Solutions for a flexible dual-mode TDD/FDD physical layer in EPoC
(TDD feasibility Part II)

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Summary

- Rate adaptation is needed at the physical layer irrespectively of specific transmission mode (TDD/FDD):
  - Adapt to the (fixed) MAC/PHY interface rate → **Idle insertion / deletion**
  - PHY rate depends on semi-static physical layer parameters (e.g., channel bandwidth, US/DS time split) → **Addressed in this deck**
  - PHY rate may be asymmetric for US/DS → **Addressed in this deck**

- This presentation:
  1. Recaps the solution proposed during the last 802.3 meeting in San Diego
     - Rate adaptation is performed at the PCS layer
  2. Introduces an alternative solution
     - Rate adaptation is performed at the PMD layer
  3. Evaluates the impact of TDD operation on PHY acquisition procedures

Assumptions

- The *information rate* supported by the PHY is known by MAC Control
  - Depends on modulation order and FEC (assumed not to change dynamically in time)
- The Media-Independent Interface between MAC and PHY (xMII) runs at a fixed rate R_{xMII}
- The PCS/PMD bit rate (coded bits / second) for transmission is $R_{PCS/PMD,TX}$
- The PMA layer does not change the bit rate (coded bits / second)
- For the sake of simplicity, fixed delays incurred in each operation are not considered here

PHY Rate in EPoC /1

- The PHY rate depends on specific PHY parameters (e.g., bandwidth, MCS) and can be different in the transmit and the receive direction
  - Example #1: FDD with asymmetric bandwidth allocation:
    - OFDM symbol duration: 100us
    - Number of subcarriers available for Tx: 10000 (100 MHz bandwidth)
    - Number of subcarriers available for Rx: 2500 (25 MHz bandwidth)
    - Modulation order Tx/Rx: 1024-QAM (10 bits)

    → **R_{TX} = 1.0 Gbps**

    → **R_{RX} = 0.25 Gbps**
  - Example #2: FDD with different Modulation and Coding Schemes:
    - OFDM symbol duration: 100us
    - Number of subcarriers available for Tx/Rx: 10000 (100 MHz bandwidth)
    - Modulation order Tx: 1024-QAM (10 bits)
    - Modulation order Rx: 256-QAM (8 bits)

    → **R_{TX} = 1.0 Gbps**

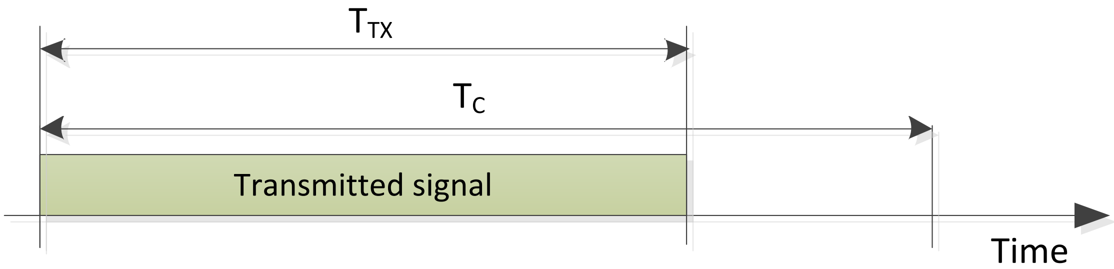
    → **R_{RX} = 0.8 Gbps**

PHY Rate in EPoC /2

- Example #3: TDD with a given US/DS split:
  - OFDM symbol duration: 100us
  - Number of subcarriers available: 12000 (120 MHz bandwidth – same for US and DS)
  - Modulation order Tx/Rx: 1024-QAM (10 bits)

→ **R_{TDD} = 1.2 Gbps**

→ **$R_{TX} = R_{TDD} \times T_{TX} / T_C$**

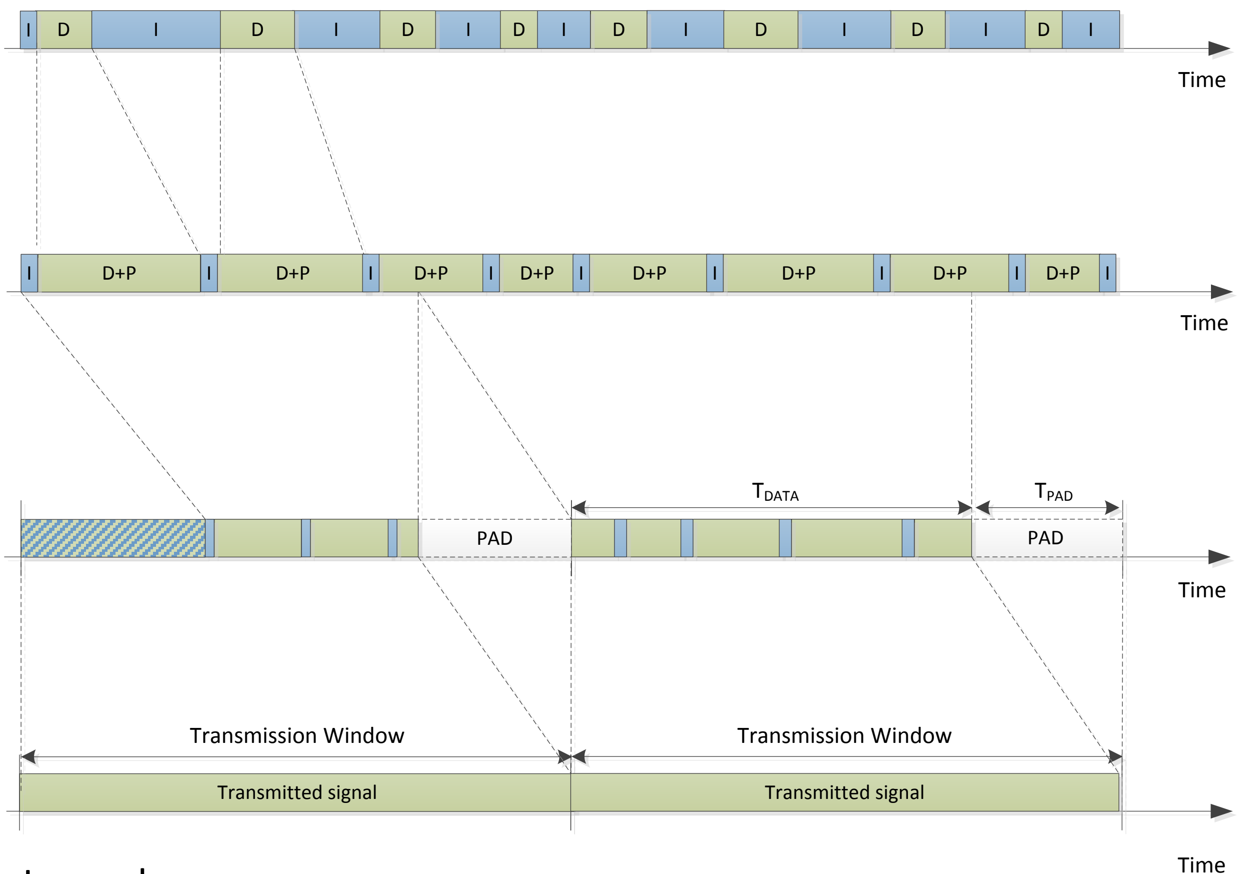


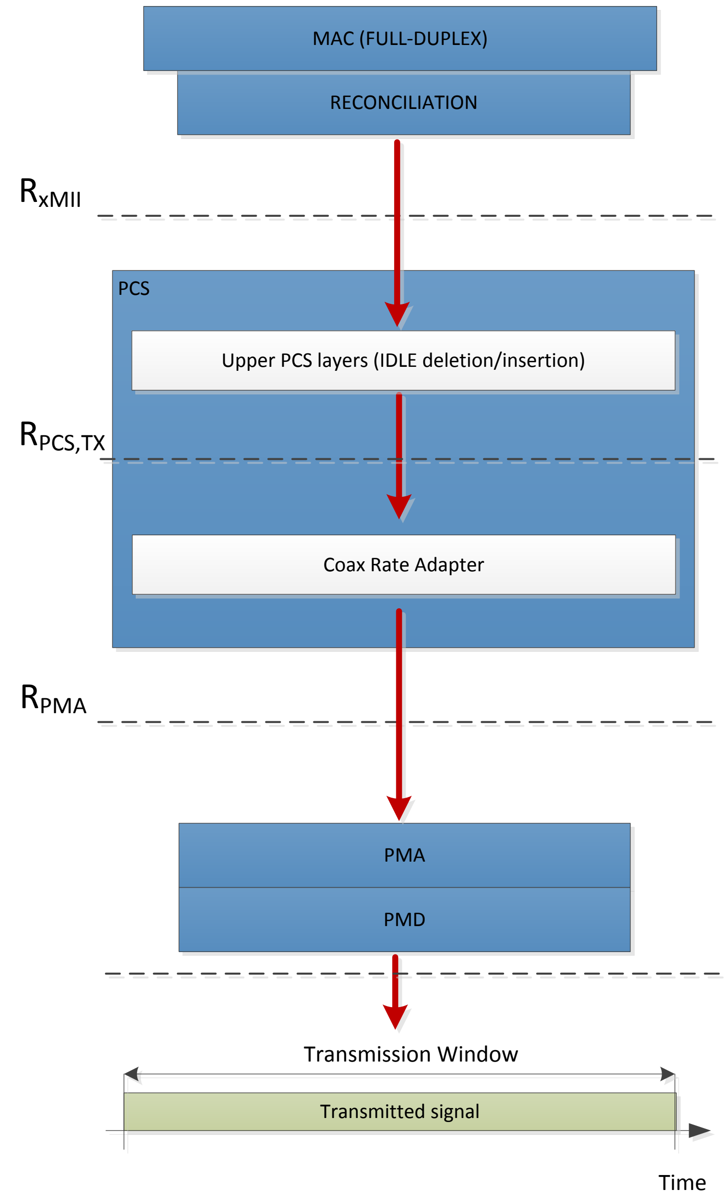
We introduce a Coax Rate Adapter to cope with different possible PHY rates :

- **Solution 1: At the PCS**
- **Solution 2: At the PMD**

Solution 1:
Rate adaptation at PCS layer

FDD Stack Operation during Transmission





Legend :

D = Data bits (Ethernet frame)

I = Idle characters

P = Parity bits from FEC

$$R_{PCS,TX} = R_{PMA} \times \frac{T_{DATA}}{T_{DATA} + T_{PAD}}$$

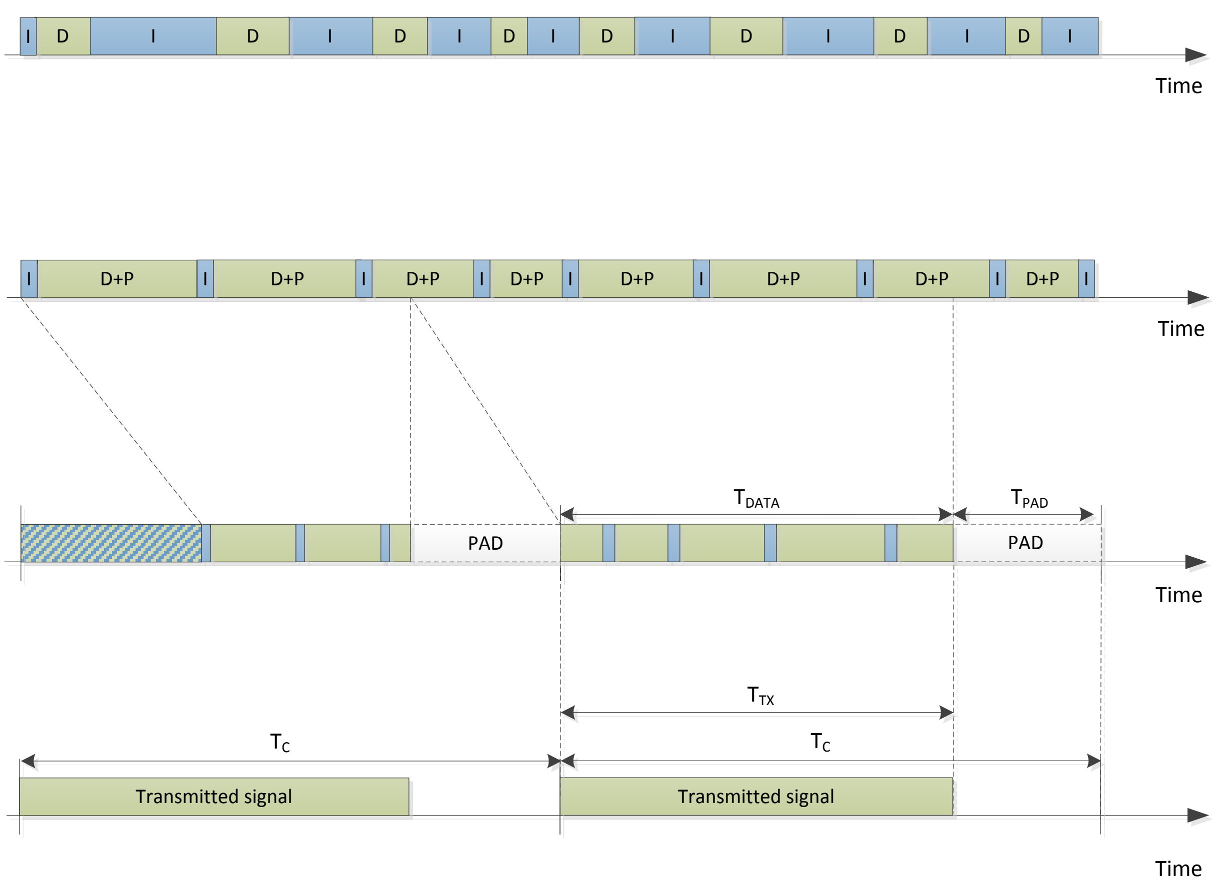
By transmission, we cover DS operation for the CLT and US operation for the CNU

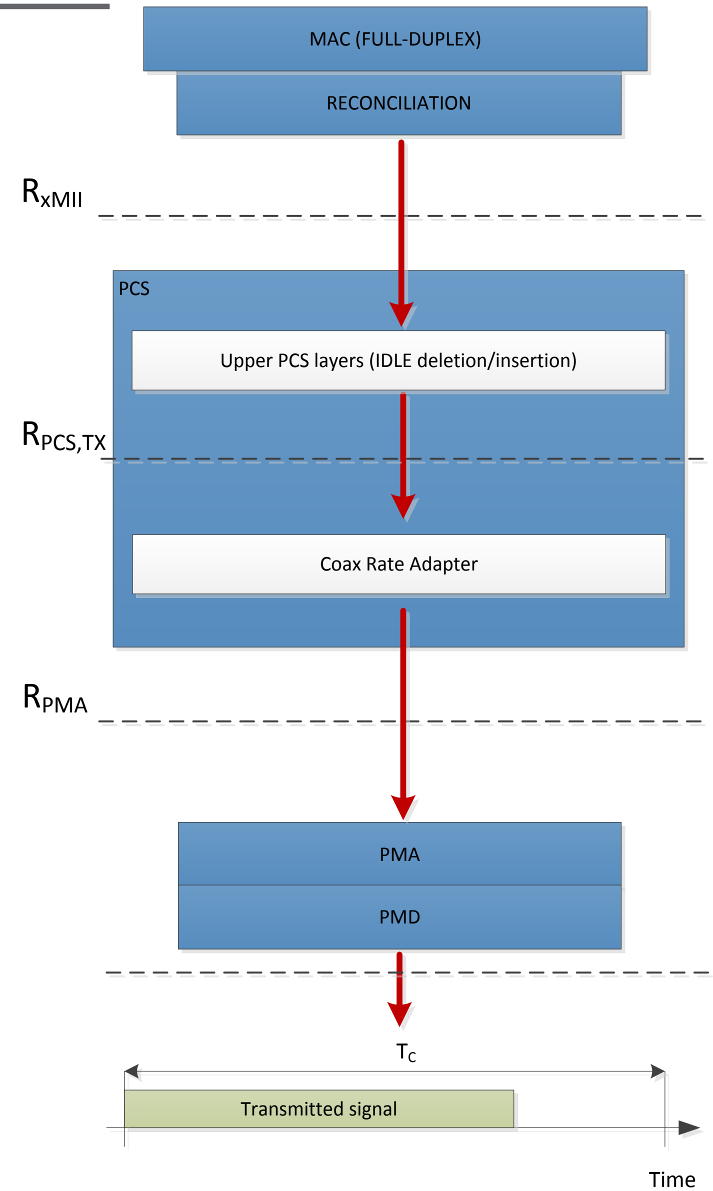
Details on FDD Stack Operation

- Operation:
  - The upper sub-layers of the PCS layer:
    1. Performs idle deletion in order to leave space for parity bits introduced by FEC (this operation does not change the bit rate)
    2. Re-times the bit-stream in order to match the bit-rate $R_{PCS,TX}$
  - The Coax Rate Adapter:
    1. Divides the incoming bitstream in slices according to the transmission window size
    2. Re-times each slice with the PMA rate $R_{PMA} > R_{PCS,TX}$
    3. Pads with zero symbols the portion of the transmission window left empty
  - The PMA layer converts the received slice into a physical signal spanning the whole transmission window
  - Example computation of T_{DATA}/T_{PAD}:
    – **R_{PMA} = 1.2 Gbps**
    – **$R_{PCS,TX}$ = 1.0 Gbps**

$$\Rightarrow \quad T_{PAD} = \frac{R_{PMA} - R_{PCS,TX}}{R_{PMA}} = \frac{1}{6} T_{DATA}$$

TDD Stack Operation during Transmission





Legend :

D = Data bits (Ethernet frame)

I = Idle characters

P = Parity bits from FEC

$$R_{PCS,TX} = R_{PMA} \times \frac{T_{DATA}}{T_{DATA} + T_{PAD}}$$

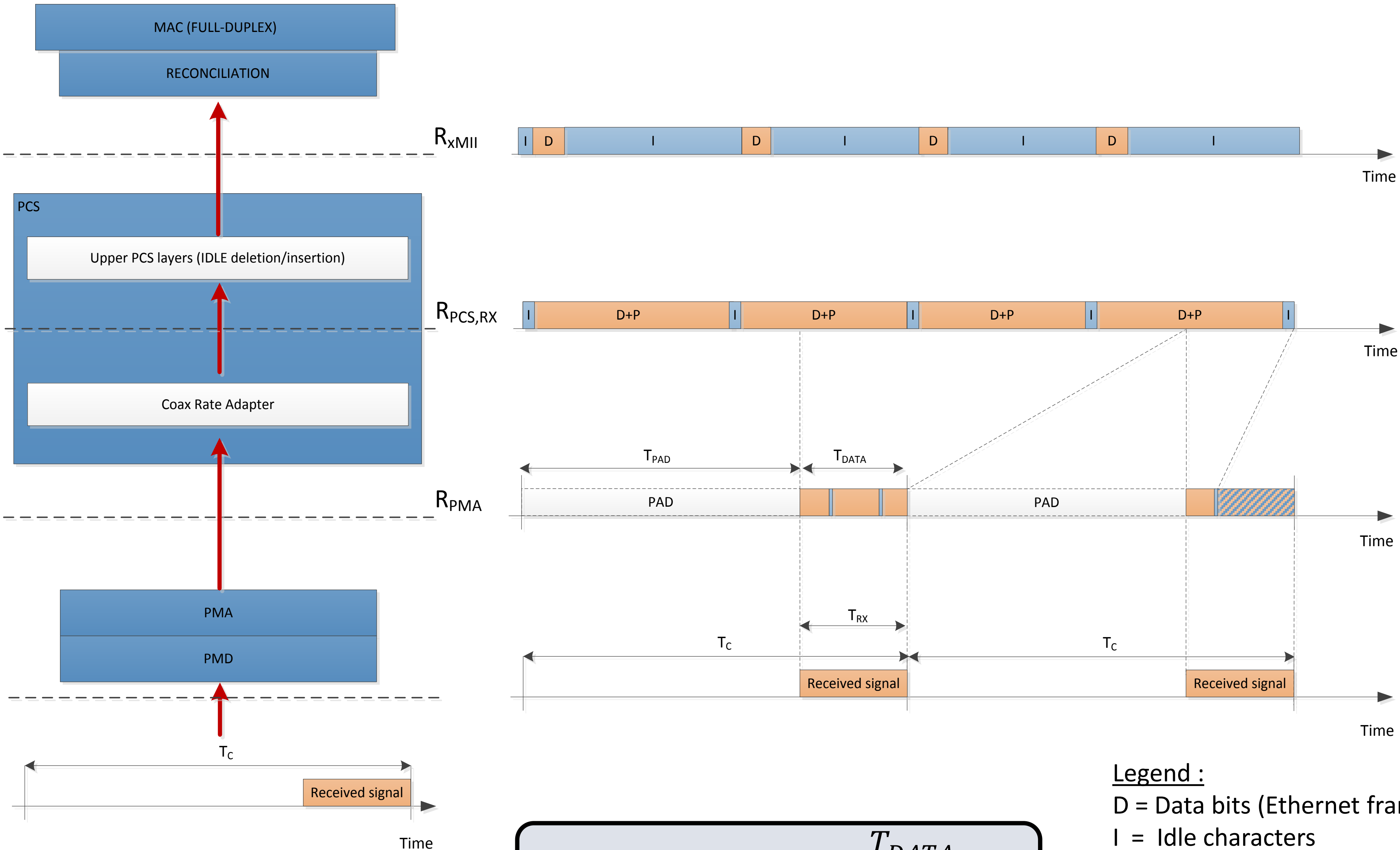
By transmission, we cover DS operation for the CLT and US operation for the CNU

Details on TDD Stack Operation

- Operation: **SAME AS FDD**
  - The upper sub-layers of the PCS layer:
    1. Performs idle deletion in order to leave space for parity bits introduced by FEC (this operation does not change the bit rate)
    2. Re-times the bit-stream in order to match the bit-rate $R_{PCS,TX}$
  - The Coax Rate Adapter:
    1. Divides the incoming bitstream in slices according to the transmission window size
    2. Re-times each slice with the PMA rate $R_{PMA} > R_{PCS,TX}$
    3. Pads with zero symbols the portion of the transmission window left empty
  - The PMA layer converts the received slice into a physical signal spanning only the transmission window
  - T_{DATA} and T_{PAD} determined by T_{TX} and T_C

$$\boxed{R_{PCS,TX} = R_{PMA} \times \frac{T_{TX}}{T_C}}$$

TDD Stack Operation during Reception



$$R_{PCS,RX} = R_{PMA} \times \frac{T_{DATA}}{T_{DATA} + T_{PAD}}$$

Legend :

D = Data bits (Ethernet frame)

I = Idle characters

P = Parity bits from FEC

By reception, we cover US operation for the CLT and DS operation for the CNU

Details on TDD Stack Operation

- Operation:
  - During the reception slot, the PMA layer converts the received signal into a bitstream at rate R_{PMA} , filling with PAD symbols the remaining part of the reception window
  - T_{DATA} and T_{PAD} determined by T_{RX} and T_C

$$\boxed{R_{PCS,RX} = R_{PMA} \times \frac{T_{RX}}{T_C}}$$

- During the reception slot, the TDD adapter reproduces the incoming bit stream from PMA at the reception bit rate $R_{PCS,RX}$ (smaller than R_{PMA}).
  - PAD bits are discarded

- The upper sub-layers of the PCS layer:

SAME AS FDD

  - Perform idle insertion in order to adapt the PCS reception bit-rate $R_{PCS,RX}$ to the xMII rate R_{xMII}
  - fill spaces left empty by parity bits removed by FEC (this operation does not change the bit rate)

Solution 2:

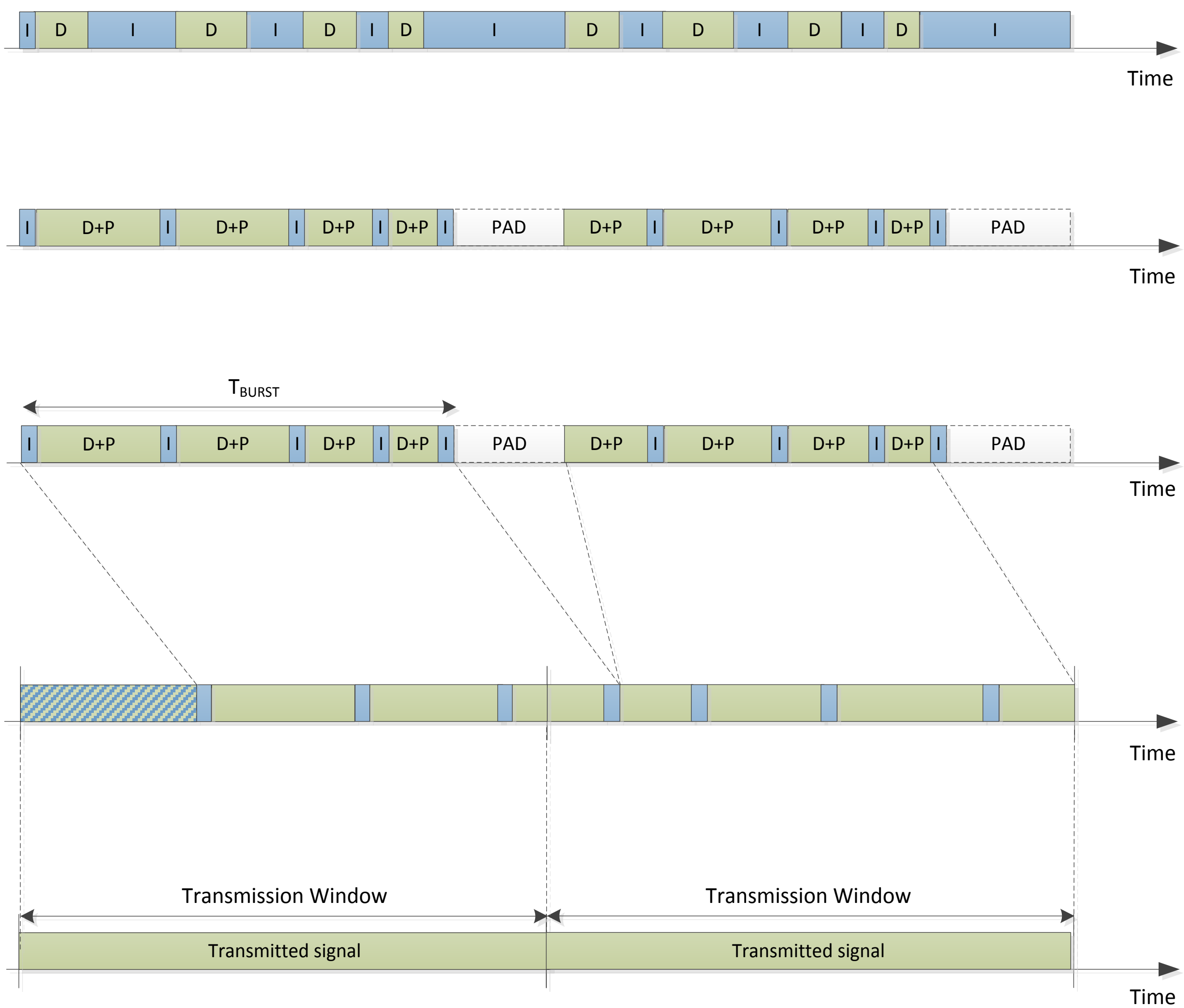
Rate adaptation at PMD layer

Motivation for an alternative approach

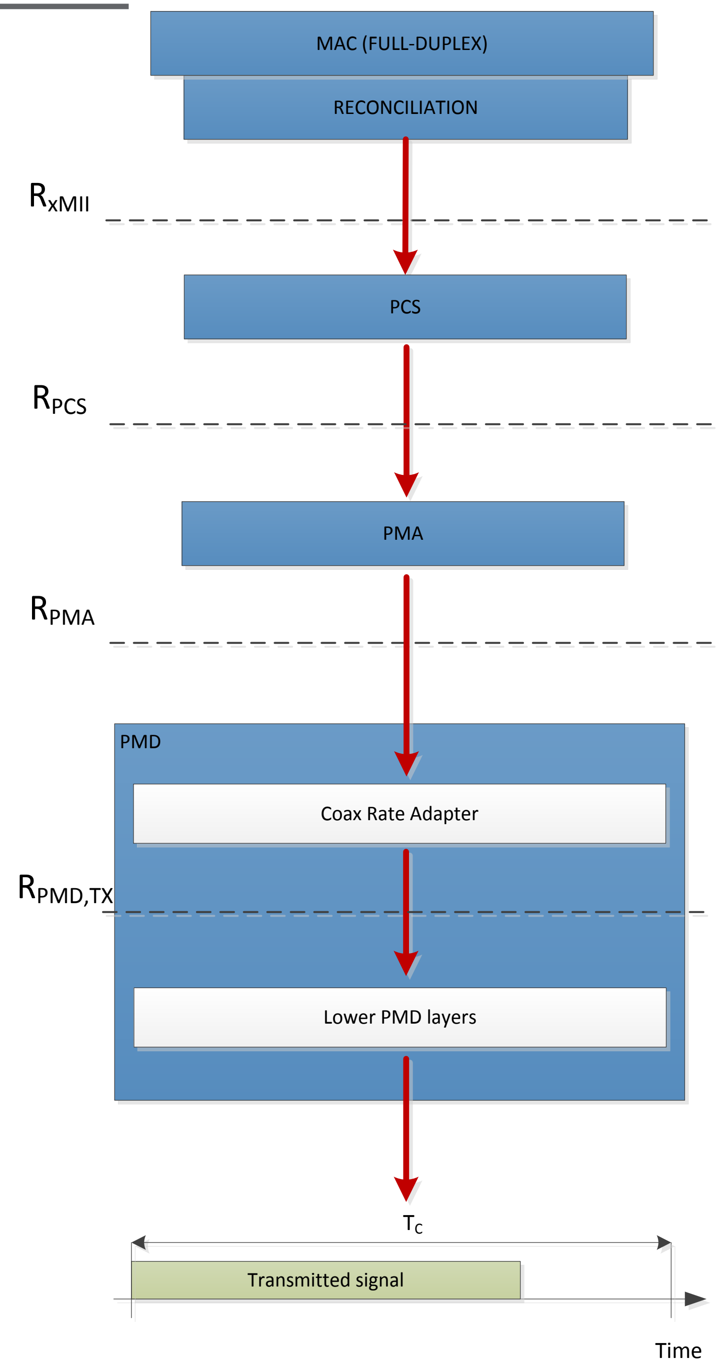
- Rate adaptation at the PCS layer:
  - If we chose $R_{PMA} = R_{xMII}$, operating at a different rate R_{PCS} within PCS seems to be a questionable choice.
  - PMA/PMD layers may still need to perform some form of re-timing (especially for FDD).
    - It is of interest to investigate a solution based exclusively on PMD-based rate adaptation

- Rate adaptation at the PMD layer:
  - Assumes $R_{PMA} = R_{xMII}$ as a working assumption
  - Adds rate adaptation functionalities into PMD layer only
    - Support for multiple PHY configurations (e.g., different bandwidths)
    - Support for both TDD and FDD modes of operation (as for Solution 1).

FDD Stack Operation during Transmission



$$R_{PMD,TX} = R_{PMA} \times \frac{T_{BURST}}{T_{BUSRT} + T_{PAD}}$$



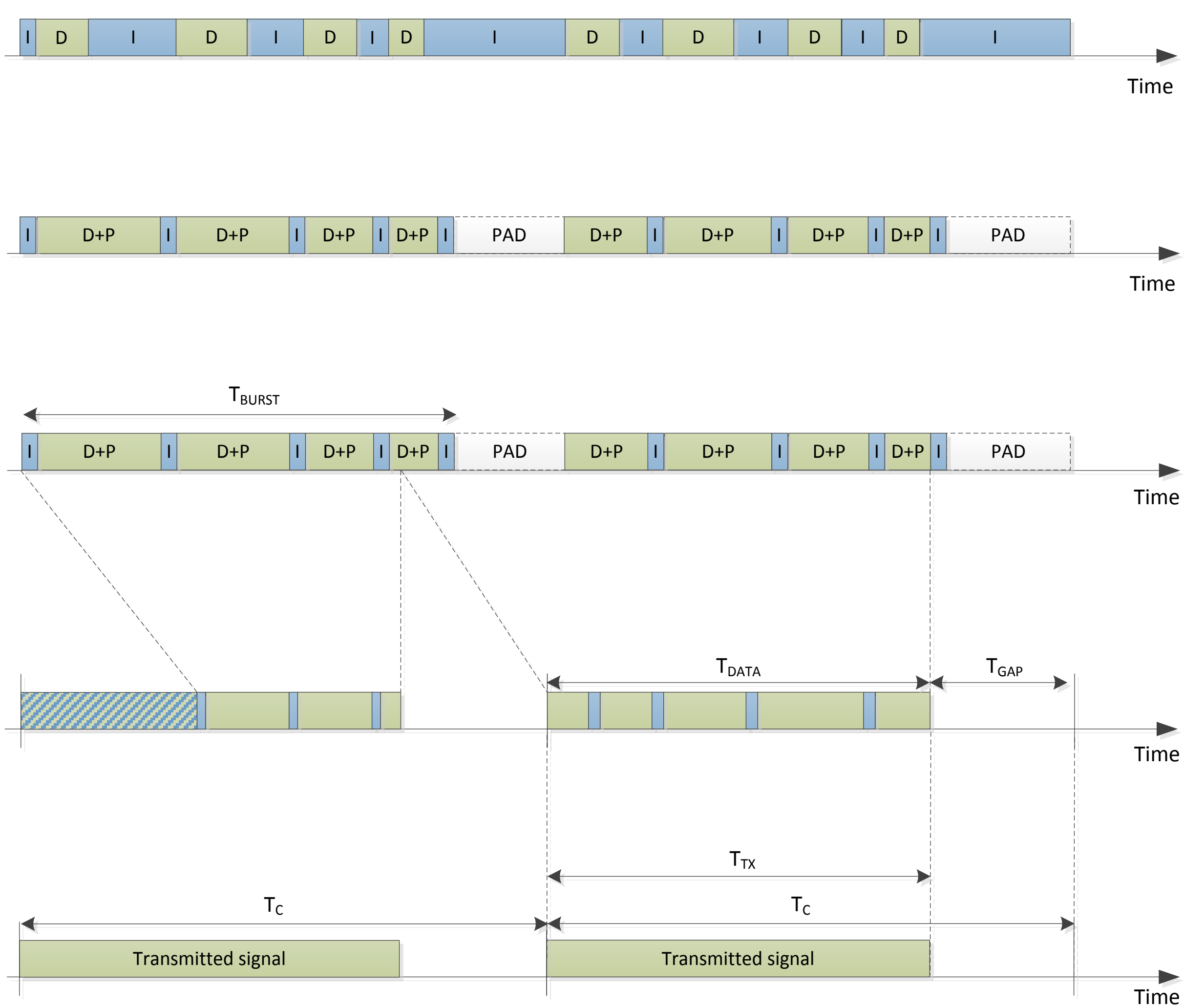
Details on TDD Stack Operation

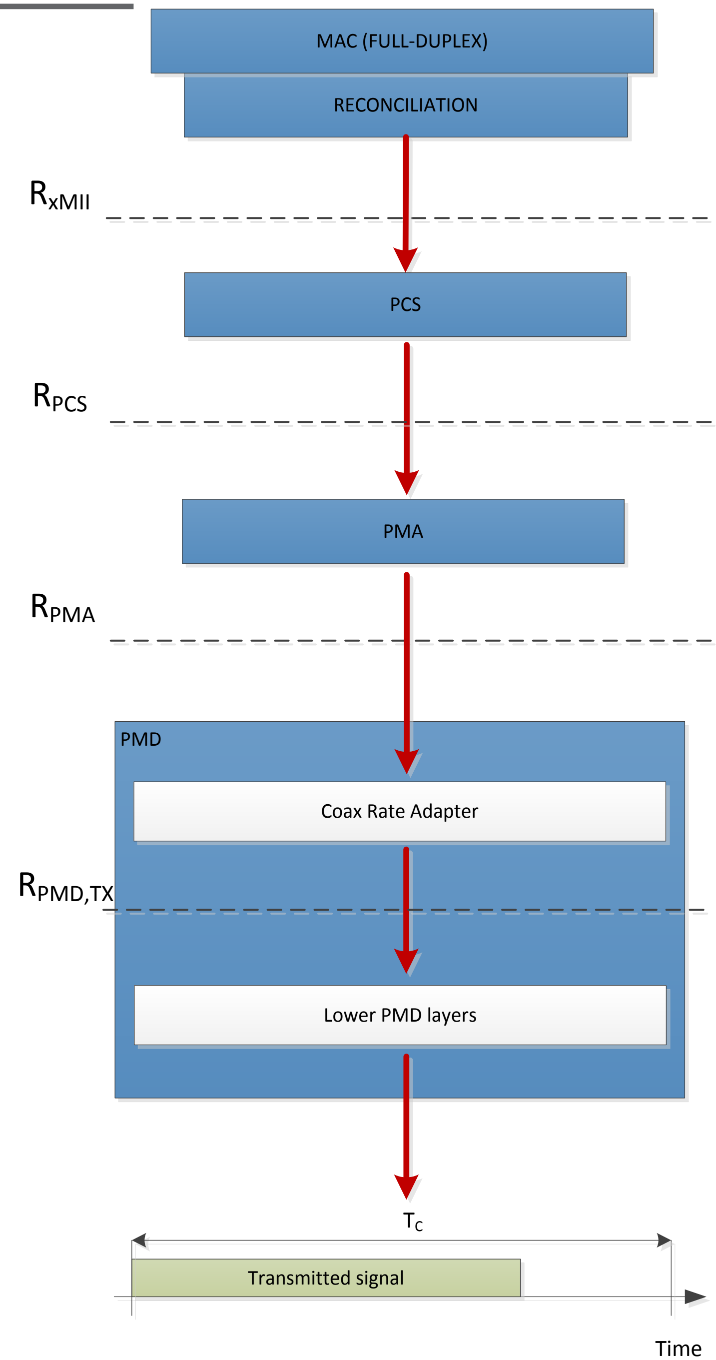
- Operation:
  - Extra Idle characters are inserted to match the information rate supported by PMD;
  - At PMD, padding bits (or a transmission gaps) take the place of some Idle characters
    - The bit stream **retains the xMII rate**
  - The Coax Rate Adapter in PMD
    1. discards padding bits (or transmission gaps)
    2. re-times each slice with the PMD rate $R_{PMD,TX} < R_{PMA}$

- Observations:
  - At the PMA/PMD interface, the bit stream can be divided in Bursts (Data, Parity and Idle bits) and Padding bits (or gaps)
  - The relation between bit rate and *average* duration of each Burst and Padding sequence is

$$R_{PMD,TX} = R_{PMA} \times \frac{T_{BURST}}{T_{BURST} + T_{PAD}}$$

TDD Stack Operation during Transmission





$$R_{PMD,TX} = R_{PMA} \times \frac{T_{BURST}}{T_{DATA}} \times \frac{T_{DATA} + T_{GAP}}{T_{BURST} + T_{PAD}}$$

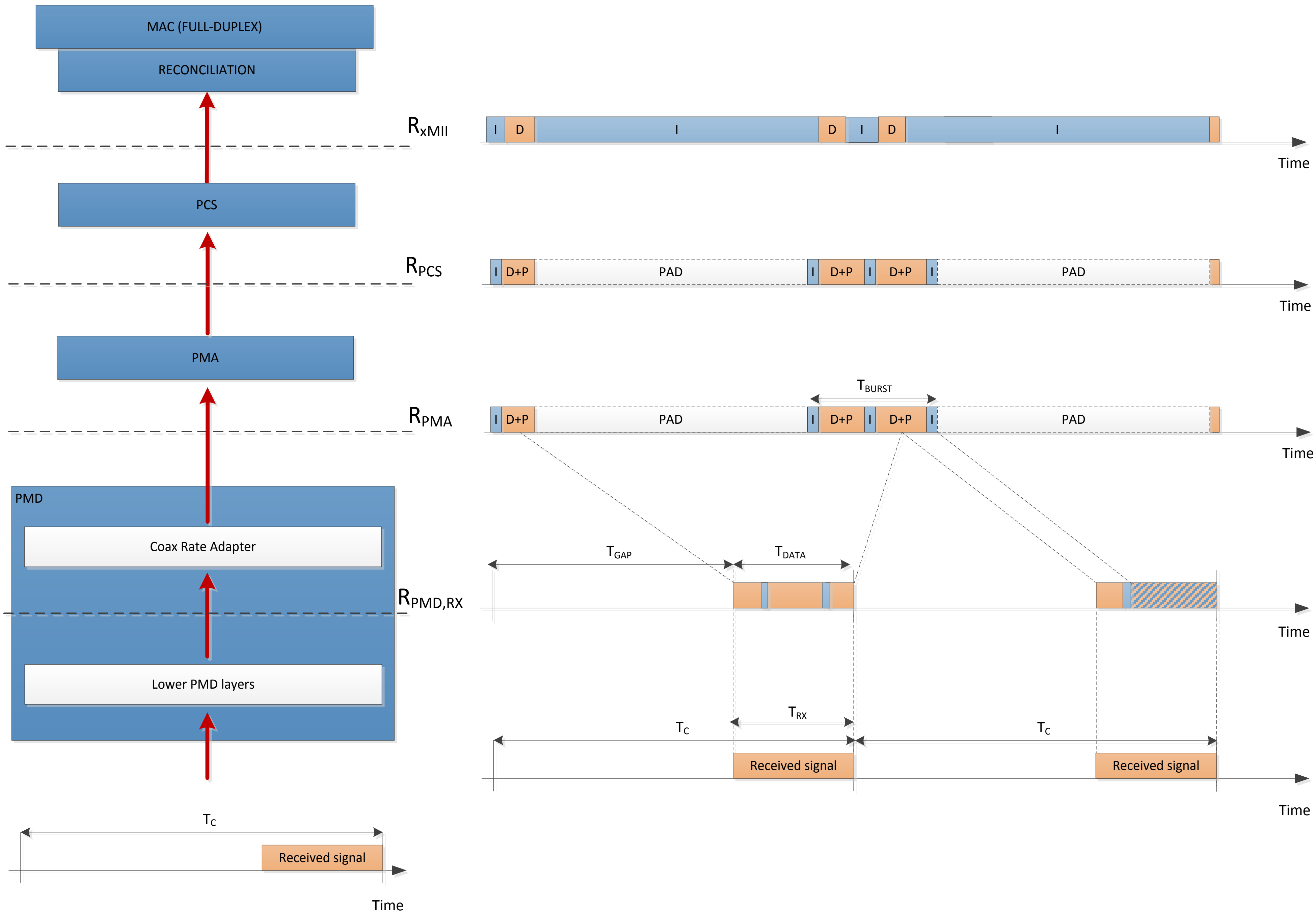
Details on TDD Stack Operation

- Operation: **SAME AS FDD**
  - Extra Idle characters are inserted to match the information rate supported by PMD;
  - At PMD, padding bits (or a transmission gaps) take the place of some Idle characters
    - The bit stream **retains the xMII rate**
  - The Coax Rate Adapter in PMD
    1. discards padding bits (or transmission gaps)
    2. re-times each slice with the PMD rate $R_{PMD,TX} < R_{PMA}$
    3. provides data to lower PMD layers in regular bursts of duration T_{DATA}

- Observations:
  - The relation between bit rate and *average* duration of each Burst and Padding sequence is

$$R_{PMD,TX} = R_{PMA} \times \frac{T_{BURST}}{T_{DATA}} \times \frac{T_{DATA} + T_{GAP}}{T_{BURST} + T_{PAD}}$$

TDD Stack Operation during Reception



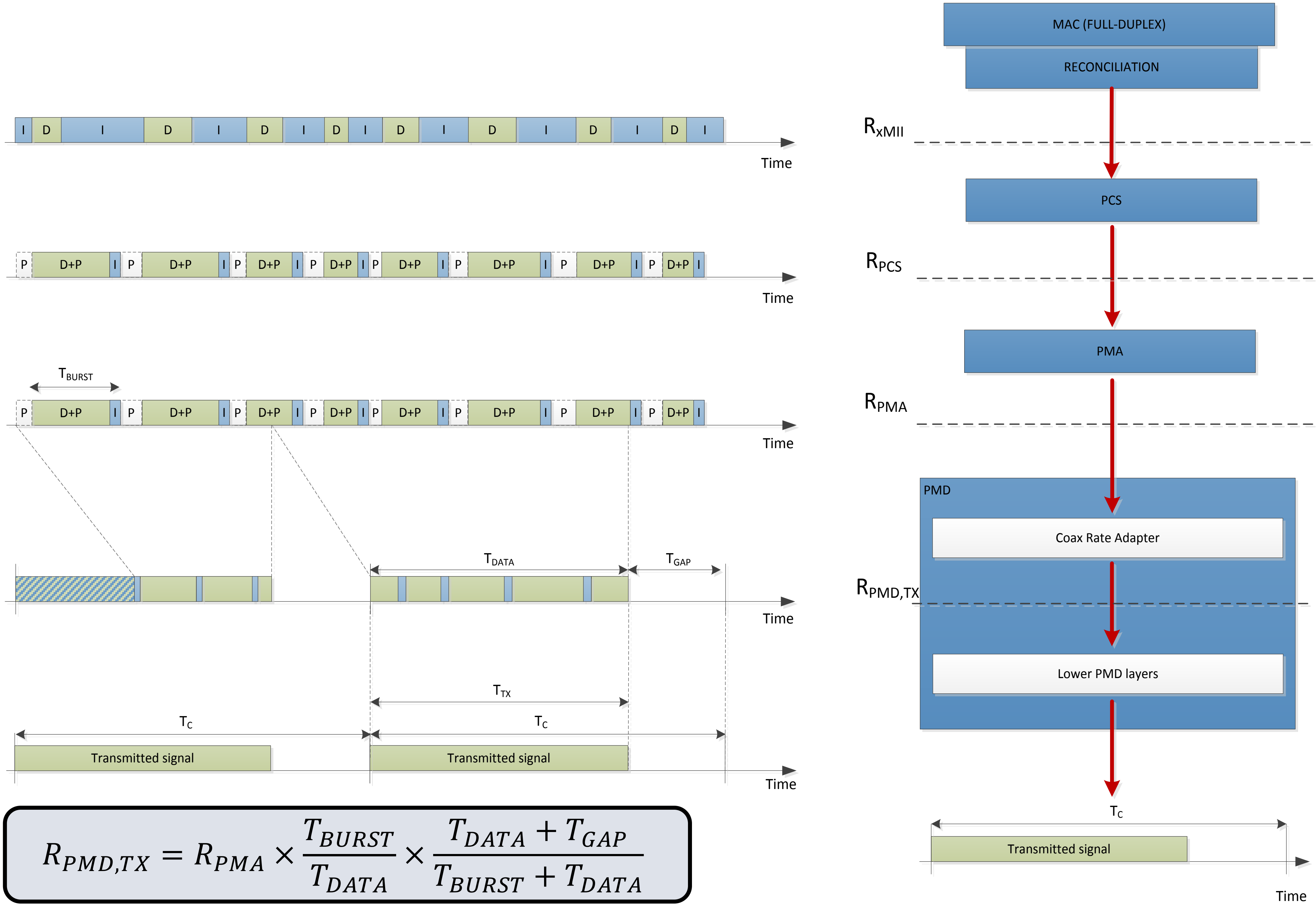
Observations on the Described Solutions

- Solution 1:
  - Fully transparent to MAC layer
    - Re-generates a continuous bit-stream
  - Most of the functionality resides in the PCS layer

- Solution 2:
  - Need to find a good criterion to define how bursts are created. Alternatives (see also next slide):
    - Ethernet frames
    - FEC codewords
  - The best criterion would depend on the specific functionalities embedded in each PHY sub-layer
    - Each block should correspond to an entity that the PMD layer would be able to detect

- Both solutions:
  - Enable to implement a PMA interface with the same rate as the xMII interface
  - Concentrate variable bit-rate capabilities within a PHY sub-layer
  - Applicable to any transmission mode (TDD/FDD)

TDD Stack Operation during Transmission – Alternative



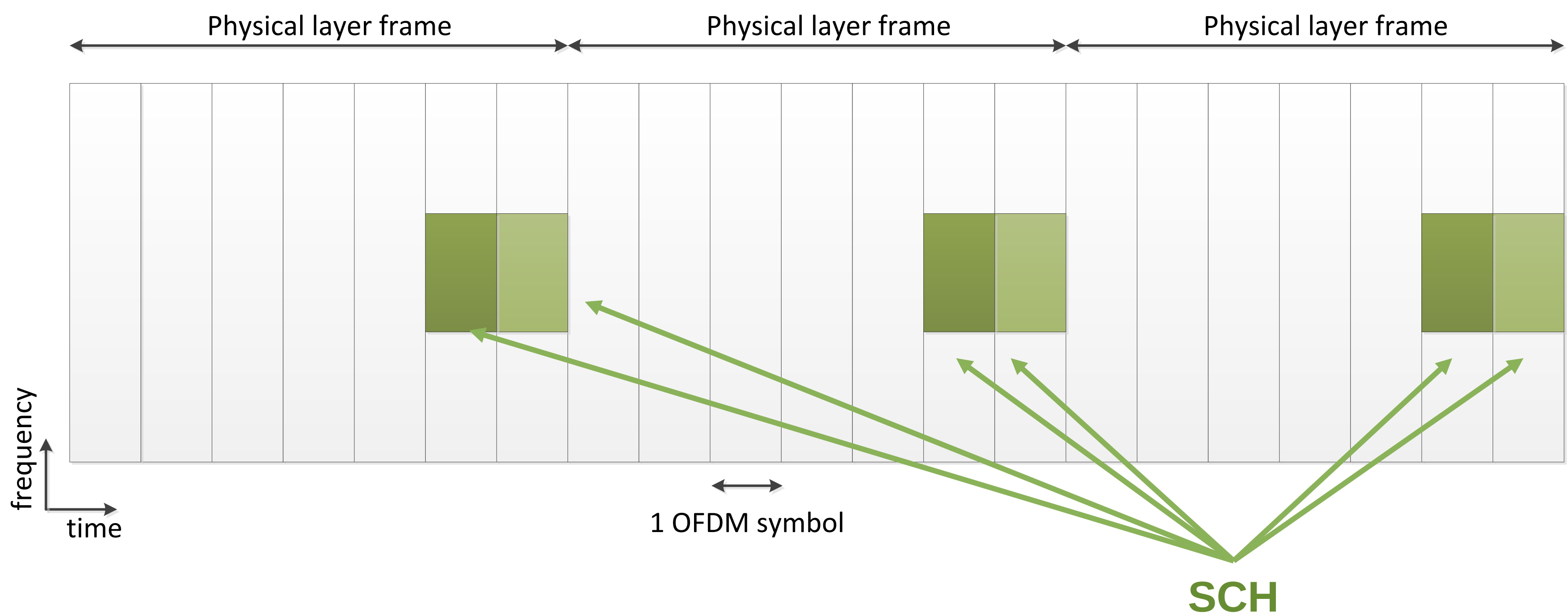
$$R_{PMD,TX} = R_{PMA} \times \frac{T_{BURST}}{T_{DATA}} \times \frac{T_{DATA} + T_{GAP}}{T_{BURST} + T_{DATA}}$$

Impact of TDD on PHY Acquisition Procedures

PHY acquisition phase

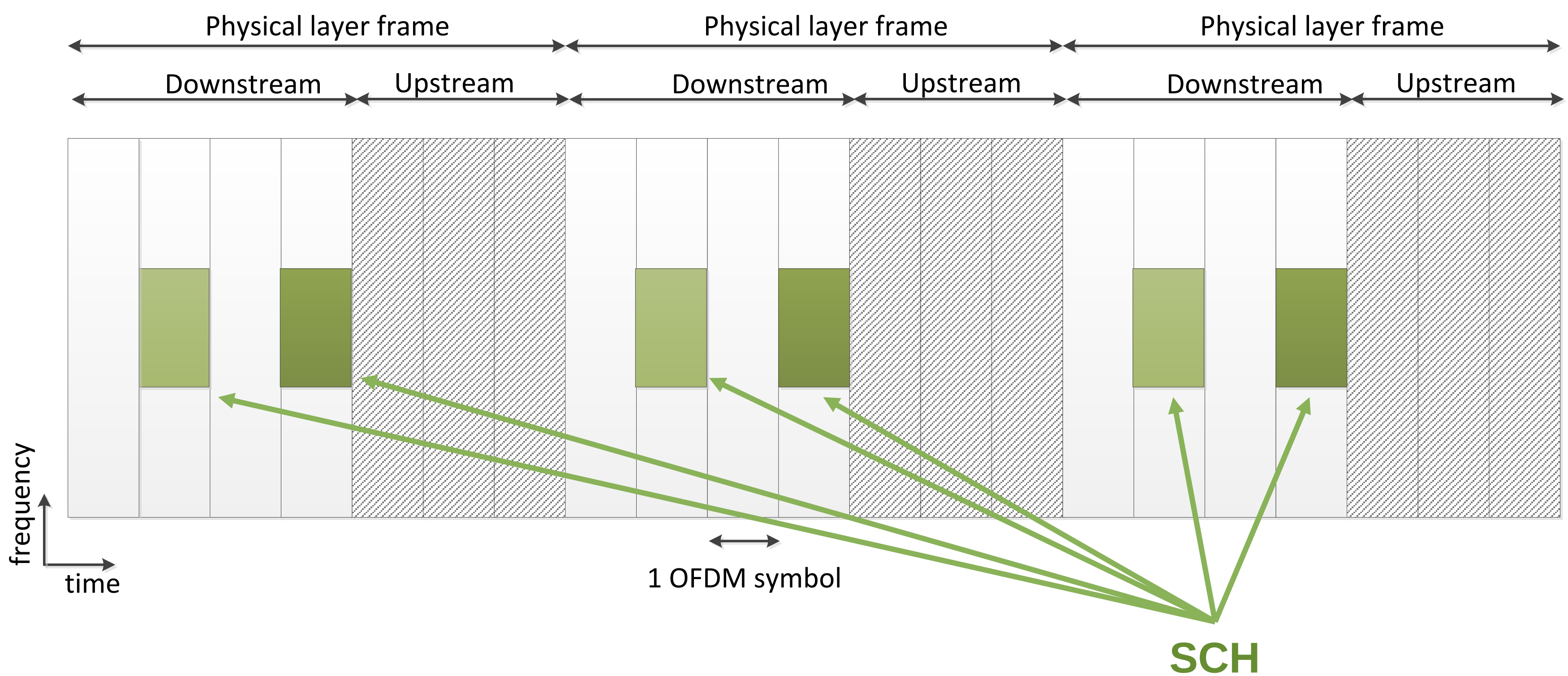
- At start-up, any OFDM modem needs to perform basic PHY procedures, e.g.:
  - Physical layer frame synchronization / OFDM symbol synchronization
  - Carrier frequency synchronization

- Synchronization signals are present in any OFDM system:
  - LTE, Wi-Fi, HomePlug, others
  - E.g., LTE-like Synchronization channel -SCH (FDD Downlink):



PHY acquisition phase

- FDD and TDD will use the same physical layer signals
  - No reason to use different signals (e.g., from LTE experience)
  - Specific physical frame structure will necessarily be different
  - TDD/FDD transmission mode can be detected autonomously by the physical layer without any further aid of upper layer protocols / management parameters



Proposal

Baseline Proposal

- The EPoC PHY shall include a rate adaptation functionality between PCS and underlying layers (PMA/PMD)
  - Allowing the use of bi-directional, fixed-rate interface between PCS and underlying layers (PMA/PMD)
  - Common block for all transmission modes (FDD/TDD)
  - The precise design solution and related details are for further study

- Moved by:
- Seconded by:
- Technical motion (>=75%)
- Yes / No / Abstain