of-Column/Width-of-Resource-Block)
  - The number of bits in a column of Resource Blocks must be calculated.
    - Determine the number of data carrying symbols in Resource Block (assume no markers)
    - The Overhead bits (excluding markers) must be excluded.

1D-to-2D Basic Concept



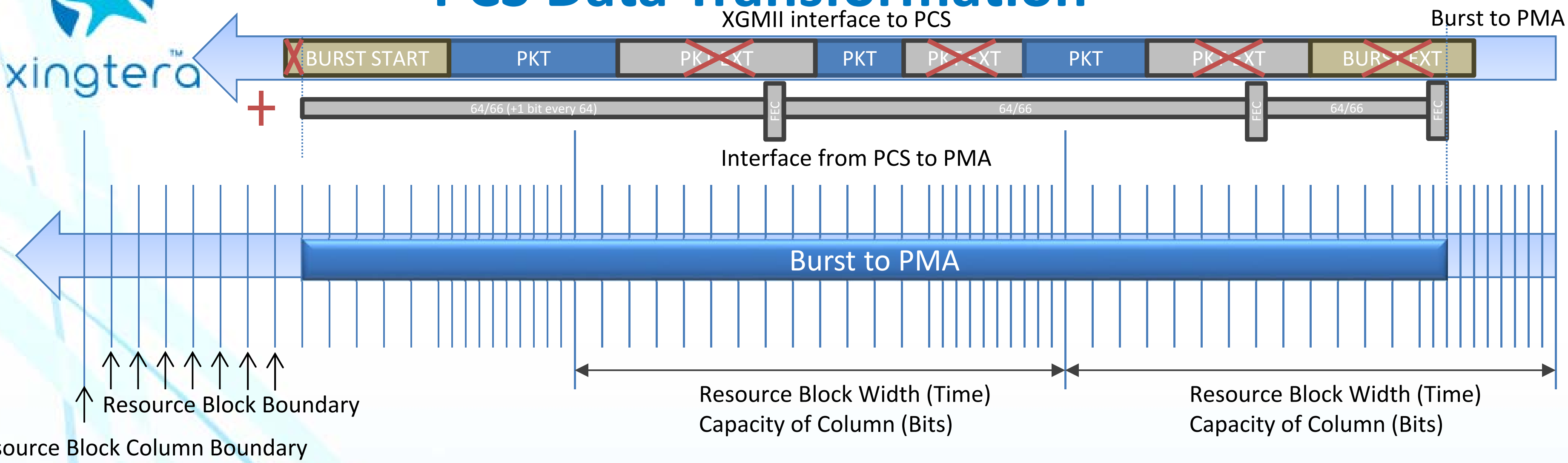
- CNU PCS to CNU PMA
  - Data is streamed from PCS to PMA at the sustained data rate.
  - Data stream is split into resource blocks based on capacity of resource blocks.
  - Upstream Bursts start and stop on resource blocks.
  - All upstream data time is transmitted from PCS to PMA (Data maybe marked no transmit when not bursting upstream)
- PMA Outputs
  - CNU PMA receives all serial data over a resource block and sends it out parallel. (1 Resource block of constant delay)
  - CLT PMA receives all parallel data and stream out serially at the sustained data rate. (1 Resource block of constant delay)
- Upstream Alignment
  - All delays in PHY are constant based on propagation and resource block width (NOTE: it is not based on capacity)
  - PLC aligns the start of the resource block from the PCS to a common time reference point in CLT.
  - EPON MAC will guarantee that bursts into PCS from XGMII are at unique times.
  - If PCS/PMA time is unique and represents specific resource blocks, the CNUs will not share a resource block.

MAC-to-PHY burst extension



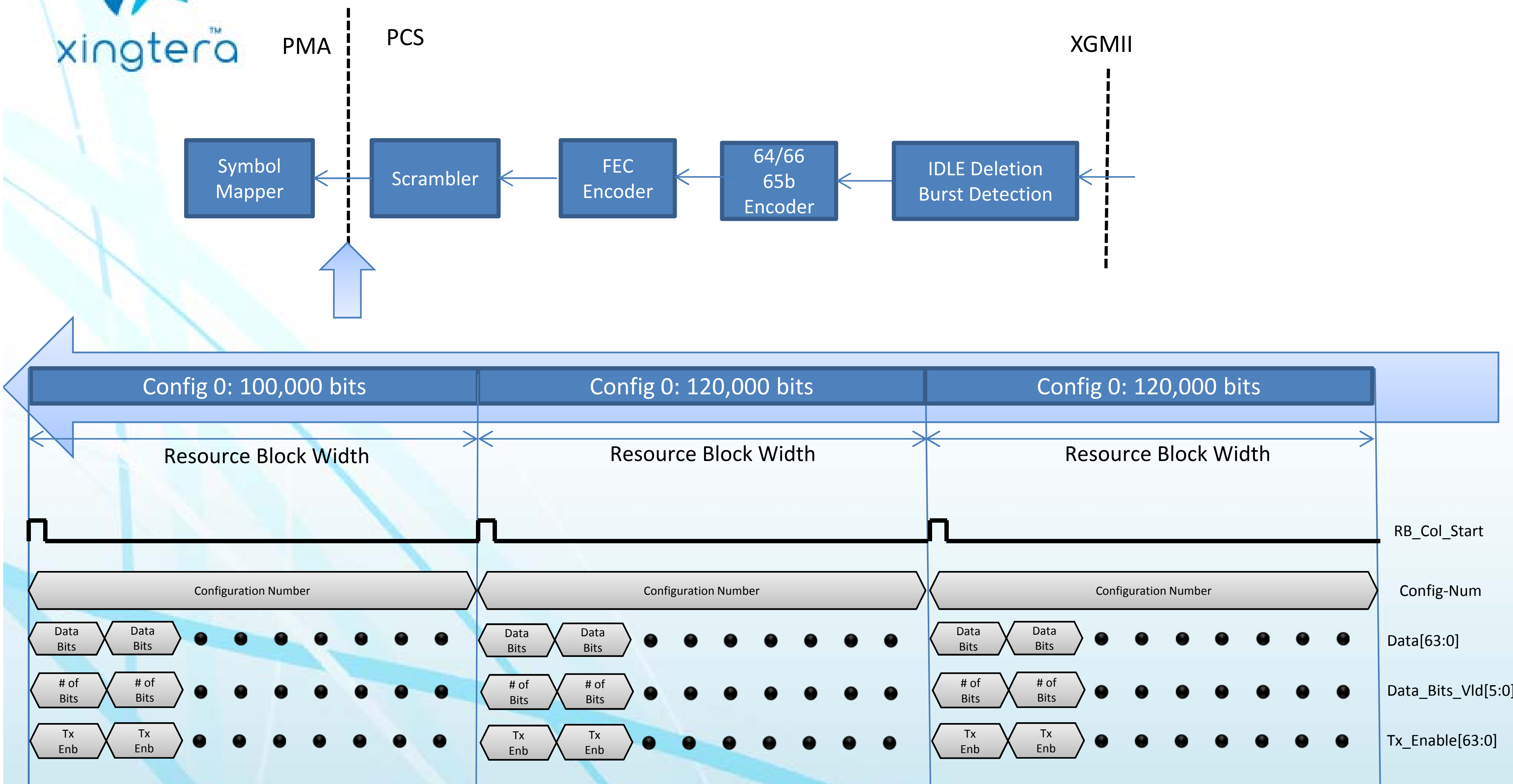
- Burst Start
  - The MAC is not aware of the Resource Block boundaries, the burst will most likely not align to the start of resource block.
  - The data at the start of the burst will be dropped if it doesn't align to the start of a resource block.
  - The burst start is a string of IDLE characters that can be discarded without shifting the burst.
  - The burst start must be greater than the maximum resource block capacity. (28x12 bits=336 bits in my example)
  - Burst Start is similar to sync time in EPON except the loss of characters happens in the transmitter and not the receiver.
- Packet Extension
  - Packets from XGMII at 10Gbps must be extended to match the data rate of the PHY minus overhead.
  - The sustained data rate minus the FEC and 64/66 encoding determine the amount of packet extension
- Burst Extension
  - The burst consumes additional capacity due to FEC block termination and alignment to the Resource Block Boundary.
  - The Burst Extension is a dead time between bursts in addition to the upstream slot jitter.

PCS Data Transformation



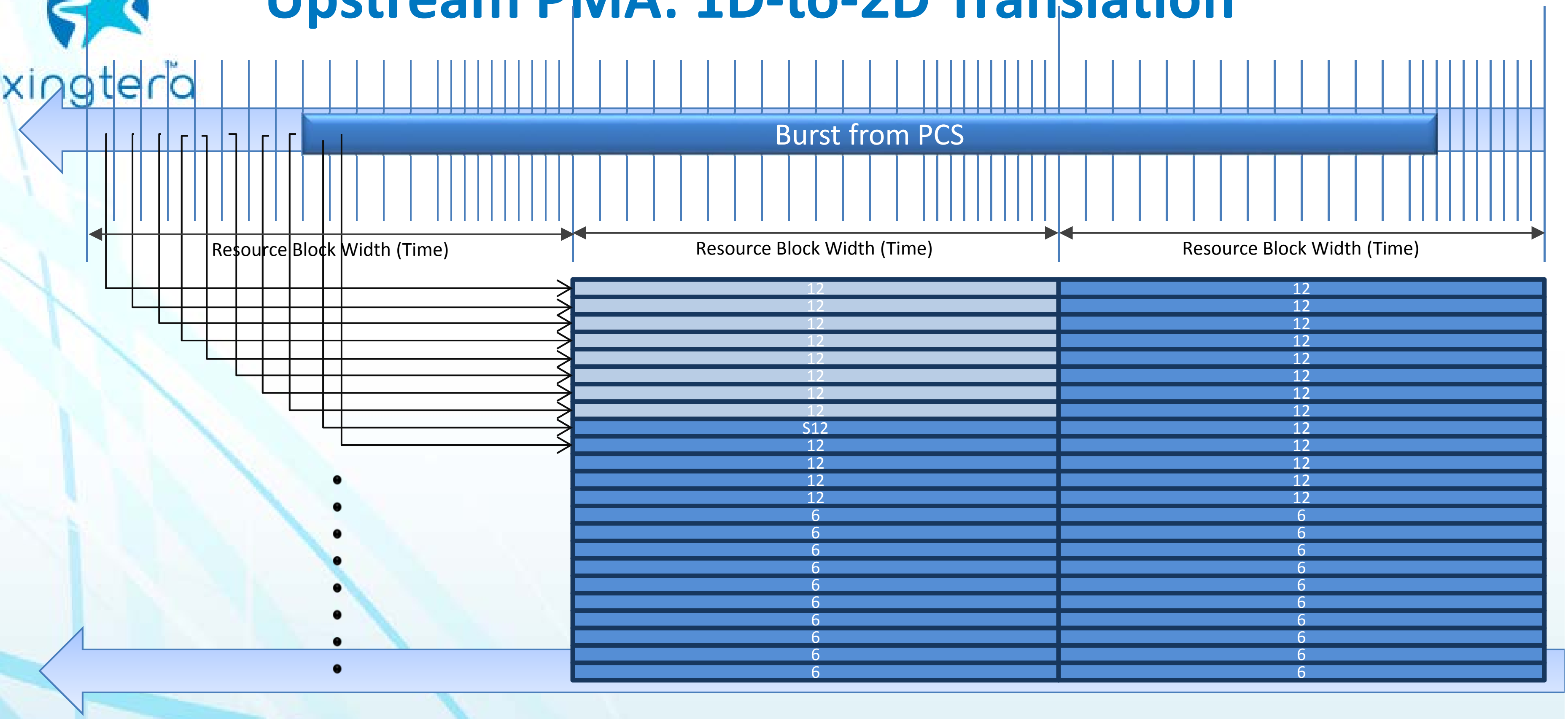
- PCS to PMA
  - The PCS provides a constant data rate stream of data to the PMA (for a configuration)
  - The PCS identifies the bits in a burst and out side of burst (a laser enable equivalent)
  - The PCS/PMA are aware of the Resource Boundaries and Resource Block Boundaries in the data stream.
  - The data rate is determined by the Resource Block Column Capacity (total bits) over the width of a Resource Block (time).
- PCS Data Transformation
  - Bits from a burst start are discarded until a Resource Block Boundary is reached.
  - Bits for Start Marker are discarded.
  - 64/66 encoding and FEC encoding starts on data stream.
  - IDLE deletion occurs on the data stream.
  - At the end of burst, bits from the burst extension are taken until a Resource block boundary is reached after FEC has been inserted.

PCS/PMA Boundary (CNU Upstream)



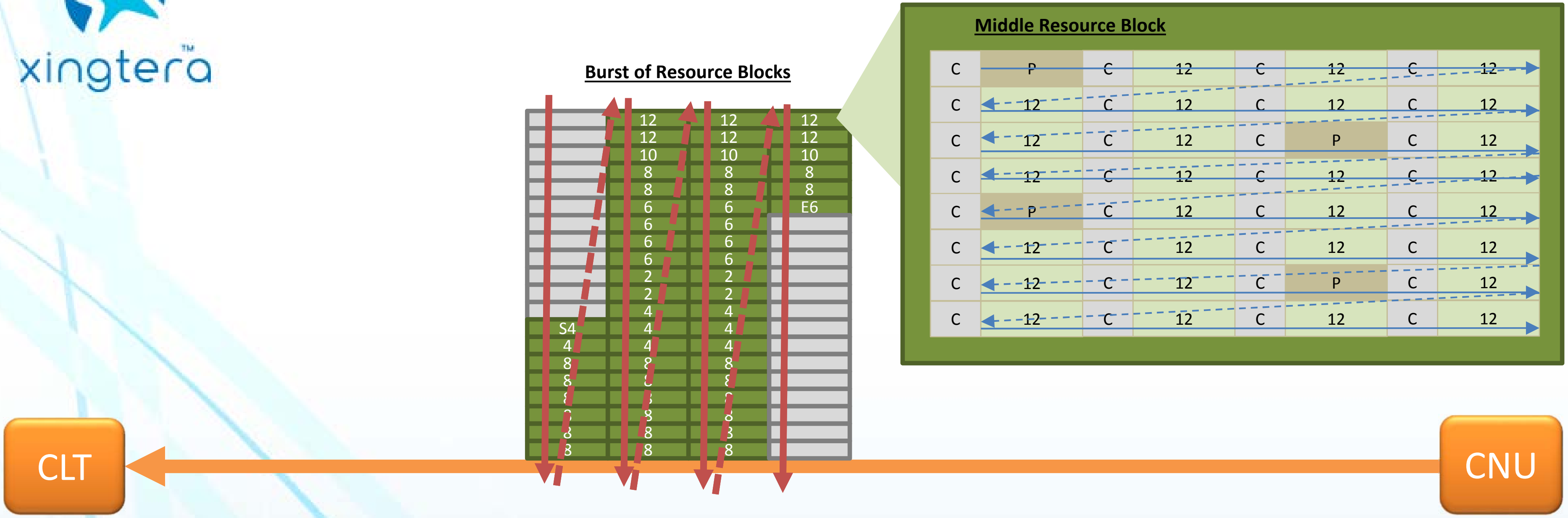
- RB_Col_Start indicates the first bit of the first Resource Block in the column.
- Config_Num allows for switching the bit loading (capacity) between Resource Blocks.
- Data is transferred in blocks of 64 bits with 204.8MHz clock (supports over 10Gbps)
- Data_Bits_Vld allow for ending on non-64 bit boundaries (if required)
- Tx_Enable identifies the bits that are part of a burst.

Upstream PMA: 1D-to-2D Translation



- The bits in a PCS data stream are mapped into the resource blocks.
  - Mapping can be direct and simple as shown or a translation table to create a frequency interleaving function.
- The PCS data indicates if the bits (and related Resource blocks) are the start of burst, middle of burst, end of burst, or non-burst bits.
- The PCS guarantees that bursts start and end on resource block boundaries.

Upstream PMA: Filling Resource Blocks



- Serial Data from PCS is split into Resource Blocks based on Fixed known capacity.
  - Serial Data Stream may indicate "No Transmit Bits" that the PMA would use to indicate Resource blocks for another CNU
- Serial Stream to Resource Blocks
  - Highest-to-Lowest Frequency through an entire Resource Block Column.
- Resource Blocks to sub-carriers
  - The highest frequency sub-carrier is loaded across the entire resource block (skipping any pilot)
  - The next highest frequency is loaded and so on until the end of the resource block.
  - The loading across a resource block creates a block time interleaving function.
- Frequency Interleaving
  - The symbol mapper could have a function that loads the Resource Blocks in an order different than the default "High Frequency to Low Frequency".
  - The configuration of the order would provide frequency interleaving.

Key Guidelines for 1D-to-2D

- The PLC must align the start of resource blocks from the CNUs PHY to a common reference point at the CLT.
- If PHY delay is constant, MAC ranging will guarantee that bursts don't share resource blocks.
- The PCS must know the capacity in the resource blocks and be aligned to the resource block column start and end time.
- The PCS must have a fixed delay from start of packet input to output.
  - Trimming characters at the start of burst eliminates the need to shift bursts into resource blocks.
- Resource blocks with any bit loading can be supported.
- Pilot location in Resource Block is not important to the PCS.
- 1D-to-2D mapping is a simple function in the PMA.

Conclusions

- OFDMA and 1D-to-2D translation has much lower overhead than pure TDMA or aligned TDMA.
- OFDMA and 1D-to-2D translation can be easily implemented in the PMA Symbol Mapper.
- PCS must be aware of resource block boundaries and resource block capacities.