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# ITU-T G Suppl. 45 (09/2022)

SERIES G: Transmission systems and media, digital systems and networks

# Power conservation in optical access systems

ITU-T G-SERIES RECOMMENDATIONS

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# Supplement 45 to ITU-T G-series Recommendations

## Power conservation in optical access systems


### Summary

Supplement 45 to ITU-T G-series Recommendations consolidates power-saving proposals for various optical access systems in order to facilitate their consideration and comparative analysis for the satisfaction of requirements, on one hand, and overall system impact, on the other. This Supplement takes the form of a white paper summarizing efforts to gather requirements, specifying a wide spectrum of potential solutions, as well as their comparative analysis.



### History

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### Keywords

Cyclic sleep, dozing, FTTR (fibre to the room), line rate switching, optical access network, point-to point optical transmission, PON, power shedding, reach extenders, single fibre (aka BiDi), watchful sleep.


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## Introduction

Power conservation (and its consequent carbon footprint reduction) has been embraced by ITU as a necessary goal. ITU-T has been exploring potential solutions to improve power conservation through reduced power consumption and other techniques within optical access networks. These solutions can have an impact on improving equipment performance and service longevity in battery-powered operation, as well as on power conservation and $CO_2$ emissions in general.

Since 2006, the Full Service Access Network [FSAN] and ITU-T have run three rounds of requirement-gathering power-saving surveys. The results of those surveys have revealed two foci of power-saving efforts by improving: the power consumption characteristics of the optical access equipment to reduce its contribution to greenhouse gas emissions; and the performance of optical access equipment in mains outage situations. The survey results have also demonstrated considerable variability in regulatory and operating environments where the gigabit-capable passive optical network (GPON) and its follow-up generations is being or is planned to be deployed. Thus, the acceptable effect of any special power-saving mode on perceived quality of service varies from a zero tolerance approach and full operator control to allow a certain degree of trade-offs and user freedom of choice.

To satisfy requirements that may vary by region, operator and application, multiple power conservation methods can be proposed and need to be documented and analysed. Such methods differ in achievable savings, as well as in the amount of required system architecture and system-provisioning changes. One possible approach to classification of such methods is based on the depth of impact upon the existing GPON transmission convergence (GTC) layer as specified in [ITU-T G.984.3].

Since the first edition [b-ITU-T G.Suppl.45 (2009)], major changes have happened that rendered this revision necessary:

- finalization of the sleep mode messaging and state machines for GPON;
- motion of optical network unit (ONU) management and control interface (OMCI) material from [ITU-T G.984.4] to [ITU-T G.988] with additions of relevant managed entities (MEs);
- *Code of conduct on energy consumption of broadband communication equipment* (latest edition [BBCoC v8.0]) reports major progress in integration of ONU functions specifically with the emergence of small form-factor pluggable (SFP) form factors;
- standardization of the 10 Gbit-capable (symmetric) passive optical network (XG(S)-PON) (in [ITU-T G.987] [ITU-T G.987.1] [ITU-T G.987.2] [ITU-T G.987.3] [ITU-T G.987.4] [ITU-T G.9807.1]) with some revision of initial sleep modes;
- standardization of the 40 Gbit-capable passive optical network (NG-PON2) (in [ITU-T G.989] [ITU T G.989.1] [ITU T G.989.2] [ITU T G.989.3]) with parallel channels and tuneable ONU optics enabling the shutdown of unused wavelength channels;
- development of low-power reach extender devices, enabling network consolidation without frame processing also enabling smoother introduction of newer passive optical network (PON) technologies with overlay;
- development of line rate agility in both PON and point to point (PtP) technologies (also known as line rate switching);
- in some possibly close future flexible FEC algorithms in the higher-speed PON (HSP) (in [ITU-T G.9804.1], [ITU-T G.9804.2] and [ITU-T G.9804.3] ) generation.

# Supplement 45 to ITU-T G-series Recommendations

## Power conservation in optical access systems

### 1 Scope

This Supplement summarizes, in clause 2: the Full Service Access Network [FSAN] and ITU-T optical access systems power savings survey results; the principles and targets set by the *Code of conduct on energy consumption of broadband communication equipment* ([BBCoC v8.0]), and optical access system power savings requirement profiles. Clauses 3, 4 and 5 specify the proposed power-saving techniques partitioned by their relation to the GPON transmission convergence (GTC) layer into the following groups:

– techniques involving introduction of physical layer operation, administration and maintenance (PLOAM) messages or embedded operation, administration and maintenance (OAM) fields;

– techniques involving changing the semantics of existing PLOAM messages or embedded OAM) fields;

– one-sided techniques that avoid changes to the GTC layer.

NOTE – The "fast sleep" method has been renamed "Cyclic Sleep" and later simplified into a single "Watchful Sleep"; initial concepts have been kept.

Clause 6 analyses comparatively the proposed techniques with respect to the specified requirements and clause 7 presents conclusions.

### 2 References


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[ITU-T G.984.2] Recommendation ITU-T G.984.2 (2019), *Gigabit-capable passive optical networks (GPON): Physical media dependent (PMD) layer specification*.

[ITU-T G.984.3] Recommendation ITU-T G.984.3 (2014), *Gigabit-capable passive optical networks (G-PON): Transmission convergence layer specification.*

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[ITU-T G.987.2] Recommendation ITU-T G.987.2 (2016), *10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification*.

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[ITU-T G.9804.2] Recommendation ITU-T G.9804.2 (2021), *Higher speed passive optical networks – Common transmission convergence layer specification*.

[ITU-T G.9804.3] Recommendation ITU-T G.9804.3 (2021), *50-Gigabit-capable passive optical networks (50G-PON): Physical media dependent (PMD) layer specification*.

[ITU-T G.9805] Recommendation ITU-T G.9805 (2022), *Coexistence of passive optical network systems*.

[ITU-T G.9806] Recommendation ITU-T G.9806 (2020), *Higher speed bidirectional, single fibre, point-to-point optical access system (HS-PtP).*

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## 3 Definitions

None.

## 4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

| | |
|---|---|
| 50G-PON | 50-Gigabit-capable Passive Optical Network |
| AC | Alternating Current |
| ANI | Access Node Interface |
| AP | Access Point |
| ASIC | Application-Specific Integrated Circuit |
| BiDi | Bidirectional |
| CATV | Cable Television |
| CO | Central Office |
| CPE | Customer Premises Equipment |
| CPU | Central Processing Unit |
| CT | Channel Termination |
| DBA | Dynamic Bandwidth Assignment |
| DC | Direct Current |
| DPU | Distribution Point Unit |
| EE | Energy Efficiency |
| EONU | Engine for ONU |
| EPON | Ethernet Passive Optical Network |
| FPGA | Field Programmable Gate Array |
| FTTB | Fibre To The Business |
| FTTH | Fibre To The Home |
| FTTR | Fibre To The Room |
| FTTx | Fibre To The x |
| FXS | Foreign exchange station |
| GPON | Gigabit-capable Passive Optical Network |
| GTC | GPON Transmission Convergence |
| HGU | Home Gateway Unit |
| H-QoS | Hierarchical Quality of Service |
| HSP | Higher-Speed PON |
| HS-PtP | High Speed Point to Point |
| IGMP | Internet Group Management Protocol |
| IoT | Internet of Things |
| IP | Internet Protocol |
| LAN | Local Area Network |
| LOS | Loss of Signal |
| $LOS_i$ | loss of signal for ONU *i* |

| | |
|---|---|
| LRS | Line Rate Switching |
| LWI | Local Wake-up Indication |
| MDU | Media Distribution Unit |
| ME | Managed Entity |
| MITM | Man-In-The-Middle |
| MoCA | Multimedia over Coax Alliance |
| MPLS | Multi-Protocol Label Switching |
| NG-PON2 | 40 Gbit-capable Passive Optical Network |
| NT | Network Termination |
| OAM | Operation, Administration and Maintenance |
| ODN | Optical Distribution Network |
| OEO | Optical-Electronic-Optical |
| OLT | Optical Line Termination |
| OMCC | ONU management and control channel |
| OMCI | ONU Management and Control Interface |
| ONT | Optical Network Termination |
| ONU | Optical Network Unit |
| OPEX | Operating Expenditure |
| PC | Personal Computer |
| PD | Photodiode |
| PHY | Physical |
| PLOAM | Physical Layer Operation, Administration and Maintenance |
| PMD | Physical Media Dependent |
| PoE | Power over Ethernet |
| POL | Passive Optical Local area network |
| PON | Passive Optical Network |
| POTS | Plain Old Telephone Service |
| PSync | Physical Synchronization |
| PtP | Point to Point |
| QoS | Quality of Service |
| RE | Reach Extender |
| RF | Radio Frequency |
| RGW | Residential Gateway |
| RJ11 | Registered Jack 11 |
| RJ45 | Registered Jack 45 |
| Rx | Receiver |
| SFP | Small Form-factor Pluggable |

| | |
|---|---|
| SFU | Single Family Unit |
| SLA | Service Level Agreement |
| SLIC | Subscriber Line Interface Circuit |
| SNI | Server to Network Interface |
| TA | Terminal Adaptor |
| TBD | To Be Determined |
| TC | Transmission Convergence |
| TDMA | Time Division Multiple Access |
| TV | Television |
| TWDM | Time and Wavelength Division Multiplexing |
| Tx | transmitter ( |
| UNI | User to Network Interface |
| USB | Universal Serial Bus |
| VoIP | Voice over Internet protocol |
| WAN | Wide Area Network |
| WDM | Wavelength Division Multiplexing |
| Wi-Fi | Wireless Fidelity |
| XFP | 10 Gbit small form Factor Pluggable |
| XG(S)-PON | 10 Gbit-capable (Symmetric) Passive Optical Network |
| XG-PON | 10 Gbit-capable Passive Optical Network |
| XGS-PON | 10 Gbit-capable Symmetric Passive Optical Network |

# 5 Conventions

None.

# 6 Power savings requirements

## 6.1 Survey results

### 6.1.1 Survey No. 1

The first ITU-T power consumption survey, which was answered by four companies, was conducted in early 2007.

Overall, while there was some scattering of data on many of the questions, there was insufficient response to say that a consensus answer had been achieved on any question. Despite this difficulty, it seemed clear from the responses that power saving is of lower priority than service quality, availability and interface variety. This led to the conclusion that power-saving features should be carefully designed so that they would not impede these other priorities.

### 6.1.2 Survey No. 2

Survey No. 2 was distributed in September 2007. It was addressed specifically to the operator community.

Four operators responded to the survey by the meeting deadline and one more provided the responses post factum. All would like an energy saving mode to economize on battery power for back-up of essential services such as telephony (two would like it to be same as the low-power mode in the then current edition of the BBCoC). The responders showed strong interest in a digital telephony interface of ≤ 300 kbit/s. All would like an energy saving mode; however, most required the trigger to be mains failure, rather than unused ports or lack of traffic. Some requirements were formulated:

- same port shutdown sequence was agreed as suggested in the questionnaire;
- programmable data rates (but no consensus on specific values);
- <5 s recovery time to full power mode.

While patchy support was shown for the power save mode when traffic was light or ports remained unused, the decision was made for the vendors to focus on power saving for power backup under supply failure.

#### 6.1.3 Survey No. 3

Survey No. 3 was formulated after the November 2007 meeting with the aim of clarifying service requirements for power-saving performance under mains power outage. Four operators provided responses, confirming the importance of power savings; however, no consistent set of service requirements and acceptable trade-offs appeared as a result of the survey.

#### 6.1.4 Survey No. 4

The survey No, 4 questionnaire was drafted from the June 2021 interim meeting and was issued in August 2021. The answers were collected in time for a summary to be established for the October 2021 interim meeting.

This survey aimed to refresh the expression of interest in or necessity for further exploration of power savings after the 14 year lapse in which many deployments of optical access had taken place worldwide based on diverse technology generations.

Questions covered the following aspects related to power savings:

- motivation: for internal company decisions or regulation driven reasons;
- high-level focus expected: optical line termination (OLT), optical network unit (ONU) both, passive optical network (PON) dedicated, PtP, etc.;
- applications or ONU types to be considered: choice of which fibre to the x (FTTx), whether ONUs should be dedicated or shared;
- service considerations: lifeline services with or without battery back-up, radio frequency (RF) video;
- interest in identified power-saving methods: at the OLT/ONU, shedding, Watchful Sleep.

The nine answers received were predominantly from operators, most of them acting in Europe, represented the current diversity of business model and operating conditions, far from the incumbent local exchange carriers' vision dominating the previous surveys. Various reasons prevented other members from answering despite in principle supporting the effort.

This variety of respondent profiles did not enable the elimination of many options, but confirmed some trends:

– savings on OLTs are of significant interest since they impact operating expenditure (OPEX) of operators;

– operators responsible for ONUs show awareness that the biggest win will be on the ONU side in the fibre to the home (FTTH) market, in which by far single family unit (SFU) types represent the bulk market, followed by the home gateway unit (HGU) type;

– RF video is recessing and has been presented as a dedicated extension outside the ONU;

–	mixed FTTH and fibre to the business (FTTB) PON deployments are becoming popular;
–	full service optical access network with copper phasing out, with inclusion of lifeline services with battery back-up is not yet common ground.

It remains clear that despite the major progress in protocol description of power-saving modes for ONUs, and availability of some implementations, most respondents have not yet proceeded with laboratory testing, so that uncertainties both in benefits on percentage of saved power and the impact on quality of experience of both end users and the operator are impeding them from taking the next steps.

Taking power-saving methods to the next step of conformance certification and interoperability testing should help to alleviate some of these uncertainties. Making use of common traffic patterns to share results could be another step to assess the benefits for all parties.

#### 6.1.5 Survey No. 5

After presentation of a contribution on possible specifics power conservation for new uses cases beyond the access network, with related new assumptions, it was decided to collect general interest through a new questionnaire sent 2022-04.06, see clause I.5.

This survey aimed specifically at investigating the interest in power conservation when applying the access network technologies to domestic networks either for private usage (fibre to the room (FTTR)) or corporate usage (passive optical local area network (LAN) (POL)).

It was intended to get a comprehensive collection of the diverse parameters necessary to efficiently enable low-power modes across the various telecom and energy architectures to be considered. It intended eventually to extract the necessary management features that needed to be added to the legacy ones to be found in the various PLOAM and ONU management and control interface (OMCI) Recommendations.

Thus questions covered the following aspects:

- general interest in FTTR or POL;
- private PON/PtP technologies and managers to be considered for FTTR or POL;
- power-provisioning scheme;
- services and relationship with service operator options;
- interest in specific power-saving capabilities.

Only two answers have been received, one from an operator, one from a supplier. This shows that the topic either goes beyond what participants are expecting from this context or the topic is considered as premature.

Still the primitives in [ITU-T G.988] [ITU-T G.984.1] [ITU-T G.984.2] [ITU-T G.984.3] [ITU-T G.984.4] [ITU-T G.984.5] [ITU-T G.984.6] [ITU-T G.984.7] [ITU-T G.987] [ITU-T G.987.1] [ITU-T G.987.2] [ITU-T G.987.3] [ITU-T G.987.4] [ITU-T G.9807.1] have proven successful worldwide providing volumes for basic building blocks that might fit the domestic networks with minimal customizing to be identified.

The set of questions is reproduced in clause I.5 should a future revision of this Supplement be prepared to resume any investigations on the topic.

### 6.2 EU code of conduct on energy consumption

The *Code of conduct on energy consumption of broadband communication equipment* (BBCoC) is a document issued by the European Commission that sets out the basic principles to be followed by all parties involved in broadband equipment, operating in the European Community, in respect of energy-efficient equipment. All service providers, network operators, equipment and component manufacturers are invited to sign this document on a voluntary basis.

There have been eight published versions of the BBCoC:

– BBCoC v1: Ispra, 2006-07-19
– BBCoC v2: Ispra, 2007-07-17
– BBCoC v3: Ispra, 2008-11-18
– [b-BBCoC v5.0];
– [b-BBCoC v6];
– [b-BBCoC v7.0];
– [b-BBCoC v7.1];
– [BBCoC v8.0].

NOTE 1 – Basic principles can be found in [b-BBCoC E3P].

The BBCoC establishes the general principles of power savings in broadband equipment, provides the functional definitions of operation states, and sets the target power levels along with the time schedule for compliance. It classifies an OLT as network equipment and the optical network termination (ONT) as customer premises equipment (CPE) of the HGU type.

It is noted that BBCoC power consumption values are based on specifications of idle state and on-state with a traffic pattern that does not intend to represent real observed traffic.

Consider as an example three typical ONT configuration styles as defined in Table 6-1.

NOTE 2 – The usage of the terms ONT and ONU throughout this Supplement follows the convention of [ITU-T G.984.3]. In addition, in the context of a particular reference discussion, preference is given to the term used within the specific reference.

**Table 6-1 – Typical ONT configuration styles**

| **Typical ONT configurations** | **Interfaces** | | | |
|---|---|---|---|---|
| | **Wide area network+ (WAN+) central function** | **Gigabit Ethernet** | **Plain old telephone service (POTS)** | **Multimedia over coax alliance (MoCA)** |
| Style 1 – HGU | 1 | 1 | 2 | 1 |
| Style 2 – Small business unit | 1 | 4 | 2 | 0 |
| Style 3 – SFU | 1 | 1 | 0 | 0 |

NOTE – In addition to the different user to network interface (UNI) configurations, the three types of ONT address different types of market. A style 3 ONT in most cases is meant to be used in conjunction with a residential gateway (RGW) in a two separate box architecture.

[BBCoC v8.0] would impose the power level requirements listed in Tables 6-2 to 6-7 on these ONTs.

Values are a combination of power values for home gateway central functions plus WAN interface taken from Table 10 of [BBCoC v8.0] and power values for home gateway LAN interfaces and additional functionality taken from Table 11 of [BBCoC v8.0].

**Table 6-2 – Target power levels for a style l GPON ONT**

| Function | Tier 2009/2010<br>2009-01-01/2010-12-31 | | Tier 2023<br>2023-01-01/2023-12-31 | |
|---|---|---|---|---|
| | Low-power state (W) | On state (W) | Low-power state (W) | On state (W) |
| General functions + GPON interface | 5.0 | 9.7 | 2.7 | 2.9 |
| 1 gigabit Ethernet port | 0.3 | 1.7 | 0.2 | 0.3 |
| Dual subscriber line interface circuit (SLIC) foreign exchange station (FXS) (Note) | 0.8 | 3.0 | 0.4 | 1.0 |
| MoCA (2.0 from Tier 2020) | 0.4 | 4.0 | 1.5 | 2.0 |
| **Total equipment** | **10.1** | **18.4** | **4.8** | **6.2** |
| NOTE – Assuming one interface is totally off in the low-power state in tier 2009, while [b-BBCoC v7.1] specifies for tier 2020 two values; for FXS first interface; and an additional one that has been summed up | | | | |

**Table 6-3 – Target power levels for a style l 10 Gbit-capable passive optical network (XG-PON) ONT**

| Function | Tier 2013/2014<br>2013-01-01/2014-12-31 | | Tier 2023<br>2023-01-01/2023-12-31 | |
|---|---|---|---|---|
| | Low-power state (W) | On state (W) | Low-power state (W) | On state (W) |
| General functions + XG-PON interface | 4.8 | 6.5 | 2.8 | 4.5 |
| 1 gigabit Ethernet port | 0.2 | 0.6 | 0.2 | 0.3 |
| Dual SLIC (FXS) | 0.6 | 2.0 | 0.4 | 1.0 |
| MoCA (2.0) | 1.8 | 2.2 | 1.5 | 2.0 |
| **Total equipment** | **7.4** | **11.3** | **4.9** | **7.8** |
| NOTE – Values for XG-PON ONUs tier 2013/2014 are taken from [BBCoC v5.0], which does not distinguish FXSs, so values have been doubled. [b-BBCoC v7.1] for tier 2020 specifies two values: for FXS first interface; and an additional one that has been summed up. | | | | |

**Table 6-4 – Target power levels for a style 2 GPON ONT**

| Function | Tier 2009/2010<br>2009-01-01/010-12-31 | | Tier 2023<br>2023-01-01/2023-12-31 | |
|---|---|---|---|---|
| | Low-power state (W) | On state (W) | Low-power state (W) | On state (W) |
| General functions + GPON interface | 5.0 | 9.7 | 2.7 | 2.9 |
| 4 port gigabit Ethernet switch | 1.5 | 4.5 | 0.8 | 1.2 |
| Dual SLIC (FXS) (Note) | 0.8 | 3.0 | 0.4 | 1.0 |
| **Total equipment** | **7.3** | **17.2** | **3.9** | **5.1** |
| NOTE – Assuming one interface is totally off in the low-power state in tier 2009, while [b-BBCOC v7.1] specifies for tier 2020 two values: for FXS first interface; and an additional one that has been summed up | | | | |

**Table 6-5 – Target power levels for a style 2 XG-PON ONT**

| Function | Tier 2013/2014<br>2013-01-01/2014-12-31 | | Tier 2023<br>2023-01-01/2023-12-31 | |
|---|---|---|---|---|
| | Low-power state (W) | On state (W) | Low-power state (W) | On state (W) |
| General functions + XG-PON interface | 4.8 | 6.5 | 2.8 | 4.5 |
| 4 port gigabit Ethernet switch | 1.5 | 4.5 | 0.8 | 1.2 |
| Dual SLIC (FXS) (Note) | 0.8 | 3.0 | 0.4 | 1.0 |
| **Total equipment** | **7.1** | **14.0** | **4.0** | **6.7** |
| NOTE<br>– values for XG-PON ONUs tier 2013/2014 are taken from [b-BBCoC v5.0].<br>– [b-BBCoC v5.0] does not distinguish FXSs, so values have been doubled.<br>– [b-BBCoC v7.1] for tier 2020 specifies two values; for FXS first interface: and an additional one that has been summed up.<br>– Tier 2023 allowances for XGS-PON are 3.0 W (idle-state) and 4.8 W (on-state) | | | | |

**Table 6-6 – Target power levels for a style 3 GPON ONT**

| Function | Tier 2009/2010<br>2009-01-01/2010-12-31 | | Tier 2023<br>2023-01-01/2023-12-31 | |
|---|---|---|---|---|
| | Low-power state (W) | On state (W) | Low-power state (W) | On state (W) |
| General functions + GPON interface | 5.0 | 9.7 | 2.7 | 2.9 |
| 1 gigabit Ethernet port | 0.3 | 1.7 | 0.2 | 0.3 |
| **Total equipment** | **5.3** | **11.4** | **2.9** | **3.2** |
| Table 12 of [BBCoC v8.0] lists power targets for simple broadband access devices (modems and network terminations (NTs)); alternative tier 2023 values of 2.1 W (idle state) and 2.4 W (on state) are proposed. | | | | |

**Table 6-7 – Target power levels for a style 3 XG-PON ONT**

| Function | Tier 2013/2014<br>2013-01-01/2014-12-31 | | Tier 2023<br>2023-01-01/2023-12-31 | |
|---|---|---|---|---|
| | Low-power state (W) | On state (W) | Low-power state (W) | On state (W) |
| General functions + XG-PON interface | 4.8 | 6.5 | 2.8 | 4.5 |
| 1 gigabit Ethernet port | 0.2 | 0.6 | 0.2 | 0.3 |
| **Total equipment** | **5.0** | **7.1** | **3.0** | **4.8** |
| NOTES:<br>– Table 12 of [BBCoC v8.0] lists power targets for simple broadband access devices (modems and NTs); alternative tier 2023 values of 3.4 W (idle state) and 4.2 W (on state) are proposed.<br>– Table 12 of [BBCoC v8.0] specifies XGS-PON with 1 GigE LAN interface tier 2023 values of 3.7 W (idle state) and 5.2 W (on state).<br>– [BBCoC v8.0] includes for 10 GigE LAN interfaces allowances of 1.5 W (idle-state), and 3.5 W (on-state up to 2022, to be determined (TBD) for 2023). | | | | |

In addition to figures for maximum recommended power for ONUs shown above, the BBCoC also specifies target power consumption values for OLT interfaces in diverse chassis configurations.

This can enable network planners to refine their network designs when it comes to optimizing their access network architecture. [BBCoC v8.0] does not yet include the option of further network consolidation brought by reach extenders (REs) specified in [ITU-T G.984.1] [ITU-T G.984.2] [ITU-T G.984.3] [ITU-T G.984.4] [ITU-T G.984.5] [ITU-T G.984.6] [ITU-T G.984.7] [ITU-T G.987] [ITU-T G.987.1] [ITU-T G.987.2] [ITU-T G.987.3] [ITU-T G.987.4] [ITU-T G.9807.1] [ITU-T G.9807.2].

Figures for OLT power consumption are taken from [BBCoC v8.0]. See Tables 6-8 to 6-10.

**Table 6-8 – Target power levels for a GPON OLT configurations**

| Power targets for OLTs for PON ports | ≤32 PON ports | | ≥32 PON ports | |
|---|---|---|---|---|
| | Tier 2019 2019-01-01/2019-12-31 (W) | Tier 2023 2023-01-01/2023-12-31 (W) | Tier 2019 2019-01-01/2019-12-31 (W) | Tier 2023 2023-01-01/2023-12-31 (W) |
| GPON (2.5G/1G) | | | | |
| OLT (GPON, fully equipped with maximum configuration implementing standard layer 2 (Ethernet) aggregation functionalities, including multicast) | 5.0 | 5.0 | 4.5 | 4.0 |
| OLT (GPON, fully equipped with maximum configuration implementing also functionalities at the Internet protocol (IP) layer such as routing, multi-protocol label switching (MPLS), and IP quality of service (QoS) or more advanced layer 2 functionalities such as QoS, shaping and policing) | 5.5 | 5.5 | 5.0 | 4.5 |

**Table 6-9 – Target power levels for an XG-PON OLT configuration**

| Power targets for OLTs for PON ports | ≤32 PON ports | | ≥32 PON ports | |
|---|---|---|---|---|
| | Tier 2019 2019-01-01/2019-12-31 (W) | Tier 2023 2023-01-01/2023-12-31 (W) | Tier 2019 2019-01-01/2019-12-31 (W) | Tier 2023 2023-01-01/2023-12-31 (W) |
| XG-PON (10G/2.5G) \| (based on an application-specific integrated circuit (ASIC)) | | | | |
| OLT (XG-PON 10G/2.5G, fully equipped with maximum configuration implementing standard layer 2 (Ethernet) aggregation | 11.0 | 9.5 | 9,0 | 6.5 |

**Table 6-9 – Target power levels for an XG-PON OLT configuration**

| **Power targets for OLTs for PON ports** | **≤32 PON ports** | | **≥32 PON ports** | |
|---|---|---|---|---|
| | **Tier 2019 2019-01-01/2019-12-31 (W)** | **Tier 2023 2023-01-01/2023-12-31 (W)** | **Tier 2019 2019-01-01/2019-12-31 (W)** | **Tier 2023 2023-01-01/2023-12-31 (W)** |
| functionalities, including multicast) | | | | |
| OLT (XG-PON 10G/2.5G, fully equipped with maximum configuration implementing also functionalities at the IP layer such as routing, MPLS, and IP QoS or more advanced layer 2 functionalities such as QoS, shaping and policing) | 12.0 | 10.5 | 10,0 | 7.5 |
| Additional per port allowance for XG-PON OLT implementing layer 3 functionalities of an edge router (at least IP/MPLS routing and interface and policy-based hierarchical QoS (H-QoS)), providing extendable capability to evolve adding new functionalities currently under discussion, and variable traffic-processing functions or market specific customization requirements | 2.0 | 2.0 | 2.0 | 2.0 |

**Table 6-10 – Target power levels for an XGS-PON OLT configuration**

| **Power targets for OLTs for PON ports** | **≤32 PON ports** | | **≥32 PON ports** | |
|---|---|---|---|---|
| | **Tier 2019 2019-01-01/2019-12-31 (W)** | **Tier 2023 2023-01-01/2023-12-31 (W)** | **Tier 2019 2019-01-01/2019-12-31 (W)** | **Tier 2023 2023-01-01/2023-12-31 (W)** |
| XGS-PON (10G/10G) | | | | |
| OLT (XGS-PON 10G/10G, fully equipped with maximum configuration implementing standard layer 2 (Ethernet) aggregation functionalities, including multicast) | 13.0 | 11.0 | 9.5 | 7.0 |

**Table 6-10 – Target power levels for an XGS-PON OLT configuration**

| Power targets for OLTs for PON ports | ≤32 PON ports | | ≥32 PON ports | |
|---|---|---|---|---|
| | Tier 2019 2019-01-01/2019-12-31 (W) | Tier 2023 2023-01-01/2023-12-31 (W) | Tier 2019 2019-01-01/2019-12-31 (W) | Tier 2023 2023-01-01/2023-12-31 (W) |
| OLT (XGS-PON 10G/10G, fully equipped with maximum configuration implementing also functionalities at the IP layer such as routing, MPLS, and IP QoS or more advanced layer 2 functionalities such as QoS, shaping and policing) | 14.0 | 12.0 | 10.5 | 8.0 |
| Additional per port allowance for XGS-PON OLT implementing layer 3 functionalities of an edge router (at least IP/MPLS routing and interface and policy-based H-QoS), providing extendable capability to evolve adding new functionalities currently under discussion, and variable traffic-processing functions or market specific customization requirements | 2.0 | 2.0 | 2.0 | 2.0 |

On some PONs, particularly those that are fully loaded with ONUs and the customers are heavy users, the odds are low that all ONUs will simultaneously be in low-power modes or off state, so that the OLT interface can also enter low-power mode. However, in other scenarios or deployments, some PONs will have either low numbers of ONUs or less active users, when it is likely that there will be significant portions of the day when all ONUs could be in low-power modes for periods of time and allow the OLT interface to enter a low-power mode.

When using multiple interfaces, associated with ONU wavelength tunability (e.g., 40 Gbit-capable passive optical network (NG-PON2) ([ITU-T G.989] [ITU-T G.989.1] [ITU-T G.989.2] [ITU-T G.989.3])) and in PtP transmission schemes (e.g., bidirectional (BiDi) ([b-ITU-T G.9806]) or routed wavelength division multiplexing (WDM) PON) the savings that can be obtained are likely to match on both sides.

See Tables 6-11 and 6-12.

**Table 6-11 – Target power levels for a NG-PON2 OLT configuration**

| **Power targets for OLTs for PON ports** | **≤32 PON ports** | | **≥32 PON ports** | |
|---|---|---|---|---|
| | **Tier 2019 2019-01-01/2019-12-31 (W)** | **Tier 2023 2023-01-01/2023-12-31 (W)** | **Tier 2019 2019-01-01/2019-12-31 (W)** | **Tier 2023 2023-01-01/2023-12-31 (W)** |
| NG-PON2 (10G/10G per lambda) | | | | |
| OLT (NG-PON2 10G/10G per lambda, fully equipped with maximum configuration implementing standard layer 2 (Ethernet) aggregation functionalities, including multicast) | 14.0 | 14.0 | 10.5 | 10.5 |
| OLT (NG-PON2 10G/10G per lambda, fully equipped with maximum configuration implementing also functionalities at the IP layer such as routing, MPLS, and IP QoS or more advanced layer 2 functionalities such as QoS, shaping, policing) | 15.0 | 15.0 | 11.5 | 11.5 |
| Additional per port allowance for NG-PON2 (10G/10G per lambda) OLT implementing layer 3 functionalities of an edge router (at least IP/MPLS routing and interface and policy-based H-QoS), providing extendable capability to evolve adding new functionalities currently under discussion, and variable traffic-processing functions or market specific customization requirements | 2.0 | 2.0 | 2.0 | 2.0 |

Table 6-12 – Target power levels for a PtP OLT configurations

| Power targets for OLTs for PtP ports | Tier 2019 2019-01-01/2019-12-31 (W) | Tier 2023 2023-01-01/2023-12-31 (W) |
|---|---|---|
| PtP 1 000 Mbit/s | | |
| OLT (PtP up to 1 000 Mbit/s, up to 100 ports, fully equipped with maximum configuration) | 2.8 | 2.5 |
| OLT (PtP up to 1 000 Mbit/s, from 100 and 300 ports, fully equipped with maximum configuration) | 2.4 | 2.4 |
| OLT (PtP up to 1 000 Mbit/s, with more than 300 ports, fully equipped with maximum configuration) | 1.7 | 1.7 |
| Additional per port allowance , implementing layer 3 functionalities of an edge router (at least IP/MPLS routing and interface and policy-based H-QoS), providing extendable capability to evolve adding new functionalities currently under discussion, and variable traffic-processing functions or market specific customization requirements | 0.3 | 0.3 |
| PtP 10 Gbit/s | | |
| OLT (PtP at 10 Gbit/s, up to 16 ports, fully equipped with maximum configuration) | 18 | 18 |
| OLT (PtP at 10 Gbit/s, from 16 to 48 ports, fully equipped with maximum configuration) | 13 | 13 |
| OLT (PtP at 10 Gbit/s, with more than 48 ports, fully equipped with maximum configuration) | 8 | 8 |
| PtP 25 Gbit/s | | |
| OLT (PtP at 25 Gbit/s, up to 16 ports, fully equipped with maximum configuration) | N/A | 28 |
| OLT (PtP at 25 Gbit/s, from 16 to 48 ports, fully equipped with maximum configuration) | N/A | 23 |
| OLT (PtP at 25 Gbit/s, with more than 48 ports, fully equipped with maximum configuration) | N/A | 20 |
| PtP 100 Gbit/s | | |
| OLT (PtP at 100 Gbit/s, up to eight ports, fully equipped with maximum configuration) | N/A | 150 |
| OLT (PtP at 100 Gbit/s, from eight to 16 ports, fully equipped with maximum configuration) | N/A | 130 |
| OLT (PtP at 10 Gbit/s, with more than 16 ports, fully equipped with maximum configuration) | N/A | 120 |

At the time of publication, no figures are available for higher line rates in PONs and PtP; 40 Gbit/s are to be included in the scope of a later edition of [BBCoC v8.0].

## 6.3 Requirements profile summary

As the surveys indicate, ONU power savings requirements can be associated with one of the two dominating underlying objectives. On one hand, the effort is driven by emergency service support under alternating current (AC) mains power failure and is targeted at the prolongation of the battery operation time. On the other hand, the requirements focus on conserving power in regular (mains-powered) operations and minimizing $CO_2$ emissions generated by information and communications technologies. The key difference between the two objectives and the two associated requirement profiles is the degree of compromise on the scope and quality of service that is considered acceptable. There are also varying approaches to the degree of freedom delegated to the end user in asserting their preferences with regard to transmission technology functions under controlled power outage.

The highest power savings will be obtained through action by the end user switching off their device, but that will result in loss of any connectivity and must be anticipated by the network provider through a reliable Dying Gasp report, to prevent any confusion with network outages that would result in an unnecessary truck roll.

NOTE – This is similar to the deep sleep mode (see clause 4.2) in that the OLT-ONU connectivity is temporarily lost without any ability for the operator to perform any action. It is the ONU internal timer that fixes the periodicity between two connectivity checks.

Individual operators may focus on only one or both of the two objectives given the telecommunications regulations for the specific jurisdiction and [BBCoC v8.0]. It has been observed that, in many cases, existing regulations tend to suit the conventional copper plant (which provides power from the central office (CO)) and are yet to address the specifics of fibre access.

In the wholesale open access model, the authority to establish service requirements, priorities and the degree of end user configurability may lie outside the network operator's decision-making domain, in which case the requirements may become subject to significant variability within the same access network.

In the 2000s, many operators considered FTTH as an overlay mainly for high-speed internet access keeping copper in place for lifeline services. Now more and more operators are moving to all-IP networks and removing copper. Thus always-available and very low-duty services are likely to become more important, for instance for the Internet of things (IoT), alarm generators and health services. Whether this function is provided by the fibre network alone or by a combination of fibre, mobile and high-altitude platform station will depend on the location.

Back-up battery dimensioning to prevent mains outage side effects and enhance the availability to the five "9" are likely to become more important in some jurisdictions. Battery backup may be implemented on ONUs directly or in other areas achieved with other power solutions or service backup via mobile networks.

Network-controlled ONU low-power modes should in most use cases provide significant power savings to the end user without their awareness, which could be a great claim for operators.

### 6.4 New use cases for the optical access technologies

Success of PON technologies in the access network begins to inspire promoters of connex worlds that envision new application domains for them. This could broaden, at minimum effort, the market and further extend energy savings thanks to the existing specified low-power mode mechanisms, at the cost of some additions and possibly simplifications. This requires the corresponding context to be effectively described and managed. This clause explores additions to the OLT and ONU for them to be applicable in such extensions.

Among the new application domains, domestic networks either in the home (FTTR) or LAN (POL) are being targeted as promising.

If nowadays the dominating initial use case appears to be domestic coverage with wireless fidelity (Wi-Fi), other applications including IoT are more and more often quoted as requiring focus.

Being deeper in the private domain or closer to the application terminal, adherence to the service served by each ONU will increase. So, it is likely that sensitivity to power conservation will increase. Also because of greater sensitivity to mains outages when it comes to security services and the necessity to get long lasting battery back-up, some specific details would be required.

Monitoring and survivability of the communication and energy network is likely to become essential, as energy is going to become an expensive and scarce resource in which outages are to be increasingly expected.

### 6.4.1 General considerations

Whereas in the access network versatility is required to accommodate any type of service and service bundles, preferably for a long time, to secure some return on investment for the network operator, under pressure of competition and control of a regulation authority, requirements for private networks use cases investigated both in POL and FTTR differ at least slightly.

There, the end user is the full and only master of investment strategy and determination of tolerance to the total cost of ownership, especially when it comes to power consumption and device renewal pace. Also adherence to the applications of optical terminations is likely to become much more closely optimized to each local use case.

If stringent applications require an extremely high level of availability (e.g., access control, intrusion detection, smoke detection, fall detection), it is likely that both path protection and powering source monitoring take another level of importance, compared to that given in the access segment.

NOTE – Figure 6-1 represents an example of separation of an access ONU and private domain OLT with independent OMCI stacks.

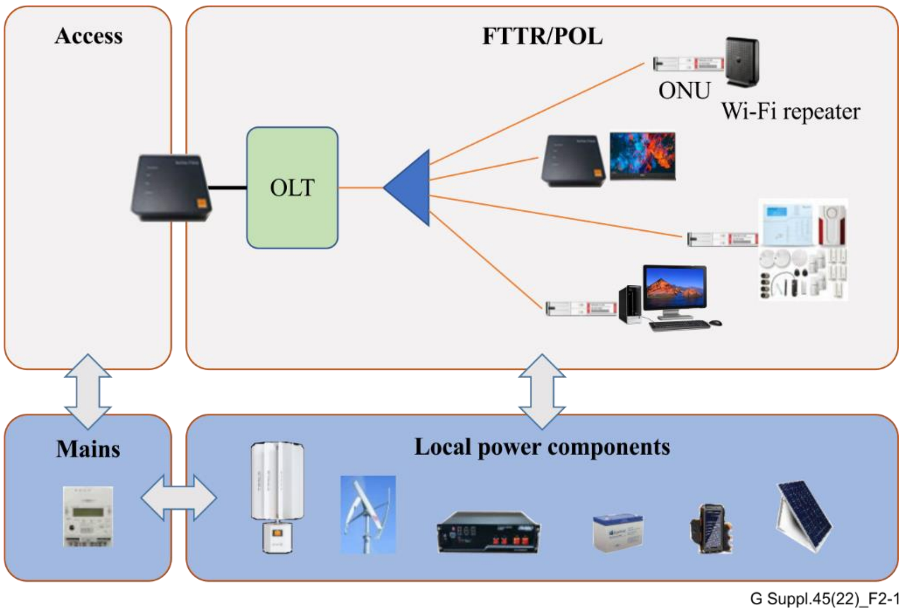


**Figure 6-1 – Interdependency: who is managing and monitoring whom? What about powering?**

Requirements are also likely to differ depending on the LAN or remote (telecommunication) connectivity requirements of the applications. Local access control and remote intrusion monitoring do not necessarily respond to the same constraints.

Thus the appropriate management domain of the access system OMCI, local OMCI and interaction with the power management capability are likely to require some coordination or knowledge and responsibility sharing, to determine the most carbon virtuous configuration and adjust the power source according to local conditions and possibly the high- or low-tariffs periods imposed by the mains provider.

Therefore also the notions of centralized powering (ONU plus appliance powered from the local OLT through hybrid cables and power over Ethernet (PoE)) or on the opposite reverse ONU powering by the terminal (ONU through its appliance terminal interface, e.g., PoE) are new domains to be investigated, to check whether additions would be required to the legacy mechanisms or need to be added as parameters for monitoring and control.

The basic mechanisms attached to the access network usage of the protocols are believed to remain valid power consumption reduction tools, but will probably need to be augmented towards greater energy cancellation and carbon neutral solutions.

A special case needs to be considered when this 'private' communication network is involved in coordinating the local energy sources by gathering the local information of mains, solar panels, wind energy and energy storage. It then becomes an essential element of a broader scale power smart grid, shutting down mains when alternative local sources are sufficient and back-up batteries are replenished and alternatively resuming powering through the mains when conditions require it.

### 6.4.2 Application considerations

Whereas optical access tends to consider aggregation of services and users with limited traffic-less periods, private networks are likely to offer greater opportunities with more frequent idle times.

On one hand, similarities might be expected when an ONU serves Wi-Fi access points (APs), but increasing IoT applications are likely to develop terminals of low duty and sporadic connectivity to a central or remote monitoring portal, offering major opportunities to save power under certain conditions. For IoT, the set and forget behaviour of the terminal over a lifetime is becoming mainstream.

There, time to wake up associated with sleep modes might not be so stringent, but any loss of information is prohibited. Collapsing the two expectations leads to consideration of an autonomous power source attached to the terminal, that powers up at minimal consumption the transmission link (ONU) on a need-to-transmit basis, as opposed to a network approach that periodically needs to make sure the link is up and running to secure the service level agreement (SLA).

Finding the right trade-off between certainty of connectivity quality and minimal power consumption is likely to require the network to be versatile, with various application-related power behaviour profiles.

### 6.4.3 FTTR or POL local OLT central powering of ONUs

To simplify energy generation for distribution and stability in a building or /campus to the diverse locations of ONUs, it might be optimal to centralize it.

In such a case, when new cables are to be deployed, it might make sense to deploy fibre-copper pair hybrids to provide mains supply to the ONUs and optionally to the appliances to which they are connected. PoE seems nowadays to be the obvious interface to forward the amount of energy, if remaining within its capacity for devices such as cameras, sensors or Wi-Fi APs), Nevertheless this will hardly be the case for higher consumption devices such as computers, television (TV) sets or similar.

Also for diverse reasons, even if the ONU is able to provide the necessary power, the terminal can have its own power source and back up battery. This can happen because of its mobility basic feature (e.g., tablet or laptop personal computer (PC)) or because of the security aspects of the device (intrusion detection, smoke detector) that need both to generate a local alarm (siren) and send out remote information to a central security monitoring desk.

The benefit from such a centralized powering scheme is that centralized power management will enable some savings with more efficient converters, a single power manager and centralized back up batteries with easy access, thus avoiding the need to check remote batteries of each and every device that would require more complex monitoring and replacements all over a site. This provides a tight coupling of signal and powering availability in case of outages.

The counterpart of such a scheme is that limitations occur due to: structuring through the copper cable remote feeding capacity; some vulnerability to electro-magnetic compatibility: and in turn the PoE capacity of the ONUs.

### 6.4.4 FTTR or POL reverse powering of ONUs by the appliance

In contrast, given the power consumption level reached by ONUs designed for the access that can be implemented in small form-factor pluggable (SFP) sticks consuming less than 1.5 W (lower than the [BBCoC v8.0] allowance for GPON), many terminals could have the capability to provide the necessary capacity through PoE or have the capability of an SFP host cage.

This would perfectly match the case in which it is the device's initiative to light up the access node interface (ANI) to report an event and keep quiet in-between events. Although minimizing the power consumption, this Deep Sleep mode is friendly neither to the telecommunication company nor supervisor, since it prevents assessment of the link status.

With such deep sleep behaviour, it can no longer be the responsibility of the OLT to ensure the necessary energy is available to make it to the next unpredictable wake up period.

The compromise is then about determination of an agreed continuity check cycle duration, during which knowledge of the status of all monitoring parameters would be updated.

The obvious conclusion is that not one powering scheme will cover all use cases and that some redundant or collaborative powering scheme is likely to be necessary. Even if not adopted, it should be made possible through the data exchange specification and monitoring capability of power sources from both the communication and possibly the powering side.

### 6.4.5 Power cancellation or carbon neutrality considerations

The latest prospective studies of energy production and consumption have shown that to secure the network, significant reconfigurations are needed not to prevent but minimize shortages. To smooth the peak hours, energy tariffs are published and modified according to diverse predictions including the weather forecast. These allow companies and consumers to delay some non-real-time applications to minimize their bill. However, this is also a strong incentive to start producing its own energy, thus partially cancelling presence on the energy grid.

Most industries have now announced programmes to reduce their carbon footprint and reach neutrality, which also means an increasing number of solar panels on buildings and energy windmills with associated storage batteries.

The telecommunication industry is no exception and can help by intelligent power management of its devices. This means monitoring the power status of the constitutive elements and activating charging outside energy busy hours or when alternative renewable power sources are available.

Whether the decision belongs to the energy producer, the telecommunication company or the end user will need to be debated; nevertheless, the certainty is that the nature and status of the power sources of network elements will need to be investigated more in-depth.

### 6.4.6 Tentative list of parameters to cover

Given the previous considerations, for full FTTR or POL coverage, the following domains need to be monitored to cover the landscape. Thus, a common database will be made available for decisions to be made, whoever will be in charge. Seen from the communication point of view, this results in specifying:

- powering features managed by the local OLT (data collected through OMCI);
- exchanges necessary with an external powering facility manager;

- exchanges necessary with the self-standing appliance devices and application manager(s). that might result in an extension of the common T-interface (like that specified for low latency with the open radio access network group.

Obviously more in-depth investigations will be necessary once a thorough knowledge of confirmed use cases of interest have been agreed.

# 7 Classification of power-saving techniques

## 7.1 Taxonomy

In the course of the study within ITU-T, several power-saving techniques have been proposed and discussed. While it is important to be able to view them in a systematic way, there is more than one way to classify those techniques. One classification criterion that has been applied initially to solicit the power-saving proposals is the depth of the GTC layer impact. In the course of the discussion, it became appearent that a more meaningful criterion is the behaviour of the ONU receiver (Rx) and transmitter (Tx) while the ONU is in a power save mode.

From the point of view of ONU Rx and Tx behaviour, the proposals under discussion fall into the following four protocol-controlled power-saving categories specified in Annex E of [ITU-T G.984.3] for GPON that have been developed and carried on in the later PON generations:

**ONU power shedding** is characterized by powering off or reducing power to non-essential functions and services while maintaining a fully operational optical link. The power-shedding configuration managed entity (ME) in OMCI is specified as ME 9.1.7 in [ITU-T G.988] under the name "ONU power shedding".

**ONU Doze (Dozing)** is associated with additional powering off of the ONU Tx for substantial periods of time on the condition that the Rx remains continuously on. Note the ITU-T recommendations adopted "Doze" mode instead of "Dozing".

**ONU Cyclic Sleep** means that both ONU Tx and ONU Rx are turned off for preset periods of time with periodic wake up time to check the link status.

**ONU Watchful Sleep mode** collapsing Dozing and Cyclic Sleep in a single state machine has been specified and adopted as replacement since the introduction of XG-PON.

Finally, **ONU Deep Sleep,** whereby the Tx and Rx remain off for the entire duration of the power save state period where the connectivity between OLT and ONU is lost as in the case of deactivating the ONU using the on/off switch.

In addition to GPON-initiated low-power modes, other power-saving modes have been made possible through the specification of multiple line rate options that might with some dynamicity adjust to the actual payload observed.

As an example, an XGS-PON ONU might fall back to the XG-PON upstream line rate and for PtP bi-directional hitless line rate changes between those specified in [ITU-T G.9806] can be envisioned on a per interface basis. Recall that unlike in time division multiplexing PONs, PtP links and wavelength router-based WDM PON channels, power savings will be observed on both sides of the link.

See Figure 7-1.

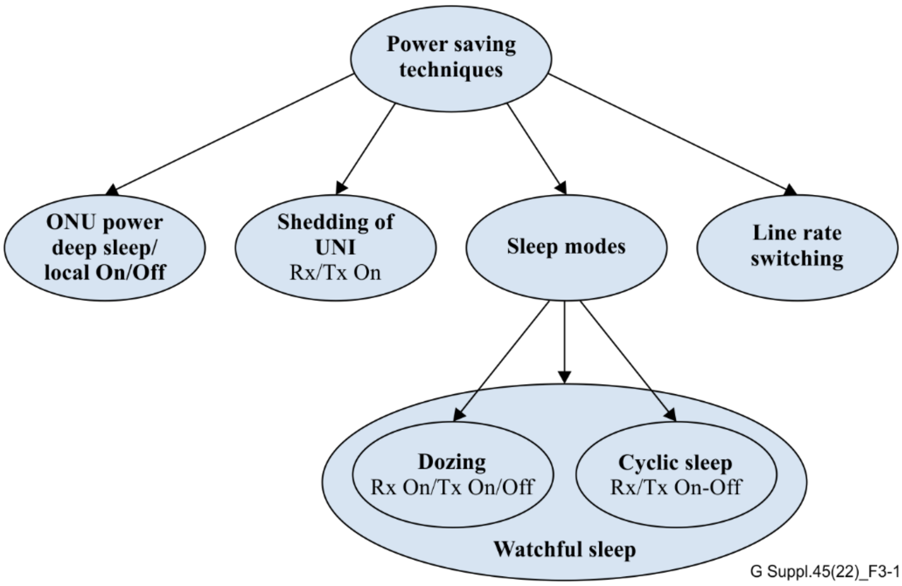


**Figure 7-1 – Taxonomy of power-saving techniques**

The specific power management capabilities are subject to operator system requirements, and for each ONU are negotiated over OMCI upon ONU activation and effectively implemented through specific Sleep_Allow and Sleep_Request PLOAM messages.

For the OMCI ME describing power-saving techniques capabilities, the ONU dynamic power management control, see clause 9.1.14 of [ITU-T G.988].

In the case of dual managed ONUs, power shedding and other low-power features can be handled directly through an alternative management channel such as that in [BBF TR-069] or [b-ITU-T G.9980], although that requires then some disambiguation of responsibilities.

## 7.2 Unified approach to ONU power-saving signalling

Most of the proposals presented to the group in the course of the study described the elements of the power save mode maintenance mechanism (OLT support of a particular power save mode) coupled with the elements of the power save mode signalling mechanism (establishing transitions to and from a particular power save mode). Any given signalling mechanism can form a feasible combination with any maintenance mechanism (with the exception of power shedding, which may not require signalling), and the selection of an optimal power save approach or approaches can be partitioned into selection of the signalling mechanism and the selection of the maintenance mechanism.

The following power save enabling mechanisms have been specified:

- PLOAM-based handshake utilizing new message type(s);
- ONU-G ME associated alarms augmented to include extra diagnostic and status information;
- a Dying Gasp message with redefined semantics prompting OLT to perform extra diagnostic actions could also have been an option, but has not been retained as of today;
- OMCI-based power-saving configuration with implicit state inference based on the prior negotiated capabilities.

Clauses 7.3 and 7.4 are devoted to consideration of the power save maintenance and power save signalling mechanisms, respectively.

### 7.3 Power saving in the context of dual managed ONU

While some operators rely for operation only on an ONU management and control channel (OMCC) or OMCI, others use a combination of managers in a so called dual managed or by extension a multi-managed scheme.

While the ANI aspects remain under an OMCC or OMCI, the UNI aspects and service mapping are configured and operated through an alternative manager with flows transparently crossing the OLT. An example of such a flow is described in [BBF TR-069], an extension introduced for digital subscriber line technologies.

The main benefit of such a scheme is for the service provider to have an access technology agnostic experience, hence this is appropriate for wholesale contexts especially when multiple service operators have to co-exist in an ONU.

See Figure 7-2.

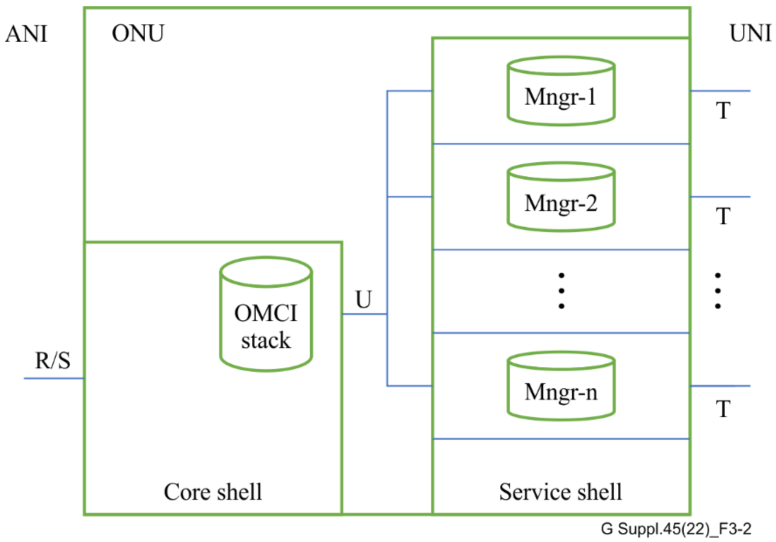


**Figure 7-2 – Generic multi-managed ONU architecture**

#### 7.3.1 Multi managed ONU context assumptions

In order to secure PON availability and security, with its level of QoS to ensure a stable SLA capability, the ANI is under control of a single operator, be it redundant or not.

Service operators with a partial view of a PON are not entitled to have direct control, but have to proceed through the access network operator for any action that might affect it.

All service operators have equal access to the ONU resources and do not need to be aware of the presence of one another in the ONU operation, as this is already the case on PON across the ONUs.

All operations on the service shell need to be validated by the access network operator whenever common resources are involved, to check that there is no override of ONU capability.

To secure continuity of PON operation, when updating the software of a service shell in an ONU, any reboot is limited to that service shell without touching any others.

When a core shell reboot cannot be avoided, the operation is performed by the access network operator who will inform other service operators of the event so they do not to mistake the reboot for an outage.

### 7.3.2 Multi managed ONU information exchange conditions

In order to maintain equity across the service operators in a multi managed ONU, it seems best for a service shell to have a single management interface with the core shell that has knowledge of all service shells in operation.

Thus the core shell will be in charge of coordinating all operations that might impact several service shells. It will then be the duty of the core shell to inform the OLT through the OMCI and each service shell of the necessary information to proceed so that all parties can cooperate without causing unpredicted disruptions.

Conversely, the access network manager, having no direct connection to the service manager, has to establish through exchanges with the service shell manager, to learn about the tolerance to low-power modes, so that coordinated actions can be undertaken.

Specifically information must be exchanged in time for each party, network and service manager to have time to prepare for whatever event. Speaking low-power periods, this involves time to wake up, time to sleep and time to switch between two operating modes.

### 7.3.3 Multi managed ONU information to be exchanged

As already mentioned, to enable low-power modes and periods, the following elements require coordination and the related exchanges are listed as follows.

- Dying gasp or reboot announcement.
- Eligibility to sleep periods with related parameters:
  - time to wake up;
  - time to sleep;
  - maximum sleep duration;
  - announcement method.
- Eligibility to lower duty periods;
  - time to switch;
  - minimum payload at lowest throughput;
  - announcement method.

NOTE – Further development of this clause is under study.

## 7.4 OLT side power savings

### 7.4.1 General considerations

Interest in OLT side power savings is closely related to the number of watts that can be saved by using the latest technologies available, since this directly impacts the operator's energy bill.

Nevertheless even the more efficient basic designs can benefit from further savings through addition of some power as the operator grows (provisions) behaviour, in which case the interesting metric might become a second level, expressed in percentage of savings expected compared to regular full capacity operation, depending on the actual and local operator use cases.

So it is not only a matter of using the latest generation of chipsets in a static mode, but also the possible benefit of improving powering granularity of OLT constitutive elements that can be turned off when not in use, in addition to dynamic adjustment to the number of ONU provisioned and actual payload.

Obviously these additional power-saving gains will be greatly dependent on optical access applications and observed traffic profiles likely to be location specific and evolve in time, as coverage extends.

Taken very early in the chipsets and OLT global design, beyond the latest BBCoC power consumption allowance tolerated, significant margin is still left to improve opportunistic power savings. Implementations still have to fulfil some operational conditions in order to be practical for operators.

It is also essential to maximize common capabilities across OLT vendors to simplify operating experience, by making common features available across designs and avoiding as much as possible vendor specific engineering rules.

### 7.4.2 OLT side power savings main power-saving methods

In the OLT portfolio, finding the energy efficiency optimum depends both on the vendor's design and on the operator's environmental conditions and local use case.

The optimum needs to be determined by each operator, based on exposition of OLT performance by vendors, including: size and layout, modularity of its elements, cooling requirements and also deepness of low-power modes and time to enter or leave them.

As an example, since fan power consumption is significant, guidelines could be given to optimize progressive physical provisioning of boards in the OLT. This might help determine whether OLT boards should be spaced, to limit the necessary forced air flow, or grouped, to delay the powering on of additional fans.

Whether PON or PtP transmission is considered, specific mechanisms might be used to implement traffic-related low-power modes; nevertheless, convergence of high-level principles of methods should apply.

When OLTs are in operation, two obvious main periods for power saving are to be investigated: before actual provisioning; and once in service. In turn, two mechanisms can enable further in-operation savings as follows.

- Switching off all OLT elements that are not effective if only partially provisioned.
- Taking advantage of idle periods through temporary sleep periods towards the zero traffic-zero watt asymptote. Note that this might result in temporary loss of connectivity with side effects that might not be tolerable, e.g., clock maintenance for sensitive voltage-controlled crystal oscillators.
- Adjusting the resources to the actual payload to be conveyed, with a power consumption proportional to the actual payload.

### 7.4.3 Operation constrains for global and OLT side power savings

Even the fanciest power-saving design ideas might not be considered if they do not take all phases of operation into account. These include auto-test on initial powering, inventory discovery, logical provisioning of the resources, upgrades, regular operation and decommissioning.

So, before any ONU can be provisioned and possibly low-power methods applied, the following principles should be followed:

- initial discovery of OLT component, and exposure of power-saving features to the operator;
- co-engineering with end users to determine their eagerness, willingness and tolerance to low-power mode, and capture in some power-saving profile;
- appropriate powering of functions or devices of the OLT should occur when conditions are met to be efficient over the full OLT responsibility domain (segment from the server to network interface (SNI) to UNI);
- according to the established power-saving profile, setting of OLT parameters to optimize low duty or idle periods of channel termination (CT) ports and ONUs without any loss of information;

- according to the established power-saving profile, setting of OLT parameters to enforce proportionality to number of activated ports, ONUs and traffic load, with respect to the QoS required by the services conveyed.

These principles can be translated into more detailed conditions for activation and usage in or through the OLT, its subsystems and interfaces (SNI, ANI also known as OLT CT) as follows.

- OLT parameters determining the energy efficiency are made accessible to the access operator:
  - o to accommodate the full operating process;
  - o to meet their architecture and service requirements;
  - o possibly through templates for each of the OLT constitutive elements.
- After the OLT power-up phase during which an initial inventory discovery and auto-test is performed, the OLT is expected to fall back into sleep, waiting for the next wake-up period for audit, upgrade or provisioning operations. Thus, its power consumption can be minimized. Ideally, initially only management and synchronizing interfaces need to be alive, in minimal consumption mode.
- OLTs and their constitutive subsystems only enter full powering mode when all service-provisioning conditions are met from SNI to UNI (e.g., logical provisioning of traffic flows or based on operator demand for back office applications).
- Low-power functions are optional to use per OLT CT and per ONU, especially if they prove to affect service or ONU availability, e.g., if they are not able to comply with required timings or cycles.
- Low-power functions do not induce any security threat, i.e., give undetected access to a malevolent user during a power standby state, to a running system harming feature.
- Low-power functions do not induce any breach in interoperability to certified ONUs claiming compliance to low-power mode specifying recommendations.
- Since several actors can be affected when power-saving capabilities are implemented, they are all informed of an OLT entering a low-power state, in order not to misinterpret it as an alarm.
- OLT CT supports simultaneous power savings configurations to cover cases where several architectures featuring different ONU types, several user types, several service sets are offered over the interfaces (e.g., various PON generation, PtP links).
- OLT CTs offer for each ONU Watchful Sleep mode to exploit idle periods.
- Watchful sleep parameters are configurable (per chassis, card, port, ONU) to meet service provider and end user requirements.
- OLT CTs meant for multi-channel operation with colourless ONU (e.g., NG-PON2) enable the fall-back on a reduced number of channels to enable the switching off of the reminder in low-duty periods.
- OLT CT implements the fall back on the lowest consumption transmission mode (e.g., using line rate switching (LRS)) to optimize the power consumption in reduced traffic periods for optical technologies and in presence of ONUs implementing it.

### 7.4.4 OLT power reductions by varying the split ratio

During periods of low PON activity and data use, the number of active ONUs connected to the OLT on any given optical distribution network (ODN) can be small in number. For example, an ODN may connect 32 ONUs but only one or two may be active with data at any given time during an overnight period. Given that this traffic situation is likely for multiple ODNs during the same period, it would be advantageous to reduce power consumption at the OLT by optically routing the active ONUs to a single OLT port and powering down unused OLT ports. The idea is to use an optical switch close to the OLT to connect different ODNs together, so that the PON split ratio is dynamically adjusted to connect active ONUs to a single OLT port.

Figure 7-3 shows an example of two ODNs connected via an optical switch. In this example, ONU(A) and ONU(B) are normally connected to separate ODNs and separate OLT ports (A and B). The ODNs have optical 1 × 2 splitters inserted in line, so that ODN(B) can be re-routed to ODN(A) via the optical switch and to connect a photodiode (PD) to ODN(A). In order to save power during low traffic activity on ODN(A) and ODN(B), the PD on ODN(A) monitors when OLT(A) is turned off and then controls the switch to combine ONU(A) and ONU(B) on to a common ODN with a modified split ratio. The data traffic for ONU(A) is switched to OLT(B) while the OLT(A) port is powered down to save electrical power. The system can be restored by opening the optical switch and re-routing the data traffic to OLT(A) as required.

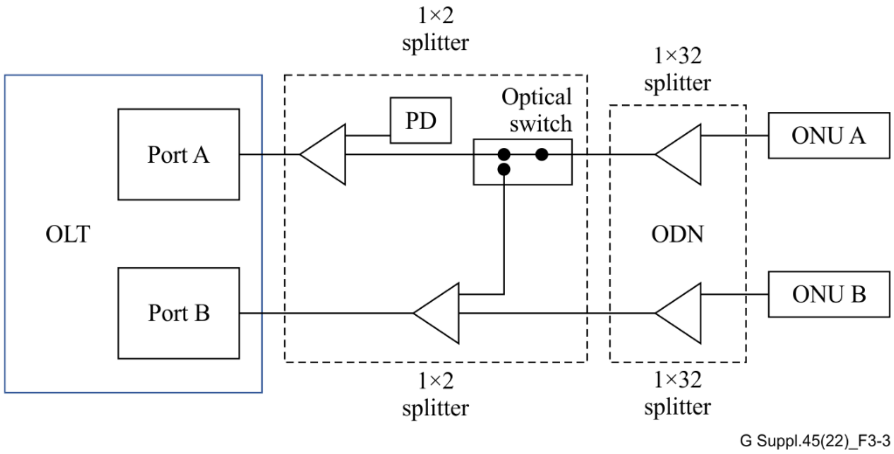


**Figure 7-3 – Example of split ratio implementation**

In this example, the OLT(B) can contain higher class (higher optical power) optics to account for the excess optical loss in the combined ODN and maintain system margin for the optical signals.

Any implications for the PON PMDs and protocols are for further study.

## 7.5 ONU side power savings

### 7.5.1 General considerations

Although ONU power consumption may only account for a small part of household power consumption, ONU power saving is non-negligible when large numbers of ONUs are deployed with the popularization of various FTTx technologies.

With the continuous development of PON technology and the increasing demand of new services from users, ONU functions are becoming more complicated and powerful. For example, smart home gateway devices usually require multi-core processing, to support: Wi-Fi 5, Wi-Fi 6 or Wi-Fi 7 in the near future; a 1 Gbit/s, 2.5 Gbit/s or 10 Gbit/s Ethernet port; a downlink optical port; a universal serial bus (USB); etc.

In the context of global carbon neutrality, operators continue to pay more attention to ONU power consumption, as well as the consumption test requirements for different scenarios. For example, efficient reduction in power consumption is required no matter whether an ONU operates at full load or without load. In addition, both the needs of operators and the user experience should be considered; reduction in ONU power consumption should strive to avoid any perception by the user.

### 7.5.2 Main power-saving methods

Depending on operator needs and the user use case, an optimal energy saving method in the ONU portfolio will be found. For each operator, there may be different requirements for the various devices for the various use cases, such as broadband access devices, home gateway devices, devices that support a 1 Gbit/s, 2.5 Gbit/s or 10 Gbit/s Ethernet port or Wi-Fi 5, Wi-Fi 6 or Wi-Fi 7. Besides, ONUs can be implemented with modular design and heat dissipation design according to special product requirements.

ONU power consumption is usually dispatched in various dedicated chips, such as PON chips, physical (PHY) chips, and Wi-Fi chips. In addition to the actions specified in the specific Recommendation, chip power reduction should be also considered. For example, when user data traffic is small or the sleep time is up, the following measures can be implemented in order to reduce power consumption, and if the user data traffic increases or the sleep time expires, measures such as reducing power consumption are turned off, so that the purpose of saving energy and reducing consumption can be achieved, for example, by:

- chip automatic or reduction in fixed frequency;
- turning off power or clocking of chip unused modules;
- turning off central processing unit (CPU) idle cores;
- reduction through negotiation of the rate of the LAN port, e.g., from 10 Gbit/s to 100 Mbit/s:
- reduction in the number of working antennas, such as 4*4 to 1*1.

## 8 Power-saving maintenance mechanisms

The protocol-enabled power-saving mechanisms retained in the suite of ITU-T PON standards, and beyond, are based on the following basic principles.

- The OLT uses OMCI to discover the power management capabilities of an ONU and to configure its power management attributes and modes.
- To control the power management behaviour of a given ONU, the ONU and the OLT maintain a pair of power management state machines.
- The ONU state machine and the corresponding OLT state machine operate in partial state alignment.
- The primary signalling mechanism used to coordinate the ONU and OLT state machines is based on PLOAM messages. The two PLOAM Sleep_Allow and Sleep_Request PLOAM messages are described in clause 5.2.
- The output PLOAM messages are generated and queued for transmission at the time of state transitions.
- The states of both ONU and OLT state machines can be classified into two mutually exclusive subsets: the full power states; and the low-power states.
- Only state transitions between the full power and low-power state subsets generate an output PLOAM message.
- If the sojourn in the target state of a transition is controlled by a timer, it is not started until the actual transmission of the message.
- As a secondary signalling mechanism used to speed up or wake up a sleeping ONU, the forced wakeup indication bit is carried within a bandwidth map allocation structure.

### 8.1 Cyclic Sleep (ex-Fast Sleep) power-saving technique

#### 8.1.1 Editorial summary

This clause presents key aspects developed within ITU-T. The proposal introduces the Cyclic Sleep mode behaviour. The proposal advocates synchronized sleep and active periods that can be achieved with a specified set of PLOAM messages that enable individual ONUs to enter such a low-power mode.

#### 8.1.2 Cyclic Sleep mode maintenance

An ONU in the Cyclic Sleep mode alternates between sleep periods, when the optical transceiver is completely powered off along with all non-essential functions and only the timing and activity detection functions remain active, and active periods when the optical transceiver as well as the necessary supporting functions are powered on. An active period and the subsequent sleep period constitute a sleep cycle.

The transitions from active periods to sleep periods and from sleep periods to active periods (wake-ups) are synchronized by all the ONUs in the Cyclic Sleep mode and are controlled by the OLT by means of a sleep PLOAM message. The sleep message is a unicast or broadcast PLOAM message that is transmitted by the OLT at its discretion as soon as active period processing is completed.

Upon receipt of a sleep PLOAM, an ONU in the Cyclic Sleep mode starts the sleep period. While in a sleep period, the ONU maintains a free-running clock that generates a wake-up signal powering up the Rx in advance of the scheduled wake-up frame. The Rx wake-up lead time should be sufficient for the ONU to complete the physical synchronization (PSync) and superframe acquisition before the scheduled wake-up frame with reasonably high probability. The cyclic ONU sleep mode maintenance states and state transitions are shown in Figure 8-1.

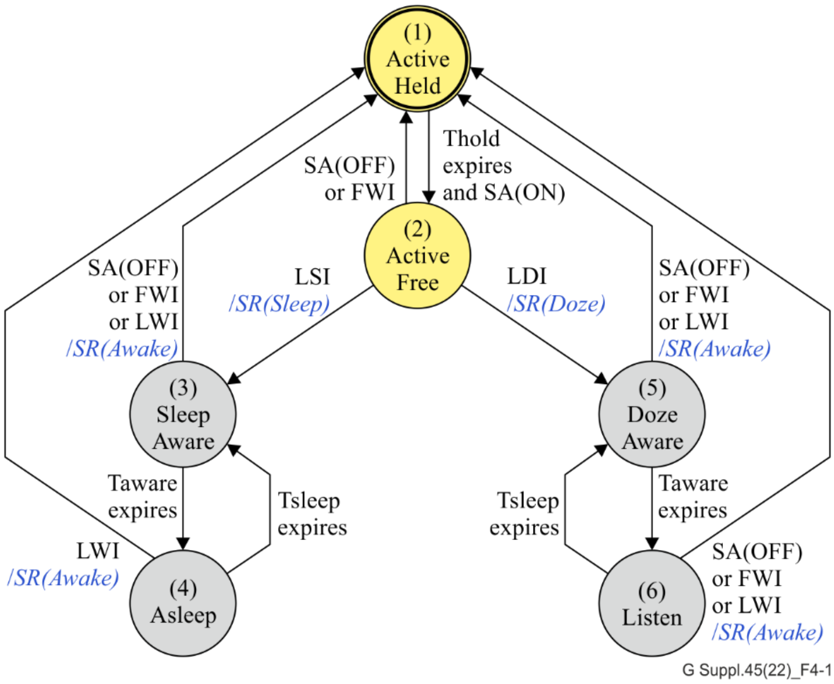


**Figure 8-1 – ONU Sleep mode state transitions (as in [ITU-T G.987.3])**

The power management parameters for each ONU are discovered at ONU discovery through OMCI messaging reproduced in clause 8.6.3. After processing, they will result into the following generic parameters that support to cover Doze, Cyclic Sleep and Watchful Sleep power-saving modes (see Table 8-1 (source: Table 16-1 of [ITU-T G.987.3]).

**Table 8-1 – Power management parameters**

| Parameter | Description | Defined by | Known to |
|---|---|---|---|
| Ilowpower | The maximum time the ONU spends in a LowPower state (i.e., Asleep, Listen or Watch state), as a count of 125 μs frames. Local wake-up indications (LWIs) or remote events, if detected, may truncate the sojourn of an ONU in these states. | OLT | ONU, OLT |
| Tlowpower | Local timer at ONU. Upon entry to a LowPower state (i.e., Asleep, Listen or Watch state), the ONU initializes Tlowpower to a value equal to or less than Ilowpower. Secondary internal timers may be required to guarantee that the ONU will be fully operational when it enters an Aware state after an interval not to exceed Ilowpower. | ONU | ONU |
| Iaware | The minimum time the ONU spends in an Aware state (i.e., SleepAware, DozeAware or WatchAware) before transitioning to a LowPower state, as a count of 125 μs frames. During the Iaware interval, local or remote events may independently cause the ONU to enter the ActiveHeld state rather than returning to a LowPower state. | OLT | ONU, OLT |
| Taware | Local timer at ONU, initialized to a value equal to or greater than Iaware once downstream synchronization is obtained upon entry to an Aware state (i.e., SleepAware, DozeAware or WatchAware). Taware controls the dwell time in an Aware state before the ONU re-enters the corresponding LowPower state. | ONU | ONU |
| Itransinit | The worst-case transceiver initialization time: the time required for the ONU to gain full functionality when leaving a LowPower state, measured in units of 125 μs PHY frames, and known by design. A value of 0 indicates that the ONU in a low-power mode can respond to a bandwidth grant without delay. | ONU | ONU, OLT |
| Itxinit | Transmitter initialization time: the time required for the ONU to gain full functionality when turning on the Tx while the Rx has remained on, measured in units of 125 μs PHY frames. A value of 0 indicates that the ONU in a low-power mode can respond to a bandwidth grant without delay. | ONU | ONU, OLT |
| Irxoff | The maximum time the OLT can afford to wait from the moment it decides to wake up an ONU in one of the low-power modes until the ONU is fully operational, specified as a count of 125 μs PHY frames. The ONU timer Trxoff and the OLT timer Talerted are initialized based on Irxoff. | OLT | ONU, OLT |
| Trxoff | Local timer at ONU. The ONU uses this timer in the Watch state of the Watchful sleep mode while checking the downstream signal for the remote wakeup indications to ensure that the time between two consecutive checks does not exceed the provisioned Irxoff interval. | ONU | ONU |

**Table 8-1 – Power management parameters**

| Parameter | Description | Defined by | Known to |
|---|---|---|---|
| Talerted | Local timer to limit the time that the OLT state machine remains in an alerted state before entering the AwakeForced state.<br>Talerted should be initialized to at least Irxoff + Itransinit + round-trip delay + tolerances for Rx synchronization, bandwidth grant irregularities, and processing time. | OLT | OLT |
| $Ter_i$ | Local handshake timer at the OLT that determines the latest instant at which an upstream burst is expected from ONU *i* when it is in one of the low-power modes. The OLT reinitializes and starts this timer when its state machine for the given ONU transitions into the LowPowerSleep, or LowPowerDoze or Watch state and each time an upstream burst is received from the ONU while in that state. If $Ter_i$ expires, the OLT declares a handshake violation and attempts to force the ONU awake.<br>To determine the initial value of $Ter_i$, the OLT is responsible for consideration of the provisioned Ilowpower interval and any possible effects of transceiver initialization, synchronization, and irregularities in the bandwidth grant cycle. | OLT | OLT |
| Ihold | Minimum sojourn in the ActiveHeld state. | OLT | ONU, OLT |
| Thold | Local timer at the ONU that is initialized to Ihold upon transmission of SR(Awake) after entry into ActiveHeld state and that enforces the minimum sojourn in the ActiveHeld state. | ONU | ONU |

The OLT buffers the incoming downstream traffic destined to the ONUs in the sleep period, delivering it upon ONU wake-up. This ensures the preservation of downstream services for the power-saving ONUs. The structure of the OLT buffers and the associated scheduling discipline are left to implementers.

For a full description of the mechanism details, see clause 16 of [ITU-T G.987.3].

To provide for speedy recovery in case of possible state mismatch between the OLT and ONU, and to ensure that the ONU may promptly signal termination of the fast sleep mode whenever necessary, the OLT should provide regular PLOAM allocations to the subtending ONUs regardless of whether they are awake or asleep.

### 8.1.3 Specification impact

To provide support to the Cyclic Sleep power save technique, the transmission convergence (TC) layer in [ITU-T G.984.3] [ITU-T G.987.3] [ITU-T G.989.3] [ITU-T G.9804.2] [ITU-T G.9806] [ITU-T G.9807.1] should be extended to include the following:

- Sleep_Allow and Sleep_Request PLOAM messages;
- the Cyclic Sleep mode power-save state machines at OLT and ONU and the associated descriptions;
- an accelerated transition path of the Activation state machine for PSync and Superframe acquisition on transition from the ReSync power save state to the Awake power save state;
- the implementation recommendations for the OLT use of the Sleep message and PLOAM allocations for the ONUs in Cyclic Sleep mode.

### 8.1.4 Implementation of Cyclic Sleep in ITU-T Recommendations

Cyclic Sleep has been specified since GPON and can be found from 2014 onwards in Annex E of [ITU-T G.984.3]. It has been part of XG-PON since 2010 in clause 16 of [ITU-T G.987.3].

Note that Doze and Cyclic Sleep mode are tied together, and an implementation must include at least both of them to be compliant with the appropriate Recommendations.

Since NG-PON2 ([ITU-T G.989.3]) and 10 Gbit-capable (symmetric) passive optical network (XG(S)-PON) ([ITU-T G.9807.1]), Watchful Sleep has become the standard collapsing both Doze and Cyclic Sleep into one mode. Doze and Cyclic Sleep were maintained whenever a backward compatibility with older ONU generations was necessary.

## 8.2 Deep sleep power-saving technique

### 8.2.1 Editorial summary

The deep sleep technique achieves the maximum possible power saving by powering off all ONU functions and services except, perhaps, activity detection, at the expense of the loss of incoming downstream traffic and signalling. The ONU may wake up to a local stimulus only when the ONU is switched on, in the off-hook condition or at the expiration of a locally maintained timer.

The transition into the Deep Sleep mode should be signalled to the OLT in order to avoid unnecessary alarms and operations support. The original proposal specified a modified Dying Gasp signalling method, other signalling techniques, such as OMCI handshake, can be applicable as well.

The Deep Sleep mode makes sense, for example, when the end user switches the ONU off, or when, from the service provider perspective, the loss of the incoming services can be tolerated. The behaviour is similar to a "virtual blue button", as the downstream channel is effectively shut down and the ONU wakes up on a local stimulus only; however, the service restoration time is expected to be much faster than the normal activation process.

### 8.2.2 Deep Sleep mode maintenance

The ONU in a Deep Sleep mode powers off its optical transceiver completely along with most other functions and services. The timing and activity detection functions may optionally remain active. The OLT should suppress the PON alarm for the given ONU, but retain GTC and management information base configuration. It may continue sending the downstream traffic (or, optionally, discard it) and provide upstream allocations, but it should consider the absence of the upstream traffic as normal. To support timely recovery of the ONU waking up on a local stimulus, the OLT shall allocate regular targeted (i.e., narrow) ranging windows to the sleeping ONUs.

### 8.2.3 Specification impact

To provide support to the Deep Sleep power save technique, the TC layer standard should be extended to include the following:

- an accelerated transition path of the Activation state machine for PSync and superframe acquisition and re-ranging on locally initiated wake-up;
- a targeted (reduced size) Quiet window allocation mechanism;
- the implementation of recommendations on the application and frequency of the targeted Quiet window for the ONUs in Deep Sleep mode.

### 8.2.4 Implementation of Deep Sleep in ITU-T Recommendations

As interrupting the link, this was not a preferred option for operators and as such has not been further developed so far.

Nevertheless low-power modes managed directly through a management channel transparent to the OLT as for example specifed in [b-ITU-T G.9980] can be considered as belonging to the Deep Sleep category.

As such it is mandatory that those involving the ANI include the sending of a Dying Gasp message prior to interface shut down.

## 8.3 Dozing/Doze power-saving technique

### 8.3.1 Editorial summary

The Doze mode has been specified as complementary to the Cyclic Sleep mode of clause 8.1. A Dozing ONU keeps the downstream channel open and operational but ignores upstream allocations as long as it has no traffic to send, while avoiding loss of signal for ONU *i* ($LOS_i$) declaration by the OLT. The Dozing ONU may instantaneously wake up on an OLT request, as well as on a local stimulus. Its major benefit over Cyclic Sleep is that it maintains all ONU clocks.

### 8.3.2 Dozing/Doze mode proposal

See clause 8.1.2, since the mechanisms are the same and Figure 8-2 collapses both Doze and Cyclic Sleep.

### 8.3.3 Specification impact

To provide support to the Doze power save technique, the TC layer standard has been extended from the version of GPON without power saving to include the following:

- the implementation of recommendations on $LOS_i$ suppression;
- the implementation of recommendations on the regularity of bandwidth allocation and periodicity of the allocations that require response to perform drift adjustment, thus preventing the need of re-ranging upon termination of the Dozing mode.

### 8.3.4 Implementation of Dozing/Doze mode in ITU-T Recommendations

Doze mode sleep has been specified since GPON and can be found from 2014 onwards in Annex E of [ITU-T G.984.3]. It has been part of XG-PON since 2010 in clause 16 of [ITU-T G.987.3].

Note that Doze and Cyclic Sleep mode are tied together and an implementation must include at least both of them to be compliant with the appropriate Recommendations.

Since NG-PON2 ([ITU-T G.989.3]) and XG(S)-PON ([ITU-T G.9807.1]), Watchful Sleep has become the standard collapsing both Doze and Cyclic Sleep into one mode. Doze and Cyclic Sleep were maintained whenever a backward compatibility with older ONU generations was necessary.

## 8.4 Watchful sleep saving technique

### 8.4.1 Editorial summary

In the course of implementing Doze and Cyclic Sleep mode, implementers found out that only one set of state machines was needed and that all functionalities could fit in a simplified state machine, with capture of the intended mode in the PLOAM message parameters. This is described in NG-PON2 [ITU-T G.989.3], which was the first Recommendation that did not need compatibility to a legacy ONU.

### 8.4.2 Watchful Sleep mode proposal

For the full description of parameters used, see clause 8.1.2.

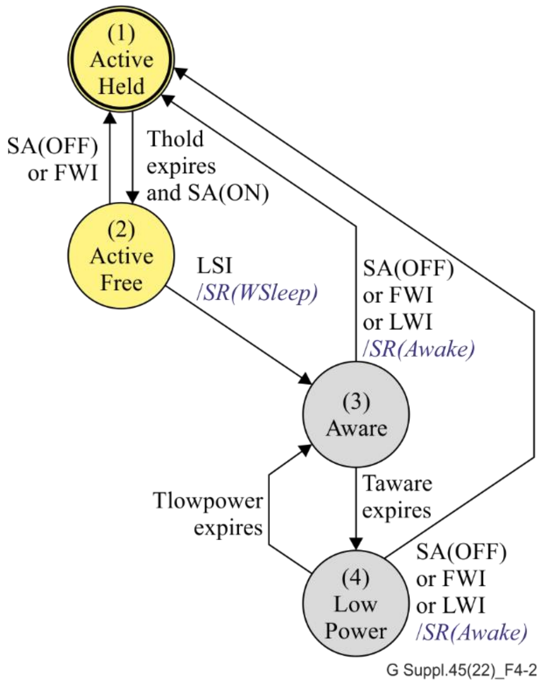


**Figure 8-2 – ONU state transition diagram (initial state circled)**

### 8.4.3 Specification impact

The Watchful Sleep mode combines the semantic features of the Doze and Cyclic Sleep modes while reusing the states and transition of the Doze mode on the ONU side, and those of the Cyclic Sleep mode on the OLT side. To support XG-PON ONUs, the XGS-PON OLT must support all three modes. For XGS-PON ONU, only the Watchful Sleep mode needs to be supported.

The TC layer-supported ONU power management modes are negotiated via OMCI and may be combined with any of the other power reduction techniques.

### 8.4.4 Implementation of Watchful Sleep in ITU-T Recommendations

Watchful Sleep mode became mainstream from 2016 on, both for NG-PON2 in [ITU-T G.989.3] and in XG(S)-PON ([ITU-T G.9807.1]). To operate a mix of XG-PON and XGS-PON ONUs, XG(S)-PON OLTs have to the maintain Doze mode and Cyclic Sleep low-power methods.

## 8.5 Power shedding

### 8.5.1 Editorial summary

[ITU-T G.988] allows the ONU to perform controlled power shedding, i.e., to switch off specific services when the ONU operates under battery power. The feature is controlled by the power-shedding ME, specified in clause 9.1.7 of [ITU-T G.988].

### 8.5.2 Power-shedding proposal

Power shedding is the ability of an ONU to reduce power consumption during AC power outages. It is predicated on the assumption that the ONU is attached to a power source that contains a battery back-up and the ability to notify the ONU of AC power loss and restoration. When the ONU is notified by the power source that AC power has been lost, the ONU may reduce power consumption by shutting down selected ONU interfaces. For the purposes of provisioning, these interfaces are divided into classes that may be individually provisioned to shed power after AC power loss is reported to the ONU.

### 8.5.3 Power-shedding specification impact

Provisioning of ONU power shedding is accomplished through the use of two OMCI MEs. These are the ONU power-shedding ME and the circuit pack ME. The ONU power-shedding ME contains most of the attributes associated with power shedding. The circuit pack ME contains a single attribute, power-shed override, that allows for the override of power shedding on a per port basis.

The power-shedding ME is auto-created by an ONU if that ONU supports power shedding.

The power-shed override attribute within the circuit pack ME is a bit map that can be used on a per port basis to override the settings contained in the ONU power-shedding ME. This attribute is determined as a 4 byte bit map with port 1 as most significant bit. When a bit in this attribute is set to 1, the corresponding port in its circuit pack is exempt from the ONU power-shedding ME.

If the hardware associated with the circuit pack does not support individually powering off its ports, then the entire attribute is taken as a single composite value. In this case, any bit of value 1 exempts all ports on that circuit pack from the ONU power-shedding ME. Intermediate cases are also possible, e.g., where the hardware permits ports to be powered down in groups of four. The point is to retain power on ports designated as essential, while powering down all other ports within the capabilities of the hardware.

Of particular interest in the management of ONU power shedding is the expected behaviour of the ONU during various power-shedding scenarios. This is especially true for the relationship between the two timers represented by the attributes restore power reset interval ($T_r$) and shedding interval ($T_s$). This behaviour is depicted in Figure 8-3, in which the following terms are used.

- Start timer – The timer is started or resumed from its existing value. A start timer action does not imply a reset of the timer.
- Stop timer – The specified timer is stopped and not reset.
- Reset timer – Stops and resets a timer. The timer is not started.

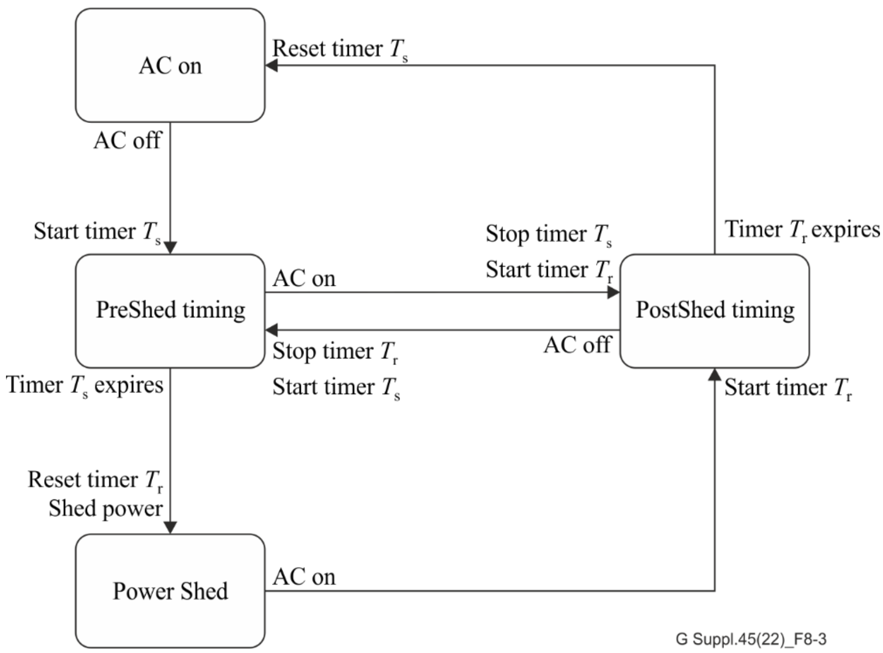


**Figure 8-3 – Power-shedding state diagram**

### 8.5.4 Implementation of power shedding in ITU-T Recommendations

The power-shedding ME has been available from the start in clause I.2.7 of [ITU-T G.988] as part of the equipment management clauses.

Power shedding is configured through OMCI, then operates autonomously only reporting ONU interface status upon demand; it does not require signalling operations apart from status reporting and has no TC layer specification impact.

## 8.6 OMCI control of power-saving techniques

### 8.6.1 Editorial summary

The ONU and OLT may support multiple optional power-saving techniques. The specific technique or techniques that are activated in a particular PON deployment depend on the technical capabilities of the equipment and the operational requirements. The capability versus requirements negotiation takes place on initial ONU configuration via the OMCI management channel. OMCI extensions can be added as necessary for this purpose. They will give the OLT an opportunity to learn the capabilities of the ONU and to activate or configure support of specific techniques.

### 8.6.2 OMCI control proposal

From the operational perspective, it could be beneficial for more than one power-saving technique to be supported by an ONU in a particular deployment. Different techniques would apply in different circumstances. As an example, power shedding can be combined with any ANI sleep mode, with the former being applicable in the presence of mains power, and the latter serving as an extra means to conserve battery capacity in the case of outage when emergency service support is required.

### 8.6.3 Specification impact

OMCI ME attributes defined for ONU dynamic power management control (clause 9.1.14 of [ITU-T G.988]) are as follows.

**Managed entity ID**: This attribute uniquely identifies each instance of this ME. There is only one instance, number 0. (R) (mandatory) (2 bytes)

**Power reduction management capability**: This attribute declares ONU support for managed power conservation modes, as specified in [ITU-T G.987.3]. It is a bit map in which the bit value 0 indicates no support for the specified mode, while the bit value 1 indicates that the ONU does support the specified mode. (R) (mandatory) (1 byte)

Codepoints are assigned as follows.

| **Value** | **Meaning** |
|---|---|
| 0 | No support for power reduction |
| 1 | Doze mode supported |
| 2 | Cyclic Sleep mode supported |
| 3 | Both Doze and Cyclic Sleep modes supported |
| 4 | Watchful Sleep mode supported |
| 5..255 | Reserved |

**Power reduction management mode**: This attribute enables one or more managed power conservation modes of an ONU. It is a bit map in which the bit value 0 disables the mode, while the value 1 enables it. Bit assignments are the same as those of the power reduction management capability attribute. The default value of each bit is 0. (R, W) (mandatory) (1 byte)

**Itransinit**: This attribute is the ONU vendor statement of the complete transceiver initialization time: the worst-case time required for the ONU to regain full functionality when leaving the asleep state in Cyclic Sleep mode or low-power state in Watchful Sleep mode (i.e., turning on both the Rx and the Tx and acquiring synchronization to the downstream flow), measured in units of 125 μs frames. The value 0 indicates that the sleeping ONU can respond to a bandwidth grant without delay. (R) (mandatory) (2 bytes)

**Itxinit**: This attribute is the ONU vendor statement of the Tx initialization time: the time required for the ONU to regain full functionality when leaving the listen state (i.e., turning on the Tx), measured in units of 125 µs frames. The value 0 indicates that the Dozing ONU can respond to a bandwidth grant without delay. If Watchful Sleep is enabled, the ONU ignores this attribute. (R) (mandatory) (2 bytes)

**Maximum sleep interval**: The Isleep/Ilowpower attribute specifies the maximum time the ONU spends in its asleep, listen or low-power states, as a count of 125 µs frames. Local or remote events may truncate the sojourn of an ONU in these states. The default value of this attribute is 0. (R, W) (mandatory) (4 bytes)

**Maximum receiver-off interval**: The Irxoff attribute specifies the maximum time the OLT can afford to wait from the moment it decides to wake up an ONU in the low-power state of the Watchful Sleep mode until the ONU is fully operational, specified as a count of 125 µs frames. (R, W) (mandatory) (4 bytes)

**Minimum aware interval**: The Iaware attribute specifies the time the ONU spends in its aware state, as a count of 125 µs frames, before it re-enters asleep or listen states. Local or remote events may independently cause the ONU to enter an active state rather than returning to a sleep state. The default value of this attribute is 0. (R, W) (mandatory) (4 bytes)

**Minimum active held interval**: The Ihold attribute specifies the minimum time during which the ONU remains in the active held state, as a count of 125 µs frames. Its initial value is zero. (R, W) (mandatory) (2 bytes)

**Maximum sleep interval extension**: This attribute designates maximum sleep interval values for Doze mode and Cyclic Sleep mode separately. When it supports this attribute, the ONU ignores the value of the maximum sleep interval attribute.

| | |
|---|---|
| Maximum sleep interval for Doze mode | 4 bytes |
| Maximum sleep interval for Cyclic Sleep mode | 4 bytes |

The maximum sleep interval for Doze mode specifies the maximum time the ONU spends in its listen state, as a count of 125 µs frames. Local or remote events may truncate the sojourn of an ONU in these states. The default value is 0.

The maximum sleep interval for Cyclic Sleep mode specifies the maximum time the ONU spends in its asleep state, as a count of 125 µs frames. Local or remote events may truncate the sojourn of an ONU in these states. The default value is 0. If Watchful Sleep is enabled, the ONU ignores this attribute.

(R, W) (optional) (8 bytes)

**Ethernet passive optical network (EPON) capability extension**: has also been defined

**EPON setup extension**: has also been defined

**Missing consecutive bursts threshold**: The $Clob_i$ attribute specifies the maximum number of missing consecutive scheduled bursts from the ONU that the OLT is willing to tolerate without raising an alarm. The value of this attribute defaults to 4. (R, W) (mandatory) (4 bytes)

### 8.6.4 Implementation of OMCI control of power savings in the ITU-T standards

From 2012, clause 9.1.14 of [ITU-T G.988] describes the ME-entitled ONU dynamic power management control.

### 8.7 Savings in the context of upstream multi-rate

Whenever a standard generation offers an option in which multiple line rates can co-exist on a link, adoption of the lowest possible one is expected to offer savings.

So far ITU-T Recommendations on PONs have specified a permanent downstream transmission rate, so this clause will concentrate on the upstream direction involving the ONU Tx and OLT Rx.

#### 8.7.1 Editorial summary

Most editions of ITU-T Recommendations on PON initially required a set of line rate combinations before settling for a preferred one, as a result of market concentration.

Nevertheless, from [ITU-T G.987] [ITU-T G.987.1] [ITU-T G.987.2] [ITU-T G.987.3] [ITU-T G.987.4] [ITU-T G.9807.1] [ITU-T G.9807.2], one set of combinations remained so that both 2.5 Gbit/s and 10 Gbit/s transmitting ONUs can operate simultaneously under a dual rate time division multiple access (TDMA) scheme.

When optimizing costs of dedicated XG-PON ONUs, no additional power consumption optimization can be obtained besides the sleep modes. However, when using an XGS-PON ONU in low duty periods, if the design allows, there is no reason to keep working at full speed, within the boundary of the tolerated SLAs.

#### 8.7.2 Upstream multi-rate mode proposal

Take the example of an XG(S)-PON dual rate capable ONU able to operate at both 10 Gbit/s and 2.5 Gbit/s. The dynamic bandwidth assignment (DBA) principles could be used to trigger entry into the relevant line rate for a given ONU for the purpose of saving power.

Assuming figures from [BBCoC v8.0] are based on an industry survey with consensus values from Table 6-5, it can be seen that the 2023 allowances for ONUs are as listed in Table 8-2.

**Table 8-2 – XG-PON and XGS-PON ONU port consumption allowances**

| ONU consumption | XG-PON | | XGS-PON | |
|---|---|---|---|---|
| Tier 2023<br>2023-01-01/2023-12-31 | Low-power state (W) | On state (W) | Low-power state (W) | On state (W) |
| General functions + PON interface | 2.8 | 4.5 | 3.5 | 4.9 |

Assuming figures from [BBCoC v8.0] are based on an industry survey with consensus values from Tables 6-9 and 6-10, it can be seen that the 2023 allowances for OLTs are as listed in Table 8-3.

**Table 8-3 – XG-PON and XGS-PON OLT port consumption allowances**

| OLT consumption | XG-PON | | XGS-PON | |
|---|---|---|---|---|
| Tier 2023<br>2023-01-01/2023-12-31 | ≤32 PON ports | ≥32 PON ports | ≤32 PON ports | ≥32 PON ports |
| OLT (XG-PON 10G/2.5G, fully equipped with maximum configuration implementing standard layer-2 (Ethernet) aggregation functionalities, including multicast) | 9.5 | 6.5 | 11.0 | 7.0 |

It is believed that at least part of the power consumption gap indicated through BBCoC figures could be obtained without the end user even noticing the change and with a lower latency to changes in traffic load than would be seen with sleep modes.

Based on the BBCoC allowances, additional savings of 0.4 W on the main XG(S)-PON ONU module through LRS between 10 Gbit/s and 2.5 Gbit/s upstream transmission could be obtained, accounting for another 8% for type 3 ONUs.

It is likely that the OLT Rx switching to lower line rate would be much less frequent than ONUs switching to the lower rate.

### 8.7.3 Specification impact

For XG(S)-PON ONUs, a dual stack should be implemented so as to support switching back and forth between 2.5 Gbit/s and 10 Gbit/s line rates depending on the DBA buffer status reports.

### 8.7.4 Implementation of upstream multi-rate in ITU-T Recommendations

XG/XG(S)-PON Recommendations [ITU-T G.987] [ITU-T G.987.1] [ITU-T G.987.2] [ITU-T G.987.3] [ITU-T G.987.4] [ITU-T G.9807.1] [ITU-T G.9807.2]implement the necessary primitives enabling co-existence of dual rate TDMA.

NG-PON2 [ITU-T G.989] also has the dual upstream line rate option on the OLT-CT.

Furthermore, given the dramatic increase in power consumption at both ends at higher line rates, it is predictable that higher speed PON ([ITU-T G.9804.1] [ITU-T G.9804.2] [ITU-T G.9804.3]) is also likely to maintain a set of upstream line rate combinations associated to its 50 Gbit/s downstream line rate. Requirements mentioned 12.5 Gbit/s, 25 Gbit/s and 50 Gbit/s. The latter to be developed in a second step.

NOTE – No specific text for such switching intended for energy efficiency (EE) has been developed so far in XGS-PON, but it is believed to be straightforward.

## 8.8 Savings in the context of multi-channel transmission

### 8.8.1 Editorial summary

In time and wavelength division multiplexing (TWDM) PONs, an additional dimension comes into the game, this time bringing benefits on the OLT side when wavelength multiplexed channels are provided on the PON. When considered together with the ability of ONUs to tune to any of the channel of the OLT bouquet, the shutdown of underused OLT-CT becomes possible in low duty periods.

NG-PON2 ([ITU-T G.989] [ITU-T G.989.1] [ITU-T G.989.2] [U-T G.989.3]) provides a set of channel pairs differentiated by the wavelength pair on the given channels. Requirements expressed an interest in 4 or 8 times 10 Gbit/s channels.

### 8.8.2 Multi-channel low-power mode proposal

Whenever OLT-CT designs enable full shutdown of an interface without the served ONU being impacted, e.g., losing in clock recovery accuracy, it is possible to save all processing and optoelectronic device power consumption, until a signal triggers the necessity to resume.

An example of NG-PON2 expected gain when switching off an OLT-CT after collapsing ONUs to a lower count of OLT-CT in low duty periods can be found in the Table 6-11 with figures taken from [BBCoC v8.0].

The expectation peaks at 10.5 W per OLT-CT shutdown.

### 8.8.3 Specification impact

An addition to the DBA state machine to trigger the re-tuning of low-duty ONUs on a lower number of OLT-CT and reactivate them seems the only addition, since all basic PMD and TC building blocks provide the necessary functions.

### 8.8.4 Implementation of Multi-channel low-power in ITU-T Recommendations

NG-PON2 in [ITU-T G.989] [ITU-T G.989.1] [ITU T G.989.2] [ITU T G.989.3] and higher-speed PON (HSP) in [ITU-T G.9804.1] [ITU-T G.9804.2] [ITU-T G.9804.3] both providing TWDM channels are eligible for this power-saving mode.

NOTE – Text describing the necessary OLT-CT behaviour is for further study, if any addition to the existing building blocks is necessary, which remains to be confirmed.

## 8.9 Savings obtained through the use of reach extenders

### 8.9.1 Editorial summary

Reach extenders mentioned here are re-amplification, reshaping optical signal repeater or regenerators inserted in the ODN. The principle of an optical-electronic-optical (OEO) RE consists in reverting the OLT and ONU pluggable optics in back to back so as to double the available optical budget, without any complex and power hungry frame processing. All complex ONU discovery and traffic management remains within the originating OLT that proceeds across the transparent RE.

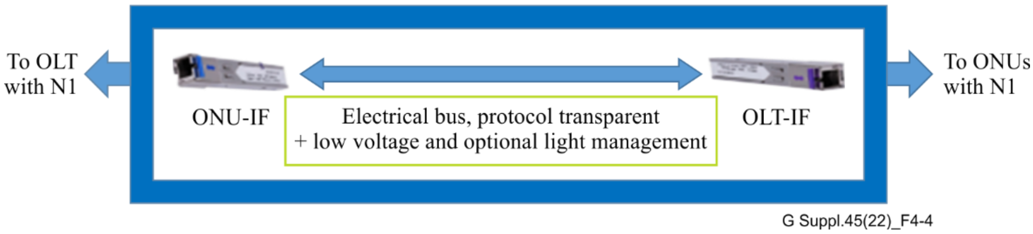


**Figure 8-4 – Typical OEO reach extender structure**

In specific network conditions: specifically low density areas or low termination count in a 20 km radius, introduction of a new technology at low take rate, might not enable OLTs even in pizza box formats to prove-in.

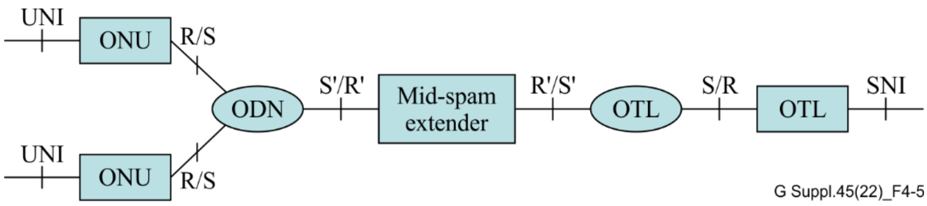


**Figure 8-5 – Typical mid span reach extended architecture (source [ITU-T G.9807.2])**

Both OLT and ONU remain unimpacted by the presence of an RE except for the OLT side when optional REs are remotely operated through the OLT. This means that an engine for ONU (EONU) is added to the RE for all information exchanges specified in the recommendations.

In addition to the savings in each remote small CO through the installed active devices themselves, expensive technical environment control and maintenance services can be greatly simplified, e.g., on temperature control, possibly cooling, power converters, dimension of back-up batteries in the case of mains failure and physical or logical access for local traffic engineering.

### 8.9.2 Reach extender savings proposal

**First use case**: serving remote low ONU count areas

Considering small communities at distances exceeding 20 km from the CO where an OLT is located, the use of single port mid-span RE or several parallel ones can enable to collect bunches of 64 terminations per fibre at minor local complexity and OPEX.

It can be noted that considering the constitutive parts, both the maximum voltage and power can be easily estimated, in Figure 8-6 for XG(S)-PON constrained by the SFP+ and 10 Gbit small form factor pluggable (XFP) optical modules format added to the EONU, which can be estimated at its highest at the BBCoC value.

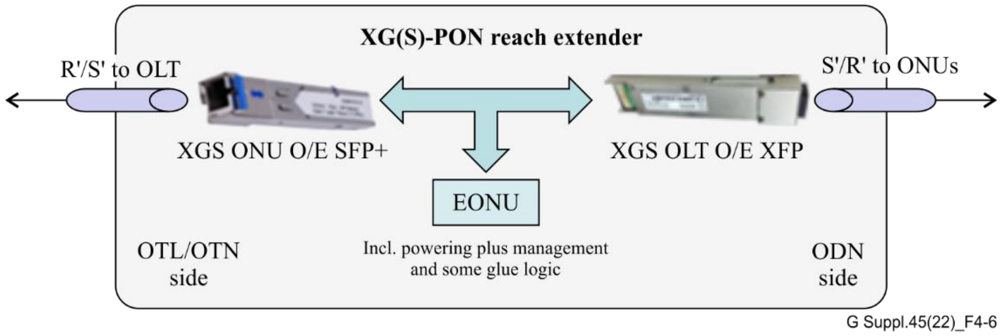


**Figure 8-6 – Details of XG(S)-PON OEO RE constitutive elements**

It is expected that with the progress in technology integration, the motion from SFP+ to SFP and XFP to SFP+ will bring further savings. See Table 8-4.

**Table 8-4 – Breakdown of the RE constitutive powering requirement**

| RE parts | Max voltage (V) | Max power (W) |
|---|---|---|
| SFP+ | 3.3 | 1.5 |
| XFP | 3.3 | 3.5 |
| EONU | 5.0 | 4.5 |
| Summary | 5.0 | 9.5 |

Note that these are maximum values from various standards and multi-source agreements are subject to additional power-saving methods. Specifically, when it comes to the EONU, there is no need to keep the link to the OLT permanently active, functions other than the internal bus and module status monitoring can be subject to sleep modes.

These values in addition to an OLT-CT power consumption have to be compared to the power consumption of an OLT serving 64 ONUs.

Stacking of RE sharing a single EONU can also be an option although association of each RE to its OLT-CT for management purposes can require special care.

**Second use case:** fast and smooth introduction of a new technology in co-existence scenario

[ITU-T G.984.5] and its future extensions in [ITU-T G.9805] specify a multiple PON module option combining two generations of PON systems in pluggable modules thus enabling co-existence on a single OLT chassis.

Nevertheless, to provide the full speed experience of the newest generation of technology to end users, the OLT backplane and SNIs have to operate at high speed, even with low take rate from users. This might not be optimal as long as lower capability PON generation remains dominant.

Additionally, given the maximum optical split of the ODN sharing ratio, the global efficiency improvement for one technology results in one lower for the other.

Therefore, instead of necessarily binding the two co-existing technology generations on a single chassis with all its side effects, it might be interesting to decouple them with an OLT consolidation option, thanks to RE: specifically fan-out RE.

Using fan-out RE enables optimization of the number of OLT-CTs across legacy ODN, even when the optical budget has been exhausted by the initial technology network designers.

In the example given in Figure 8-7, using a four port fan-out RE, one OLT-CT will enable access to new technology services across four ODNs without any change to legacy users, provided a WDM1r devices can be accommodated in the smaller CO.

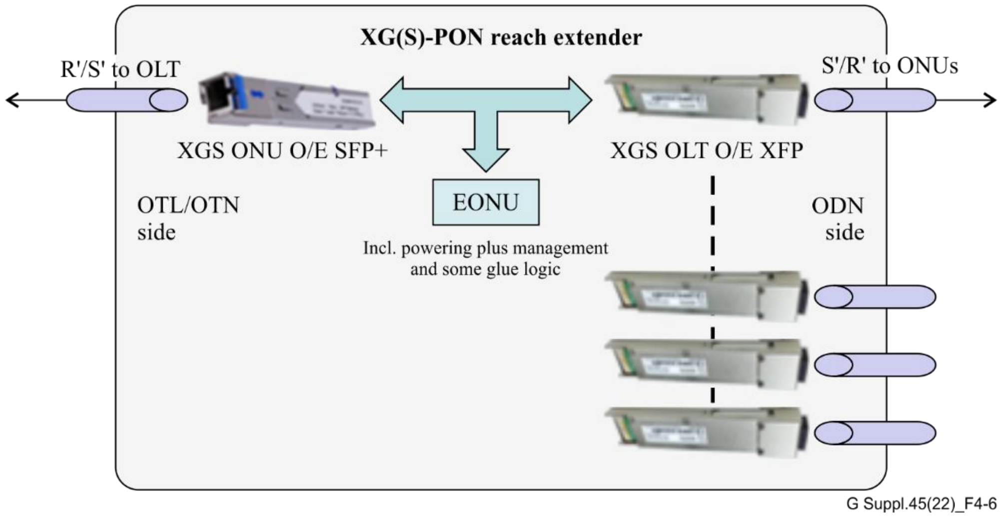


**Figure 8-7 – Details of XG(S)-PON OEO RE fan-out constitutive elements**

Thus, both optimal power consumption for lower end applications on the legacy chassis and for heavy traffic stringent service requiring end users can be simultaneously offered without tedious legacy user migration to the new shelf without any experience improvement. See Figure 8-8.

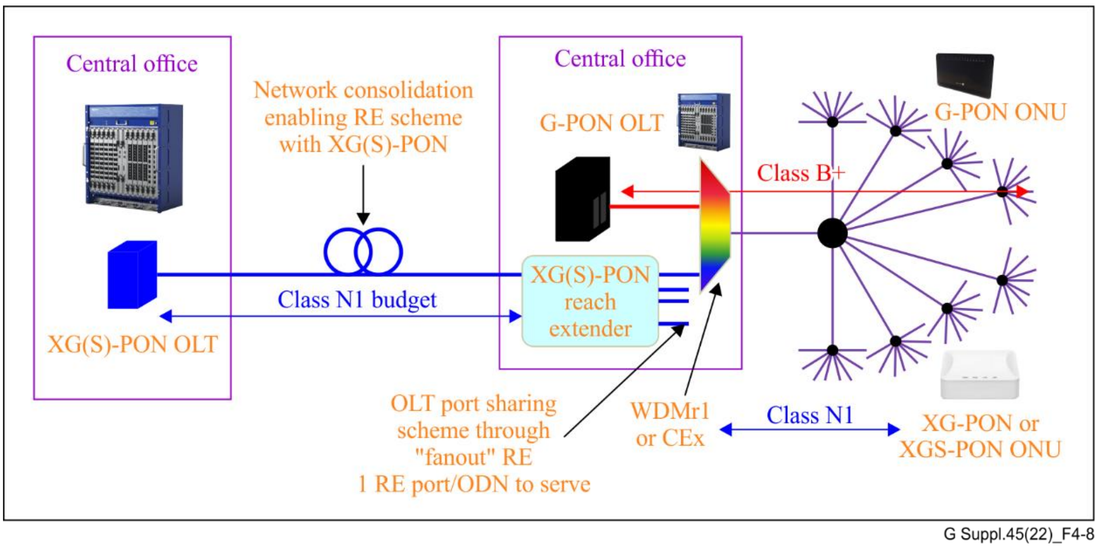


**Figure 8-8 – Example of XG(S)-PON introduction**

Not all technologies will have to be installed in every CO, and deployment of new technologies can be dramatically accelerated within a given take rate limit, which should be when the same OLT-CT sharing ratio is achieved with and without using an RE.

Furthermore, it is pointed out that the necessary fibre count between the COs is only incremented by one when considering PON signals in RE schemes, while legacy SNIs still heavily require dual fibre interfaces. Turning to a single fibre on an SNI can help reclamation of the necessary fibre capacity to consider RE schemes. See Table 8-5.

**Table 8-5 – breakdown of the eight port fan-out RE constitutive powering requirement**

| Eight port RE part | Max voltage (V) | Max power (W) |
|---|---|---|
| SFP+ | 3.3 | 1.5 |
| XFP * 8 | 3.3 | 28 |
| EONU | 5.0 | 4.5 |
| Summary | 5.0 | 34 |

In the example of an eight port fan-out RE, one OLT-CT can serve up to eight ODNs initially serving 512 ONUs as long as the take rate remains lower than 12.5%. Beyond that, some updates will be needed, e.g., through addition of other RE, hopefully then balanced through significant average revenue per user receipts.

From the power consumption point of view, obviously ODN-side RE ports will be individually activated or powered on demand as new users require migration to high-bandwidth-demanding services.

### 8.9.3 Specification impact

ONUs remain unaware that REs are used in the link to the OLT. OLTs are only affected when they are supposed to manage the RE, i.e., to activate and monitor its status.

No impact is expected for series in which REs have been specified, since both necessary additions to OMCI and to the TC layers have been made to enable all identified types of remote control operations through the OLT-CT.

The question of studying REs for NG-PON2 and HSP is open.

### 8.9.4 Implementation of reach extenders in ITU-T Recommendations

Reach extenders for GPON are specified in [ITU-T G.984.6].

Reach extenders for XG-PON are specified in [ITU-T G.987.4].

Reach extenders for XG(S)-PON are specified in [ITU-T G.9807.2].

## 8.10 Savings obtained through line rate switching techniques

Whereas in PON transmission each generation comes with a specific downstream frame format that has to be permanent and understood by all ONUs, in PtP transmission it is possible to dynamically optimize the consumed power depending on the traffic load observed. Here again, transmission of buffer occupancy known in DBA can be re-used.

Thus, depending on the link termination capabilities, it is possible to define a set of line rates across which to perform hitless switching to the needs in conformance to SLA.

This has been described in [ITU-T G.9806] for high-speed point-to-point (HS-PtP) transmission.

### 8.10.1 Editorial summary

Because digital gate power consumption is proportional to the clock rate and transitions, whenever adoption of the lowest line rate in a set of options (e.g., 1 Gbit/s, 10 Gbit/s, 50 Gbit/s) is enabled by end device designs, power savings can be obtained.

Best results can be obtained when similar "framings" TC layer mechanisms are used at different speeds, thus minimizing the specific complexity of the necessary ASICs. To minimize the modification and maintain the operating team experience as stable as possible, the option retained was to elaborate on the existing low-power mode PLOAM messages, extending their capabilities.

In contrast to sleep modes although compatible with them, no connectivity is lost through LRS. Specifically clock synchronization is maintained, which is a major point for some applications, in which time to recover synchronization is critical.

Note also that in contrast to the PON context, in PtP transmission, power savings resulting from LRS are symmetrical and benefit both the end user and operator.

The LRS principle applies to either the single or multiple channel contexts, such as WDM-PON. when passive wavelength routing devices are used in addition to the sleep modes.

### 8.10.2 Line rate switching proposal

The LRS state diagram in Figure 8-9 depicted here is reproduced from Figure 9-1 of [ITU-T G.9806].

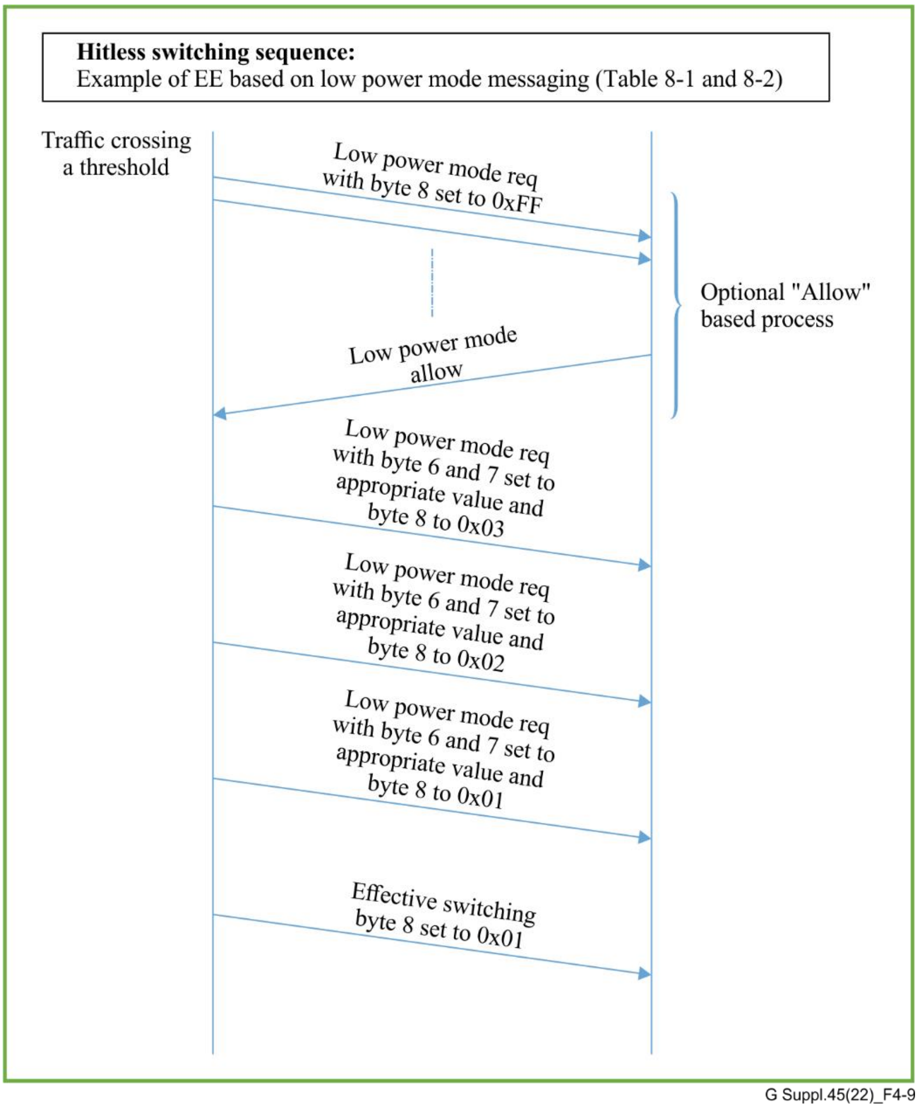


**Figure 8-9 – Hitless switching protocol**

Ideally the switching does not require any bi-directional messaging exchange; on PtP, switching can rely on simple preliminary redundant and protected announcements by the Tx. Nevertheless, to secure switching, it is preferred to get acknowledgement of the process from the remote end.

In the specific case of low-power modes in PONs, operations are handled in a single PLOAM message per direction. For PtP and here the addition of LRS to the existing sleep mode (Watchful Sleep), this messaging needs to extend the PLOAM legacy (dedicated to Watchful Sleep) in [ITU-T G.9807.1] and has been therefore re-branded as "low-power mode" with two messages, one for upstream and the other for downstream.

In order to avoid multiple mapping of messages, it is proposed to shorten the related PLOAM messages to 40 bytes for PtP, to adopt the mapping used for OMCI described in clause 8.2.1 of [ITU-T G.9806].

Messages retained are listed in Tables 8-6 and 8-7.

**Table 8-6 – Low_power_mode_Allow message**

| Octet | Content | Description |
|---|---|---|
| 1-2 | 0x03FF | As a broadcast message, ONU-ID = 0x03FF |
| 3 | Message type ID | 0x12, "Low.power mode allow" |
| 4 | SeqNo | 8 bit unicast or broadcast PLOAM sequence number, as appropriate |
| 5 | Control flag | 0000 000A, where:<br>A = 0: Sleep allowed OFF<br>A = 1: Sleep allowed ON<br>Other values reserved |
| 6 | Current line rate | 0xLR where LR represents an integer in the variety of possible values in gigabits per second (e.g.,<br>0x01 for 1 Gbit/s<br>0x0A for 10 Gbit/s<br>0x32 for 50 Gbit/s) |
| 7 | Line rate switching status | 0000 000S, where:<br>S = 0: Line rate switching not ready<br>S = 1: Line rate switching authorized<br>Other values reserved |
| 8 | Nature of transition | 0000 00CD, where C stands for the direction, D for a single or the max step<br>CD = 00: Transition to next lower speed<br>CD = 01: Transition to lowest speed<br>CD = 10: Transition to next higher speed<br>CD = 11: Transition to highest speed<br>Other values reserved |
| 9-32 | Padding | Set to 0x00 by the Tx; treated as "do not care" by the Rx |
| 33-40 | MIC | Message integrity check, computed using the default PLOAM_IK in case of broadcast message, and using the ONU-specific derived shared PLOAM_IK in case of directed message |

**Table 8-7 – Low_power_mode_Request message**

| Octet | Content | Description |
|---|---|---|
| 1-2 | ONU-ID | ONU-ID of the message sender if such an ID remains used for PLOAM, else set to 0x0000 and ignored by the Rx |
| 3 | Message type ID | 0x10, "Low-power mode_Request" |
| 4 | SeqNo | Always 0x00 |
| 5 | Activity _level | Activity Level:<br>0x00: Sleep_Request (Awake)<br>0x03: Sleep_Request (WSleep)<br>Watchful sleep mode request: when in a LowPower state, the ONU periodically checks the downstream traffic for wake-up indications from the OLT<br>Other values are reserved |
| 6 | Current line rate | 0xLR where LR represents an integer in the variety of possible values in gigabits per second (e.g.,<br>0x01 for 1 Gbit/s<br>0x0A for 10 Gbit/s<br>0x32 for 50 Gbit/s) |
| 7 | Nature of transition | 0000 00CD, where C stands for the direction, D for a single or the maximum step<br>CD = 00: Transition to next lower speed<br>CD = 01: Transition to lowest speed<br>CD = 10: Transition to next higher speed<br>CD = 11: Transition to highest speed<br>Other values reserved |
| 8 | Switching count down | Set to 0x00 by default<br>Set to 0xFF to request the other end to send a "low-power mode allow" message<br>Counter is set to 0x03 and decremented upon each "Low-power mode_Request" PLOAM message transmission, either upon reception of an allow message or freely if no acknowledgement is needed<br>Switching effective with 0x00 |
| 9-32 | Padding | Set to 0x00 by the Tx and treated as "do not care" by the Rx |
| 33-40 | MIC | Message integrity check, computed using the ONU-specific derived shared PLOAM integrity key |

Expected benefits from low-power modes can again be estimated from the values in [BBCoC v8.0] from the PtP interface allowances for OLT and ONU across line rates. See Table 8-8.

**Table 8-8 – [BBCoC v8.0] figure extractions for line rate switching-saving expectations**

| Power targets for PtP ports<br>Tier 2023 1.1.2023-31.12.2023 | OLT (W) | ONU (W) |
|---|---|---|
| PtP 1 000 Mbit/s | | |
| OLT: (PtP up to 1000 Mbit/s, up to 100 ports, fully equipped with maximum configuration)<br>ONU: Home gateway central functions plus WAN interface | 2.5 | 4.1 |
| PtP 10 Gbit/s | | |
| OLT (PtP at 10 Gbit/s, with more than 48 ports, fully equipped with maximum configuration) | 8 | Missing |
| PtP 25Gbit/s | | |
| OLT (PtP at 25 Gbit/s, with more than 48 ports, fully equipped with maximum configuration) | 20 | Missing |
| PtP 100 Gbit/s | | |
| OLT (PtP at 100 Gbit/s, with more than 16 ports, fully equipped with maximum configuration) | 120 | Missing |

Here again saving expectations assume that the chip design has been optimized.

Curiously, whereas figures are given for interfaces with a 10 Gbit/s PtP copper WAN and LAN, none is given for 10 Gbit/s fibre for the ONU side.

Figures for 40 Gbit/s PtP links are announced as part of the revision of [BBCoC v8.0], while work in ITU-T has already specified 50 Gbit/s and has been started for 100 Gbit/s single fibre HS-PtP links.

#### 8.10.3 Line rate switching specification impact

LRS requires the ability of both the OLT and ONU to speak languages and understand an LRS protocol across line rates, losing the often expected transparency from router or switch vendors compared to managed access network systems that are based on master-slave behaviour.

[ITU-T G.9806] describes the protocol necessary, but it is likely that ONU capability discovery requires some further development possibly through OMCI enhancement in [ITU-T G.988].

Note that to benefit from such power savings, a local protocol has to be specified and knowledge of the ability of the intended service to value this type of saving is necessary, e.g., the Ethernet might be a good candidate, while common public radio interfaces are not.

#### 8.10.4 Implementation of line rate switching in ITU-T Recommendations

LRS mechanisms for PtP transmission are introduced in [ITU-T G.9806].

It is expected that LRS mechanisms will be carried on in WDM PON technologies, as applicable.

## 9 Signalling of ONU operations in a power-saving mode

### 9.1 Dying Gasp signalling

[ITU-T G.984.3] specifies the Dying Gasp message and clarifies the conditions under which it is generated. The Dying Gasp allows the ONU to signal that it is powering off, it is transitioning into a low-power or battery conservation mode, or otherwise experiences or desires to change the powering conditions that may impact the ability of an ONU to respond to the upstream bandwidth allocations.

For the Dying Gasp PLOAM message specification, see clause 9.2.4.3 of [ITU-T G.984.3].

In subsequent PON generations, the Dying Gasp mapping has been made part of the upstream framing sublayer header, to speed-up its report and minimize the amount of energy necessary. Specifically it has been hosted as bit 0 of the Ind Field.

An alarm notification explanation related to power has been inserted in [ITU-T G.988] as part of ONU-G and ONU2-G capabilities instead of increasing the Dying Gasp indication complexity. The list of such alarms can be found in clause 9.1.1 of [ITU-T G.988] describing the ONU-G ME.

In particular, the alarm code assists the OLT in identifying the following scenarios:

– the user switches the ONU off;
– the power input to a battery-less ONU fails;
– the ONU operating from a battery turns itself off to conserve power in order to support future emergency communication;
– the ONU operating under regular external power goes into Cyclic Sleep/Doze mode to reduce power consumption during the inactivity period.

## 9.2 PLOAM-based signalling

The PLOAM-based power save mode signalling method has been developed in the context of the sleep modes power-saving techniques (see clause 4.1).

Two PLOAM message types have been defined: Sleep_Allow; and Sleep_Request. The usage of PLOAM messages is specified in power management clauses (e.g., clause 16 of [ITU-T G.987.3]).

**Sleep_Allow PLOAM message from OLT to ONU**

The OLT sends Sleep_Allow to enable or disable power saving in real time. If ONU power management has not been enabled via OMCI, the ONU silently discards this message. See Table 9-1.

**Table 9-1 – Sleep_Allow PLOAM message**

| Octet | Content | Description |
|---|---|---|
| 1-2 | ONU-ID | Directed or broadcast ONU-ID. As a broadcast message, ONU-ID = 0x03FF. |
| 3 | 0x12 | Message type ID "Sleep_Allow". |
| 4 | SeqNo | Unicast or broadcast PLOAM sequence number, as appropriate. |
| 5 | 0000 000A | This byte is a bit field with the following significance:<br>A = 0-Sleep allowed OFF.<br>A = 1-Sleep allowed ON.<br>Other values reserved. |
| 6-40 | Padding | Set to 0x00 by the Tx; treated as "do not care" by the Rx. |
| 41-48 | MIC | Message integrity check. |

**Sleep_Request PLOAM message from ONU to OLT**

An ONU sends Sleep_Request to signal its intention to start or terminate power saving. See Table 9-2.

**Table 9-2 – Sleep_Request PLOAM message**

| Octet | Content | Description |
|---|---|---|
| 1-2 | ONU-ID | Sender identity |
| 3 | 0x10 | Message type ID "Sleep_Request". |
| 4 | SeqNo | Always 0. |
| 5 | Activity_level | 0: Sleep_Request (Awake).<br>Non-zero values of the parameter indicate a request to initiate a specific power management mode: ONU alternates between an Aware state (SleepAware, DozeAware or WatchAware), when the ONU receives and transmits traffic, and a corresponding LowPower state (Asleep, Listen or Watch), when the ONU does not transmit upstream.<br>1: Sleep_Request (Doze). Doze mode request: when in a LowPower state (the Listen state) the ONU Rx remains active, the ONU can receive downstream traffic.<br>2: Sleep_Request (Sleep). Cyclic Sleep mode request: when in a LowPower state (the Asleep state), the ONU Rx is inactive; the ONU cannot receive downstream traffic.<br>3: Sleep_Request (WSleep). Watchful Sleep mode request: when in a LowPower state (the Watch state), the ONU periodically checks the downstream traffic for wakeup indications from the OLT.<br>Other values reserved. |
| 6-40 | Padding | Set to 0x00 by the Tx; treated as "do not care" by the Rx. |
| 41-48 | MIC | Message integrity check |

### 9.3 Security aspect of power save mode signalling

The ONU activation method allows a malicious man-in-the-middle (MITM) well-equipped observer to learn the equalization delays of the ONUs on the PON. In principle, knowing when an ONU enters a power save mode opens for such an observer a window of opportunity to initiate a spoofing attack, if the observer is located closer to the OLT than the object of the attack. Note that addition of an MITM analysis tool will result in a detectable PON disruption, either a global one if inserted in the feeder section or only one ONU in case of insertion in the drop after the lower splitter. A similar attack without waiting for a target ONU to enter a power save mode would likely cause an upstream collision and trigger a rogue ONU protective action on the part of the OLT.

Further work may be required to assess the possible scope and impact of such an attack, as well as the means of protection against it.

## 10 Comparative analysis of PON low-power modes

### 10.1 Methodology

The study of the proposed power-saving technique led to the observation that power save signalling and maintenance methodologies can be considered and evaluated separately. The signalling methods under evaluation are:

- Dying Gasp message;
- dedicated PLOAM types.

The power-saving maintenance techniques under evaluation are:

- Dozing/Cyclic Sleep;
- Watchful Sleep;
- power shedding.

### 10.2 Power save mode signalling discussion

Power save mode signalling based on PLOAM message types was retained as achieving completion of the mode transition faster.

### 10.3 Power save mode maintenance discussion

#### 10.3.1 ONU Dozing mode vs Cyclic Sleep mode

Proposals have been made for ONUs to go into a so-called Sleep mode when it is not in use. It is assumed that the OLT or ONU have some way to distinguish real traffic from the idle state. Whether this is possible remains to be proven; examples follow.

– When the subscriber falls asleep with the TV on. The definition of real traffic in this case is ambiguous: the subscriber may consider the flow to be background music or the visual equivalent, and wake up angry if it is discontinued.

– When the subscriber turns off the TV but leaves the set-top box powered up.

– When an intrusion detection system is deployed.

To circumvent this problem, proposals have been made for the OLT or ONU to buffer traffic until such time as the ONU reawakens. As well as issues of memory capacity and overflow prioritization, the continuing flow of real time poses difficulties. Examples follow.

– Internet group management protocol (IGMP) queries and responses need to be timely (see the foregoing background music application).

– A voice over Internet protocol (VoIP) agent may exchange periodic heartbeat messages with a voice gateway.

– IEEE 802.1ag continuity check messages must be sent and received periodically.

– Spanning tree or route messages need to be delivered in a timely fashion.

– The ONU needs to be able to send a Dying Gasp message before its momentary power reserve is exhausted.

To the extent that both ends of such an exchange are local to the OLT or ONU, it is at least conceivable that software could be adapted to deal with timeouts during sleep intervals, though the complexity of such adaptations should not be underestimated. When one or both endpoints of a transaction – possible in the first four examples – lie beyond the scope of the OLT or ONU, the various timeouts are not likely to be accessible for change.

For completeness, it should also be noted that the concepts surrounding 15 min performance monitoring intervals will need to be re-thought, since presumably there may be less than 15 min of valid time in each interval.

Sleep mode proposals have responded to these concerns by reducing the proposed sleep interval, though not to the point of proposing actual numbers. In any event, it seems unlikely that meaningful power reductions will be possible in an OLT/ONU system that can be robustly demonstrated to deliver carrier-grade service under all real-world application scenarios.

The conclusion is that disruption of TC layer continuity is to be avoided. This need not prevent power savings in the optics and MAC layers of an ONU, however.

### 10.3.2 Example of power shedding

Power shedding is a technique practiced throughout the cellular phone, laptop PC and display monitor industries, to name a few. The fundamental principle of operation is to turn off or shut down gracefully elements of a device that are not in use. The power profile of an ONU depends on the services it supports. For an ONT that is used in North America to deliver gigabit Ethernet, MoCA, cable television (CATV) and two lifeline POTS ports, the power profile of the key components is as shown in Figure 10-1.

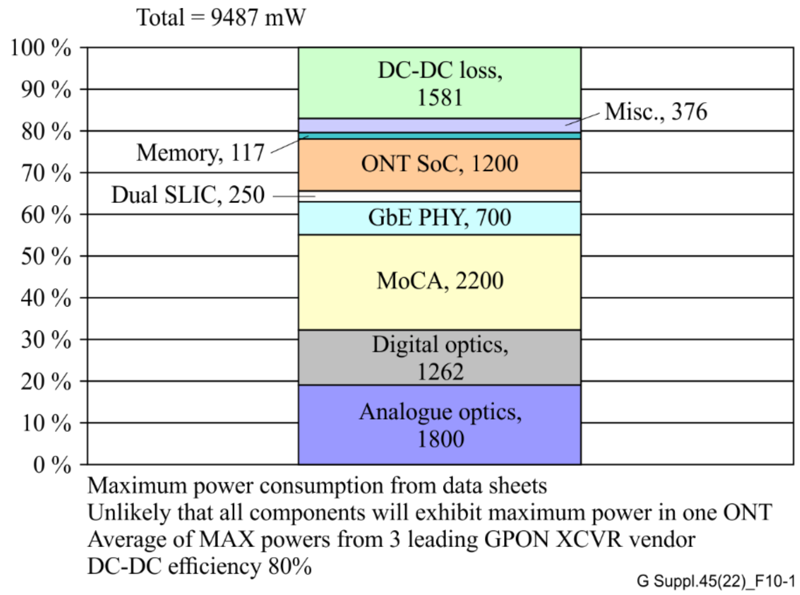


**Figure 10-1 – Example power profile**

The major contributors to the power profile of any ONU are the optics and the PHY interfaces. For a three-wavelength optical transceiver that supports CATV, as commonly used in the North American market, about 60% of power is used for the analogue video portion. This analogue video portion operates on a separate power supply rail to that of the digital section, which allows for the turning off of the video section of the transceiver. Thus, during a power failure of the AC mains in a home, the ONU can shed the video and data services while still maintaining the lifeline POTS. The amount of power saved during this situation is as shown in Figure 10-2.

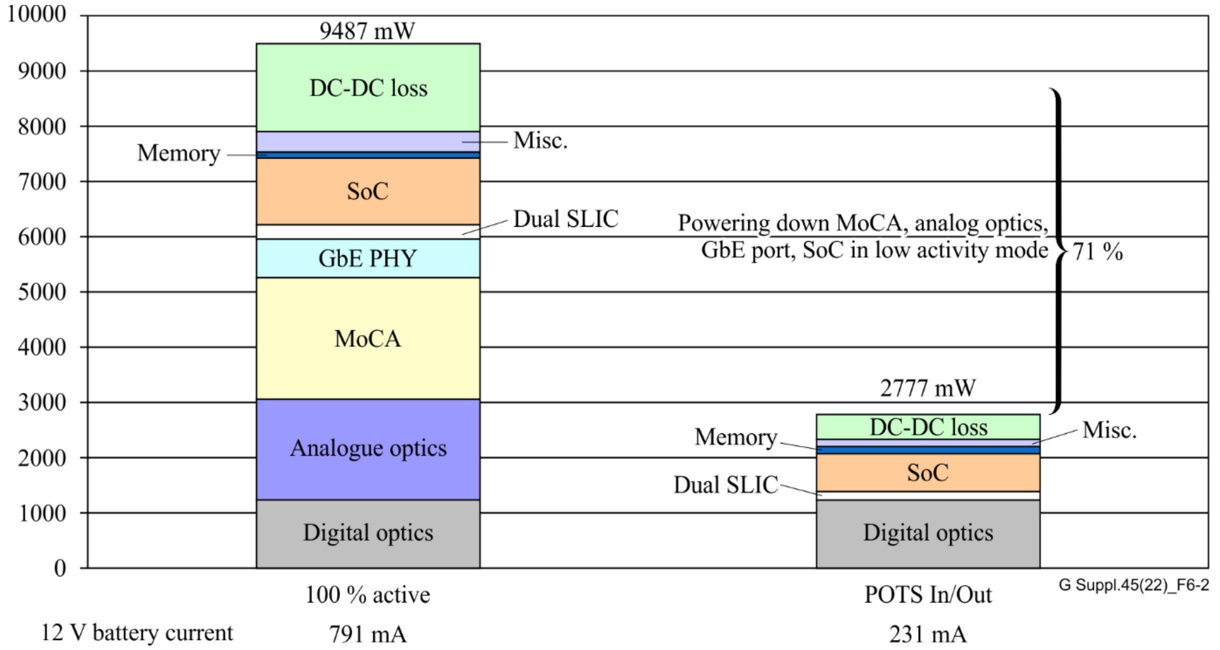


**Figure 10-2 – Example power savings**

To summarize the case for power shedding, the following can be stated:

– Power shedding is specified in [ITU-T G.988].

– Power shedding can save over 70% of active ONU power.

– Power shedding is well understood, as it is used across a range of industries for laptop PCs, monitors, cell phones, etc.

– The size of the battery required to support emergency operations of a North-American ONU under AC power failure can be reduced by more than 50% with the currently available technology.

### 10.3.3 Proposal comparison table

Table 10-1 presents a summary of the comparative analysis of the proposals, using the following criteria.

– **Power**: Power in power down mode.

– **Net capacity for backup**: Net capacity for battery backup mode. The assumption is that the backup time is 8 h with 1 h of talking (5.2 W). The capacity does not try to take account of real life battery considerations like average utilization and Peukert constant, so the value is only for comparison and cannot be used directly to select a battery type. Also some more accurate calculations are needed, including ringing time and real overheads, a real life operation scenario and shutdown time of different services.

– **ONU complexity**: Implementation complexity in the ONU.

– **OLT complexity**: Complexity of changes needed in the OLT, if at all.

– **Services implications**: What are the implications, if at all, on the services and service model?

– **User implication**: What are the implications, if at all, on users?

**Table 10-1 – Proposal comparison table**

| | Power shedding | ONU Dozing mode | On-Off/Deep Sleep mode | Cyclic Sleep mode |
|---|---|---|---|---|
| Power | 2.8 W (Note 1) | 1.7 W (Note 1) | <0.7 W (Note 1) | 0.8–1.0 W (Note 3) |
| Net capacity for backup | 24.8 W/h (Note 2) | 17.1 W/h (Note 2) | 10.1 W/h (Note 2) | 10.1 W/h (Note 2) |
| ONU support | Power shedding, as specified in [ITU-T G.988]. | Allocation suppression (shedding plus turning off of Tx); forced allocations. | Activity suppression (shedding plus turning off of Tx and Rx); local stimulus wake-up, fast re-ranging. | Activity suppression (shedding plus turning off of Tx and Rx); autonomous wake-up timer, local stimulus wake-up, PSynch and frame acquisition; active period PLOAM handshake. |
| OLT support | Implementation of OMCI control. | Regular PLOAM allocations (no loss of signal (LOS)); periodic drift adjustment (only as often as reasonably required to avoid re-ranging). | Periodic targeted ranging window allocation (as often as needed for the ONU to re-range quickly upon wake-up). | Regular PLOAM allocations (no LOS).<br>Periodic Sleep messages with scheduled wake-ups. |
| Downstream critical traffic impact | None. | Delivered without delay. | Lost. | Delivered with delay dependent on sleep period duration; contingent on OLT buffering; ultimate success subject to service delay requirements. |
| Upstream critical traffic impact | No delay. | Delay [minimal] dependent on PLOAM allocation period. | Delay dependent on ranging window allocation period. | Delay dependent on sleep period duration. |
| User implication | Minimal impact on user experience associated with finite wake-up time on. | Minimal impact on user experience associated with finite wake-up time and PLOAM allocation period. | Loss of incoming services during sleep; tangible additional delay associated with finite wake-up time and re-ranging. | Extra delay (or loss) of incoming services; minimal additional delay for outgoing services. |

NOTE 1 – Assuming just voice services for this power.

NOTE 2 – The assumption is a cycle of operation of 15 min talking (5.2 W) in an hour.

NOTE 3 – Based on the assumptions that the active period is limited to 3 ms, whereas the sleep period varies from 20 to 100 ms, and that the power consumption in the active period approaches the level achievable by power shedding.

## 11 Conclusions

The most basic conclusion of this Supplement is that power saving is important. Operators, system vendors and component manufacturers all must play a role in achieving this goal.

Considering the objectives for power saving, the primary target is to reduce the size and cost of backup batteries, and therefore power-saving modes that operate during main power failure are of primary interest. The secondary goal is to reduce the average power consumption at all times. Also, there is an overarching requirement that we should not sacrifice service quality or availability. In particular, lifeline telephony services should always be available.

This Supplement considers many techniques that could be employed to reduce power consumption. Each has its own unique benefits and costs. The implementation of a particular power-saving feature has to be prioritized relative to all the other features in equipment development. Such prioritizations may vary from implementer to implementer, and operator to operator. However, the study results suggest that the approaches to power saving will likely follow the following priorities.

**First priority**: The equipment design should be continuously improved to reduce its power consumption even when operating at full capability. This includes the design of electronic circuitry such that it consumes power only when absolutely necessary, and the construction of microelectronics with higher levels of integration or advanced fabrication processes. The power consumption of the power adapters (and other peripherals) should also be considered in the design.

**Second priority**: The ONU power-shedding technique should be supported to provide an additional power-saving capability. These methods seem to result in a considerable amount of power reduction (perhaps 60% from full power mode), and can be implemented with little to no change in the hardware of existing PON systems. It also seems to have the minimum of service impact, in that these modes maintain the PON link at all times.

**Third priority**: The ONU dozing can be supported in addition to power shedding to achieve further incremental power conservation at the cost of minimal change and service impact and without losing the downstream PON link. The technique would require OLT cooperation in supporting the controlled loss of upstream connectivity.

**Fourth priority**: The more aggressive power-saving modes, such as "ONU sleeping" offer additional power reductions (perhaps 90% from full power mode), but at a higher cost in complexity and system impact. Importantly, these modes have been designed not to cause a periodic loss of connectivity at the physical layer.

Lastly, it should be noted that the use of broadband fibre access systems may have significant energy savings in other sectors of the economy. For example, the widespread availability of true broadband will promote teleconferencing and teleworking. This will reduce the need for business travel and everyday commuting, which will offer huge reductions to the carbon footprint.

# Appendix I

# Power survey results

## I.1 Power survey No.1 responses (LF08)

*Vendor information on the current and future power features of network equipment.*

1) What power architecture options do you current support?

   a) (That is, how are the three functions of ONU, primary supply and battery arranged?)

      – Company D: Power for the ONT is derived from a battery backup power supply that converts the AC mains voltage to an isolated 14 V direct current (DC) output used to charge a 12 V battery and power the ONT. Upon loss of AC mains voltage, power to the ONT is derived from the 12 V battery.

      – Company E: Rectifier + battery or remote power feeding on pairs.

2) What is the power consumption of each of your devices:

   a) In normal operation?

      – Company D: The power consumption of the SFU ONTs is about 20 W with video on, data traffic running and all POTS lines off-hook. The peak power increases to about 25 W when a line is ringing at maximum ringer equivalence number.

      – Company E: BBCoC target.

   b) In any power-saving modes?

      – Company D: With the ONT connected to the PON, no data or video and all POTS lines on-hook, the power draw is about 14 W.

      – Company E: BBCoC target.

3) Over time, how do you predict the reduction of the aforementioned power consumptions?

   – Company A: Power saving is an important issue for FTTB/M using ONT, for the FTTN SFU ONT, the power consumption in saving modes, which means battery supply is very important too; when ONT chipset parts change from FPGA to ASIC, the power consumption can be reduced quickly.

   – Company D: According to present estimates, next generation ONTs will consume 10-20% less power.

4) How much power (in a percentage of total ONU draw) can be saved by shutting down:

   a) The PON interface?

      – Company D: Shutting down digital transceiver saves 1.5 W; shutting down the entire triplexer yields 4 W in power savings.

   b) The CPU core?

   c) The RF video subsystem?

      – Company D: 2.4 W is saved by turning off video.

   d) The data UNI?

      – Company D: 0.4 W is saved by turning off data.

   e) The POTS UNI?

      – Company D: 0.7 W is saved per POTS line going on-hook.

   f) Others?

5) What power-saving features does your equipment support now? Including:

   a) UNI shutdown during power failure.

b) Total shutdown during power failure.

c) UNI shutdown during disuse.

d) Total shutdown during disuse.

– Company D: During a power failure, data and video can be shut down after a configurable amount of time.

*Information on operator intentions*

6) What is the current stance regarding powering fibre-fed CPE, including:

a) How is the power provided?

– Company A: For the OLT, AC and DC are optional, but for the ONT part, almost all are AC.

– Company B: AC (220 V) or battery arranged.

– Company C: By local power authority or company.

– Company E: Local power on mains, backfeeding (research: remote powering through light.)

b) Who provides the power equipment initially?

– Company A: The operator.

– Company B: The operator.

– Company C: The network operator or company that sells the ONT or system to the customer.

– Company E: TBD.

c) Who is responsible for maintaining the power equipment?

– Company A: The operator.

– Company B: If the CPE is arranged at home, the subscriber will maintain it (just using AC); if CPE is arranged outdoors, whether using AC or battery, the operator has to maintain it.

– Company C: Customer is seen as being responsible.

– Company E: TBD.

d) Who is responsible for replacing the battery?

– Company A: The operator.

– Company B: It depends on what the battery type is; mostly, the operator will be responsible for it.

– Company C: Customer is seen as being responsible.

– Company E: TBD.

e) Who pays for the electrical power?

– Company A: The operator pays for the electrical power for OLT equipment. The customer to whom the operator provides the service pays for the ONT electrical consumption.

– Company B: If indoors, the subscriber will pay; if outdoors, the operator will pay.

– Company C: Customer pays.

– Company E: TBD.

7) What is the outlook on the potential regulation of:

a) Normal power consumption of the CPE? (e.g., curbs on consumption, reimbursing cost of power to the user, etc.):

– Company A: For some curb using, the ONT power consumption requests will be critical, in some cases, the total power consumption of the ONT should be less than 15~20 W. But in the curb-using cases, the installation condition is not good, especially the humidity and the temperature; so we need a powerful fan solution for such power-consumption requests.
– Company B: Not sure for the exact value recently, it can be discussed based on several test results, balancing the performance and the cost.
– Company E: TBD.

b) Battery backup of fibre-fed CPE? (e.g., duration of backup, minimum availability criteria, etc.):
– Company A: The minimal fibre to the curb requirement for battery duration is at least 2 h in China.
– Company B: Also not sure for the criteria, maybe 2 h standby is the minimum.
– Company C: Regulator will provide guidance on the usage of battery backup and total power consumption. With new VoIP services, backup of the phone is uncertain, as VoIP phones and RGWs are likely to require powering. However, consideration must be given for alarm systems and panic or help systems for the elderly or infirm.

8) What is the current stance regarding power reliability? Including:

a) For how long is power backed up?
– Company A: At least 2 h for FFTB/M/C, at least 30 min for SFU FTTH;
– Company B: Not sure for this question.
– Company C: 3 h to 8 h.
– Company E: If any, 2 h to 4 h.

b) Are services maintained for different periods of time?
– Company A: No.
– Company B: Not sure for this question.

c) How is aging of the battery or loss of capacity managed?
– Company A: Usually every 2 years for FTTB, but no detailed requests for FTTH case.
– Company B: Longer than 2 years for daily use is expected.
– Company E: Voltage monitoring and recording during charge and discharge.

d) When AC power supply for ONT is shut down, is power shedding necessary to sustain operation?
– Company A: No.
– Company B: I think so, but less cost for this additional function is expected.
– Company C: These points are still to be decided within the company and with guidance from the regulator.

9) What is the perceived compromise between service availability and power savings, on a service-by-service basis?
– Company A: The priority of guaranteeing service availability is much higher than power saving; the power-saving rules should meet industry criterion.
– Company B: If there is VoIP in service, for example, service availability is more important; moreover, the purpose of the power-saving solution is to benefit service availability.

– Company C: These points are still TBD within the company.

10) In order to save power, what cost increases would be tolerable?

a) In the ONU equipment (e.g., additional circuitry to implement low-power modes)?

– Company C: 10% increase in the ONT or ONU cost.

– Company E: It depends on BBCoC application.

b) In the power equipment (e.g., different battery type, more efficient converters, etc.)?

– Company C: Previous work has enabled the company to look into new battery technologies, several of which are being investigated by technology companies, providing higher capacity, longer life and environmental safety, compared to lead-acid technologies commonly used in FTTx deployments and trials.

– Company E: TBD.

c) In the installation of the equipment (e.g., indoor or outdoor)?

– Company A: We prefer the ONU equipment part.

– Company B: Where the cost increase is not the point, the total quantity is the key, and it should be strictly controlled.

– Company C: Our company does not have a good understanding at present of the advantages and disadvantages that power supplies for the residential market may require. However, if external, we are concerned about the temperature effects. We are prohibited from taking mains power external to the residence for an external ONT/U. Thus, a power converter would have to be internal.

– Company E: TBD.

*General question*

11) Is there any other information you would like to share regarding the issue of powering of ONU devices?

– Company B: Not yet.

– Company C: At present, the company is, via a climate change task force, rolling out:

• More robust procurement principles.

• Inclusion of EU energy efficiency codes of conduct (TV, power supplies, broadband).

• Design concept of always available instead of always "on", this is critical to enable power management.

• Work is underway across the company to provide solutions in compliance with [BBCoC v8.0], this has the benefit of saving energy or reducing $CO_2$ for the company and for our customers; a true win-win that can differentiate us in the market.

– Company E: New work item proposed in the EE committee of the European Telecommunications Standards Institute on backfeeding (powering on pairs from the customer termination unit power supply). In this case, power-saving modes are especially desired to reduce customer energy bills and battery size for a given autonomy. This solution might be linked with the issue of availability of service if mains power fails. Some autonomy could be maintained for "lifeline". The IP phone function should have a power requirement not higher than old phones, i.e., 2 W in communication and almost no power on standby.

## I.2 Power survey No. 2 responses

### I.2.1 Background

Two situations can arise where power shedding or management is required. These are:

1) Loss of local power to the premises where a battery backup is provided to the ONU or ONT to maintain essential services.

2) Power saving to reduce energy cost or emissions, e.g., when traffic is low.

In the event of a total loss of power, it is possible to send a Dying Gasp message. This alerts operators to the fact that an ONU/T has lost synchronization with the OLT due to power loss, not physical fibre faults.

TC layer chip manufacturers raised the following questions.

- Which services shall be considered critical and maintained no matter what?
- Which services can be sacrificed as power goes down? (What are the criteria?)
- How to tell an active session from inactive one (this is a completely new concept within [ITU-T G.984.1] [ITU-T G.984.2] [ITU-T G.984.3] [ITU-T G.984.4] [ITU-T G.984.5] [ITU-T G.984.6] [ITU-T G.984.7]; which is service-specific and interface-specific?)
- What are the acceptable trade-offs between power saving and quality of experience (longer wait times for the services to start, etc.)?

A low-power mode is proposed for addition to the EU BBCoC. In the case of GPON, it is assumed that essential services such as telephony can be maintained in this mode.

### I.2.2 Assumptions

It is assumed that there are multiple communication or service providers (M, N, P) who may supply different voice data and video services. Each provider is allocated unique port(s) on the GPON ONT (POTS or Ethernet) (if there is only one, respond "not applicable" or "NA" to the first one; in the case of POTS, service provider No. 1 is assumed to offer essential services such as telephony).

Questions in this clause have been numbered according to a possible shut-down sequence. Please consider this sequence and change it if necessary in question (18j).

If you have multiple ONU variants for different market segments, please provide two or more responses, one for each ONU type.

### I.2.3 Survey

**Response identification part**

1) In the context of GPON ONU/Ts, is your company a supplier, operator or both?

2) What kind of ONU are you giving a response for (e.g., residential house, small- or medium-sized enterprise, media distribution unit (MDU), very high-speed digital subscriber line 2 remote node)?

**Survey part 1 – Loss of local power to the premises where a battery backup is provided to the ONU to maintain essential services such as telephony**

3) Would you like the GPON ONU/T to operate in special low-power mode to minimize the capacity of the battery (e.g., a low speed mode)? (It could maintain a communications link for reporting supervisory parameters and be used for a voice or emergency, telemedicine or burglar alarm-type services)?

   Respondents were invited to consult BBCoC v2.

4) How many ports do you need or wish to maintain in battery-only mode (e.g., one)?

5) What services do you want the battery to protect (e.g., telephony, burglar alarm, low speed telemetry)?

6) Is your battery internal to the ONU/T?

7) Is your battery external (e.g., a customer-provided option)?

8) How many hours essential service backup is required inactive (e.g., 8 h)?

9) How many hours essential service backup are required when active (e.g., 1 h, even in the final hour)?

10) Do you require a battery condition monitor/alarm?

11) If yes to (8), do you require a status reporting interface (e.g., battery present, running on battery, low battery, self-test, replace battery)?

12) If the battery is external, do you require a status reporting interface?

13) What kind of presentation do you require for telephony (e.g., registered jack 45 (RJ45), Ethernet, PoE)?

14) If the telephony interface is digital, what is its transmission rate (e.g., 130 kbit/s)?

15) What condition is detected to cause low-power mode for telephony (e.g., loss of AC power)?

16) As a first step in energy saving, would you like a customer-operated switch or remote control unit on the ONU to force the same low-power mode even when AC is present (hence a standby mode)?

17) What condition(s) are detected to cause restoration to full power (e.g., AC power restored or customer energy saving switch to off)?

**Survey part 2 – Power saving to reduce energy cost or emissions, e.g., when traffic is low**

Please add additional interfaces if required. Write "NA" if an interface is not required (it is assumed that there are multiple communication or service providers M, N and P).

18) Power-saving shutdown priorities and sequence. Under what conditions would you support reduction/shutdown of the following service interfaces.

 a) An RF video port (e.g., on mains failure or absence of an RF load or user defined)?

 b) A data UNI No. M which is configured for video (e.g., on mains failure or absence of video traffic, STB powered down or port disconnected)?

 c) A data UNI No. 1 which is configured for video (e.g., on mains failure or absence of video traffic, set top box powered down or port disconnected)?

 d) Data UNI No. N to move to power-saving/low data rate mode (e.g., input buffer showing low data rate traffic for 5 min or user-defined number of minutes, port disconnected, port powered down)?

 e) Data UNI No. 1 to move to power-saving low data rate mode (e.g., input buffer showing low data rate traffic or user-defined number of minutes port disconnected, port powered down)?

 f) Data UNI No. N in power-saving mode to shut down (e.g., when the battery, if present, is exhausted or AC mains failure)?

 g) Data UNI No. 1 in power-saving mode to shut down (e.g., when the battery, if present, is exhausted or AC mains failure)?

 h) POTS or VoIP UNI No. P (e.g., when the battery, if present, absence of traffic, no terminal adapter (TA), TA powered down, is exhausted or AC mains failure)?

 i) POTS UNI No. 1 (e.g., this is the essential service port and will only disappear when the battery is exhausted under mains failure, if possible a Dying Gasp or low battery tag should be added to the final packet sequence)?

j) Do you need to change the order of shut down (from a, b, c, d, e, f, g, h, i)?

k) Other issues (e.g., ports that are not assigned to a service should be automatically shut off or down)?

19) What data rate do you require for the energy saving mode (e.g., 130 kbit/s or programmable up to 1 Mbit/s)?

Respondents were invited to consult BBCoC v2.

20) In order to reduce power by 50%, what cost increases would be tolerable? (Note that over the 12 year life of an ONU/T, the cost of 12 W is approximately USD 250 assuming no energy price changes).

a) In the ONU/T (e.g., 1%, 2%, 3% 5%, 10%, 20%).

21) Restoration to full power mode.

a) Who has authority to change the state of an ONU/T UNI interface (e.g., operator for test and configuration, service provider, customer)?

b) Who has authority to change the state of an ONU/T ANI (optical) interface (e.g., operator for energy saving mode test and configuration, service provider, customer)?

c) What time delay is acceptable when the ONU/T is first installed (e.g., <40 s)?

d) What time delay is acceptable when AC power returns to the ONU/T (e.g., <5 s)?

e) What time delay is acceptable when the ONU/T moves from low-power mode to higher power (e.g., as soon as a low data rate input buffer is full)?

**Survey part 3 – Power targets**

**Background**

The BBCoC proposes the following targets:

A) 'Off' state = 0.3 W by 2009-12-31 (this is the state when the ONU is connected to AC but the power switch is off). This could be the essential services-only state in part 1 of the questionnaire.

B) 'Low-power' state = TBD (this is the state we refer to in part 2 of the questionnaire for low traffic energy saving.)

C) 'On' state = 12 W by 009-12-31 (this is the operational state when there is a maximum of one optical port, one Ethernet port and one USB port.)

**Survey**

22) What maximum power consumption would you like to see when the ONU/ONT is running on battery or when the power switch is off (e.g., 0.3 W by 2009-12-31)?

23) What maximum power consumption would you like to see when the ONU/ONT is running in low energy or low traffic mode (e.g., 2 W by 2009-12-31)?

24a) What interfaces and number of interfaces are operational under full power (e.g., 2 × analogue telephony, 2 × Ethernet, 2× PoE)?

24b) What is the maximum power consumption you would like to see when the ONU/ONT is running on full power (e.g., 5 W today and 2 W in 2 years time)?

*General question*

25) Is there any other information you would like to share regarding the issue of powering of ONU/T devices (e.g., dry loops, security and access issues, power reset facility)?

### I.2.4 Survey results

See Table I.1.

## Table I.1 – Survey results

| Question# | | BT | FT | VZ | TI | Company A |
|---|---|---|---|---|---|---|
| 1 | Supplier or operator. | Operator. | Operator. | Operator. | Operator. | Potential operator. |
| 2 | ONU type. | Residential. | SFU | Residential SFU. | Residential SFU. | Residential houses. |
| **2.1 Battery mode** | | | | | | |
| 3 | Battery low-power mode. | Yes. | Yes according to BBCoC standby mode to minimize the consumption applying to both situations, with and without battery back-up. | Yes, the respondent quoted BBCoC v2. | Yes, we are interested. | Yes, we are interested in it. |
| 4 | Number of ports on battery. | 2 | 1 | All ports provisioned on ONT. | At least 1 | 1 |
| 5 | Battery protected services. | Ethernet port only 135 kbit/s or 2/10 Mbit/s enabled. | Telephony in the short term, other applications to use the same interface. In the longer term, another UNI type could be retained to carry lifeline services with high availability figures. | Telephony, with simultaneous abilities for other services per operator option or selectable. | At least telephony | A premium-grade VoIP service |
| 6 | Battery internal to the ONU/T. | Not determined. | No. | No. | Yes. | Yes, if battery is used. |
| 7 | Battery external to ONU/T. | Not determined. | Yes option. | External, Verizon installed, customer owned after one year. | No. | No. |
| 8 | Hours essential service backup inactive. | NA | 4 | 8 to 10 h | >4 n | 3 h |
| 9 | Hours essential service backup are required when active. | 4 h | Not specified, human Dying Gasp/emergency call expected at least. | 8 h | 4 h | Not clear. |
| 10 | Battery condition monitor/ alarm. | Yes. | Yes via dry loops. | Yes. | Yes. | Yes, if battery used. |
| 11 | Status reporting interface. | Yes-all. | Yes. Mains loss detection and low battery to be fed in Dying Gasp conditions. | Yes. | Yes-all. | Yes, if battery used. |
| 12 | Battery is external, status reporting interface. | Yes. External or internal. | Yes. | Yes. | NA. | NA. |
| 13 | Telephony presentation. | Ethernet. | RJ45 | POTS via on-board SLC chips, registered jack 11 (RJ11). | RJ11 | RJ45 via VoIP adaptor. |

**Table I.1 – Survey results**

| Question# | | BT | FT | VZ | TI | Company A |
|---|---|---|---|---|---|---|
| 14 | Digital telephony interface. | 135 kbit/s. | 320 kbit/s mapping. | N/A at this time. | TBD. | 180 kbit/s (with margin) |
| 15 | Low-power mode trigger. | Loss of AC power. | Loss of AC power and conditionally (to wake up duration and incoming traffic detection conditions) detection of no traffic over a period might be added if efficient. | Loss of 48 V DC from intermediate power supply. | Loss of AC power or detection of no traffic for *x* min. | Loss of AC power. |
| 16 | Customer operated switch. | No. | A switch on the ONU can be added, but preferably the function should be automated to be efficient. | No, operator-configured only. | Yes. | Not when AC is present. |
| 17 | Restoration to full power. | AC power restored. | Either, the customer being warned that by switching to off the duration of the standby will be reduced. | Re-application of +48 V DC. | AC power restored or traffic detected. | AC power restored. |
| **2.2 Energy-saving mode** | | | | | | |
| 18 | Shut down sequence | | | | | |
| a | RF video. | NA. | Mains failure. Should not be powered without service provision via OMCI. | Mains failure – 15 s support or operator-configured timer to port power down. No RF load – operator-configured timer to power-saving mode. | NA. | x |
| b | Digital video UNI No. 1. | NA. | Mains failure, and shutdown of downstream possible until an IGMP report command requires a stream. | NA. | Mains failure, and shutdown of downstream possible until an IGMP report command requires a stream. | x |
| c | Digital video UNI No. M. | NA. | Mains failure, and shutdown of downstream possible till an IGMP report command requires a stream. | When present: Mains failure – 15 s support or operator-configured timer to port power down. No video traffic-operator-configured timer to power-saving mode. Port disconnected – Port power down. | Mains failure, and shutdown of downstream possible until an IGMP report command requires a stream. | x |
| d | Data UNI No. N. | Port disconnected. 1 h to low traffic status. | | NA. | No traffic for *x* min. | x |
| e | Data UNI No. 1 to move to power-saving low | We have four ports all to be treated the same. | | Low data rate detected – Operator-configured timer to low data rate or | All data ports to be treated the same. | x |

**Table I.1 – Survey results**

| Question# | | BT | FT | VZ | TI | Company A |
|---|---|---|---|---|---|---|
| | data rate mode. | | | power-saving mode. Inactivity detected – Operator-configured timer to power-saving mode or port power down. Port disconnected – Port power down. | | |
| f | Data UNI No. N in power-saving mode to shut down. | When battery is exhausted, all ports are the same. | x | NA | After a standby of *y* min. | x |
| g | Data UNI No. 1 in power-saving mode to shut. | When battery is exhausted, all ports are the same. | x | Mains failure – Operator-configured timer to low rate or power-saving mode, and then port power down. Battery exhaust – Port power down. Port disconnected – Port power down. | After a standby of *y* min. | x |
| h | POTS or VoIP UNI No. P. | NA. | x | NA. | Not clear. | |
| i | POTS UNI No. 1. | NA. | x | Mains failure – Normal operation on battery, then move to power-saving mode per operator-configured timer. Operate under a power-saving mode until battery exhaust. Dying Gasp indication near exhaust, e.g., added to final packet sequence or similar. | Not clear. | x |
| j | Change order of shutdown from a-i. | No. | * Not unless it is preferable for the end user to save one data UNI in full operational mode even after starting to shut down the interfaces N to 2. Note that, contrary to video services, data ones on a mobile computer work on a battery. | No. | Not clear. | No. |
| k | Other issues. | Yes, any unconnected port or powered down port (if possible). | | Unassigned and disconnected ports are not powered. | Unassigned and disconnected ports are not powered. | x |

**Table I.1 – Survey results**

| Question# | | BT | FT | VZ | TI | Company A |
|---|---|---|---|---|---|---|
| 19 | Data rate. | Not determined yet. | 320 kbit/s for voice. | The respondent quoted BBCoC v2. Programmable up to full data rate. | Not determined yet. | 100 to 300 kbit/s, programmable. |
| 20 | Cost for energy saving. | Not determined yet. | x | Unknown at this time. | Not determined yet. | 3% |
| **21 power restoration** | | | x | | | |
| a | UNI who has authority to change state. | Operator or communication provider or service provider may wish to disable standby mode (to make it always on). | Default by access connectivity operator, but ownership and management scheme dependent. UNI to be provisioned before entering a powered mode. When on, user should have action capability. Service provider to be aware of shutdown to ignore warnings and alarms resulting from a normal operating state of ONU/T. | Operator. | User should have action capability. Service provider to be aware of shutdown to ignore warnings and alarms resulting from normal operation. | Customer. |
| b | ANI who has authority to change state. | The operator if required or beneficial. | User and access network provider. | Operator. | User and access network provider. | Customer. |
| c | Time delay on first install. | <40 s. | Cold start value from [ITU-T G.984.3]. | <40 s. | TDB. | Not clear. |
| d | Time delay is acceptable when AC power returns. | <5 s assuming battery still alive. | <1 s. | <5 s. | <5 s. | Less than several seconds. |
| e | Delay as ONU/T moves from low-power mode to higher power. | ≤2 s. | <1 s. | AC present – as soon as return to normal trigger or condition is detected. Battery operation/no AC – immediate for POTS upon off-hook or incoming call acknowledged. | ≤1 s. | Much faster than (e.g., 40 s). |
| **2.3 Power targets** | | | | | | |
| 22 | Maximum power consumption on battery. | <2 W. | The one required in question 25. | Unknown at this time. | The NT power consumption must comply with EU BBCoC v2,specifying values to be applicable from 2009 for an ONT comprising 1 GPON interface;<br>1 10/100/1000 Ethernet UNI port | Not clear. |

**Table I.1 – Survey results**

| Question# | | BT | FT | VZ | TI | Company A |
|---|---|---|---|---|---|---|
| | | | | | and 1 USB device;<br>12 W maximum in operation. | |
| 23 | Maximum power consumption in energy saving mode. | <3 W. | The one enabling a reasonable wake up incoming data or signal (ANI chips might be always on if no satisfactory TC solution is available). | Unknown at this time. | 0.3 W off position maximum consumption.<br>TBD: standby mode consumption. | Not clear. |
| 24a | Interfaces are operational under full power. | 4 Ethernet. | 1 full rate FEthernet on RJ45, and optionally 1 POTS at least. | 2 × POTS, Ethernet, RF video. | Unassigned and disconnected ports are not powered. | 1 × telephony (via VoIP) and 1 × Ethernet (gigabit Ethernet or FE). |
| 24b | Full power consumption in watts. | 5 W today, 3 W target. | | Unknown at this time. | See BBCoC targets. | Not clear. |
| 25 | Other information | Vendors: Is there a power benefit in using 10 Mbit/s for Ethernet rather than 100 Mbit/s or 1 Gbit/s? | Underline the functions that cannot be shut down (clock/date, opening detection) to ensure full network integrity and the related power consumption for an internal battery that justify a non-zero consumption when ONU/T is turned off. | Triggers and timers set to default with ability for operator to configure. | | x |

## I.3 Power survey No. 3 responses

The term lifeline may be confusing as it applies to various services, such as the telecommunication company-provided discounted telephone service to qualifying low-income households (e.g., California Lifeline), third-party-provided medical alert services that appear as applications using the basic voice or data telecommunication services (e.g., Philips Lifeline). To avoid ambiguity, we refer here to emergency calling service (e.g., North American E911 service) and medical alert services.

*Section 1. Configurability*

Individual user preferences with respect to GPON functionality available under outage may vary both from user to user and in time for any given user. Examples may include a user who:

– would like to be able to place an outgoing emergency call for as long as possible;
– would like to maintain an automatic medical monitoring or alert service utilizing either phone or data service continuously throughout the outage;
– would like to be able to receive incoming well-check calls from family members;
– has a PC and router running off a battery or uninterruptible power supply (UPS), who intends to use some other means for emergency calling purposes, but who would like to maintain access to a finance management server throughout the outage;
– is not concerned with voice or data services, but who would like to watch a game of their favourite team in real time.

*Questions*

1.1 Under the regulations that exist in your jurisdiction, which services are you obliged to support in a power outage situation regardless of user preference? For how long should these services be supported?

- FT: Current regulation in Europe for optics does not oblige the operators to do anything since no "universal nor lifeline service" over fibre has been specified. Nevertheless, it can be predicted that within the GPON lifecycle, that PON technology must be capable of carrying POTS services with lifeline-compatible availability figures. A minimum value for maintaining a remote POTS line is 4 h; optionally, an 8 h value should be considered, given mains outage statistics.
- BT Openreach: Openreach is operator of the BT access network. Our ONT is different in concept from others as Openreach must allow equivalence of input for communication (service) providers (CPs) and currently specifies two pairs of Ethernet ports for this purpose; two for each CP. Openreach does not define the services. Battery backup will be capable of sustaining the ONT for 4 h for all CPs. Telephony service can be offered by CPs who would use Ethernet TAs to derive the service, as shown in Figure I.1.

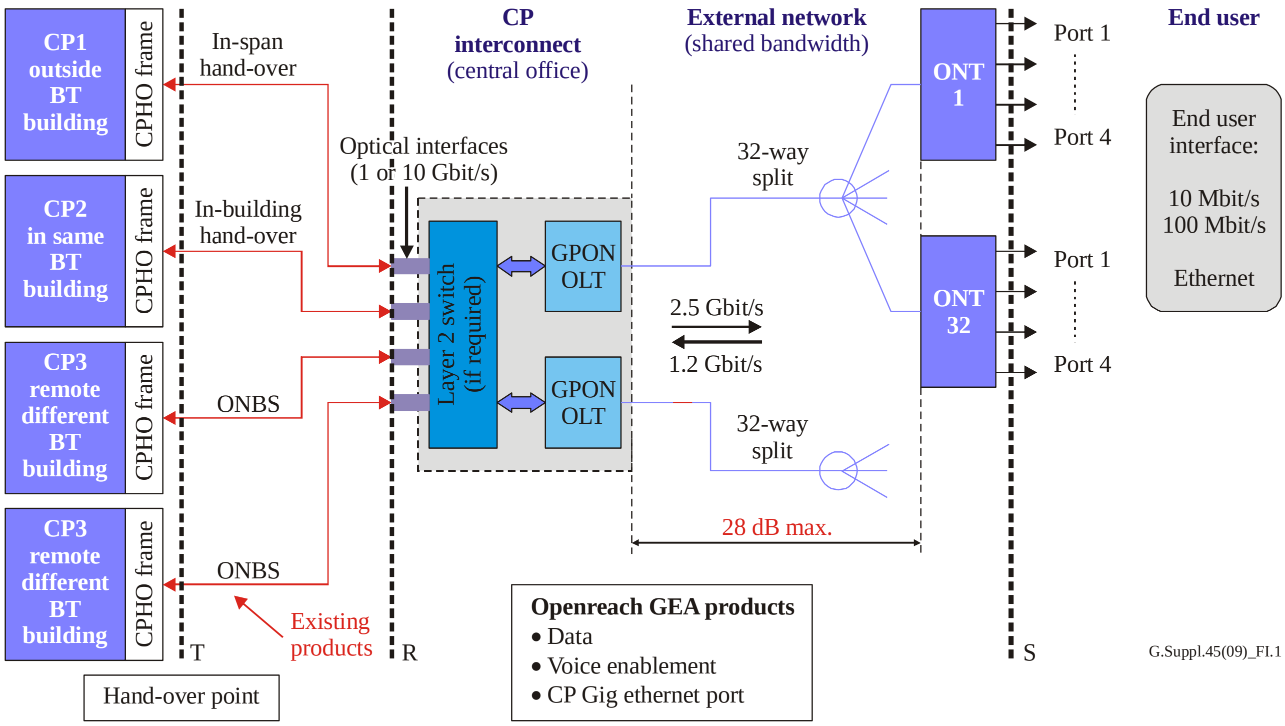


**Figure I.1 – Fibre to the premises generic Ethernet access architecture**

- Company A: Services: POTS and narrow-band ISDN. How long: No limit (because remote powering is available for these services).
- VZ: There are no federal, Federal Communications Commission or state requirements to provide POTS or other services during power outages at this time. Some states are currently considering regulatory action that may mandate specific requirements. Historically, operators in the USA have targeted 8 h of POTS support during outages via CO and remote terminal back-up systems. Customers are responsible for providing a handset capable of functioning during outages, e.g., traditional analogue POTS handset or UPS-powered handsets. For FTTH applications, Verizon provides an ONT back-up battery during initial install. The battery then becomes the customer's responsibility for ongoing maintenance or replacement. Verizon FTTH systems currently support POTS for 7 h continuous, and an additional 1 h of emergency use (outgoing only) through

manual selection by the customer. Future FTTH systems must be able to support at least this same level of service during outages.

1.2 Which other services would you classify as protected under power outage and would like to support regardless of user preference and for how long?

– FT: Rather than service, at this stage the nature and type of interface to maintain should be considered. There is a significant probability that the lifeline service, now known with Z interface, will be transferred to an Ethernet interface for VoIP or otherwise, TBD. Second application beyond human care will be the intrusion detection or home monitoring type service that is in no way imposed by regulation. Duration should nominally be of 4 h, and longer options should be developed. Another major question within the scope is whether consideration needs to be given to a single or several simultaneous interfaces (in the case of an MDU ONU).

– BT Openreach: N/A (covered by 1.1)

– Company A: Premium grade VoIP service via optical access (under study). How long: Not clear at this moment but see 3.1 for reference.

– VZ: In addition to voice service, the POTS interface must remain active during the outage support time allowing for normal burglar, CO or fire alarm system access to a monitoring centre as well as supplying the required POTS line voltage preventing false alarms. This feature is only maintained while the ONT is powered by a battery or has an AC power source. Operators should have the option to select the services or ports that are protected during a power outage and the duration the port remains active. Default duration settings may be acceptable in lieu of programmable settings. For example, data and video could be optioned independently to remain active for a period of zero to several seconds or minutes.

1.3 What are the provisions in the regulations existing in your jurisdiction that govern the power backup of the equipment deployed at the customer premises in a power outage situation?

– FT: See 1.1 so as to be coherent between OLT and ONU.

– BT Openreach: 4 h is considered reasonable.

– Company A: There is no provision for power backup of customer premises at this moment.

– VZ: As noted in 1.1, there are no specific regulations to provide service during an outage; however, operators should have the ability to provide this option.

1.4 Would you consider allowing the user to select the services (voice, data, video) that remain available during the power outage?

– FT: Surely on the OLT side the operator should match the best compromise between its service bundle requirement and the power-saving concern, but on the ONU the access network operator can only suggest a best practice default configuration, that the user should be able to override, since it provides mains. There is still a mandatory condition for that, which is that any change is reported and registered to show that any modification was made voluntarily by the user thus knowingly impacting the lifeline if it is the case.

– BT Openreach: NA.

– Company A: NA.

– VZ:

By allowing the user to configure the services him-/herself?

– FT: Yes, with direct access on ONU if inducing no security problem (PON harming).

– BT Openreach: Not within Openreach control. Any CP in UK could be asked the question.

– Company A: No.

– VZ: No, operator selectable only.

By allowing the user to register his/her preferences (via website, customer service call, etc.) for configuration by the operator?

– FT: Safer solution to avoid possible problems, but withdrawing possibly capability of emergency change of the policy.

– BT Openreach: Not within Openreach control. Any CP in UK could be asked the question.

– Company A: No.

– VZ: Yes, the capability for a customer to select options or preferences via a secure mechanism or portal would be desirable.

*Section 2. Feasibility of trade-offs*

In the situation of power outage, the quality and availability of services are in inverse relation with the duration of time the services can be supported.

2.1 Under power outage, would you consider compromising the service availability or quality in order to increase the duration of the service support? What are the conditions and the extent of the trade-off?

– FT: As long as Z and POTS interface is used we see little gain. If switching to Ethernet interface, most probably 1 GigE should be avoided, but it is arguable if auto-negotiation should fall back at 10 Mbit/s. Most probably anyway voice interface would at most be at 100 Mbit/s.

– BT Openreach: Not within Openreach control.

– Company A: Yes. e.g., bandwidth versus duration.

– VZ: POTS service is expected to perform for ≥7 h without degradation and an additional 1 h for outgoing only. Some trade-offs may be acceptable if a significant increase in battery duration can be gained through creative alternatives pr mechanisms. An acceptable trade-off might include a slight dial tone or ring delay for outgoing and incoming calls to allow for wake-up and ranging. Quality of the call should not be impacted. For data and video, operators should be able to select duration of battery back-up, if any, and service quality or performance should be maintained within that duration. In addition to battery duration, other benefits that may be enabled via power conservation measures include reducing back-up battery size and lowering battery cost.

2.2 Would you consider allowing the user to determine such a trade-off (by either direct configuration or registering the preferences with the operator)?

– FT: Under condition that no security issues are raised, and that the operator's responsibility cannot be invoked if any user were to mishandle this feature.

– BT Openreach: Not in Openreach control. Any CP in UK could be asked.

– Company A: No.

– VZ: Yes, the capability for a customer to select options or preferences via a secure mechanism or portal would be desirable.

*Section 3. Voice service and emergency calling*

3.1 Can you quantify the expected amount of call activity during power outage (in terms of number and duration of incoming and outgoing calls over the specified time interval)?

– FT: Several call attempts should be possible to take misdialling in stress situations into account – 5 min to 10 min at least should be targeted for full diagnostic report to emergency authorities.

– BT Openreach: Not within Openreach control. Any CP in UK could be asked. They operate the TAs.

– Company A: In our experience of providing POTS services via STM-PON, a power outage is assumed to last 3 h and the telephony traffic then is assumed as 0.1 Erlang. Note that this is not a regulation but just a reference.

– VZ: These numbers will vary greatly by customer and outage event, typically 1 to 2 calls/h, 1 to 10 min in duration.

3.2 Would you consider restricting the incoming call capability in a power outage situation?

(Restricting the incoming calls may amount, for example, to allowing them only within a specified time interval after an outgoing call was placed)

– FT: Not currently; could be conditionally envisioned.

– BT Openreach: Not within Openreach control. Any CP in UK could be asked.

– Company A: Not sure.

– VZ: Yes, Verizon is currently looking to deploy this type of scenario in the near future. Other options could be considered.

3.3 Would you consider foregoing the dial tone delay requirement to save battery power and increase the overall duration of outgoing emergency call support? What is the maximum dial tone delay that you are willing to tolerate, provided a comfort tone or message is generated?

– FT: Must remain compatible with POTS or Z interface specifications and timeouts to place the call. For instance, in the case of fall detection- type applications, it is not as much the delay in seconds that counts but the fact that the event is reported, because it should not happen twice.

– BT Openreach: Not within Openreach control. Any CP in UK could be asked.

– Company A: Not sure.

– VZ: Possible trade-offs need to be explored. A delay of 2 s or 3 s could be considered. Longer delays may be possible if mechanisms such as an indication to the customer are provided. For example, the customer could be provided a recorded message to alert them that there will be a delay in getting a dial tone. In this way, the dial tone delay could possibly be extended beyond 3 s to as much as 12 s. Greater delays may also be considered.

3.4 Which other aspects or requirements of the voice service (if any) you would be willing to compromise in order to save battery power and increase the overall duration of outgoing emergency call support?

– FT: Apart from the fact that the Z interface might work in a lower power mode because the line length will be short, no clear benefit is seen so far.

– BT Openreach: Not within Openreach control. Any CP in UK could be asked.

– Company A: Not sure.

– VZ: Verizon is not aware of any other aspects of voice service that could be compromised, but other solutions could be considered based on trade-offs.

## I.4 Power survey No. 4 responses

Upon request of some of the answering companies to keep theirs answers anonymous, the following collapsing of answers has been adopted. See Tables I.2 to I.6.

**Table I.2 – Section 1: Motivation**

| Questions | Answers | Comments |
|---|---|---|
| Has your company published any objective on power consumption reduction (Y/N). Please give details in the comment section | 7/8 Y | Key performance indicators (KPIs) for power consumption reduction metering<br>Mostly expressed as $CO_2$ reduction (including power type)<br>Common figures are several 10s% within 5 to 10 years |
| Has your company signed any commitment to reduce its power consumption (Y/N). Please give details in the comment section (Are specific regional texts applicable in your context?) | 6/8 Y | As of answers received today, Europe seems to be the most notable EE striving region |

**Table I.3 – Section 2: Domains to be covered**

| Questions | Answers | Comments |
|---|---|---|
| Does your company specify power reduction techniques in PON OLTs? | 6/7 Y | Still operators rely on vendor's ideas for OLT EE<br>Compliance with BBCoC is the most common requirement |
| Does your company specify power reduction techniques in PON ONUs? | 4/7 Y | Business models differ with ONUs under third party responsibility<br>Compliance with BBCoC comes first |
| Does your company specify power reduction techniques in PtP? | 3/7 Y | Not always originated from the same chassis or responsibility<br>Felt to be a different topic. Compliance with BBCoC still quoted |
| Is the saving priority on the ONU side or the OLT side? Please detail motivation | 4/8 OLT<br>4/8 Both, with ONU first | OLT comes first … because of KPI within the operators<br>Most power though to be obtained with ONUs EE modes, requiring OLT awareness, even in unbundling schemes |
| Has your company identified any energy efficiency method missing within the scope of question 2 in its recommendation portfolio? (Y/N) Please give a high level explanation. | 4/8 Y | Proportionality to real data rate seems to be the global target with various tools: escaping useless processing, burst mode in downstream, line rate agility to extend sleep periods |

**Table I.4 – Section 3: Architecture options**

| Questions | Answers **from seven operators** | Comments |
|---|---|---|
| Percentage of fibre to the antenna/fibre to the wall ONUs? | 3 Y<br>≤1% | Considered by most as a specific system |
| Percentage of MDU/maximum transmission unit?<br>Multi-user ONUs, and if there are more than one type, please elaborate. | 2 Y<br>≤10% | Very minor share of distribution point unit (DPU) for two respondents |
| Percentage of fibre to the office ONUs? Business or Enterprise users | 4 Y<br>≤10% | Small amount, mostly over PON for one respondent, but with comparatively small amount of BiDi PtP |
| Percentage of FTTH SFU, residential ONUs? | >90% for 4 operators<br>30% for 3 operators | Largely dominating market share |
| Percentage of FTTH, HGU, residential ONUs? | 60% for 3 operators<br>10% for 1 | Mentioned by three respondents, with rapid growth for one of them mentioning 60% SFP ONU integrated here |
| Percentage of ONU types not previously mentioned? | 3/7 Y | Outdoor DPU and IoT ONU with minor volumes so far |
| Is your company considering a mix of architectures and ONU types above? (Y/N) | 5/7 Y | Only to *N* indicating that different networks will be used for different markets |

**Table I.5 – Section 4: Service considerations**

| Questions | Answers | Comments |
|---|---|---|
| Are lifeline services supported? (Y/N) | 2/7 Y | Do not know and Ns recover uncertainties, among which full migration from copper.<br>Very limited volumes so far |
| On which type of interface will they be provided? | POTS/FXS/Ethernet | Migration from copper puts FXS first but answers show ongoing studies |
| Is RF video overlay supported? (Y/N) | 2/7 Y | On specific limited markets, not integrated in the ONU in one case |
| Are battery back-up solutions provided? (Y/N) | 2/7 Y | Comes with the lifeline services |

**Table I.5 – Section 4: Service considerations**

| Questions | Answers | Comments |
|---|---|---|
| Are battery back-up monitoring solutions provided? (Y/N) | 1/7 Y | |
| Are your ONUs dual managed? (Y/N) | 3/7 Y | [BBF TR-069] used for UNIs in addition to OMCI for ANI.<br>Responsibility limit with voice retailer mentioned. |

**Table I.6 – Section 5: Interest in specific mechanisms**

| Questions | Answers | Comments: Answers pending amount of savings and sustainable impact on user experience |
|---|---|---|
| Is your company interested in OLT low-power modes? (Y/N) | 9/9 Y | As expected. operators are careful and willing to use them if effective, bringing significant savings and no affect the user experience |
| Is your company interested in ONU power shedding? (Y/N) | 6/9 Y | Except for SFU only operators or those not providing the ONUs. Not necessarily considered as an EE tool |
| Is your company interested in ONU Watchful Sleep? (Y/N) | 7/9 Y | Except for operators not providing the ONUs |
| Is your company interested in PON upstream line rate switching? (Y/N) | 4/9 Y | Reservations have been made about the amount of power savings. Further studies clearly needed |
| Is your company interested in PtP sleep modes? (Y/N) | 6/9 Y | One respondent indicated that wake up time might generate some delay so appropriate before actual connectivity to an ONU is established. Check IEEE's energy efficient Ethernet |
| Is your company interested in PtP line rate switching? (Y/N) | 5/9 Y | Reservations have been made about the amount of power savings because of the multiple stacks |
| Is your company interested in investigating the savings possible through RE-enabled architectures? (Y/N) | 4/9 Y | Interest for the future, pending further study. Doubts about savings expressed, when limited to the network elements, a more holistic approach to get savings with technical environment is needed |

## I.5 Power survey No. 5 questions

The fifth survey questionnaire (see Table I.7) gave power conservation in domestic network a go in an holistic approach to probe the collaboration between telecommunication and energy networking that seem closer and close.

**Table I.7 – Survey No. 5 questions**

| Question | Answer | Comments |
|---|---|---|
| **General interest in FTTR or POL** | | |
| Does your company already propose FTTR or POL solutions? | | |
| Does your company investigate the FTTR or POL domains? | | |
| **Private PON/PtP technologies and managers to be considered for FTTR or POL** | | |
| Will solutions include PON technologies? | | |
| Will solutions include PtP optical technologies? | | |
| Should access ONU and private OLT be integrated? | | |
| Should access ONU and private OLT managers be integrated? | | |
| Should access ONU and private OLT be kept separated? | | |
| Should access ONU and private OLT managers be kept separated? | | |
| **Power-provisioning scheme** | | |
| Are different powering strategies for the access ONU and the private OLT to be considered? | | |
| Is a private OLT backup power source in case of mains outage to be considered? | | |
| Is centralized power feeding to the private ONUs to be considered? | | |
| Is power feeding via optical fibre to be considered? | | |
| Is power feeding via hybrid (fibre + copper) cables to be considered? | | |
| Is power feeding through ONU individual access to mains to be considered? | | |
| Are you considering ONUs reverse power feeding through PoE or similar from the terminal? | | |
| Are you considering power feeding of terminals from the ONU through PoE or similar? | | |
| Is a backup power source of at least part of the ONUs to be considered? | | |
| **Services and relationship with service operator options** | | |
| Is only local management of services to be considered? | | |
| Is only remote management of services to be considered? | | |
| Are dual managed services to be considered?<br>Some by a remote operator, some from a local platform | | |

**Table I.7 – Survey No. 5 questions**

| Question | Answer | Comments |
|---|---|---|
| Are services beyond best effort to be considered for FTTR?<br>Best effort is when mains outages cut all services | | |
| Are services beyond best effort to be considered for POL?<br>Best effort is when mains outages cut all services | | |
| Have lifeline services to be supported? (Y/N) | | |
| Have security services to be supported? (Y/N) e.g., access control, intrusion detection, smoke detectors | | |
| Have real time IoT devices to be considered?<br>Understand 0 delay information push by the device upon events | | |
| Have non real time IoT devices to be considered?<br>Understand cyclic polling from a central manager | | |
| Have local power facilities control/management to be considered? (Y/N) e.g., smartgrid or local | | |
| **Interest in specific power-saving capabilities** | | |
| Versatility following mains provider(s) tariffs or constraints | | |
| Versatility following local alternative power sources conditions (wind, solar). | | |
| Other ideas. | | |

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