EPoC Performance Model
Delay and Efficiency

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Scope

- The EPoC performance model aim at providing a spreadsheet to play with tradeoff between delay and efficiency of EPoC systems, in order to have a common base for discussion/understanding

- The tool <u>does not intend</u> to provide a mean for detailed verification of the state diagrams and standards, for which more detailed modeling and simulations will be needed based on experience in EPON

- Input values are parameterized so that different solutions/option could be considered when evaluating delay and efficiency of certain proposal

- The focus of the EPoC performance model is primarily on the coax PHY and also includes additional impact due to MPCP/MAC layer
  - For additional optical backhaul connection only a input field will be provided

- …

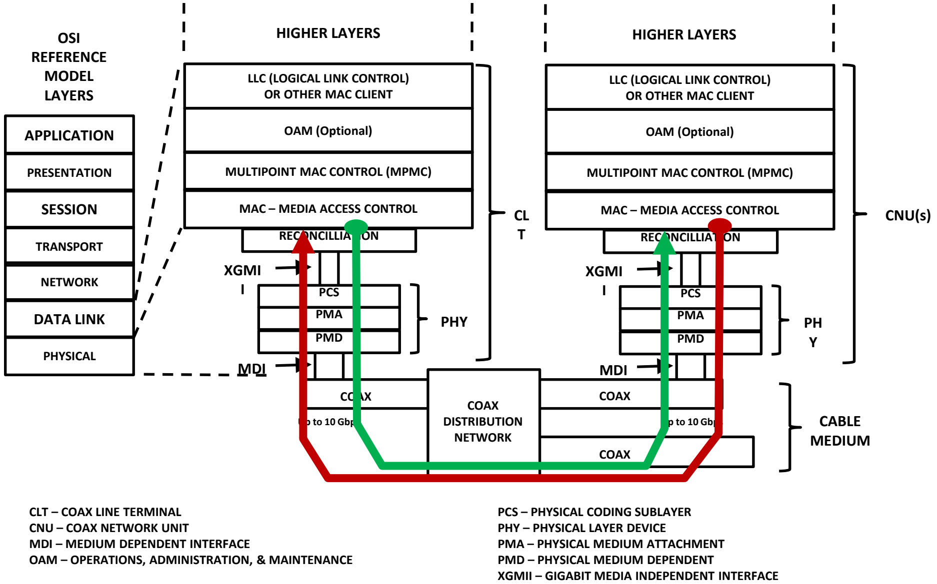
To be further refined

MAC Performance Model - Summary

- Focus on delay but also consider efficiency
  - For both delay and efficiency, two components: PHY and MAC
  - Look at worst case in supported multi-user scenarios
    - This also includes the case of single user in the system using up to 1 Gb/s
  - Efficiency: need to know how much efficiency is consumed by overhead due e.g. guard interval, guard bands, etc. – focus on relative figures and efficiency on the coax side – how the trade-off affects delay vs. efficiency
- Improve the model with further details
  - Consider symbol duration
  - Consider preamble presence/duration
  - Split propagation time (cable length) from switching time
    - Transmit/receive sharing PHY and influence on the switching time
  - Number of simultaneous transmitters
- Important question is: does the absolute numbers meet the delay/jitter requirements?

Delay Model – Latency and Jitter

- The delay model is meant to firstly characterize latency and jitter of the coax portion of the plants, with focus on the PHY and considering as reference points the interfaces between MAC and PHY (see figure)
- Optical part could be considered as well, OCU can be modeled with simple configurable delay (see next slide)

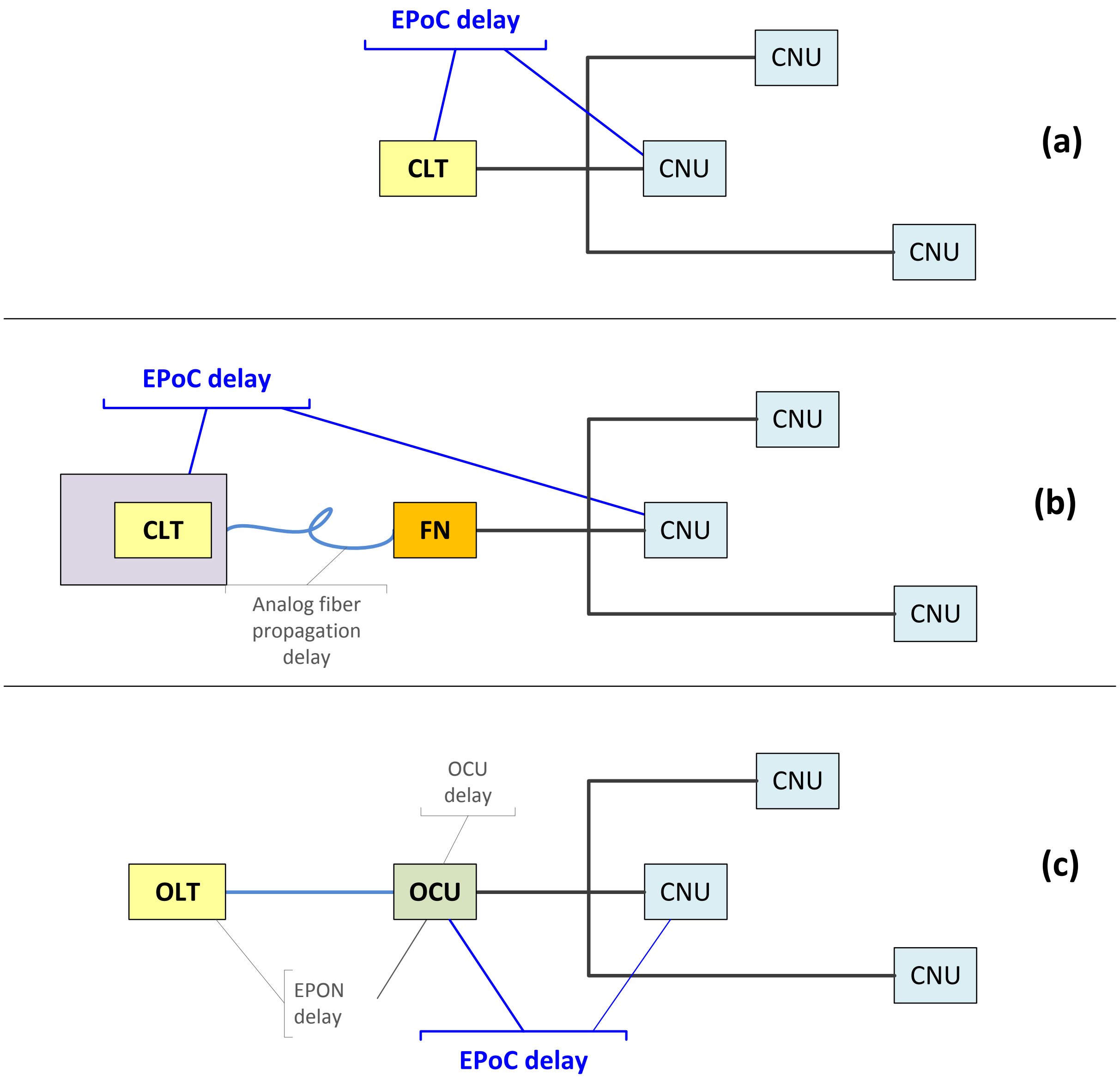


- In addition, implications at MAC layer are considered, whereby the overall delay and jitter are generally represented as a function of PHY and MAC:

delay = function(PHY, MAC)   and   jitter = function(PHY, MAC)

  - The PHY components consider the delay due to processing at the transmitter and receiver sides (e.g. symbol processing, interleavers, etc.), possible guard intervals and preambles, the number of transmitters and min/max burst sizes
    - Propagation delay is treated separately and linked to the cable length
  - The MPCP/MAC components considers the additional delay due to the resource allocation and depends primarily on scheduling/ polling cycles, the number of transmitters and min/max burst sizes, report cycle

Delay Model – Reference Scenarios



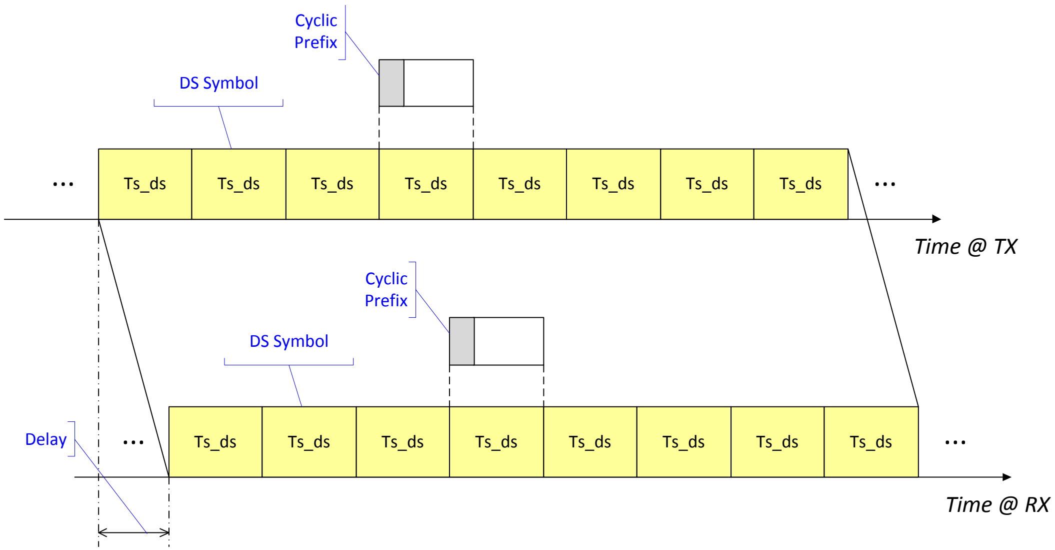
The EPoC performance model is focus on the **<u>EPoC part</u>**, for which a detailed model will be developed to characterize delay and efficiency tradeoffs.

The case of EPoC deployed with analog fiber and CLT in headend can be easily considered adding analog fiber delay as function of the optical fiber length.

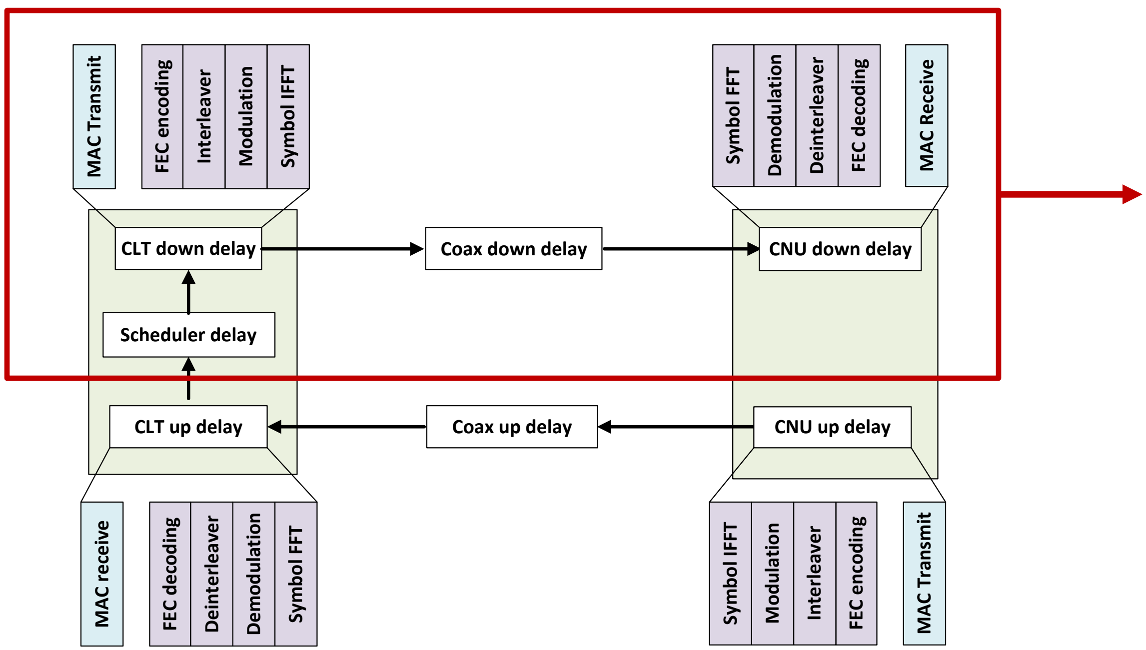
Similarly, the case of EPON with digital fiber can be easily considered adding EPON delay and OCU delay terms.

<u>Note</u>: no detailed model for EPON or HFC will be developed, only input cells are provided

Delay Model – PHY for FDD downstream



In case of FDD downstream there is a continuous transmission consisting in a sequence of DS symbols



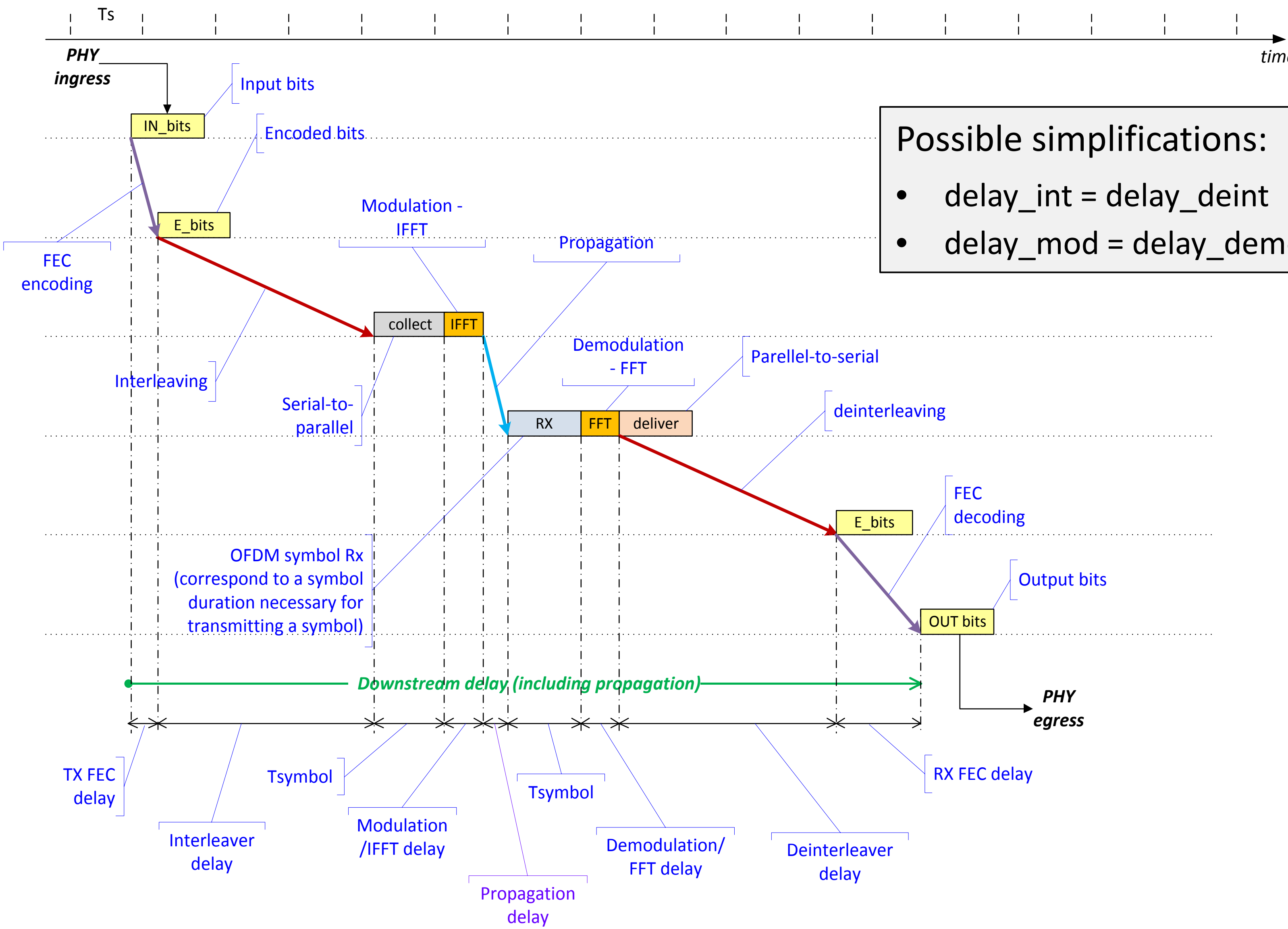
Generally speaking the PHY needs to perform operations for:

- FEC encoding/decoding
- Interleaving/de-interleaving
- Modulation/demodulation
- Symbol IFFT/FFT

Some of the operations are block-level processing related to symbol duration – some may not be present

See next slide for details

Delay Model – PHY for FDD downstream (cont.)

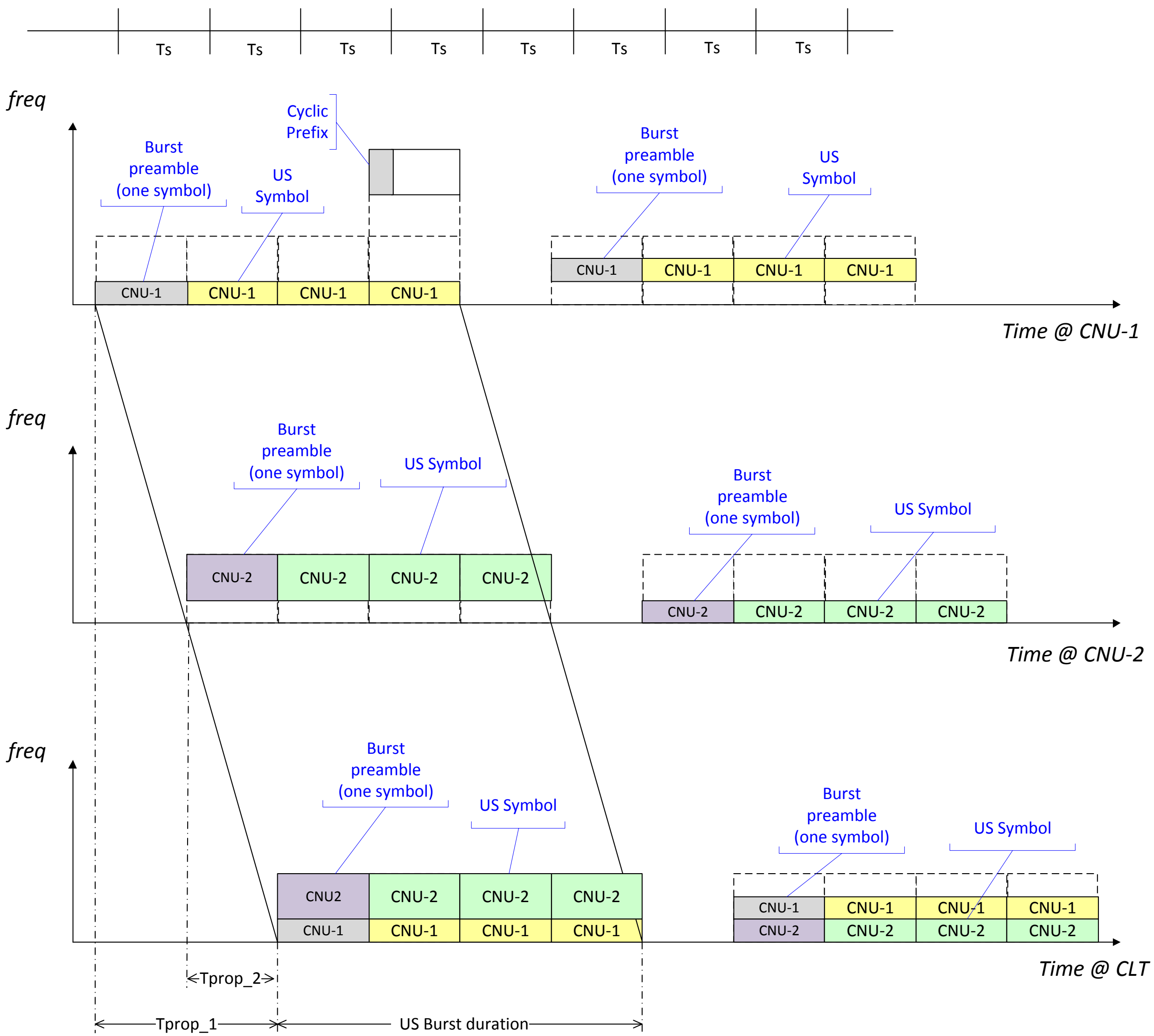


Possible simplifications:

- delay_int = delay_deint
- delay_mod = delay_demod

Note: Propagation delay depends on the cable plant and can vary significantly – this is just an example.

Delay Model – PHY for FDD upstream

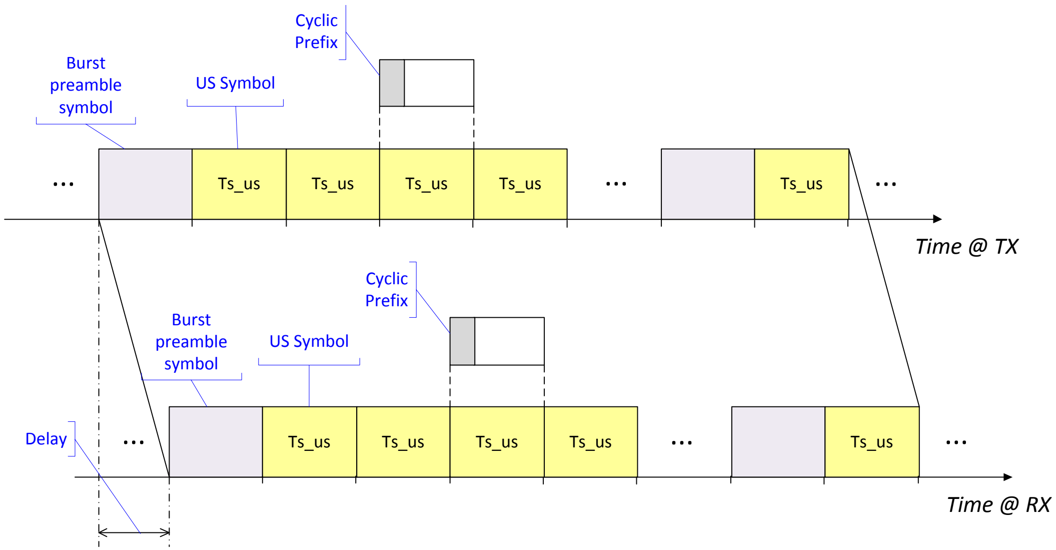


In case of FDD upstream there is a burst transmission consisting in a sequence of upstream symbols

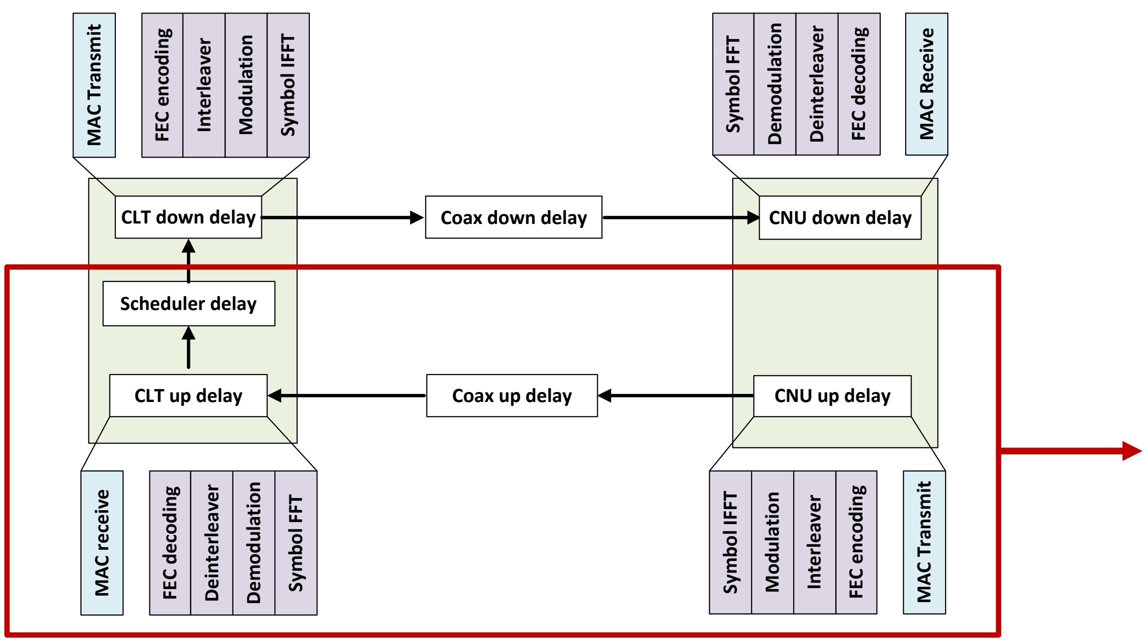
- The transmit sequence could include a burst preamble (of Np*symbol duration)
- Different CNUs are time-aligned via RTT compensation
- Concurrent transmission could be enabled in the frequency domain

Note: the burst preamble at the start of each US transmission could be included to help with clock alignment in US and with channel estimate, depending on the particular solution whether needed or not.

Delay Model – PHY for FDD upstream (cont.)



In case of FDD upstream there is a burst transmission consisting in a sequence of US symbols and potentially starting with a burst preamble (of Np*symbol duration)



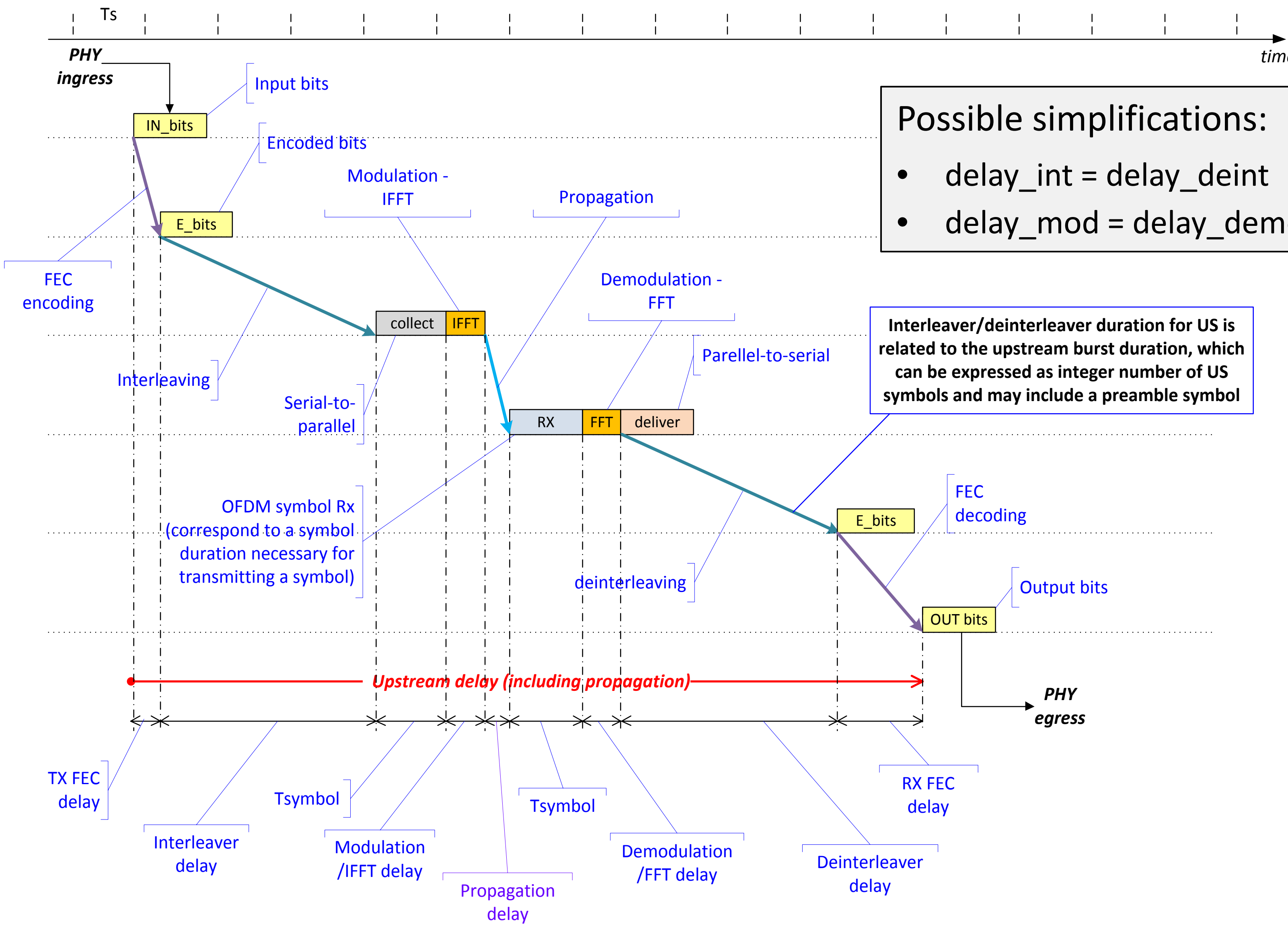
Generally speaking the PHY needs to perform operations for:

- FEC encoding/decoding
- Interleaving/de-interleaving
- Modulation/demodulation
- Symbol IFFT/FFT

Some of the operations are block-level processing related to symbol duration – some may not be present

See next slide for details

Delay Model – PHY for FDD upstream (cont.)



Possible simplifications:

- delay_int = delay_deint
- delay_mod = delay_demod

Interleaver/deinterleaver duration for US is related to the upstream burst duration, which can be expressed as integer number of US symbols and may include a preamble symbol

Note: Propagation delay depends on the cable plant and can vary significantly – this is just an example.

Delay Model – PHY for FDD summary

In case of FDD, the delay model results in the following terms:

$$PHY\_delay_{FDD\_DS} = T_{enc} + (2/n)*T_{FDD\_DS\_Int} + 2*T_{DS\_symb} + 2*T_{mod\_FFT} + T_{dec}$$

$$PHY\_delay_{FDD\_US} = T_{enc} + (2/n)*T_{FDD\_US\_Int} + 2*T_{US\_symb} + 2*T_{mod\_FFT} + T_{dec}$$

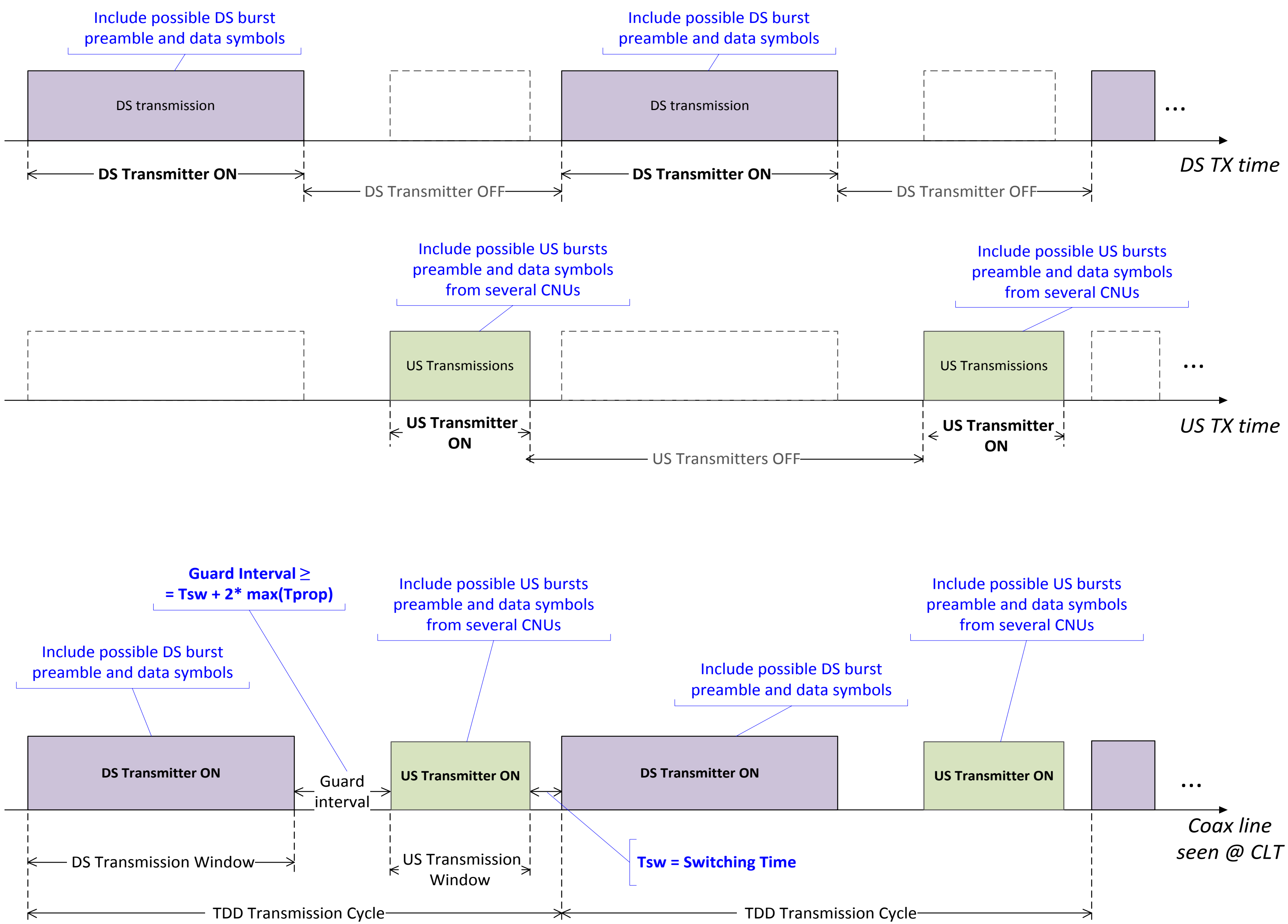
$T_{propagation\_oneway} = L_{cable} / (0.87*c)$ where *c* is the speed of light in vacuum

n = 1 for block interleaver and n = 2 for convolutional interleaver of same size

Note: The following assumption and considerations holds

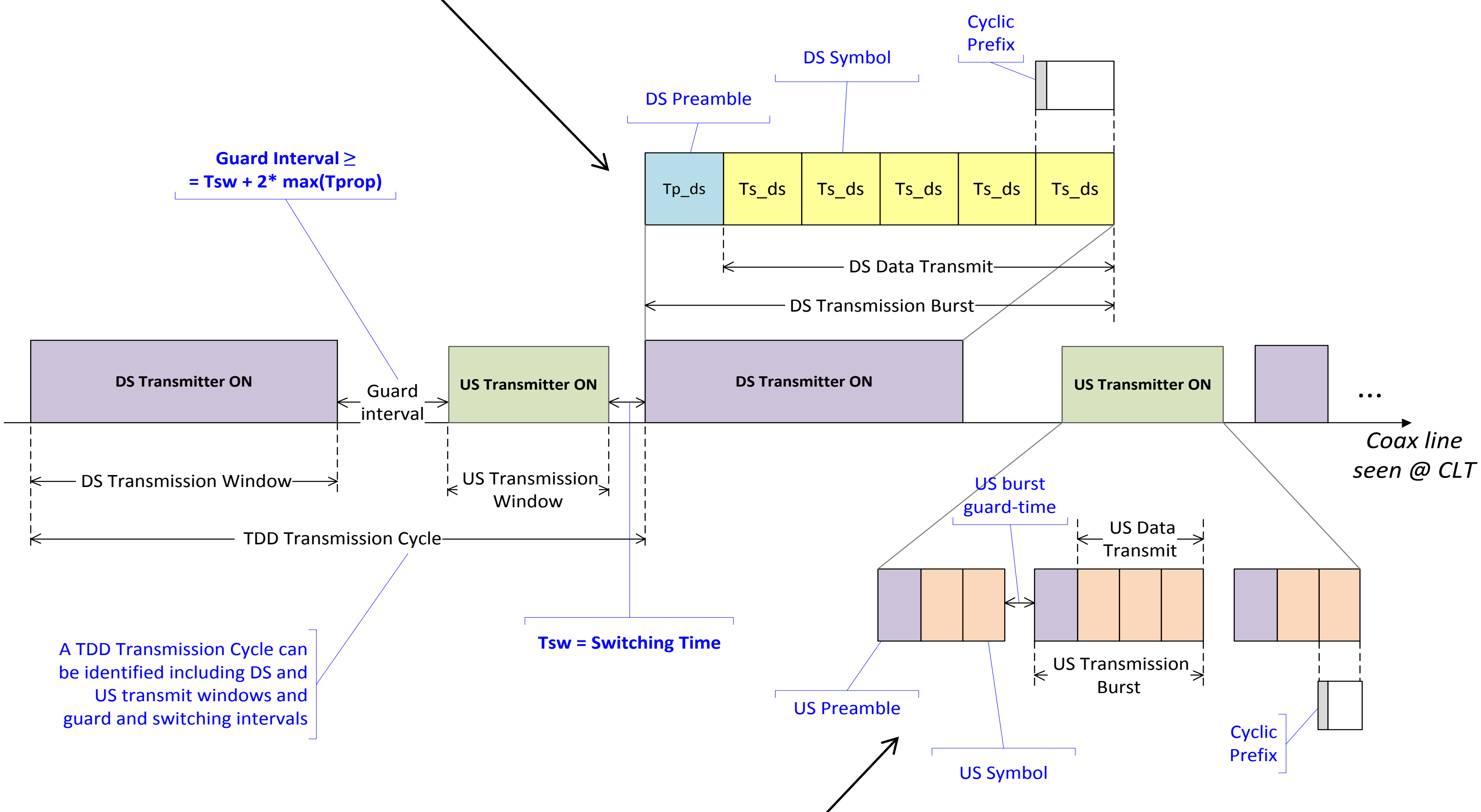
- Delay of interleaver and deinterleaver in one direction are the same
- Delay for modulation/IFFT and demodution/FFT are the same
- Encoder/decoder are the same for DS and US
- Modulation/demodulation are the same for DS and US
- Different symbol duration for DS and US are possible
- Different interleavers for DS and US are possible
  - interleaver length is related to burst noise characteristics and in case of US the transmission burst may be equal or a multiple of the interleaver length
  - US interleaver from multiple CNUs may be inefficient against burst noise

Delay Model – PHY for TDD



Delay Model – PHY for TDD (cont.)

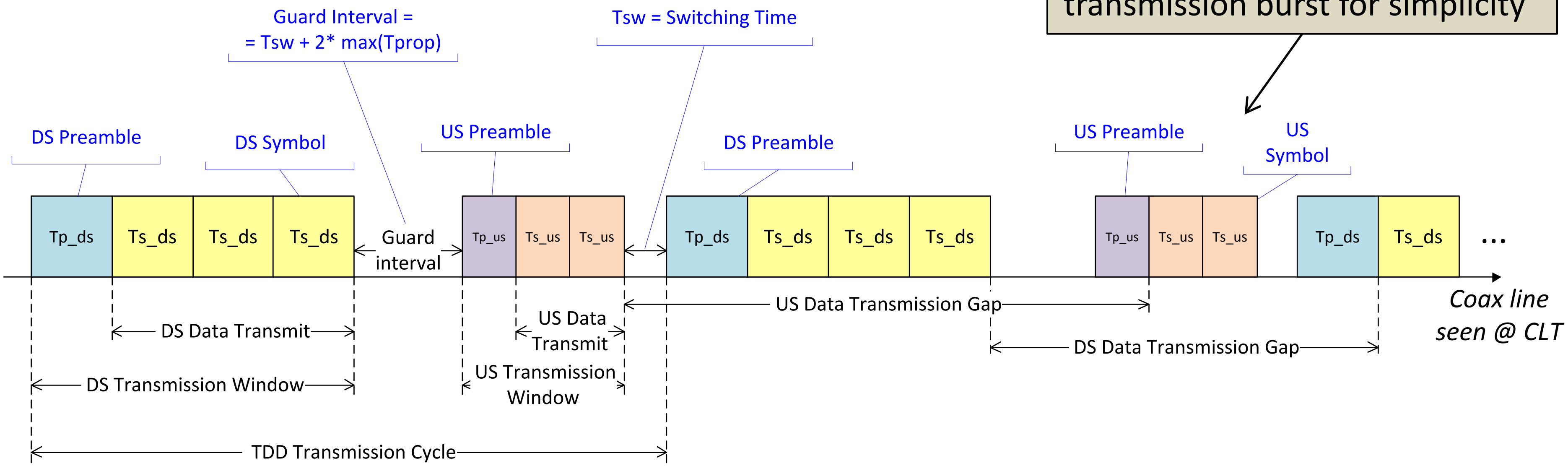
DS transmission occurs in the DS transmission window and generically consist in a sequence of data symbols (during DS data transmit time) preceded by a possible DS preamble.



US transmission occurs in the US transmission window and consist in a sequence of US transmit bursts, each of them including data symbols (US data transmit) and preceded by a possible US preamble.

Delay Model – PHY for TDD (cont.)

Example referring to single US transmission burst for simplicity



TDD Transmission Cycle $= T_{DS\_TXwin} + [\ 2*T_{SW} + 2*\max(T_{prop})\ ] + T_{US\_TXwin}$

$= T_{DS\_TXdata} + T_{DS\_TXgap}$

$= T_{US\_TXdata} + T_{US\_TXgap}$

For multiple bursts, the sum including burst guard-times shall be considered

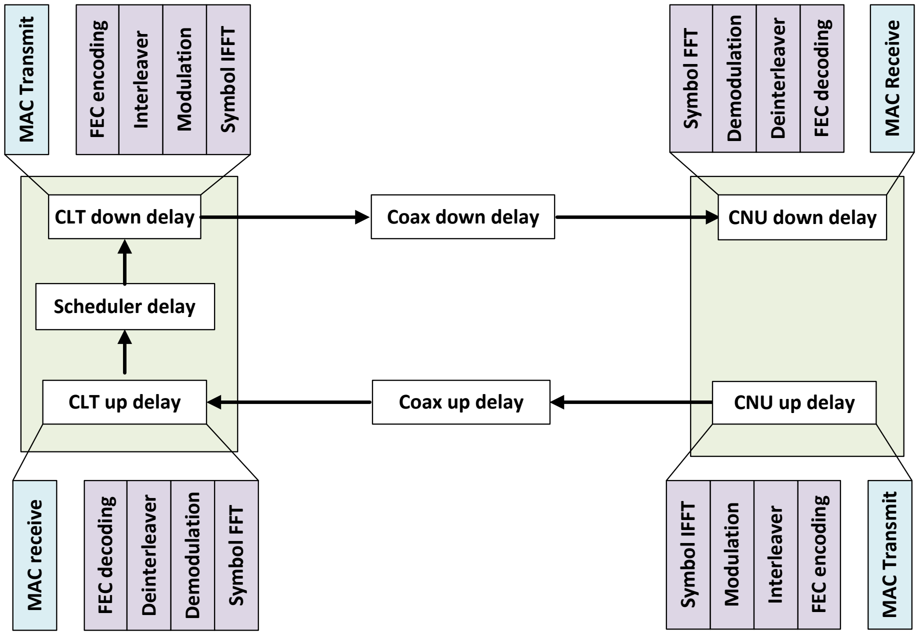
$T_{DS\_TXwin} = T_{DS\_TXdata} + T_{DS\_preamble}$ and $T_{US\_TXwin} = T_{US\_TXdata} + T_{US\_preamble}$

$T_{DS\_TXgap} = T_{US\_TXwin} + T_{DS\_preamble} + [\ 2*T_{SW} + 2*\max(T_{prop})\ ]$

$T_{US\_TXgap} = T_{DS\_TXwin} + T_{US\_preamble} + [\ 2*T_{SW} + 2*\max(T_{prop})\ ]$

Note: coax line is idle during this time

Delay Model – PHY for TDD (cont.)



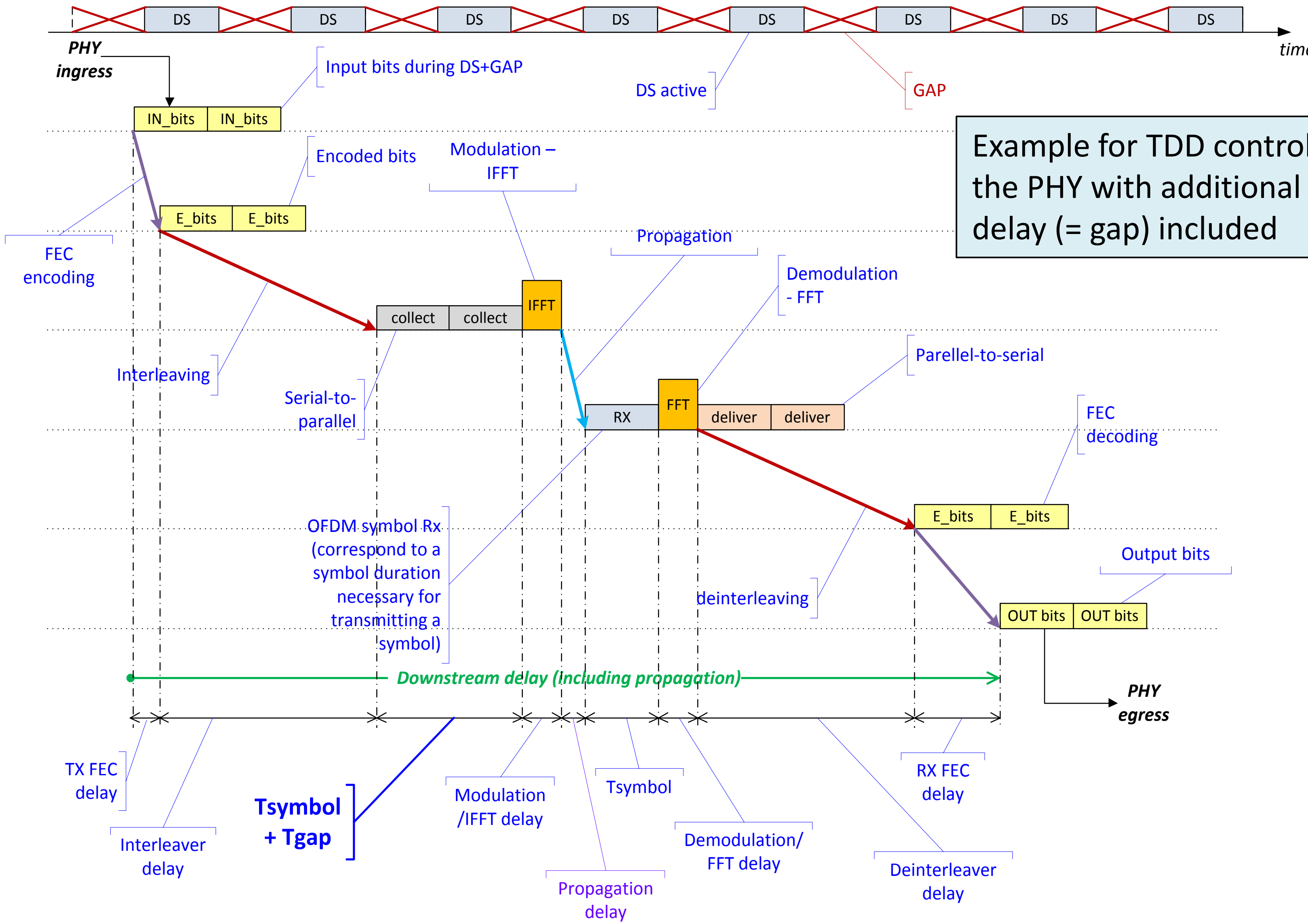
Also in case of TDD the PHY needs to perform operations for:

- FEC encoding/decoding
- Interleaving/de-interleaving
- Modulation/demodulation
- Symbol IFFT/FFT

➢ The same analysis as for FDD can be reused, with the inclusion of the DS and US data transmission gaps

- In case TDD is controlled at the PHY, data are collected over all time and transmitted during the DS transmission window and the average rate is matched over a TDD cycle)
  - In this case an additional PHY delay term accounting for the transmit gap is added
  - An example is included in the next slide
- In case TDD is controlled at the MPCP, data are both collected and transmitted only over the DS transmission window and the average rate is matched over a TDD cycle)
  - In this case there is no additional delay at the PHY and an additional (jitter) term accounting for the transmit gap shall be included in the MAC/MPCP part – see MAC/MPCP implications

Delay Model – PHY for TDD downstream example



Example for TDD controlled in the PHY with additional PHY delay (= gap) included

Note: Propagation delay depends on the cable plant and can vary significantly – this is just an example.

Delay Model – PHY for TDD summary

In case of TDD, the delay model results in the following terms:

$$PHY\_delay_{TDD\_DS} = T_{enc} + (2/n)*T_{TDD\_DS\_Int} + 2*T_{DS\_symb} + 2*T_{mod\_FFT} + T_{dec} + q*T_{DS\_Txgap}$$

$$PHY\_delay_{TDD\_US} = T_{enc} + (2/n)*T_{TDD\_US\_Int} + 2*T_{US\_symb} + 2*T_{mod\_FFT} + T_{dec} + q*T_{US\_Txgap}$$

$T_{propagation\_oneway} = L_{cable} / (0.87*c)$ where *c* is the speed of light in vacuum

n = 1 for block interleaver and n = 2 for convolutional interleaver of same size

q = 1 for TDD control in PHY and q = 0 for TDD control in MPCP

Note: The following assumption and considerations holds

- Delay of interleaver and deinterleaver in one direction are the same
- Delay for modulation/IFFT and demodulation/FFT are the same
- Encoder/decoder are the same for DS and US
- Modulation/demodulation are the same for DS and US
- Different symbol duration for DS and US are possible
- Different interleavers for DS and US are possible
- Different DS/US transmission gaps are possible, either via fixed configuration or variable in time between a minimum (at least one data symbol when transmitting) and maximum value (e.g. to meet delay/jitter requirements)

Delay Model – MAC/MPCP implications

- For simplicity, assumption is that each user has the same traffic profile and it is treated the same, with assigned resources in round-robin fashion
  - This is reasonable starting point, further refinement may be considered later
- Latency and jitter due to the MAC/MPCP components includes:
  - DS scheduler cycle and resource allocation
  - US polling cycle and resource allocation
  - Number of transmitters and min/max burst sizes
  - Report cycle (in relation with RTT)
  - TDD control (in case done at MPCP level)
- The same components also affect efficiency of the system
  - These aspects will also be considered during the further analysis

Delay Model – MAC/MPCP components (cont.)

- …

Capture here MAC explanations and formulas as needed

Efficiency Model – …

Future Work

Different questions have been identified during the development of the model, which would need to be sorted out by the task force – they are listed here.

- For the case of TDD, few points may need to be investigated further
  - Fixed vs. variable TDD transmission cycle and/or DS/US transmit window
  - Ranging in case of TDD (for US transmit time alignment)
  - Discovery window for TDD (for registration)
    - When US is not yet ranged like for registration, needs to ensure it does not hit the DS window (this is in particular relevant for the TDD control done in PHY)
  - …

Backup Material

Delay Model – Q&A to the group @ 27-July-2012

<u>**Q1**</u>: First priority should be the worst case within a reasonable scenario (e.g. multiple users in a system, taking the worst case in there): is any need to also consider typical case? If yes, what could be a definition of such typical case?

<u>A1</u>*: *The conclusion is to have worst case in realistic multi-user scenario and exclude corner cases – can be seen as typical scenario, 99%-tile. <u>Still some open points</u>:

(1) Max 1 Gb/s BW PAR Objective: to an individual CNU? Or to multiple CNUs on a coax segment? If multiple CNUs, max to an individual CNU?

(2) Consider max optical distance on HFC network – inputs needed, specification states at least 10-20 km of fibers needs to be supported in EPON, depending on scenario (clause 56.1.3)

<u>**Q2**</u>: The main objective is to analyze the delay in the PHY -> proposed reference points are from (a) packet leaves the MAC and enter the PHY in the transmitter to (b) packets leaves the PHY and is delivered to the MAC in the receiver. Once the PHY delay is modeled, the implication that this has on the MAC are also considered so that the overall delay = f(PHY, MAC) is modeled and compared with the requirements

<u>A2</u>*: *Proposed reference points and way forward are fine for the exercise. Agreed to start with coax PHY delay components and then implications and highlight transmit/receive sides separately

<u>**Q3**</u>: It is proposed to focus on coax part: like to hear opinion about including also the optical part and the OCU later on or not

<u>A3</u>*: *Will start with coax modeling, and consider adding the optical part later. OCU model may be reduced to a simple delay component to play with.

<u>**Q4**</u>: For simplicity we are planning to do the analysis for a system with equal traffic distribution. Like to hear if that is sufficient or other traffic profile should be selected.

<u>A4</u>*: *Equal traffic (all users treated the same) is good place to start with, will include a variable number of transmitters in the model. Later additional cases may be added and consider asymmetric traffic.

Delay Model – Q&A to the group @ 13-August-2012

Q5: Is 1 Gb/s PAR objective to individual CNU or on coax line at CLT output?

A5: ***The conclusion is that the 1 Gb/s refers to the line rate and it shall be supported in case of multiple and also of single CNU – the case of single user consuming entire line is a valid one to be supported***

Q6: Shall the model with OCU in slide 5 be kept or removed?

A6: ***It is kept and meant to just add a place-holder field in the final spreadsheet where people interested can include delay numbers modeling the fiber length and the EPON/OCU delay***