IEEE 802.3 NG-EPON IC Ad Hoc Draft R03, 8 March 2014

IEEE Industry Connections Ethernet

Next Generation Ethernet Passive Optical Network (NG-EPON)

Prepared by the

IEEE 802.3 Ethernet Working Group

This is a draft report on the next generation Ethernet Passive Optical Network, associated bandwidth requirements, as well as state of the art of access-grade optical technologies. It is an unapproved draft of a proposed IEEE report. As such, this document is subject to change. USE AT YOUR OWN RISK!

Draft R0.0 is prepared by the IEEE 802.3 Industry Connections Next Generation Ethernet Passive Optical Network (NG-EPON) Ad Hoc for Ad Hoc Review. This draft expires 6 months after the date of publication or when the next version is published, whichever comes first.

This report can be found at the following URL:-

Participants

[Editor's note: Include participant information here. Use IEEE 802.3 Working Group Voters as of the closing Plenary where document is approved.]

Editor's note (to be removed prior to publication): Appropriate URL to be inserted during publication process.

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Executive summary

[Editor's note: Text below was copied from ICAID form and will need to be further adapted to form an executive summary]

IEEE Std 802.3-2012 includes specifications for the Data Link and Physical layers for Ethernet Passive Optical Networks (EPON) operating at 1 Gb/s (1G-EPON) and 10 Gb/s (10G-EPON). There is a need to explore the market potential and technology options for a next generation of EPON, operating at data rates beyond 10 Gb/s. To do so, the group will raise awareness in the industry and seek input regarding the desired features and options for a next generation of EPON. Several distinct markets and applications currently rely on EPON. The largest application areas for EPON include residential and commercial subscriber access (for voice, video and data), and mobile backhaul, offered in triple- and quad-play packages. The largest geographical areas of EPON deployments can be found today in Asia and the Americas. Equipment vendors and Operators serving all of these markets are interested in exploring the technologies available for the next generation of EPON, allowing them to provide cost-effective solutions to the ever-increasing bandwidth demand of the end-customers, as well as addressing the requirements of customer applications.

1 Abbreviations

This document contains the following abbreviations:

TBD

2 Introduction

[Editor's note: This section will contain introduction to the report, outlining the need for this report, the need for the study of NG-EPON, as well as motivation for timelines, and expected deliverables of the follow-up projects. It is also critical to emphasize the timing aspect of the project and why there is no greater rush to move it forward. This section needs also to contain discussion on market demand for next generation access architecture.]

3 Taxonomy of Optical Access

There is a number of optical access architectures providing layer 2 connectivity between the central office (CO) housing the operator equipment, and the demarcation point (ONU) located either at the subscriber premises (in case of FTTH) or the local office (FTTB). These optical access architectures can take different forms depending on:

- the number of fibers between CO and ONU,
- the number of wavelengths used per direction between CO and ONU,
- the number of wavelengths used simultaneously by a single ONU,
- the existence of shared or dedicated channel per ONU,

- the type of employed data scheduler (centralized or distributed),
- the type of used modulation.

The taxonomy of optical access architectures used in this document is presented in Figure 1. Individual names of optical access architectures are used when a PHY channel represents a wavelength. Other PHY channels are possible, e.g., OFDM channel, CDM channel, but they are not reflected in Figure 1.

PHY channels per PON per direction {one, many}	**PHY channels per ONU per direction** {one, many}	**PHY channel connectivity type** {P2P, P2MP, mix}		**Type (name) of network***
one	one	P2P	→	**P2P link**
		P2MP	→	**EPON, 10G-EPON, GPON, XG-PON**
many	one	P2P	→	**WDM-PON$_1$**
		P2MP	→	**TWDM-PON$_1$**
	many	P2P	→	**WDM-PON$_n$**
		P2MP	→	**TWDM-PON$_n$ (AKA hybrid PON)**
		mix	→	**?**

Figure 1: Taxonomy of optical access architectures [1]

Figure 2 demonstrates different types of wavelength division PON architectures, where many wavelengths are used per PON. In some scenarios, an ONU may receive at least one dedicated bidirectional wavelength channel, forming a WDM-PON. In other scenarios, an ONU shares at least one wavelength with other ONUs using a TDM scheme, resulting in a hybrid WDM/TDM-PON.

3.1 WDM-PON

A WDM-PON provides each ONU (and customer(s) connected to such an ONU) with at least one dedicated pair of wavelengths, creating logical P2P data channels between the CO and the ONU. This also means that transmissions from and to individual ONUs are not scheduled (no need for centralized or distributed scheduler). Furthermore, each data channel is transparent to data rate and MAC frame format, allowing to run different data rates (e.g., 10 Mbps, 100 Mbps, 1000 Mbps, or higher) and different MAC frame formats (Ethernet, IP over glass), depending on customer demand. Ethernet has been traditionally viewed as best suited technology here (lowest cost for the given target performance), providing scalability between 10 Mbps and 100 Gbps and beyond. One of the obvious drawbacks of the WDM-PON architecture, especially for residential applications, is that each ONU is provided with dedicated data channel to the CO, which remains idle most of the time, apart from periods of peak activity when bursty data is being exchanged.

3.2 Hybrid WDM/TDM-PON

A hybrid WDM/TDM-PON provides a group of ONUs (and customer(s) connected to such an ONU) with at least one dedicated pair of wavelengths, shared among the ONUs in a TDM fashion. In this way, P2MP connections between the CO and specific group of ONUs are created. Thanks to the statistical multiplexing effect (see Clause 4), it is possible to serve the same number of ONUs (compared with WDM-PON) with fewer wavelength channels, while simultaneously observing the same SLAs. Given that transmissions from individual ONUs sharing specific wavelength channels can collide, some sort of scheduling is required in the upstream direction. The downstream channel does not require any sort of transmission scheduling, since OLT is the only device allowed to transmit data towards the ONUs. Over the years, various medium access protocols have been designed, with various generations of EPON and GPON representing the most popular P2MP medium access protocols for optical access.

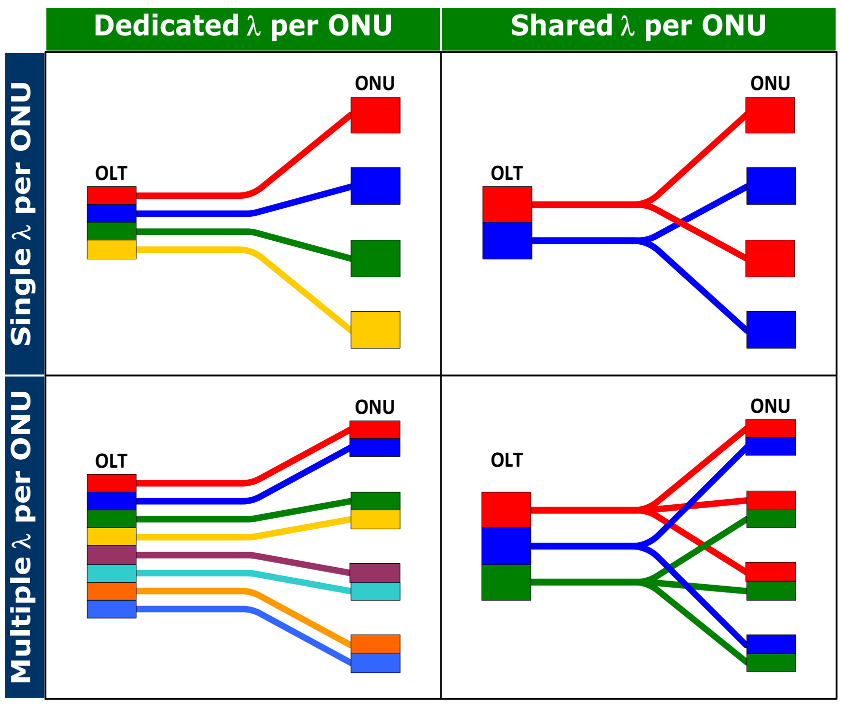


Figure 2: Various options for a WDM-PON [1]

Depending on the way data from individual ONUs sharing the given group of wavelength channels is performed, hybrid WDM/TDM-PON is further classified into WTDM-PON and TWDM-PON. For reference, in a hybrid WDM/TDM-PON PON, a group of ONUs shares at least one pair of wavelength channels – one wavelength in the downstream and one wavelength in the upstream direction. Each ONU in this group can transmit and receive on each wavelength pair. For simplicity, the difference between WTDM-PON and TWDM-PON is explained only for the upstream direction, assuming that the group of ONUs is sharing the total of 4 (four) wavelengths.

3.2.1 WTDM-PON

In the WTDM-PON, each of the upstream wavelengths is allocated to an individual ONU for as long as the given ONU requires access to the upstream direction to transmit its queued data. This means that in the WTDM-PON, each ONU transmits on one and only one upstream wavelength at a time, though such an ONU might switch wavelength channels between individual upstream transmissions, as requested by the OLT. This situation is shown in Figure 3.

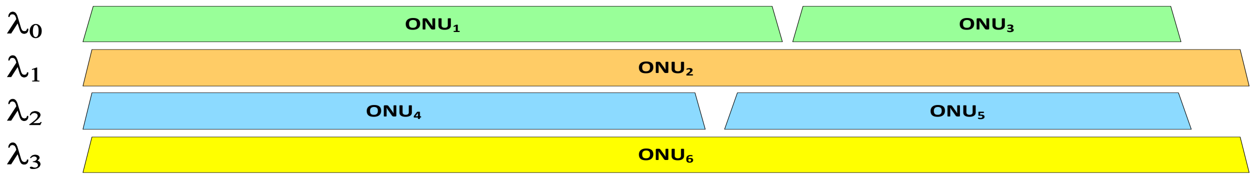


Figure 3: Upstream channel in WTDM-PON

3.3 TWDM-PON

In the TWDM-PON, each ONU is granted access to all available upstream wavelength channels for a specific period of time, transmitting across multiple wavelengths simultaneously. No other ONU is allowed to transmit during the same window of time. This situation is shown in Figure 4.

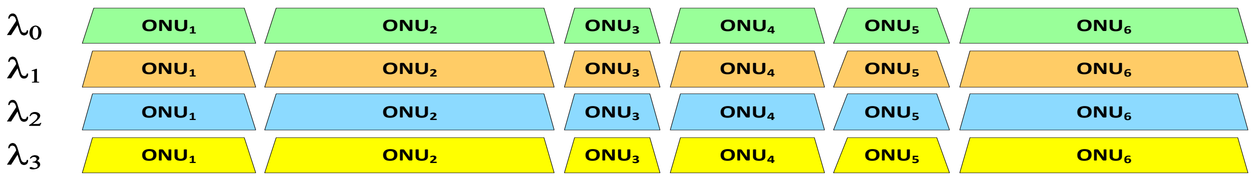


Figure 4: Upstream channel in TWDM-PON

Source presentations: remein_ngepon_01_0114.pdf]

4 Statistical Multiplexing in Access

[Editor's note: This section should address the importance of statistical multiplexing in the access, demonstrating the expected differences between throughput, delay, and jitter for selected access architectures – this could be derived from the following presentation kramer_ngepon_02_0114.pdf. This section should also finish with the motivation why and whether P2MP is the right way to go forward for next-generation access.]

5 Functional Requirements

[Editor's note: This section will contain a collection of operational requirements for next-generation access architecture, collected from end-users, and primarily – operators. This is where we should talk about applications, bandwidth requirements for access, delay, jitter, etc., as well as service types, and expected trends in the future.

Source presentations: hajduczenia_ngepon_01_0114%20R07.pdf, dai_ngepon_01_0114.pdf]

6 Optical Access Technologies

6.1 Optical Transmitters

[Editor's note: This section should focus on what trends are observed in optical access, e.g., development focus on tuneable lasers for WDM, pricing trends, etc. Primary sections (L2) could include: Transmitters, Receivers, Outside Plant (ODN).

Source presentations: ~~powell_ngepon_01A_0114.pdf~~]

6.2 Optical Receivers

6.3 Outside Plant (ODN) [2]

6.3.1.1 Spectrum Allocation Bands

The existing outside distribution network (ODN) designed for the use with optical access networks is intended to carry multiple services, requiring allocation of specific wavelength bands (spectrum ranges) that need to coexist on the same fiber strand. At the same time, fiber medium in itself has specific regions which are more favourable for telecommunication applications, while other regions remain largely unused. Figure 5 presents attenuation and chromatic dispersion curves for three most common single mode fibers found in existing ODNs designed for optical access. The existing spectrum allocation bands for 1G-EPON, 10G-EPON, OTDR, and RFoG systems are also presented for reference.

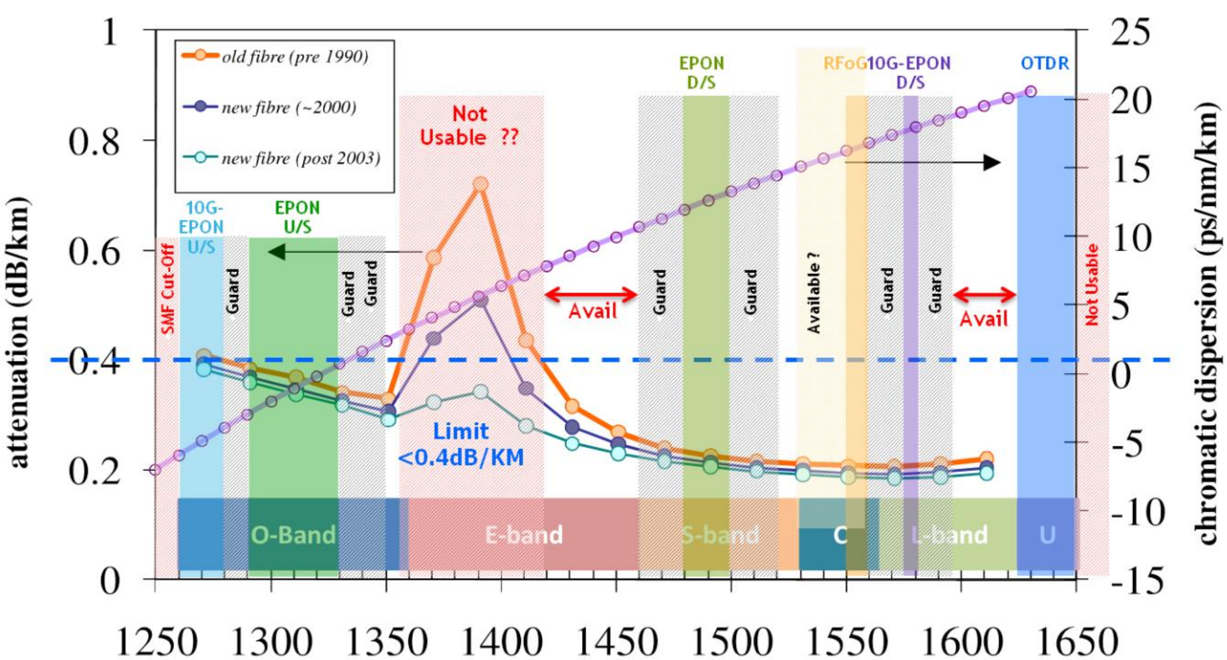


Figure 5: Attenuation and chromatic dispersion in different fiber types

From Figure 5 it is clear that the spectrum availability for next generation optical access systems is very limited if all the existing services are to be supported on the same ODN. There are effectively just two free spectrum ranges usable for transmission: one range in the upper medium E band and one range in the upper L band (marked as “Avail”).

Figure 6 presents a more detailed view of the existing spectrum allocation bands, covering not only optical access systems defined by IEEE 802.3 WG and SCTE systems, but also optical access technologies covered by ITU-T recommendations. The spectrum range above 1440 nm is already covered with either allocated transmission channels or guard bands for legacy systems. Any newly specified optical access standard will have to either operate within existing guard band regions, or displace one of the existing systems, breaking potentially backward compatibility across three generations of equipment.

Also, of note is the fact that the continued use of 1610nm return channel for RFoG impedes deployment of next generation ITU-T systems, overlapping with the downstream channel of TWDM option.

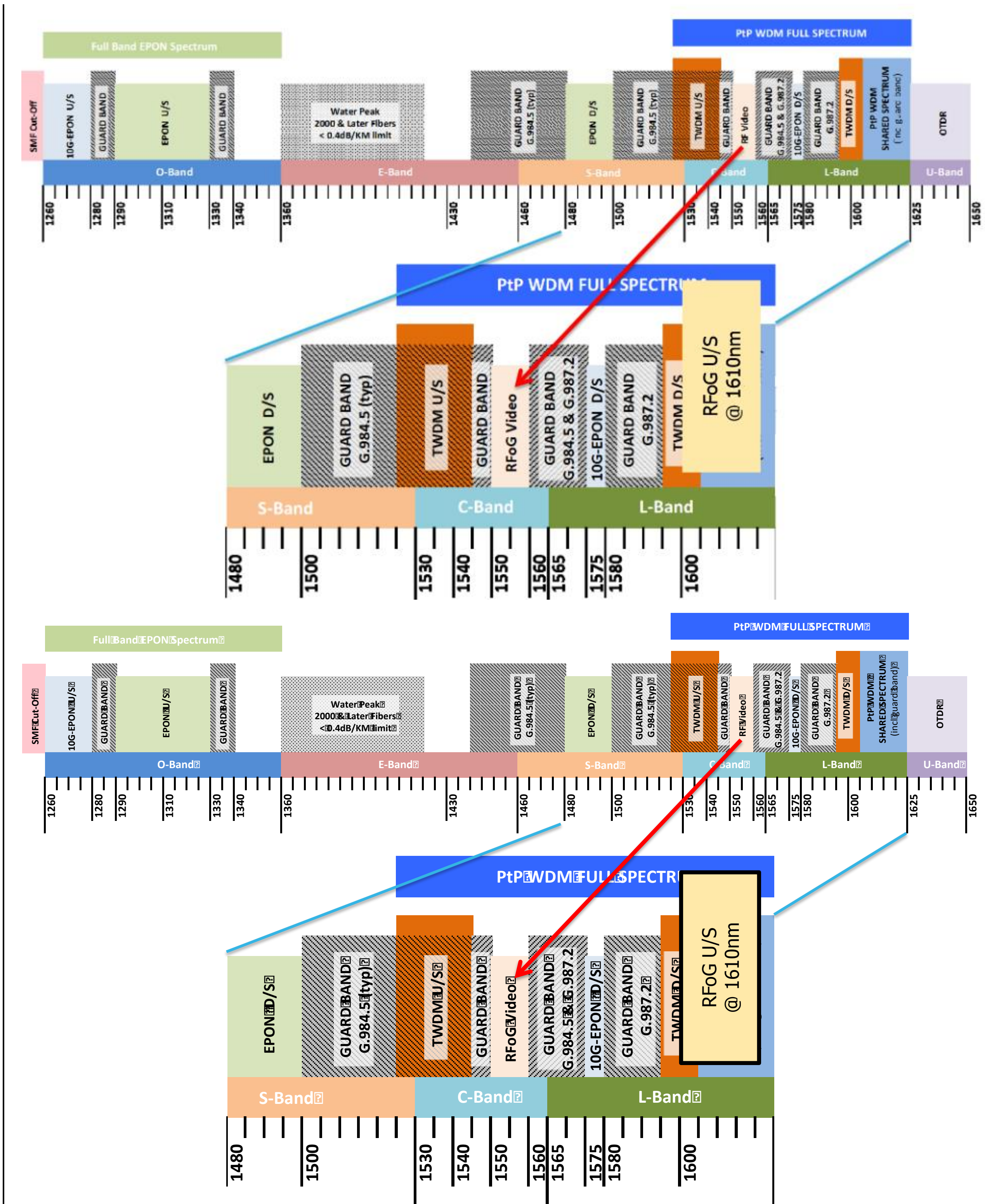


Figure 6: Spectrum allocation bands for optical access defined in IEEE 802.3, SCTE, and ITU-T

Example of wavelength allocation plans for several IEEE 802.3, SCTE, and ITU-T optical access systems are shown in Table 1.

Table 1: Wavelength allocation plans for selected IEEE 802.3, SCTE, and ITU-T optical access systems

System	Downstream [nm]	Upstream [nm]
1G-EPON	1480-1500	1260-1360[1] ~~for FP lasers~~ 1290-1330[2] ~~for DFB lasers~~ 1300-1320[3]
10G-EPON	1575-1580	1260-1280
GPON	1480-1500	1260-1360 (regular) 1290-1330 (reduced) 1300-1320 (narrow)
NGPON2 (TWDM)	1596-1603	1524-1544
NGPON2 (P2P WDM)	1524-1625	

7 Evolution Scenarios [1]

Backward compatibility and coexistence with legacy generation of EPON have been always considered as key requirement for the development of EPON as the optical access technology. A gradual evolution from 1G-EPON systems towards 10G-EPON, while allowing operators to take full advantage of deployed active equipment, was one of the corner stone requirements during the development of 10G-EPON technology [4]~~[2]~~. The resulting development of a dual-rate OLT (capable of operating in 1G-EPON and 10G-EPON mode in the upstream and downstream directions), provided a clear evolution path to 10G-EPON.

7.1 Evolution from 1G-EPON to 10G-EPON

Figure 7~~Figure 5~~ presents the starting point for the evolution from 1G-EPON to 10G-EPON, where all active devices in the TDM-PON access are of 1G-EPON type. During one of the maintenance windows, an operator would replace the line card on the OLT located in the CO, converting a dedicated 1G-EPON line card to dual-rate line card capable of operating at 1G-EPON and 10G-EPON modes simultaneously. This situation is presented in Figure 8~~Figure 6~~. All ONUs connected to this port continue to operate in 1G-EPON-mode only.

[1] Typical for Fabry Perot lasers
[2] Typical for DFB lasers without temperature control
[3] Typical for DFB lasers with temperature control

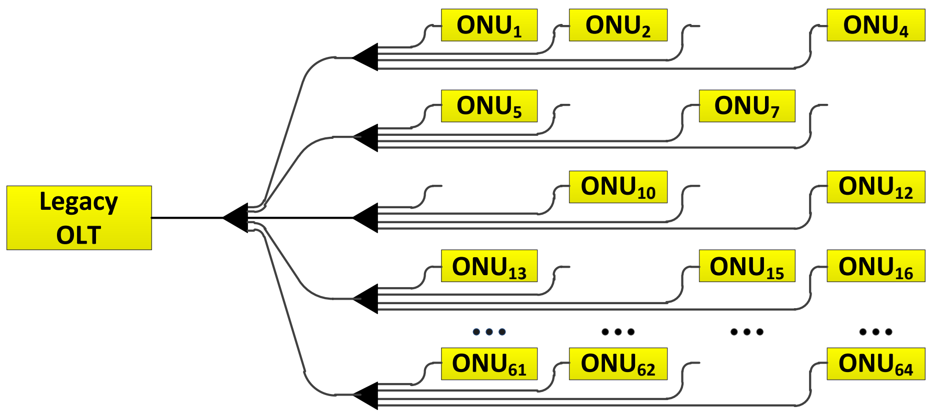


Figure 7: EPON access: starting point with 1G-EPON devices

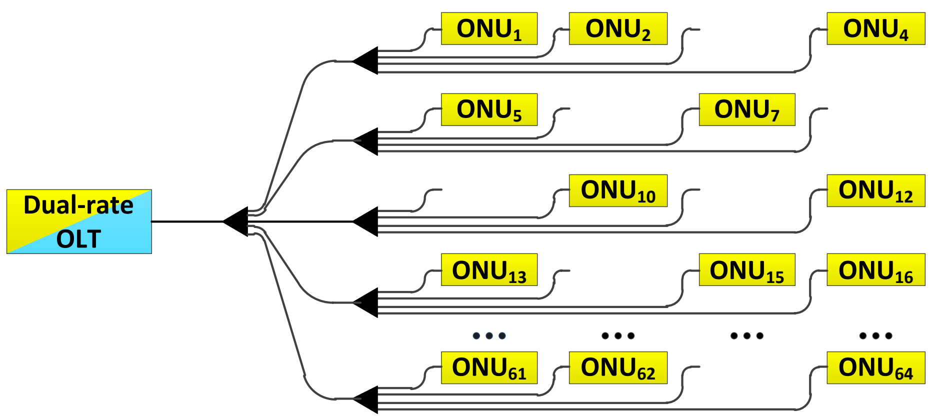


Figure 8: EPON access: dual-rate OLT port

Once the maintenance on the OLT port has been completed, new customers may be connected to currently unoccupied ports on the splitter(s) and be served with 10G-EPON ONUs. It is also possible to upgrade some of the existing customers served with 1G-EPON ONUs to higher speed 10G-EPON ONUs. Such a decision is typically driven by higher tier services purchased by selected customers. This situation is shown in Figure 9~~Figure 7~~, where 1G-EPON and 10G-EPON ONUs coexist on the same PON.

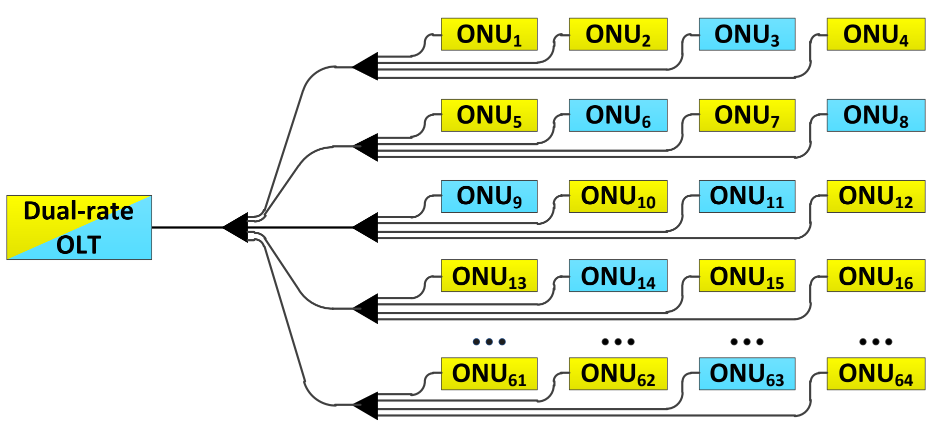


Figure 9: EPON access: 1G-EPON and 10G-EPON ONUs coexist on the same ODN

Over time, most of the existing ONUs will be upgraded to 10G-EPON, as the cost of 10G-EPON devices decreases and becomes similar to the cost of 1G-EPON devices. This situation is shown in Figure 10~~Figure 8~~. Note that this the resulting EPON network may operate in a dual-rate mode for a very long time, since the transition from 1G-EPON to 10G-EPON is primarily motivated by the service upgrades for existing customers, as well as cost decrease of 10G-EPON devices.

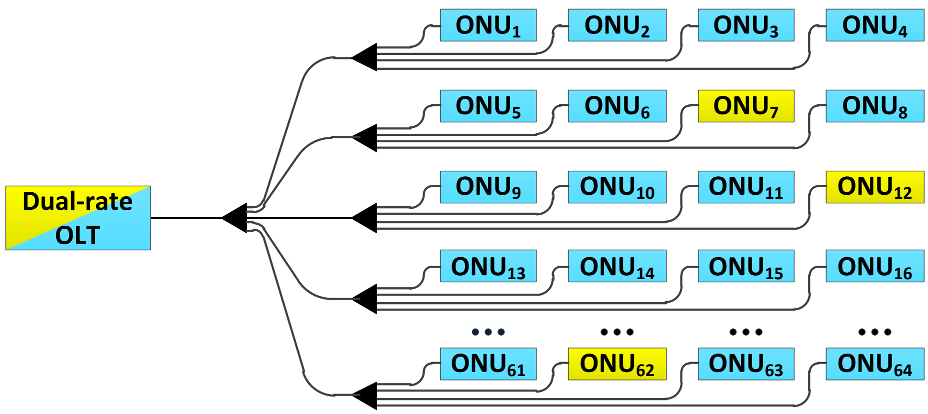


Figure 10: EPON access: 1G-EPON and 10G-EPON ONUs coexist on the same ODN

The evolution scenario described above assumes the deployment of a dual-rate OLT, capable of operating at 1G-EPON and 10G-EPON modes simultaneously, while time-interleaving 1G-EPON and 10G-EPON transmission in upstream using the dual-rate burst mode receiver at the OLT as described in Annex 75A in [5]~~[3]~~. The one drawback of this approach is the need to repurchase 1G-EPON ports that have been already paid for the moment when 1G-EPON network was first deployed. The other drawback is the practical aspect of dual-rate 1G-EPON/10G-EPON OLT ports, which provide lower port density per line card when compared with dedicated 1G-EPON or 10G-EPON line cards.

However, it is also possible for an operator to deploy separate 1G-EPON and 10G-EPON OLT ports, and then combine downstream 1G-EPON and 10G-EPON wavelengths and split the respective upstream wavelengths using a discrete wavelength splitter / combiner device external to the OLT ports. This solution provides a higher OLT port density per line card, and eliminates the need to repurchase the OLT ports, though the operator needs to make sure that 1G-EPON and 10G-EPON upstream wavelengths can be WDM-separated into dedicated OLT ports. In practice, this requires the use of 1G-EPON ONUs equipped with more narrow-band upstream transmitters, typically centered around 1310nm with 40 or even 20 nm band rather than 100 nm band allowed by the 1G-EPON standard.

7.2 Evolution to NG-EPON

The migration to NG-EPON needs to essentially assume that at the time when NG-EPON becomes commercially available, the access network features a mixture of 1G-EPON and 10G-EPON devices, operating with either dual-rate OLT port, or dedicated 1G-EPON and 10G-EPON OLT port with external wavelength splitter / combiner. Assuming that 1G-EPON ONUs remain in the network and coexist on the same ODN with both 10G-EPON as well as NG-EPON ONUs, a triple-rate OLT has to be deployed first during one of the maintenance windows, preparing the given ODN for NG-EPON ONUs. Only when the NG-EPON OLT port becomes available, new NG-EPON ONUs may be connected to the ODN, occupying previously unoccupied drop fibrers, or replacing 1G-EPON or 10G-EPON ONUs, as service requirements for selected customers exceed the capacity of 1G-EPON or 10G-EPON systems. This evolution approach becomes increasingly complex, especially because of the exhaustion of the fiber spectrum. It is also inefficient for the operator to repurchase 1G-EPON and 10G-EPON OLT port that has been already paid for by the time 1G-EPON and 10G-EPON have been deployed.

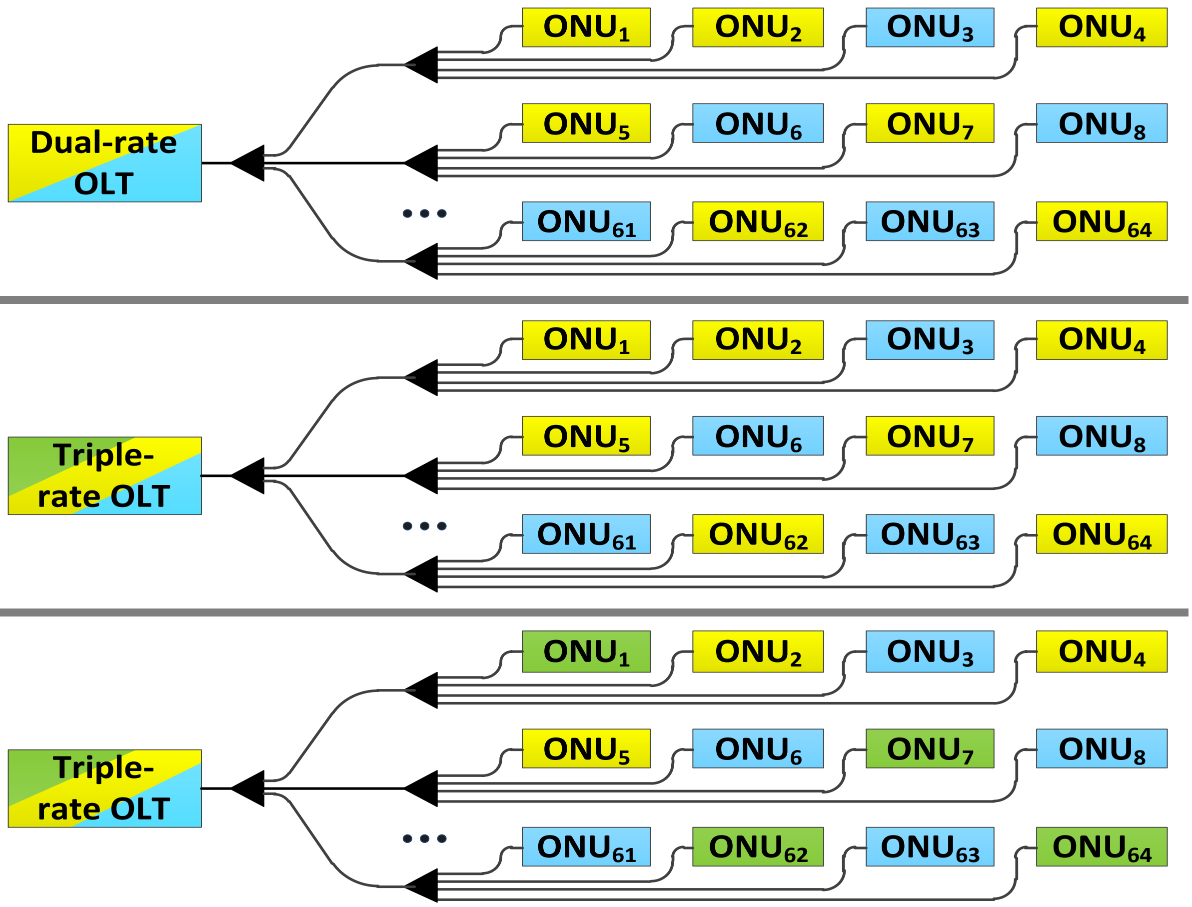
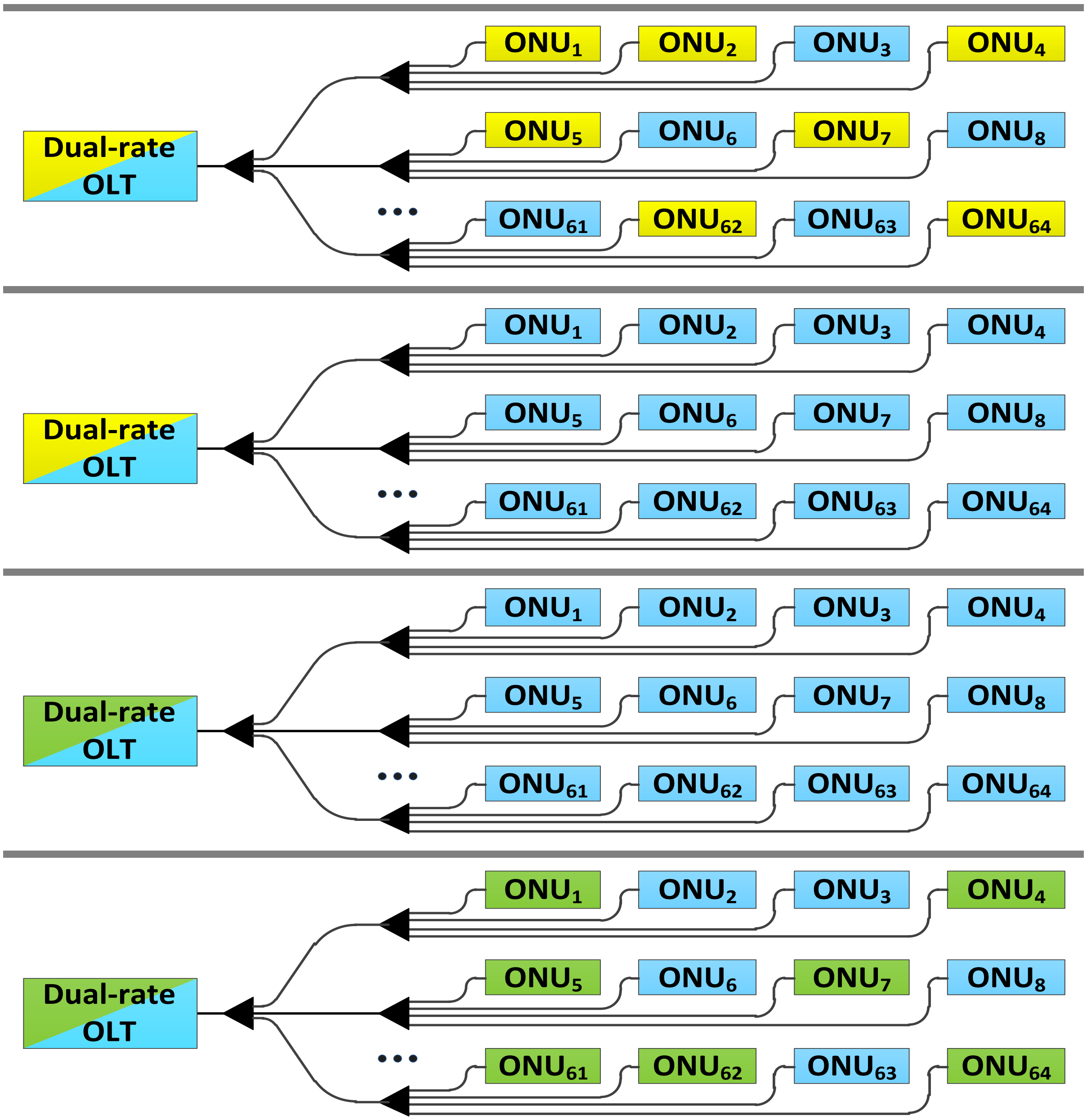


Figure 11: Evolution from 1G-EPON and 10G-EPON network to three generation EPON access

The alternative approach assumes coexistence of only two EPON generations on the same ODN. Before deploying NG-EPON devices, the operator upgrades all 1G-EPON ONUs to 10G-EPON ONUs, replacing the dual-rate OLT port operating in 1G-EPON and 10G-EPON with a dual-rate OLT port capable of operating in 10G-EPON and NG-EPON modes. Once the OLT port upgrade is done and all 1G-EPON active devices have been removed from the given ODN, the NG-EPON ONUs can be rolled out. In this particular scenario, the NG-EPON may partially or completely reuse 1G-EPON downstream and/or upstream spectrum, assuming that wither TDM or WDM separation between 10G-EPON and NG-EPON upstream channels is possible.



7.3 Coexistence and Blocking Filters in ONUs [2]

To allow for smooth evolution from one generation of EPON to another, as well as for coexistence of multiple generations of EPON on the same ODN, ONUs need to be equipped with wavelength blocking filters (WBF) to receive optical signals only within the nominal receive window described by the respective standard and reject all optical transmissions outside that window. For example, 1G-EPON ONUs need to receive only downstream 1G-EPON wavelength range of 1480-1500 nm, and reject downstream 10G-EPON wavelength range of 1575-1580 nm, as well as any other signals (RFoG, CWDM, etc.).

7.4 Coexistence and Raman Depletion [2][3]

Higher speed versions of EPON operate at higher power levels than 1G-EPON, causing interaction between analog RFoG and digital EPON carriers, as discussed in more detail in [3]. In effect, analog modulated RFoG carriers are depleted into high power digital carriers of EPON, causing signal to noise ratio (SNR) degradation and in extreme cases – service outage.

As EPON moves to higher power, and potentially parallel wavelength systems, Raman effect mitigation techniques will become increasingly important [2].

8 Conclusions

[Editor's note: this will be the most creative section of the document, requiring detailed review and consent from all participants and then from the WG membership as well.]

References

[1] Glen Kramer, "Taxonomy of PON", kramer_ngepon_01_0114.pdf, January 2014

[2] Bill Powell, "Optical Wavelength Considerations for NG EPON", powell_ngepon_01A_0114.pdf, January 2014

[3] Sergey Y. Ten, Silvia Pato, "Non-linear effects in PON fiber channel", 3av_0611_ten_1.pdf, November 2006

[4] Call for Interest, "10Gbps PHY for EPON - Call for Interest", cfi_0306_1.pdf, March 2006

[5] IEEE 802.3 Standard for Ethernet, December 2012