International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.984.3
Amendment 2
(11/2009)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Optical line systems for local and access networks

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Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification

Amendment 2: Time-of-day distribution and maintenance updates and clarifications

Recommendation ITU-T G.984.3 (2008) – Amendment 2

ITU-T

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Recommendation ITU-T G.984.3

Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification

Amendment 2

Time-of-day distribution and maintenance updates and clarifications

Summary

Amendment 2 to Recommendation ITU-T G.984.3:

– describes a method of ToD (time of day) distribution in a G-PON system, and

– addresses regular recommendation maintenance items, including updates and clarifications.

Source

Amendment 2 to Recommendation ITU-T G.984.3 (2008) was approved on 13 November 2009 by ITU-T Study Group 15 (2009-2012) under Recommendation ITU-T A.8 procedures.

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Recommendation ITU-T G.984.3

Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification

Amendment 2

Time-of-day distribution and maintenance updates and clarifications

1) Introduction

The primary purpose of this amendment is to explain the issues that are relevant to distributing accurate time of day (ToD) over a G-PON network.

Various in-band methods have been described to distribute ToD over packet transport networks. These may not deliver adequate phase accuracy over PON systems, because the in-band methods assume that the delay is symmetric, whereas in PON systems the delay is not symmetric. Fortunately, PON systems continuously measure the transmission delay between the optical line termination (OLT) and the optical network unit (ONU), and this measurement can be used to transfer the accurate ToD from the OLT to the ONU.

In addition, this amendment addresses regular ITU-T G.984.3 maintenance items involving updates to the Ind field semantics and the size of the OMCI PDU, as well as clarifications to PLEN decoding procedure and DBA stationary bandwidth assignment.

2) Time of day distribution

2.1) New clause 10.4.6

Add new clause 10.4.6 with the following text:

10.4.6 Time of day distribution over G-PON

This clause describes the TC layer method that is used in obtaining the accurate ToD in G-PON systems, the timing relations between OLT and ONU, and the timing error analysis. The required accuracy of the ToD clock at the ONU is ±1 μs.

The principle of operation is as follows. It is assumed that the OLT has an accurate real time clock, obtained through means beyond the scope of this Recommendation. The OLT informs the ONU of the time of day when a certain downstream GTC frame would have arrived at a hypothetical ONU that has zero equalization delay and zero ONU response time. The certain downstream frame is identified by ***N***, the value of its superframe counter, which is an existing feature of the protocol. The information transfer is accomplished using the OMCI channel, and does not need to be in real time. When the selected frame arrives at the ONU, the ONU can use this ToD information, its equalization delay, and its response time to compute its local clock with very high accuracy.

10.4.6.1 Notation

$\boldsymbol{T}\mathbf{stamp}_N$ – This term refers to the exact ToD at which the first bit of downstream GTC frame ***N*** arrives at a hypothetical ONU that has an EqD of zero and a response time of zero. The arrival of the signal at the ONU is defined to be the instant at which the optical signal crosses the optical connector or splice that is the boundary between the ODN and the ONU.

$Tsend_N$ – The exact ToD at which the first bit of downstream frame N departs from the OLT. The departure of the signal is defined to be the instant at which the optical signal crosses the optical connector or splice that is the boundary between the OLT and the ODN.

$Trecv_{N,i}$ – The exact ToD at which the first bit of downstream frame N arrives at ONU i. The arrival of the signal at the ONU is defined to be the instant at which the optical signal crosses the optical connector or splice that is the boundary between the ODN and the ONU.

$RspTime_i$ – The value of the response time for ONU i, which can be in the range of 34 to 36 microseconds.

***T*eqd** – The "zero distance" equalization delay, equal to the offset between the downstream and upstream frames at the OLT location. The OLT adjusts the equalization delay of each ONU such that, for all ONUs, the start of the upstream frame at the OLT occurs ***T*eqd** seconds after the start of the downstream frame. See Figure 10-8 below and clause 10.4.3.3.

n_{1310} – The group velocity refractive index for 1310 nm wavelength light in the ODN.

n_{1490} – The group velocity refractive index for 1490 nm wavelength light in the ODN.

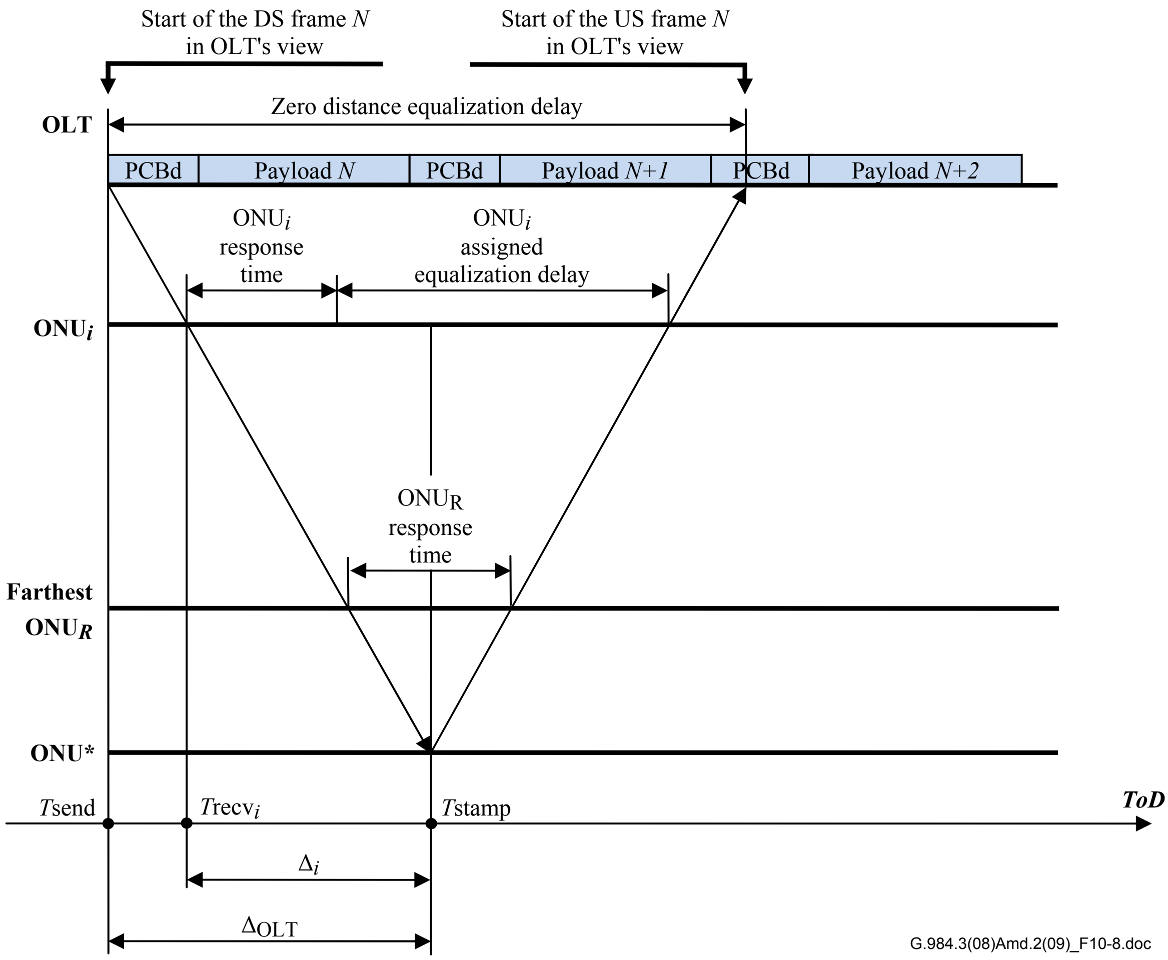

Figure 10-8 – "Zero-distance" equalization delay and time of day calculations

10.4.6.2 Timing process

The following process synchronizes the slave clock of the ONU to the master clock of the OLT:

1) The OLT selects a downstream GTC frame to be used as the timing reference. This frame is identified by the superframe counter N . This frame should be sufficiently far in the future to ensure that all the involved ONUs are ready when it occurs. A suggested processing

delay time is 10 seconds. Since the superframe counter rolls over in approximately 37 hours (at 2.5 Gbit/s), the OLT may select the timing reference frame up to 37 hours in advance. It is recommended that the OLT performs this procedure at least once every 24 hours, and also whenever a new ONU has been activated.

2) The OLT calculates the $\boldsymbol{T}\mathbf{stamp}_N$ value, which is based on the predicted $\boldsymbol{T}\mathbf{send}_N$ of frame $\boldsymbol{N}$. This calculation is given by:

$$Tstamp_N = Tsend_N + \Delta_{OLT}\text{, where}$$

$$\Delta_{OLT} = Teqd \frac{n_{1490}}{n_{1310} + n_{1490}}$$

Note that the $\boldsymbol{T}\mathbf{send}_N$ and $\boldsymbol{T}\mathbf{stamp}_N$ values are all referenced to the optical interface to ensure that they are invariant to the implementation. The OLT is responsible for compensating for all its internal delays.

3) This value pair ($\boldsymbol{N}$, $\boldsymbol{T}\mathbf{stamp}_N$) is stored locally at the OLT side.

4) The OLT sends this value pair ($\boldsymbol{N}$, $\boldsymbol{T}\mathbf{stamp}_N$) to one or more ONUs via OMCI.

5) ONU $\boldsymbol{i}$ calculates the predicted $\boldsymbol{T}\mathbf{recv}_{N,i}$ based on $\boldsymbol{T}\mathbf{stamp}_N$ and its own equalization delay. This calculation is given by:

$$T\text{recv}_{N,i} = T\text{stamp}_N - \Delta_i\text{, where}$$

$$\Delta_i = \left(EqD_i + RspTime_i\right)\frac{n_{1490}}{n_{1310} + n_{1490}}$$

The exact value of the response time for ONU $\boldsymbol{i}$ must be used. Note that the $\boldsymbol{T}\mathbf{stamp}_N$ and $\boldsymbol{T}\mathbf{recv}_N$ values are all referenced to the optical interface to ensure that they are invariant to the implementation. The ONU is responsible for compensating for all of its internal delays.

6) When ONU $\boldsymbol{i}$ receives the downstream frame $\boldsymbol{N}$, it can set its ToD clock to the predicted value $\boldsymbol{T}\mathbf{recv}_{N,i}$. To guard against the superframe counter rolling over, setting of the ToD clock at the ONU should be a one-time event for each communication of the ($\boldsymbol{N}$, $\boldsymbol{T}\mathbf{stamp}_N$) value pair via OMCI.

7) Whenever the ONU's equalization delay is adjusted while setting of the ToD clock is still pending, the ONU makes the commensurate adjustment in its predicted $\boldsymbol{T}\mathbf{recv}_{N,i}$ value. In this way, the ToD clock tracks any drifts in the propagation delay in the PON system.

It is assumed (and holds true for a common G-PON system) that the OLT supports one and only one ToD clock domain. If this is the case, then the G-PON system clock can be synchronized to the ToD clock thus allowing the periodicity of the ToD distribution procedure to be relaxed (for example, once every 24 hours). The case of multiple ToD clock domains per OLT is out of scope.

10.4.6.3 Performance analysis

10.4.6.3.1 EqD accuracy

The accuracy of the EqD in the 1.244 Gbit/s G-PON network is ±4 bits, which is approximately ±3 ns. This is very much smaller than the overall system timing requirement of 1 µs, so this can likely be neglected.

10.4.6.3.2 Fibre propagation delay

For typical SMF-28 fibres, $\boldsymbol{n}_{1310} = 1.4677$, $\boldsymbol{n}_{1490} = 1.4682$. The difference between the two is 0.0005. The index correction factor is thus:

$$\frac{n_{1490}}{n_{1310} + n_{1490}} = 0.500085$$

Note that using the approximate value of 0.5 for this constant would result in a systematic error of 170 ppm, which over a 200 μs PON is an error of 34 ns. It should be noted that different fibres may exhibit different absolute refractive indices; however, the relative dispersion between 1310 nm and 1490 nm is very well controlled. See Appendix VII for the details of the error analysis.

10.4.6.3.3 Internal timing corrections

Both the OLT and ONU are responsible for compensating for their internal delays from wherever the logical computations/event triggers are performed to the optical interfaces. In the PON system, the TDMA requirements imply that these internal delays are stable at least over each ranging life-cycle to the accuracy given above (±4 bits). The stability and predictability of PON equipment over longer time periods is not specified. However, the variability should be contained within ±16 bits at 2.5 Gbit/s, which corresponds to two uncontrolled 16-bit serializer-deserializer delays in the downstream link, which are a likely source of timing variability in a G-PON system. Even here, the resulting timing uncertainty of ±6.4 ns is very small.

2.2) New Appendix VII

Provide a new informative appendix at the end of the Recommendation, with the following text:

Appendix VII

Time of day derivation and error analysis

(This appendix does not form an integral part of this Recommendation)

This appendix provides the mathematical details for the time of day transfer model derivation and error analysis. It is based on the notation of clause 10.4.6.1. In addition,

$\boldsymbol{T}_{1310}$ is the upstream propagation delay at the 1310 nm wavelength, and

$\boldsymbol{T}_{1490}$ is the downstream propagation delay at the 1490 nm wavelength.

By construction (see Figures 10-6 and 10-8 with accompanying text), the zero-distance equalization delay can be represented using the parameters of ONU $\boldsymbol{i}$ as:

$$\begin{aligned} Teqd &= T_{1490,i} + RspTime_i + EqD_i + T_{1310,i} \\ &= T_{1490,i}\frac{n_{1310}+n_{1490}}{n_{1490}} + RspTime_i + EqD_i \end{aligned} \qquad \text{(VII-1)}$$

Then, by expressing $\boldsymbol{T}_{1490,i}$ from equation VII-1 as:

$$T_{1490,i} = (T\text{eqd} - RspTime_i - EqD_i)\frac{n_{1490}}{n_{1310}+n_{1490}} \qquad \text{(VII-2)}$$

substituting this expression into the formula for the receive instance of GTC frame $\boldsymbol{N}$,

$$T\text{recv}_{N,i} = T\text{send}_{N,i} + T_{1490,i} \qquad \text{(VII-3)}$$

and regrouping appropriately, we can obtain the representation of the actual ToD instance when GTC frame ***N*** is delivered to ONU ***i***:

$$T\text{recv}_{N,i} = T\text{send}_N + T\text{eqd}\left[\frac{n_{1490}}{n_{1310}+n_{1490}}\right]_{\text{OLT}} - \left(EqD_i + RspTime_i\right)\left[\frac{n_{1490}}{n_{1310}+n_{1490}}\right]_{\text{ONU}} \quad \text{(VII-4)}$$

where the positive additive term can be computed by the OLT and communicated downstream, while the negative additive term can be computed by the ONU.

Note that for the model to hold, the measurements of ***T*****eqd**, ***T*****send**$_{N,i}$, and ***T*****recv**$_{N,i}$ should be consistently referenced to the fibre interface at the OLT and ONU, respectively.

Note further that in addition to the ONU response time shown here, there are also internal delays that need to be compensated in both the OLT and ONU. These internal delay compensations directly affect the delivered time accuracy, so the resultant error is quite easy to understand. These errors are not considered further in this treatment.

It should be noted that the refractive index factors are used in calculations on both sides of the PON, and their values could differ, depending on the implementation. To eliminate the error caused by inconsistent values, it is recommended that both sides use the common value estimated below.

The resulting timing error caused by variations in the index factor is then given by:

$$T\text{error}_{N,i} = T\text{eqd}\cdot\delta\left[\frac{n_{1490}}{n_{1310}+n_{1490}}\right]_{\text{OLT}} - \left(EqD_i + RspTime_i\right)\cdot\delta\left[\frac{n_{1490}}{n_{1310}+n_{1490}}\right]_{\text{ONU}} \quad \text{(VII-5)}$$

This equation tells us that the error due to the OLT's refractive index factor variation is fixed (over all ONUs), and it is indeed at the maximum value of ***T*****eqd**, which is typically 250 microseconds. The error due to the ONU's index factor variation depends on the EqD and the response time of that ONU; therefore, nearby ONUs will have a larger error caused by inaccuracies in the ONU's index factor (a rather counter-intuitive result). It should be noted, however, that these errors may cancel out to some degree. To assure this cancellation, it is recommended that the calculation use the common value estimated below.

Looking deeper into the index factor, we can denote the group refractive index at 1490 nm with ***n*** and the difference between group indices at 1310 and 1490 nm with **Δ*n***, rewriting:

$$\frac{n_{1490}}{n_{1310}+n_{1490}} = \frac{n_{1490}}{2n_{1490}+(n_{1310}-n_{1490})} = \frac{n}{2n+\Delta n} \approx \frac{2n^2 - n\Delta n}{4n^2} = \frac{1}{2} - \frac{\Delta n}{4n} \quad \text{(VII-6)}$$

We can consider the effect of variations of ***n*** and **Δ*n*** by taking partial derivatives with respect to these variables. We can see that:

$$\frac{\partial}{\partial n}\left(\frac{1}{2}-\frac{\Delta n}{4n}\right) = +\frac{\Delta n}{4n^2} \quad \text{and} \quad \frac{\partial}{\partial \Delta n}\left(\frac{1}{2}-\frac{\Delta n}{4n}\right) = -\frac{1}{4n} \quad \text{(VII-7)}$$

It is important to note that ***n*** is about 3 orders of magnitude larger than **Δ*n***. Therefore, the first expression is very much smaller than the second one, and can be neglected. The second expression states that small changes in **Δ*n*** will be translated into small changes of the index factor in the proportion 1/4***n***.

So, we must calculate **Δ*n*** (the "index difference"), and then consider its variations.

Calculation of the index difference

The wavelength-dependent difference in refractive index **Δ*n*** depends on the fibre properties and on the actual wavelengths that are involved (as real PON transmitters may operate over a range of wavelengths). An accurate representation of the index of ITU-T G.652 fibres is difficult to obtain.

Typical spot values for the index at 1310 and 1550 nm are available, but these do not have the accuracy that we need. The dispersion of fibres is given for certain windows (the 1310 window, for example), but these formulations are not really accurate when extrapolated beyond their window. Nevertheless, we choose to proceed with the standardized dispersion factor, and suffer the potential inaccuracy that such a generalization imposes. If a better function can be determined, then the analysis can be applied to that.

The dispersion of ITU-T G.652 fibres is given by:

$$D(\lambda) = \frac{\lambda S_0}{4}\left[1 - \frac{\lambda_0^4}{\lambda^4}\right] \qquad \text{(VII-8)}$$

where $\boldsymbol{S}_0$ is the dispersion slope (maximum 0.092 ps/nm^2/km), and λ_0 is the zero dispersion wavelength (ranging from 1300 to 1324 nm).

The index of refraction and $\boldsymbol{D}$ are related by $\frac{\mathrm{d}n}{\mathrm{d}\lambda} = cD(\lambda)$, and the fundamental theorem of calculus tells us that:

$$n = n_0 + c\int_{\lambda_0}^{\lambda} D(\lambda)d\lambda \qquad \text{(VII-9)}$$

Integrating, we find that:

$$n - n_0 = \frac{cS_0}{8}\lambda^2\left[1 - \frac{\lambda_0^2}{\lambda^2}\right]^2 \qquad \text{(VII-10)}$$

The index difference function is graphed for the two extreme cases of ITU-T G.652 fibres in Figure VII.1, where the zero dispersion wavelengths are 1300 and 1324 nm. Also shown are the wavelength ranges for the "reduced" type G-PON transmitters (1290 to 1330 nm for the upstream and 1480 to 1500 nm for the downstream). The maximum index difference is 0.000481, and the minimum index difference is 0.000285.

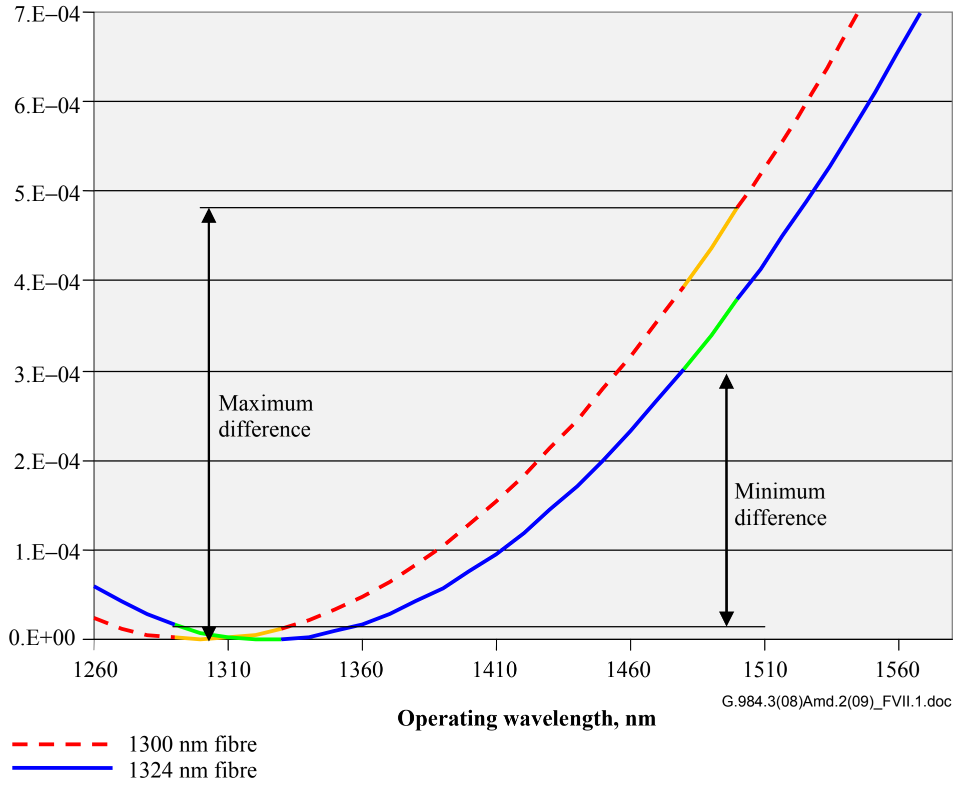

Figure VII.1 – Refractive index difference as a function of operating wavelength

In practical systems, operating wavelengths are not monitored, nor is the exact fibre dispersion known. Hence, the index difference is truly an unknown quantity. Qualitatively, the variation of the 1310 nm transmitter has little effect, because it is close to the minimum of the curve. Interestingly, variation of the fibre dispersion zero wavelength and variation of the 1490 nm transmitter wavelength have nearly equal effect in modifying the index difference.

Index factor variability

Using equation VII-4 and substituting the value $\boldsymbol{n}$ = 1.47, which is a valid approximation for the group refractive indices of the commonly deployed fibres (precision is not important here), we find that the index factor can range from 0.500049 to 0.500082. The most plausible refractive index factor value is 0.500065, but this may be incorrect by an amount of up to ±0.000017. The most accurate solution is achieved when both the OLT and ONU use these common values:

$$\frac{n_{1490}}{n_{1310}+n_{1490}} \approx 0.500065$$

$$\delta\left[\frac{n_{1490}}{n_{1310}+n_{1490}}\right] \leq 0.000017$$

eliminating the error due to differing values on either side of the PON. The inaccuracy of the time then amounts to ±0.000017 times the round trip time of the fibre. For an ONU at 20 km, the round trip time is approximately 200 microseconds and, therefore, the inaccuracy is ± 3.4 ns and is negligible.

2.3) New acronym

Add an item to the acronym list (clause 4):

ToD Time of Day

3) Maintenance items

3.1) Ind field

Amend the function of bit 7 in the Ind field definition in clause 8.2.2.3 as follows, dropping "urgent":

Bit position	Function
7 (MSB)	A PLOAMu message waiting (1 = PLOAM waiting, 0 = no PLOAMs waiting)

3.2) OMCI PDU size

Remove explicit 48-byte restriction on OMCI PDU size. In the last paragraph of clause 14.1, drop the first sentence and rephrase the remainder as follows:

The OMCI payloads are encapsulated into GEM frames with a header containing the configured OMCI 12-bit Port-ID. These frames are transported over the G-PON in the GTC payload. In the upstream, the default Alloc-ID is used.

In clause 14.2, on two occasions substitute the expression "48-byte PDU" with "OMCI PDU". Underlining is used below to emphasize the change and shall be removed in the amended text of the Recommendation.

The OMCI adapter at the ONU is responsible for filtering and decapsulating frames in the downstream, and encapsulating the PDUs in the upstream. The OMCI PDUs are handed off to the logic that implements the OMCI functions.

The OMCI adapter at the management station is responsible for filtering and decapsulating frames in the upstream. Many concurrent channels must be supported, and these can be of mixed types. It is also responsible for encapsulating the OMCI PDUs from the OMCI control logic in the appropriate format for transport to the ONU.

3.3) DBA stationary bandwidth assignment target

In target performance specification of clause 7.4.7.1, replace the phrase:

"at least equal to the respective fixed plus assured bandwidth"

with the following text:

"at least equal to the respective guaranteed bandwidth (see equation 7.6)".

3.4) PLend decoding procedure

Append the following text and table after Figure 8-6 in clause 8.1.3.5:

The PLend field acceptance rules based on dual transmission of copies A and B are given in detail in Table 8-a. An asterisk in the Comparison column indicates that either the operation is not applicable or its result does not matter.

Table 8-a – PLend field decoding

Copy A syndrome	Copy B syndrome	Comparison of decoded A and B	Acceptance and Copy selection
Uncorrectable	Uncorrectable	*	Drop
Correctable	Correctable	Not equal	Drop
Error-free	Error-free	Not equal	Drop
Error-free	Error-free	Equal	A or B
Error-free	Correctable	*	A
Error-free	Uncorrectable	*	A
Correctable	Error-free	*	B
Correctable	Correctable	Equal	A or B
Correctable	Uncorrectable	*	A
Uncorrectable	Error-free	*	B
Uncorrectable	Correctable	*	B

3.5) Default PLOAM message receive events at ONU

Add the following statement as a separate paragraph after letter bullet j) in clause 10.2.5.1:

For all other downstream PLOAM messages, an ONU is required to generate an event only while in state O5.

3.6) ONU activation state table

Add the following text in the POPUP column of Table 10-1, ONU activation states functional transitions, for the Achieving PSync synchronization event:

Remain in O6; start processing PCBd field of the downstream GTC frames.

3.7) LOS and LOF cancellation actions at ONU

In clause 11.1.2, Items detected at ONU, modify the content of the Actions column for LOS and LOF alarms. Instead of "Move to standby state" specify the following:

For LOS:

Restart the PSync acquisition state machine. Once LOF is cleared, if in O1 state, move to O2 state; if in O6 state, remain in O6. Restart superframe synchronization state machine.

For LOF:

If in O1 state, move to O2 state; if in O6 state, remain in O6. Restart superframe synchronization state machine.

3.8) ONU's POPUP state semantics

In clause 10.2.2, ONU state specification, replace the entire text of item f), POPUP state (O6), with the following text. Note that underlining is used to emphasize the changes and shall be removed in the amended text of the Recommendation.

f) **POPUP state (O6)**

The ONU enters this state from the Operation state (O5) following the detection of LOS or LOF alarms. When entering the POPUP state (O6), the ONU immediately stops upstream transmission. As a result, the OLT will detect an LOS alarm for that ONU.

Once in the POPUP state, the ONU first attempts to reacquire optical signal and restore GTC frame synchronization, thus clearing LOS and LOF conditions. Once successful, the ONU begins processing PCBd field of the downstream GTC frames and restarts the superframe synchronization state machine. Note that in case of Type B protection, the signal may be coming either from the backup OLT or from the primary OLT.

While in the POPUP state, the ONU generates a PLOAM message receive event only in response to Disable_ONU-ID, Deactivate_Serial_Number and POPUP messages. If ONU receives a directed POPUP message, it transitions to the Operation state (O5). If the ONU receives a broadcast POPUP message, it transitions to the Ranging state (O4).

Once the ONU is in the Operation state (O5), the OLT can test the ONU before returning it to full service. In particular, an encryption key switch event may have been scheduled while in the POPUP state (O6). To ensure graceful recovery in such a situation, the OLT should restart the key exchange and switch-over procedure with the ONU.

If the ONU is not able to reacquire optical signal or restore GTC frame synchronization, it will not receive any POPUP messages (broadcast or directed) and will move to the Initial state (O1), following time-out (TO2).

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Printed in Switzerland
Geneva, 2010