Discussion on EPoC PHY Functions

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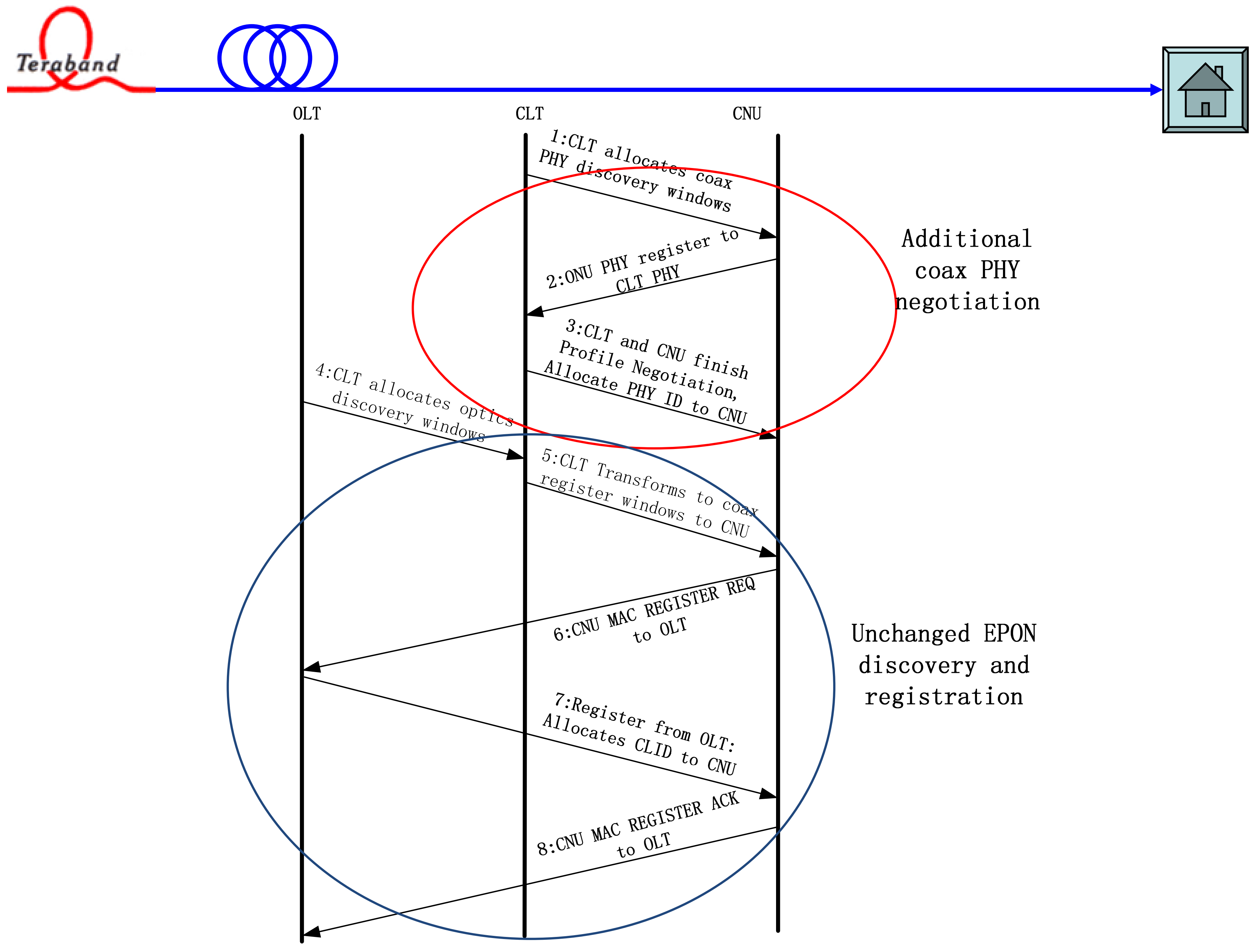
Overview

- **EPoC adopts the Data Link layer（OAM，MPCP，MAC，RS）of EPON and change the PHY layer for optical fiber to one for coaxial cable.**
- **To keep OAM and MPCP unchanged as possible，MAC Control function and PHY function should be clearly differentiated. In general，the tasks of PHY, such as RF resource configuration, allocation and management does not need the interfere from MPCP sub-layer.**

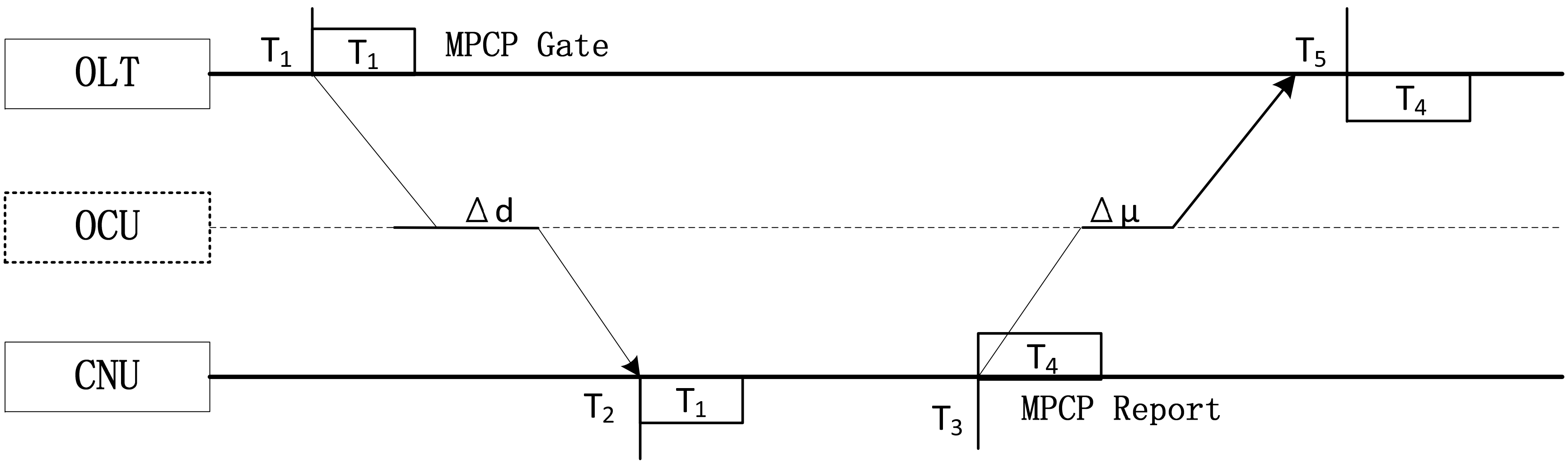
- **The situation in EPoC is quite different from other PHY on coaxial cable medium, such as DOCSIS, MoCA, and HINOC, where functions of PHY layer and Data Link layer can be designed as a whole. However when making EPoC PHY protocol the constraint on keeping MPCP and OAM unchanged as possible should be met.**
- **Therefore the Discovery process will be divided into two steps: Channel Link in PHY and Station Discovery in MPCP. The Resource Allocation and Scheduling process could be divided into two parts: RF frequency spectrum allocation in PHY and time scheduling (DBA) in MPCP.**

- In EPON there is no optical resource allocation problem, however in EPoC we are facing a series of problems: RF Resource Configuration (spectrum allocation for downstream & upstream, channel bandwidth, central frequency offset granularity) , Probe and Estimation of Channel Characteristics, Adaptive Bit Loading, Adaptive Power Control and Channel Maintenance.
- All these functions can be performed without the participation of MPCP sub-layer.



Teraband
OLT
CLT
CNU
1:CLT allocates coax PHY discovery windows
2:ONU PHY register to CLT PHY
3:CLT and CNU finish Profile Negotiation, Allocate PHY ID to CNU
4:CLT allocates optics discovery windows
5:CLT Transforms to coax register windows to CNU
6:CNU MAC REGISTER REQ to OLT
7:Register from OLT: Allocates CLID to CNU
8:CNU MAC REGISTER ACK to OLT
Additional coax PHY negotiation
Unchanged EPON discovery and registration

- On other hand, MPCP functions do not need PHY to perform. For example, Ranging between OLT and CNU does not need OCU to participate in, referring to dai_02_0712.pdf, slide 5.



T3 - T2 = T4 – T1 RTT = (T2 – T1) + (T5 – T3) = T5-T4

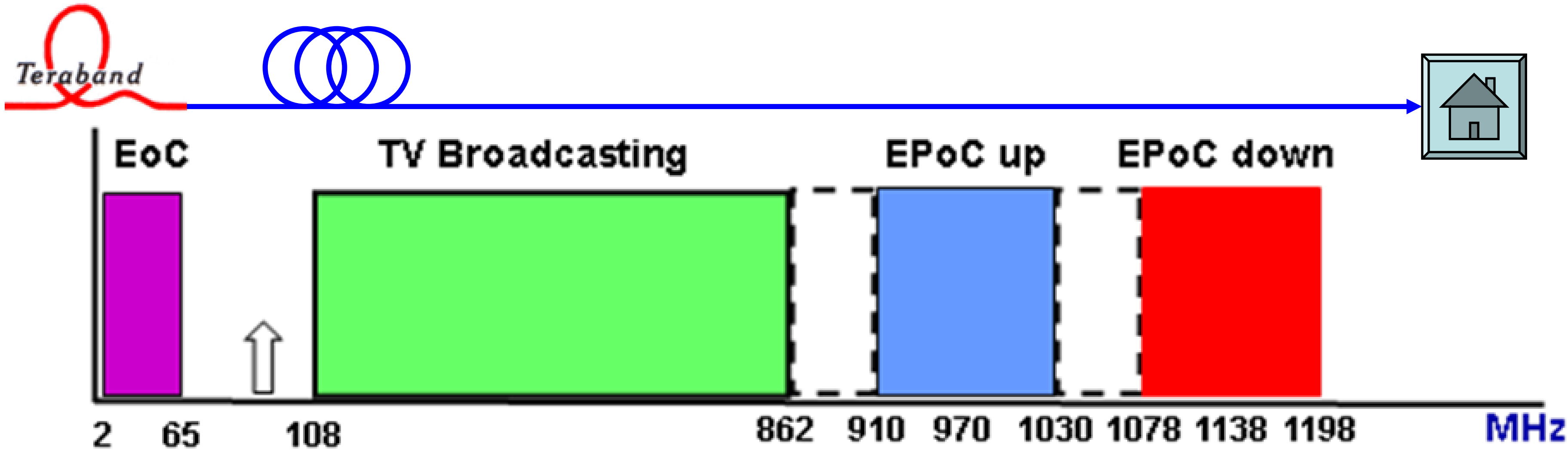
- This presentation will discuss some functions of PHY in EPoC.

1. Channel Link

1.1 RF Configuration:

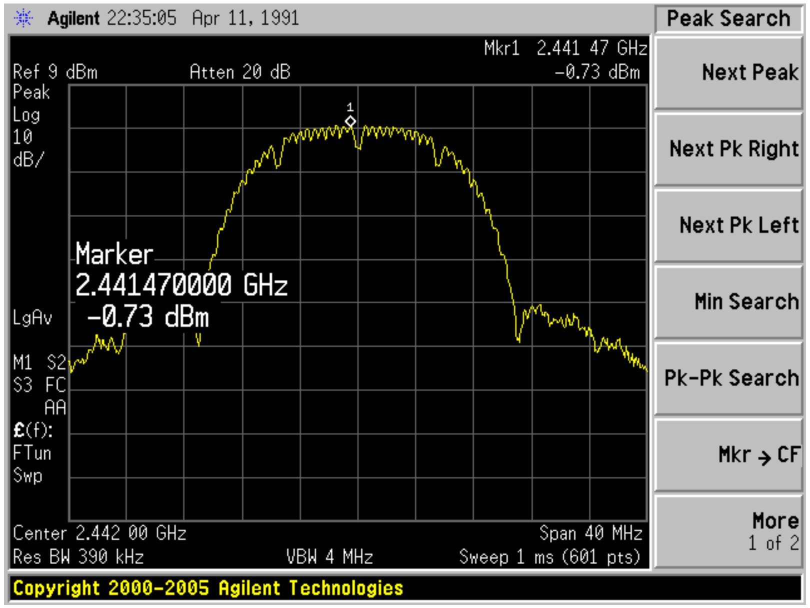
Allocation of downstream and upstream channel in RF spectrum, Granularity of frequency adjustment (Step size), Bandwidth of each channel

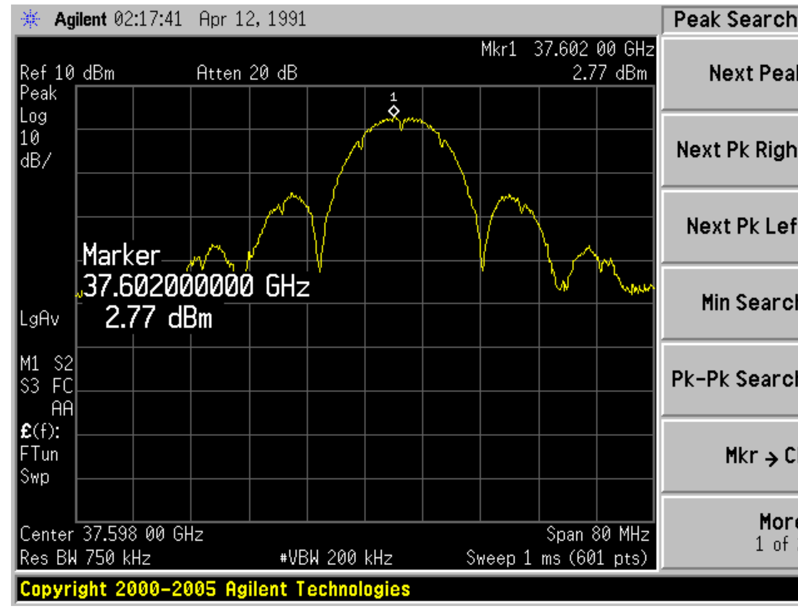
- **The configuration needs to be flexible to meet the requirements of MSOs in different countries and in different time .**



- **For China situation, the channel planning is required to be multiples of 8 MHz, therefore 120MHz bandwidth for downstream and upstream is appropriate.**
- **Guard interval of 48MHz may be needed between TV broadcast channel and the adjacent EPoC channel, EPoC up and EPoC down as well.**
- **A tune granularity of 2 MHz for the channel center frequency is suggested to provide some flexibility.**

OFDM Signal Distortion





Spectrum of OFDM signal

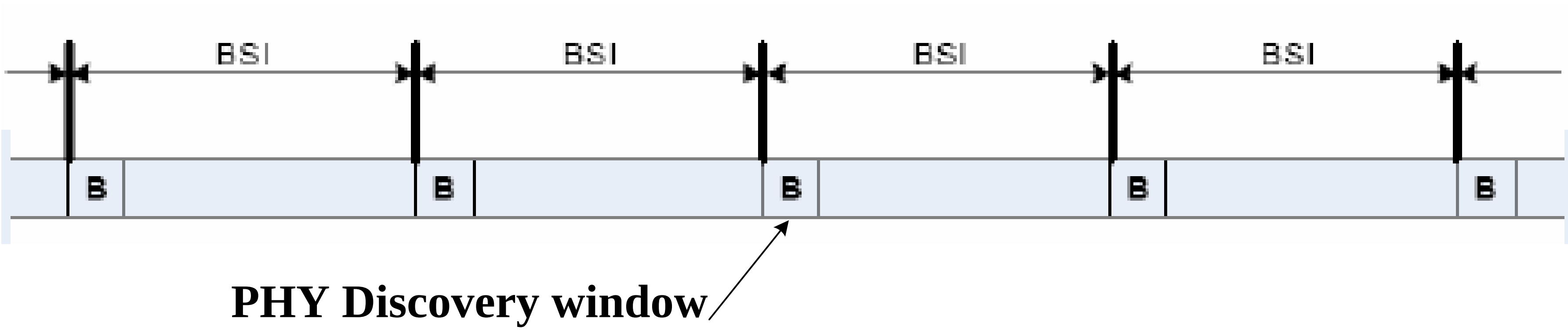
Spectrum of amplified OFDM signal

- With high PAPR OFDM signal is sensitive to channel non-linearity. If an OFDM signal is not orthogonal to another one, a guard band between the two is needed to avoid inter-channel interference. This principle should be applied to EPoC band allocation.

1.2 Channel Discovery:

CNU finds an operating channel to frequency-lock on and performs time synchronization

- **When a CNU is power-on, it tends to join in an existing EPoC by frequency scanning in order to establish synchronization to OCU. In this process, OCU via a specific sub-channel broadcasts Beacon (or other name) frame periodically. CNU changes its local oscillation frequency step by step to capture a Beacon and lock onto the OCU frequency. After decoding the beacon clock synchronization between OCU and CNU is achieved.**
- **Need to decide what carrier frequency is for Beacon and how long is the BSI (Beacon Synchronization Interval). Is 10ms adequate?**



- Beacon frame is composed of a system time stamp and some pointers. The time stamp is used for clock synchronization and the pointers indicate the start times of PHY Register Frame and next beacon. Beacon frame is un-encrypted and transmitted in the maximum power and the lowest modulation format.

- **PHY Register Frame is used for PHY identification. It may include Admission_Request message used by CNU to register to OCU, and Admission_Response message used by OCU to issue a PHY ID and channel number to CNU, concluding the Admission process.**
- **The formats of Admission_Request message and Admission_Response message need to be defined.**

1.3 Channel Probing：

Channel characteristics estimation

- **To estimate the SNR in sub-carrier bands, a pilot tone is generated in each sub-channel, or one pilot tone is used, but scanning from the low end to the high end of the channel during several tens of OFDM symbol periods. The Pilot tone carrying a PN training sequence is transmitted from OCU to CNU and the response is received by OCU. By computation on the received samples of the training sequence, SNR in each sub-channel can be decided.**

- The power of pilot tone should be as high as possible and the modulation format for training sequence should be BPSK to ensure the most reliable transmission for channel SNR estimation.
- A design example of probe frame is composed of a Preamble, a Channel Estimation Training Sequence and a Bit-loading Training Sequence.

Preamble	Channel Estimation Training Sequence	Bit-loading Training Sequence
2 Symbols 512 Bits QPSK	8 Symbols OFDM/QPSK	80 Symbols OFDM/BPSK

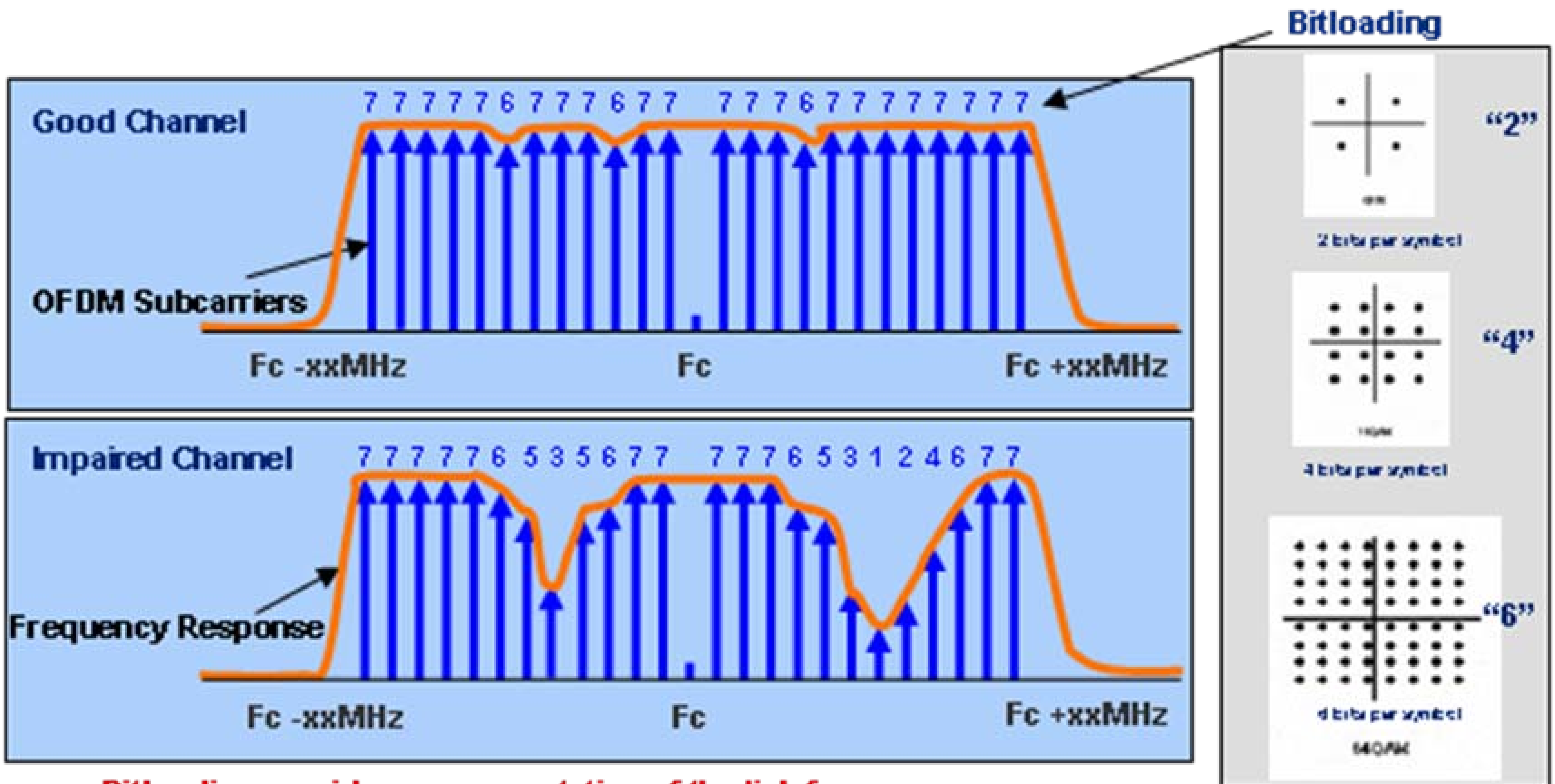
- **The Preamble of 2 symbols transmitted in time domain is used for estimating the carrier frequency offset and sample timing offset。 The Channel Estimation Training Sequence is 8 OFDM symbols carried by all sub-carriers in QPSK scheme. It is used to compute the channel transfer function . The equalization coefficients is deduced from the transfer function. After equalization the remaining part of probe message can be processed under a better channel condition.**

- **Bit-loading Training Sequence is 80 OFDM symbols , carried by all sub-carriers in BPSK scheme. By computing the statistical average over received training sequence, The SNR at each sub-carrier frequency can be decided. The bit-loading table for data traffic is generated based on the SNR distribution.**

2. Modulation Profile Adaptation

- **Modulation file for OFDM symbols is determined by the channel characteristics, mainly the SNR distribution over the channel band.**
- **An Adaptive Bit Loading algorithm maps signal bits onto each sub-carrier according to SNR time-variation in the sub-band.**

Bit Loading conceptual graph



Bitloading provides a representation of the link frequency response

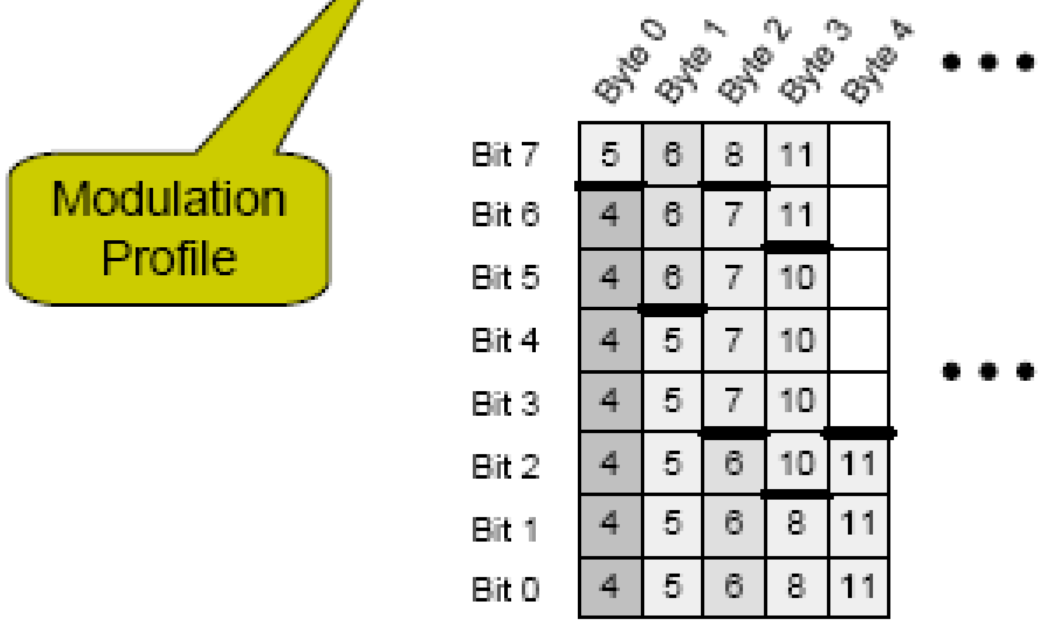
- **More bits are transmitted in the sub-carrier channel with higher SNR. This scheme complies with the Shannon Channel Capacity concept under the condition of additive white noise:**

$$\frac{C}{B} = \log_2\left(1 + \frac{S}{N}\right)$$

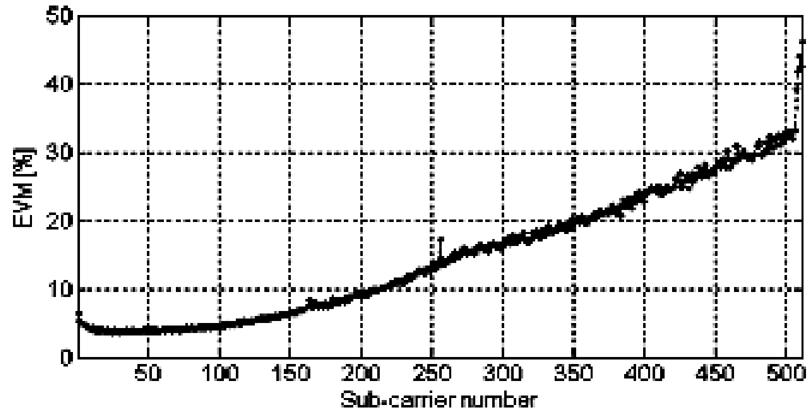
where *C* is channel capacity (bit)，*B* is channel bandwidth（Hz），*S* is average signal power（W），*N* is average noise power（W）。

- **To implement adaptive bit-loading a modulation profile is created which is the representation of SNR distribution vs sub-carrier number.**

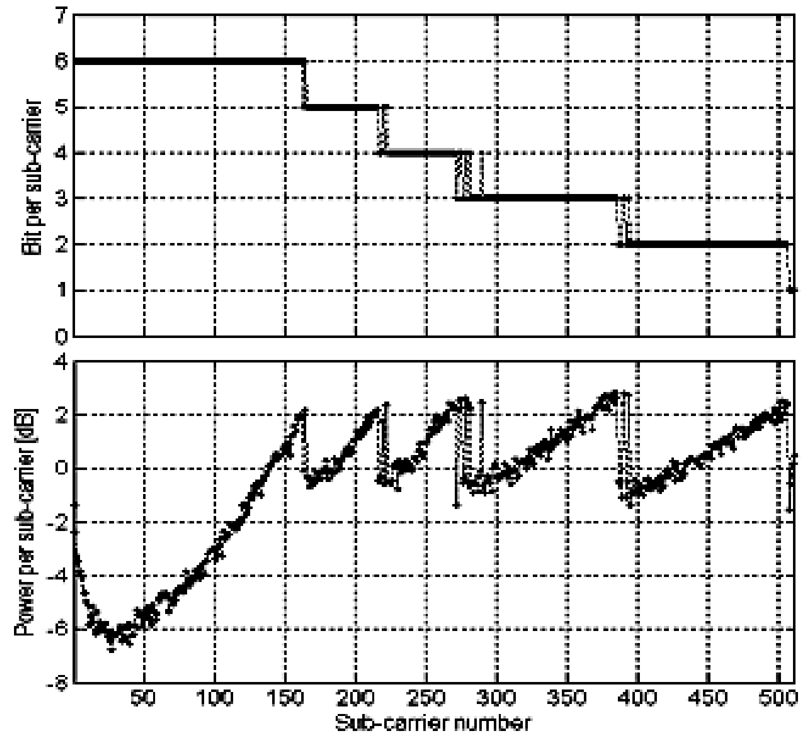
Carrier	4	5	6	7	8	9	10	11
Constellation	128	64	64	16	8	0	16	32
	7	6	6	4	3	0	4	5



- Without bit-loading, EVM may increase as sub-channel response drops with frequency.



- Adaptive bit-loading and power control



3. Power Level Control

To control power of the OFDM transmitter as low as possible to save the energy and decrease the interference to co-existing systems in the area.

- **Power level minimization can be absorbed in the probing process to decide SNR，making a joint adaptive bit-loading and power control algorithm.**

Adaptive Bit Loading and Power Control

- Basic equations

Set power of *i*-th sub-channel at transmitter:

$$P(i) \propto 1/\left|H(i)\right|^2,\ H(i)$$ -transfer function at *i*-th sub-channel

$$P_{total} = \sum_i P(i) = const$$ -prescribed

Test $SNR(i)$ at receiver and calculate

$$b(i) = \log_2\left(1 + \frac{SNR(i)}{\Gamma + \gamma_{margin}}\right)$$

-the bit number for *i*-th sub-channel; Γ is the SNR distance between Shannon limit and specified modulation scheme at a certain BER; γ_{margin} is SNR margin

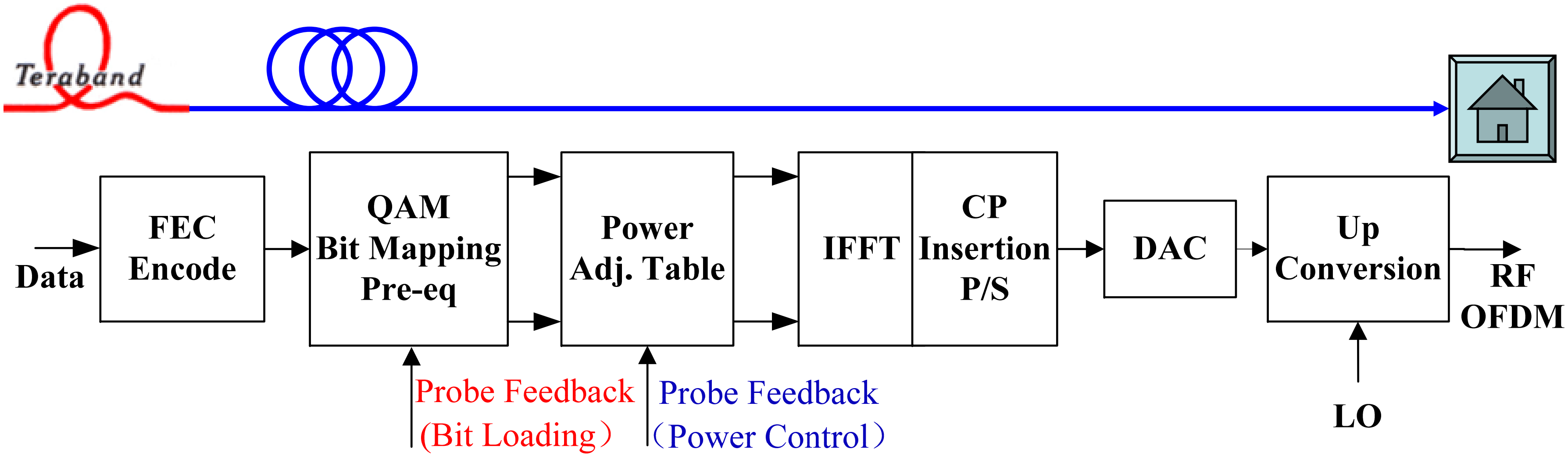
$$\hat{b}(i) = \mathrm{round}\left[b(i)\right]$$ -assigned bit number to *i*-th sub-carrier

$$B_{total} = \sum_{i=1}^{N} \hat{b}(i)$$ -system throughput

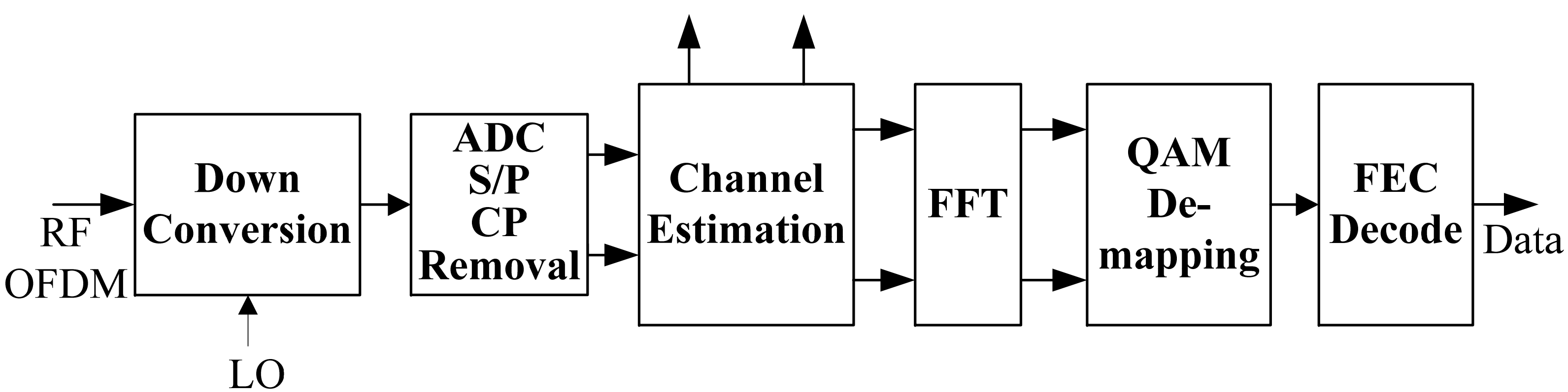
$$\gamma_{margin} = \gamma_{margin}[2^{\frac{(B_{total}-B_{target})}{UsedCarriers}}]$$ -modified SNR margin; B_{target} is system throughput target

- With the new γ_{margin}, $b(i)$ and $\hat{b}(i)$ will be recalculated. The iteration ends up when $B_{total} = B_{target}$.

Decrease the value of P_{total} and perform the above iteration process to see if B_{target} can still be reached. In this way find the minimum transmitter power needed for the target throughput at a given BER.



Implementation Block of OFDM Transmitter



Implementation Block of OFDM Receiver

4. Channel Maintenance

- The channel estimation and adaptive bit-loading can be performed in a periodical mode to keep the channel operation in healthy condition.
- Consider the quasi-dynamic feature of cable plant, the maintenance period can be taken in seconds.

5. Link with OAM

The condition and major parameters of PHY needed to be informed to OAM sub-layer in OLT

- How should OCU inform EPON OLT about parameters of the coaxial plant and what parameters should be provided to EPON OLT? How to combine this information with that of CNU device? ——Need to study.
- How can MPCP mechanisms be modified to a smallest extent possible to support CNU control? ——Need to study.

Summary

- The major function of EPoC PHY layer in nature is the transparent transmission of data traffic downstream and upstream through P2MP coaxial cable medium. Hence in addition to FEC, the most important processes is OFDM mod. and de-mod. Related problems include configuration of RF channels, channel characteristics estimation, adaptive bit-loading and channel maintenance, etc. Each problem needs to be carefully solved with parameters selection.
- It is showed that above functions are independent of Data Link layer and do not need MPCP sub-layer to be involved in. Therefore MPCP can be kept the same with 1/10G-EPON.
- But if TDD mode is concerned, the switch between downstream and upstream will need MAC control.

Thanks