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

GPON power conservation

ITU-T G-series Recommendations – Supplement 45

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Supplement 45 to ITU-T G-series Recommendations

GPON power conservation

Summary

Supplement 45 to ITU-T G-series Recommendations consolidates the various GPON power-saving proposals in order to facilitate their consideration and comparative analysis from the perspective of the requirements satisfiability, on the one hand, and the overall system impact, on the other hand. This Supplement is formatted as a white paper encompassing the summary of the requirements gathering effort, the specification of the wide spectrum of potential solutions as well as their comparative analysis.

Source

Supplement 45 to ITU-T G-series Recommendations was agreed on 15 May 2009 by ITU-T Study Group 15 (2009-2012).

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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1 Introduction

Power conservation and 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. While this Supplement focuses on GPON power savings, the results are expected to be applicable at least in part to GEPON as well as to NG-PON optical access.

Throughout the years 2006 and 2007, 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: improving the power consumption characteristics of the optical access equipment with the goal to reduce its contribution into greenhouse gas emissions and improving the performance of the optical access equipment in mains outage situations. The survey results have also demonstrated a considerable variability of the regulatory and operating environments where GPON 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 "zero tolerance" approach and full operator control to allow a certain degree of trade-offs and users' freedom of choice.

To satisfy the 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 defined in ITU-T G.984.3 (2008).

This Supplement is structured as follows. Clause 2 contains the condensed presentation of the FSAN/ITU-T GPON power savings survey results; the summary of principles and targets set by the EU Code of Conduct on Energy Consumption of Broadband Equipment, and the overview of the GPON power savings requirement profiles. Clauses 3, 4 and 5 contain the specifications of the proposed power saving techniques partitioned by their relation to the GTC layer into the following groups:

– techniques involving introduction of the new PLOAM messages or new embedded 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.

Finally, clause 6 contains the comparative analysis of the proposed techniques with respect to the specified requirements and clause 7 presents the conclusions.

2 Power savings requirements

2.1 Survey results

2.1.1 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 not a sufficient response to say that any question had a consensus answer. Despite this difficulty, it seemed clear from the responses that power saving is of lesser priority than service quality, availability and interface variety. This led to the conclusion that power saving features should be carefully designed such that they would not sacrifice these other priorities.

2.1.2 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 EU Code of Conduct on Energy Consumption of Broadband Equipment). The responders showed strong interest in a digital telephony interface of 300 kbit/s or less. 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 of the requirements were formulated:

- Same port shutdown sequence was agreed as suggested in the questionnaire.
- Programmable data rates (but no consensus on specific values).
- Less than 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.

2.1.3 Survey No. 3

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

2.2 EU Code of Conduct on Energy Consumption

Code of Conduct on Energy Consumption of Broadband Communication Equipment (referred herein as 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 three published versions of BBCoC:

– Version 1: Ispra, 19 July 2006;

– Version 2: Ispra, 17 July 2007;

– Version 3; Ispra, 18 November 2008.

The current version is available at:
http://re.jrc.ec.europa.eu/energyefficiency/html/standby_initiative_broadband%20communication.htm

The BBCoC defines 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 optical line termination (OLT) as network equipment and the optical network termination (ONT) as customer premises equipment of home gateway type.

Consider as an example two typical ONT[1] configuration styles as defined in the following table.

Table 1 – Typical ONT configuration styles

Typical ONT Configurations	Interfaces			
	GPON	GE	POTS	MoCA
Style 1	1	1	2	1
Style 2	1	4	2	0

The BBCoC would impose the following power level requirements on these ONTs.

Table 2 – Target power levels for a style l ONT

Function	Tier 2009/2010 1.1.2009-31.12.2010		Tier 2011 1.1.2011-31.12.2011	
	Low power state (W)	On state (W)	Low power state (W)	On state (W)
General functions + GPON interface	5.0	9.7	4.0	7.7
1 gigabit Ethernet port	0.3	1.7	0.3	1.3
Dual SLIC (FXS) (Note)	0.8	3.0	0.5	3.0
MoCA	0.4	4.0	2.0	2.5
Total equipment	**10.1**	**18.4**	**6.8**	**14.5**
NOTE – Assuming one interface is totally off in the low power state.				

Table 3 – Target power levels for a style 2 ONT

Function	Tier 2009/2010 1.1.2009-31.12.2010		Tier 2011 1.1.2011-31.12.2011	
	Low power state (W)	On state (W)	Low power state (W)	On state (W)
General functions + GPON interface	5.0	9.7	4.0	7.7
4 port gigabit Ethernet switch	1.5	4.5	1.2	3.7
Dual SLIC (FXS) (Note)	0.8	3.0	0.5	3.0
Total equipment	**7.3**	**17.2**	**5.7**	**14.4**
NOTE – Assuming one interface is totally off in the low power state.				

2.3 Requirements profile summary

As the surveys indicate, the ONU[1] power savings requirements can be associated with one of the two dominating underlying objectives. On one hand, the effort is driven by the emergency services support under the 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

[1] The usage of the terms ONT and ONU throughout this Supplement follows the convention of ITU-T G.984.3 (2008). In addition, in the context of a particular reference discussion, preference is given to the term used within the specific reference.

powered) operations and minimizing the carbon dioxide emissions generated by information and communications technologies (ICTs). The key difference between the two objectives and the two associated requirements 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 his or her preferences with regard to GPON functionality under power outage.

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

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

3 Classification of power saving techniques

3.1 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 has appeared that a more meaningful criterion is the behaviour of the ONU receiver and transmitter while the ONU is in a power save mode.

From the point of view of the ONU receiver and transmitter behaviour, the proposals under discussion fall into the following three categories:

ONU power shedding is characterized by powering off or reducing power to non-essential functions and services while maintaining a fully operational optical link.

ONU Dozing is associated with additional powering off of the ONU transmitter for substantial periods of time on the condition that the receiver remains continuously on.

Finally, **ONU sleeping** means that both ONU transmitter and ONU receiver are turned off for substantial periods of time. The latter category is further subdivided into **ONU Deep Sleep**, whereby the transmitter and receiver remain off for the entire duration of the power save state sojourn, and the **ONU Fast Sleep**, where the power save state sojourn consists of a sequence of sleep cycles, each composed of a sleep period and an active period.

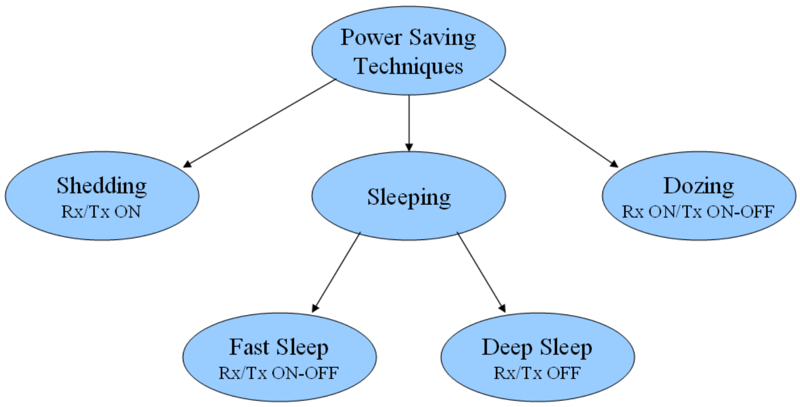

Figure 1 – Taxonomy of the power saving techniques

3.2 Unified approach to ONU power saving signalling

Most of the individual proposals presented to the group in the course of the study described the elements of the power save mode maintenance mechanism (OLT's 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). Nevertheless, the group observed that the two mechanisms are largely independent from each other. That is, 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 signalling mechanisms have been discussed:

- PLOAM-based handshake utilizing new message type(s);
- Dying Gasp message modified to include extra diagnostic and status information;
- Dying Gasp message with redefined semantics prompting OLT to perform extra diagnostic actions;
- OMCI-based handshake;
- implicit state inference based on the prior negotiated capabilities.

The two subsequent clauses are devoted to consideration of the power save maintenance and power save signalling mechanisms, respectively.

4 Power saving maintenance mechanisms

4.1 Fast Sleep power saving technique

4.1.1 Editorial summary

This clause presents key aspects under consideration within ITU-T. The proposal introduces the Fast Sleep mode behaviour, advocating the synchronized sleep and active periods across all the ONUs in the Fast Sleep mode that can be achieved with a newly defined broadcast PLOAM message along with the PLOAM-based signalling method to manage the Fast Sleep mode transitions for the individual ONUs.

The present text differs from the original contribution in that it explicitly decouples the Fast Sleep mode signalling from Fast Sleep mode maintenance, and allows for single parameterized new power save signalling PLOAM type rather than requiring multiple new signalling PLOAM messages.

4.1.2 Fast Sleep mode maintenance

An ONU in the Fast Sleep mode alternates between sleep periods, when the optical transceiver is completely powered off along with all the 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 Fast Sleep mode and are controlled by the OLT by means of Sleep PLOAM message. The Sleep message is a broadcast PLOAM message that is transmitted by the OLT at its discretion as soon as active period processing is completed, and that contains as a parameter the 30-bit superframe counter indicating the first frame of the next active period.

Upon receipt of a Sleep PLOAM, an ONU in the Fast 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 receiver in advance of the scheduled wake-up frame. The receiver wake-up lead time should be sufficient for the ONU to complete the Psync and superframe acquisition before the scheduled wake-up frame with reasonably high probability. The Fast Sleep mode maintenance states and state transitions are shown in Figure 2.

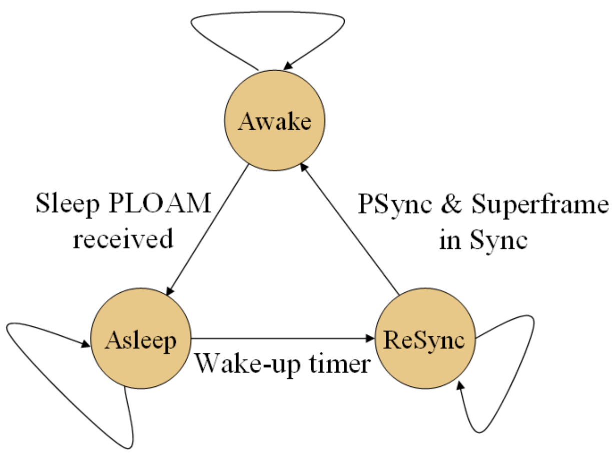

Figure 2 – Fast Sleep mode state transitions

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 the downstream services for the power saving ONUs. The structure of the OLT buffers and the associated scheduling discipline have not been addressed by the original proposal and remain an open issue.

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.

4.1.3 Specification impact

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

- A new PLOAM message of Sleep type with a single parameter, a 30-bit superframe counter of the first frame of activity after the sleep period, and the semantics of putting all the Fast Sleep ONUs to sleep with the scheduled wake-up time specified by the parameter.
- A Fast Sleep mode power-save state machine 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 Fast Sleep mode.

4.2 Deep Sleep power saving technique

4.2.1 Editorial summary

The Deep Sleep technique allows to achieve maximal power saving through powering off all the 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 alarming and operations support. Whereas 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 is waking up on a local stimulus only; however, the service restoration time is expected to be much faster.

4.2.2 Deep Sleep mode maintenance

The ONU in a Deep Sleep has its optical transceiver completely powered off along with most other functions and services. The timing and activity detection functions may optionally remain active. The OLT should suppress the PON alarming for the given ONU, but retain GTC and MIB 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. In order 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.

4.2.3 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 recommendations on the application and frequency of the targeted Quiet window for the ONUs in the Deep Sleep mode.

4.3 Dozing power saving technique

4.3.1 Editorial summary

A Dozing mode is introduced as an alternative to the Fast Sleep mode of clause 4.1. A dozing ONU ignores upstream allocations as long as it has no traffic to send, while avoiding LOSi declaration by the OLT and keeping the downstream channel open and operational. The dozing ONU may instantaneously wake up on an OLT request as well as on a local stimulus.

4.3.2 Dozing mode proposal

The OLT and ONU recognize a Dozing mode. It behaves as follows:

- A dozing ONU wakes up instantly when it receives upstream traffic of any kind from a UNI or from an internal process that generates traffic, e.g., 802.1ag CCM generation. Internal processes that generate traffic also include OMCI responses and notifications and responses to directed PLOAM messages.
- The ONU optical receiver is powered up continuously. It recognizes all downstream flows. As well as delivering traffic to CPE, this permits the ONU to awaken instantly if it needs to respond to a request from the OLT.
- The OLT continually sends upstream grants to all TCONTs, but expects the ONU to respond only if the ONU has something to say. This permits the ONU to acquire bandwidth instantly when it has traffic to send.
- The OLT may send DBA status requests, but these requests do not wake up a dozing ONU. If the ONU awakens because it has traffic to send, it can request bandwidth dynamically by responding to the status request.
- Bandwidth grants should allocate some small capacity, on the order of 100 kbit/s, such that the ONU can transmit one or a few background packets without significant delay, for example, heartbeat or query responses.
- If bandwidth grants are such that a given ONU receives a contiguous time allocation for more than one TCONT, the ONU must either respond to its entire grant or to none of it. That is, the burst must either be fully formed or not sent at all. The ONU may independently accept or ignore grants that are not contiguous in time.

It may be noted that the IEEE MPCP allows an ONU to ignore a grant if it has nothing to send, with the exception that the OLT can send a *force report* grant, which requires a response.

4.3.3 Specification impact

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

- The implementation recommendations on the LOSi suppression.
- The implementation 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.

4.4 Power shedding

4.4.1 Basic method

The 2008 suite of ITU-T G.984-series Recommendations allows the ONU to perform controlled power shedding, that is, to switch off specific services when the ONU operates under battery power. The feature is controlled by the power shedding ME. Its specification is provided in clause 9.1.7 of ITU-T G.984.4. A set of *shedding classes* is identified, one shedding class for each interface type. For each shedding class, a statically specified time interval determines the time between the moment of AC power failure and the moment the support of the respective interface type is turned off in an effort to save battery power. As presently specified, the feature allows to address the AC power failure scenario only.

4.4.2 TC layer specification impact

Power shedding is supported autonomously by the ONU; it does not require signalling operations and has no TC layer specification impact.

4.5 OMCI control of the power saving techniques

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 vs requirements negotiation takes place at initial ONU configuration via the OMCI management channel. OMCI extensions will be needed for this purpose. They will give the OLT an opportunity to learn the capabilities of the ONU and to activate and/or configure support of specific techniques.

Note that from the operational perspective, it could be beneficial that more than a single power saving technique 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 Fast Sleep, with the former being applicable in the presence of mains power, and the latter serving as an extra means to conserve battery capacity in case of outage when emergency services support is required. As another example, Dozing mode run in a normal operation can be used in combination with Deep Sleep mode, thus allowing the user to turn the ONU off if the user wishes to do so and if the operator considers it acceptable.

5 Signalling of ONU operations in a power saving mode

5.1 Modified Dying Gasp PLOAM Signalling

Amendment 1 to ITU-T G.984.3 (2008) amends the Dying Gasp message definition in order to clarify the conditions when 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 effectuate a change in the powering conditions that may impact the ONU's ability to respond to the upstream bandwidth allocations.

It has been proposed that a reason code parameter be added to the Dying Gasp message, thus making it more informative. This proposal was discussed in the context of ITU-T G.984.3 GPON, but rejected on the grounds that it required deep modifications to the GPON TC layer specifications. However, the idea itself remains a valid candidate for consideration within the XG-PON framework.

In particular, the reason code would assist 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 off a battery turns itself off to conserve power in order to support future emergency communication;

– the ONU operating under regular external power goes into sleep/doze mode to reduce power consumption during the inactivity period.

Note that as far as power saving operations are concerned, communicating the reason code within the Dying Gasp message has a timing advantage over the OMCI channel, but cannot provide anything above what is available to the OLT executing the OMCI "alarm soak" upon receiving an unmodified Dying Gasp.

5.2 PLOAM-based signalling

The PLOAM-based power save mode signalling method has been proposed in the context of the Fast Sleep power-saving technique (see clause 4.1). However, it could be applicable for other techniques as well and should be considered in a broader context.

The original proposal introduced two new PLOAM message types: an upstream Sleep Change Mode Request PLOAM message and a downstream Sleep Change Mode Acknowledgement PLOAM message, although there was a situation when the OLT was allowed to send an unsolicited acknowledgement (for power save mode deactivation on an OLT's initiative). To preserve the integrity of the signalling method, it has been subsequently agreed to consider a single PLOAM message type, herein referred to as Power Save Mode (PSM) PLOAM type, with the necessary parameterization.

A feasible format of the proposed PSM PLOAM message as established in the course of the discussions within ITU-T is shown in the following table. In comparison with the original proposal, the combination of the signalling and maintenance functionalities within the same message, along with the broadcast facility, has been abandoned.

Power save mode message		
Octet	**Content**	**Description**
1	ONU-ID	ONU-ID of the recipient in the downstream, or ONU-ID of the sender in the upstream.
2	TBD	Message identification "Power Save Mode"
3	Method [Example]	0x01: Deep Sleep 0x02: Fast Sleep 0x04: Dozing
4	Phase	0x01: Request 0x02: Indication
5	Indication	0x01: Power Save Mode ON 0x02: Power Save Mode OFF
6-12	Reserved	Set to 0x00
NOTE – Usage of this message is optional.		

The PSM message can be used by the OLT in the downstream direction as well as by the ONU in the upstream direction. The signalling handshake consists of a PSM Request message sent by either OLT or ONU followed by a PSM Indication response. In contrast with the original proposal, according to which, only the ONU could initiate the entry into a power save mode, a PSM ON Request can generally be sent either by the OLT or the ONU. However, depending on the specific set of supported power saving techniques, some semantics may remain undefined or additional restrictions may apply. For example, OLT-initiated transition into the Deep Sleep mode may not be supported. As another example, in the Fast Sleep mode, the OLT should wait until the start of the ONU's active period in order to send the PSM OFF Request and should not initiate a new sleep cycle until the acknowledging PSM OFF Indication is received.

In general, the transition into a power save mode shall be executed if both OLT and ONU agree on such a transition. A transition from a power save mode into the Normal power mode shall be executed whenever one party so requires. Since the SCM Requests by the ONU are effectively unsolicited PLOAM messages, the OLT should provide ample PLOAM allocations to the subtending ONUs regardless of their perceived operating mode and state in order to ensure the timely flow of the signalling messages.

5.3 OMCI-based signalling

5.3.1 Power save mode OMCI attributes

The handshake between OLT and ONU that is required to execute a power save mode transition can be implemented entirely within the OMCI framework. Conceptually, the following additional attributes, actions and notifications would be defined within OMCI.

Attributes

– **ONU power save capability**: A static vector indicating ONU support of the power saving techniques (R, 1 byte).

– **Negotiated power save capability**: A static vector (written by the OLT once on ONU activation) indicating the mutually supported power saving techniques that can be activated in the course of operation (R/W,1 byte).

– **Current status**: A dynamic indication of the currently active power save modes (R, 1 byte).

– **ONU power save request/indication**: A dynamic indication of ONU's desired power save modes (R, 1 byte).

– **OLT power save request/indication**: A dynamic indication of OLT's desired or consented power save modes (R/W, 1 byte).

Each attribute can be viewed as a bit vector mapping a particular power saving technique, for example:

0x01: Fast Sleep

0x02: Deep Sleep

0x04: Dozing

In steady state, all three dynamic parameters for a particular power save mode should be equal, reflecting the consensus between the OLT and ONU with respect to the current operating mode. When the ONU wishes to execute a transition, it sets the corresponding ONU power save request/indication flag and waits for the OLT's consent. Regardless of whether the requested transition is into or out of a power save mode, while waiting for OLT's consent, the ONU adjusts its behaviour and power level per the requirements of the normal power mode. Once the OLT agrees with the transition, it sets the corresponding OLT power save request/indication flag. When the ONU detects consensus, it aligns the current status bit accordingly.

If the OLT wishes to change state, the OLT sets the corresponding OLT power save request/indication flag and waits for the current status to change. Regardless of whether the requested transition is into or out of a power save mode, while waiting for the change of current status, the OLT treats the ONU as if it were in normal power mode. Once the ONU agrees with the transition, it changes both the corresponding ONU power save request/indication and current status attributes accordingly.

5.3.2 Applicability of OMCI signalling to power saving techniques

Table 4 lists the scope of applicability of OMCI handshake to execution of transitions into and out of various power saving modes.

Table 4 – Applicability of OMCI signalling

Power saving technique	Transition into a power save mode	Transition away from a power save mode
Fast Sleep	OMCI handshake initiated by either OLT or ONU.	In active period: OMCI handshake, initiated by either OLT or ONU. In sleep period: ONU responds to SN request.
Deep Sleep	OMCI handshake initiated by ONU.	ONU responds to SN request.
Dozing	OMCI handshake initiated by either OLT or ONU.	OMCI handshake initiated by either OLT or ONU.

5.3.3 Providing extra information to the OLT

While requesting a transition into a power save mode, the ONU should inform the OLT of the conditions that have preceded or caused the transition request, such as power failure, battery condition, user-initiated lower-power mode switch or soft power-off switch, etc. This is achieved by declaring the corresponding OMCI alarms. In addition, the OMCI signalling of a transition into a power save mode may be combined with the Dying Gasp PLOAM indication with or without the optional reason code (if it is accepted as a standard TC layer feature).

5.4 Extended power shedding

5.4.1 Editorial summary

An improvement to the power shedding ME has been proposed to extend the feature applicability to the power savings during the idle periods by allowing the OLT to control not only the time intervals to initiate shedding and to restore full power mode, but also the precise timing of the ONU power shedding operations. The proposal, therefore, extends the power shedding applicability to both AC power failure and the low power mode scenarios. This proposal impacts ITU-T G.984.4 only.

5.4.2 Proposal description

While ITU-T has placed priority on attempting to reduce the power consumed by ONUs, most solutions being discussed will require time to mature. This is the result of changes being required to hardware components of the ONU to implement the proposed solutions. In spite of that fact, this is an important effort that needs to continue.

In the near term, operators have the opportunity to deploy a service that will help reduce the power consumption of ONUs during idle times. This service requires no modification to existing ONU hardware implementations and can be retrofitted by way of a software upgrade into ONUs that are already deployed.

The service allows the subscriber to provide the operator with specific time periods during which designated services are not required. For example, a subscriber may inform the operator that video and data services are not required between 11:00 pm and 7:00 am on weekdays. This would then allow the operator to automatically power down the video and data interfaces of that subscriber's ONU during those time periods.

This is a very safe solution from the perspective of the operator because it places control of when ONU interfaces are powered down into the hands of the subscriber. From the perspective of the subscribers this is a desirable solution because it gives them control over the impact of the ONU on their household power consumption.

Control of the power saving service resides in the OLT and associated management systems. The ONU removes and restores power only by command from the OLT. Therefore, support for the power saving service in the ONU requires a minor addition to the ONT power shedding managed entity (ME).

5.4.3 New attribute of the ONT power shedding ME proposal

Add the following attribute to the end of the ONT power shedding ME in ITU-T G.984.4.

Shedding command: Boolean control of power shedding status for each shedding class. If this two-byte field is depicted 0b ABCD EFGH IJKL MNOP, its bits are assigned: the OLT sets each bit to one to cause the ONT to immediately shed power for the ONT components associated with that class. The OLT sets each bit to zero to cause the ONT to immediately restore power to the ONT components associated with that class. A bit set to one always takes precedence over ONT-initiated power restoral. The value of this attribute is not reflected in the shedding status attribute. This attribute may be read and compared to the shedding status attribute to determine the reason for the power removal from a class. Defaults to 0 upon instantiation (R/W) (optional) (2 bytes).

A	Data class
B	Voice class
C	Video overlay class
D	Video return class
E	DSL class
F	ATM class
G	CES class
H	Frame class
I	SONET class
J..P	Reserved and set to 0

The OLT sets each bit to one to cause the ONT to immediately shed power for the ONT components associated with that class. The OLT sets each bit to zero to cause the ONT to immediately restore power to the ONT components associated with that class. A bit set to one always takes precedence over ONT-initiated power restoral. The value of this attribute is not reflected in the shedding status attribute. This attribute may be read and compared to the Shedding status attribute to determine the reason for the power removal from a class. Defaults to 0 upon instantiation (R/W) (optional) (2 bytes).

5.5 Implicit power save mode signalling

As long as the power-saving technique support is established beforehand in the course of activation at ONU bring-up, the OLT may presume that the ONU has entered the power saving mode each time the ONU fails to respond to the upstream bandwidth allocation. In other words, the ONU implicitly signals a transition into the power saving mode by suppressing transmission to an upstream allocation.

This method could be primarily applicable to Fast Sleep and Dozing modes, provided a procedure has been negotiated for the OLT to confirm that the ONU is indeed not responsive due to transition into a power save mode and not because of, for example, a fibre cut. Such a procedure may involve restoration of transmission at the next active period in case of Fast Sleep, or a force response allocation in case of Dozing mode.

The method is applicable to the Deep Sleep mode, as in this case an effective confirmation procedure would require the definition of the mode to change, for example, for the ONU to accommodate a force response allocation or a specified pattern of such force allocations prior to ultimately turning off power.

5.6 Security aspect of power save mode signalling

The ITU-T G.984 ONU activation method allows a malicious 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 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.

6 Comparative analysis

6.1 Methodology

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

- Modified Dying Gasp PLOAM message.
- OMCI handshake, possibly with combination with Dying Gasp.
- New dedicated PLOAM types.
- Inference.

The power saving maintenance techniques under evaluation are:

- Fast Sleep.
- Deep Sleep.
- Dozing.
- Power shedding.

6.2 Power save mode signalling discussion

It is fair to say that the OMCI signalling method emerges as the most functionally powerful among the methods under evaluation. It is also simple in that it does not require TC layer modification and is backward compatible as it falls into the conventional OMCI framework.

Dying Gasp signalling involves moderate TC layer modifications that remain transparent to a non-aware OLT and, in that sense, is backward compatible. It also has limited functionality, but allows to speed up signalling with respect to the OMCI channel.

Power save mode signalling based on the new PLOAM message types has the deepest PLOAM impact, although it may achieve completion of the mode transition faster.

Finally, the implicit signalling (inference) method causes certain reliability concerns, that can be alleviated though devising an effective confirmation procedure. Implicit signalling (omission of an allocation) can be also used in place of Dying Gasp to attract the OLT's attention to OMCI alarms and handshake status.

6.3 Power save mode maintenance discussion

6.3.1 ONU Dozing mode vs Fast 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 and/or ONU have some way to distinguish real traffic from the idle state. Whether this is possible remains to be proven, for example:

– When the subscriber falls asleep with the television 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 and/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. For example:

– IGMP queries and responses need to be timely (see background music application above).

– A VoIP agent may exchange periodic heartbeat messages with a voice gateway.

– 802.1ag CCMs 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/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/ONU, the various timeouts are not likely to be accessible for change.

For completeness, it should also be noted that the concepts surrounding 15-minute PM intervals will need to be re-thought, since presumably there will be fewer than $900 * 10^6$ valid (micro)seconds in an 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 a GPON ONU, however.

6.3.2 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 GbE, MoCA, CATV and two lifeline POTS ports, the power profile of the key components is as shown in Figure 3.

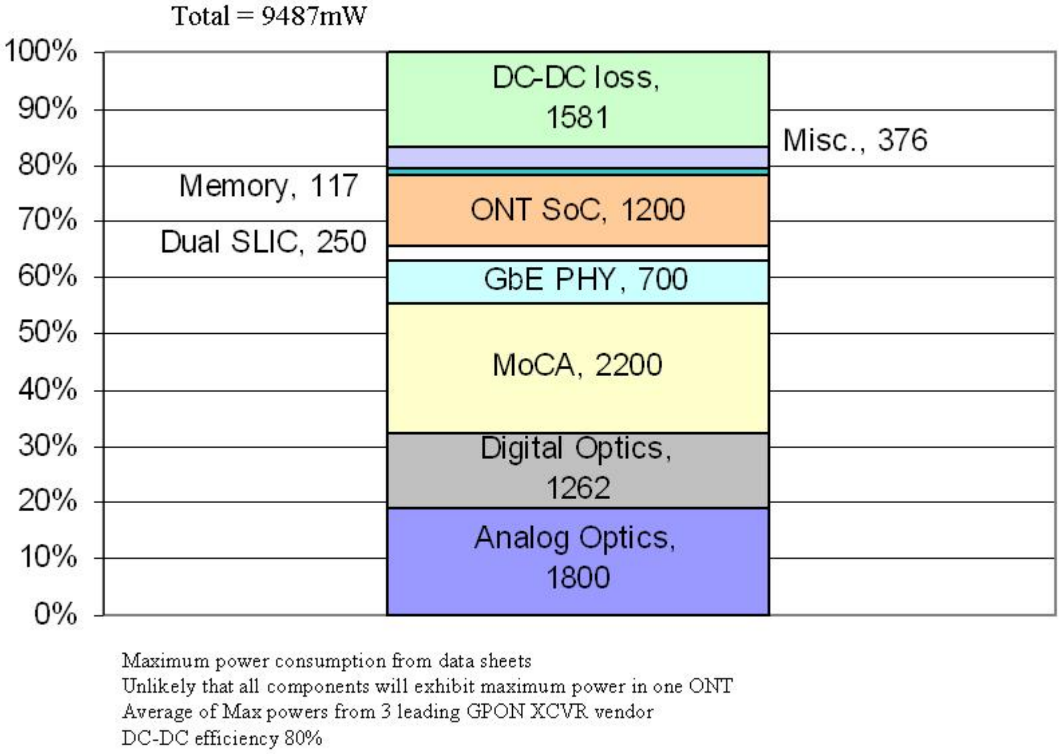

Figure 3 – Example power profile

The major contributors to the power profile of any ONU are the optics and the physical (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 service. The amount of power saved during this situation is as shown in Figure 4.

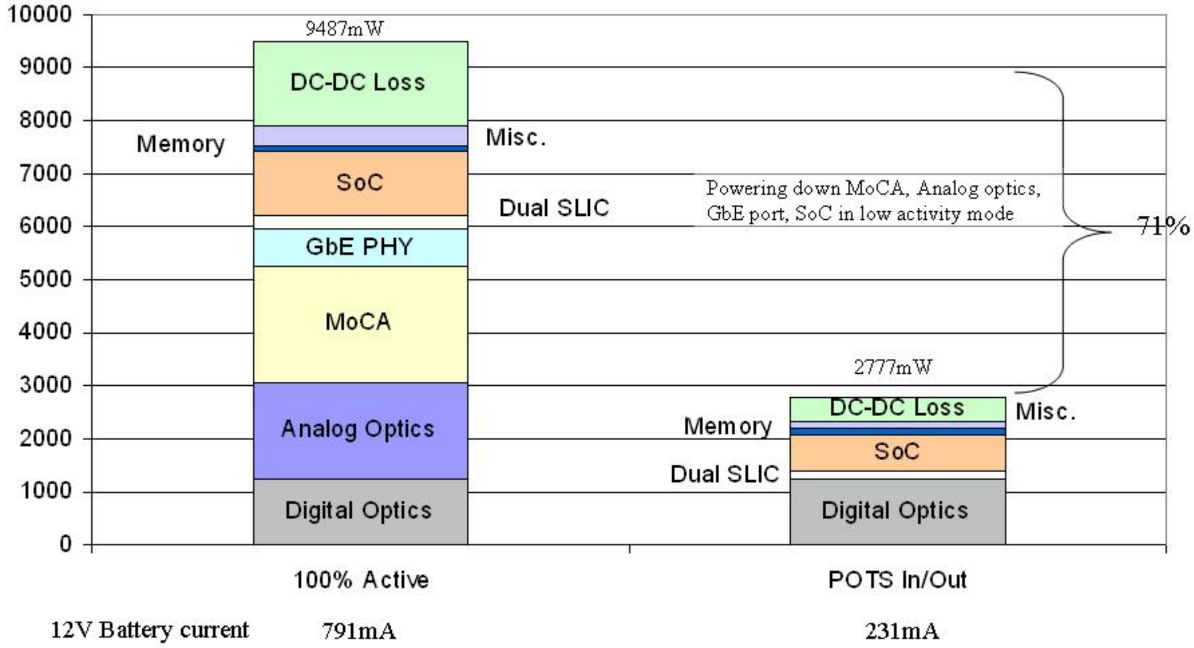

Figure 4 – Example power savings

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

– Power shedding has no impact on the ITU-T G.984 specifications.

– 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.

6.3.3 Proposal comparison table

Table 5 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 hours with one hour 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 the users?

Table 5 – Proposal comparison table

	Power shedding	**OMCI-controlled power shedding**	**ONU Dozing mode**	**Deep Sleep mode**	**Fast Sleep mode**
Power	2.8 W[1]	2.8 W[1]	1.7 W[1]	<0.7 W[1]	0.8 – 1.0 W[3]
Net capacity for backup	24.8 W/h[2]	24.8 W/h[2]	17.1 W/h[2]	10.1 W/h[2]	10.1 W/h[2]
ONU support	Power shedding, as specified in ITU-T G.984.4 and the Implementers' Guide.	Same plus extra OMCI control.	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	None.	Implementation of OMCI control.	Regular PLOAM allocations (no 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). Periodic Sleep messages with scheduled wake-ups.
Downstream critical traffic impact	None.	None.	Delivered without delay.	Lost.	Delivered with delay dependant on sleep period duration; contingent on OLT buffering; ultimate success subject to service delay requirements.
Upstream critical traffic impact	No delay.	No delay.	Delay [minimal] dependant on PLOAM allocation period.	Delay dependant on ranging window allocation period.	Delay dependant on sleep period duration.

Table 5 – Proposal comparison table

	Power shedding	OMCI-controlled power shedding	ONU Dozing mode	Deep Sleep mode	Fast Sleep mode
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.	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.

[1] Assuming just voice services for this power.

[2] The assumption is a cycle of operation of 15 minutes talking (5.2 W) in an hour.

[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.

7 Conclusions

The most basic conclusion of this study 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.

The study 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 and/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 cause a periodic loss of connectivity at the physical layer. There are schemes to mask this sporadic link character from the service layer, but these schemes in turn increase complexity.

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 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 max. REN.
      – 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: I think 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, the next generation ONTs will consume approximately 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/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/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-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 FTTC requirement for battery duration is at least 2 hours in China.

– Company B: Also not sure for the criteria, maybe 2-hour 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 residential gateways are likely to require powering. However, consideration must be given for alarm systems and panic/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 hours for FFTB/M/C, at least 30 minutes for SFU FTTH;

– Company B: Not sure for this question.

– Company C: 3-8 hours.

– Company E: If any, 2-4 hours.

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/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 to be decided 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/U 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 new battery technologies 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/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 the broadband code of conduct, this has the benefit of saving energy/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 ETSI EE on backfeeding (powering on pairs from the customer termination unit power supply). In this case, power-saving modes are especially wished to reduce customer energy bills and battery size for a given autonomy. This solution might be linked with the issue of availability of service in case of mains power failure. 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 in standby.

I.2 Power survey No. 2 responses

I.2.1 Background

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

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

2) Power saving to reduce energy cost and/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 the ITU-T G.984 series; which is service-specific and interface-specific?)
- What are the acceptable tradeoffs between power saving and quality of experience (longer wait times for the services to start, etc.)?

An addition, low power mode is proposed by the EU/COC. 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 and/or Ethernet) (if there is only one, respond "not applicable" or "NA" to the first one; in the case of POTS, service provider #1 is assumed to offer essential services such as telephony).

Clause I.2.2 questions 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, SME, MDU, VDSL2 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 communicationslink for reporting supervisory parameters and can be used for a voice or emergency, telemedicine or burglar alarm-type services)?

   See http://re.jrc.ec.europa.eu/energyefficiency/.

4) How many ports do you need/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 hours)?

9) How many hours essential service backup are required when active (e.g., 1 hour, 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., RJ45, Ethernet, power over Ethernet)?

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 and/or customer energy saving switch to off)?

Survey part 2 – Power saving to reduce energy cost and/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 #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 #1 which is configured for video (e.g., on mains failure or absence of video traffic, STB powered down, or port disconnected)?

   d) Data UNI #N to move to power-saving/low data rate mode (e.g., input buffer showing low data rate traffic for 5 minutes or user-defined number of minutes, port disconnected, port powered down)?

   e) Data UNI #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 #N in power saving mode to shut down (e.g., when the battery, if present, is exhausted and/or AC mains failure)?

g) Data UNI #1 in power saving mode to shut down (e.g., when the battery, if present, is exhausted and/or AC mains failure)?

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

i) POTS UNI #1 (e.g., this is the essential service port and will only disappear when the battery is exhausted under mains failure, if possible a 'last 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/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)?

See http://re.jrc.ec.europa.eu/energyefficiency/.

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., less than 40 seconds)?

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

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 31 December 2009 (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 31 December 2009 (this is the operational state when there is a maximum of 1 optical port, 1 Ethernet port and 1 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 31 December 2009)?

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

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

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

Question#		BT	FT	VZ	TI	Company A
1	Supplier or operator.	Operator.	Operator.	Operator.	Operator.	Potential operator.
2	ONU type.	Residential.	Single family unit.	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, see http://re.jrc.ec.europa.eu/energyefficiency/	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/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	>4	3

Question#		BT	FT	VZ	TI	Company A
9	Hours essential service backup are required when active.	4 hours	Not specified, human dying gasp/emergency call expected at least.	8	4	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, RJ11.	RJ11	RJ45 via VoIP adaptor.
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 A/C 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 VDC from intermediate power supply.	Loss of AC power or detection of no traffic for X minutes.	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 stand-by will be reduced.	Re-application of +48 VDC.	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 provisioned via OMCI.	Mains failure – 15 second support and/or operator-configured timer to port power down. No RF load – operator-configured timer to power saving mode.	NA.	x
b	Digital video UNI#1.	NA.	Mains failure, and shutdown of downstream possible till an IGMP report command requires a stream.	NA.	Mains failure, and shutdown of downstream possible till an IGMP report command requires a stream.	x

Question#		BT	FT	VZ	TI	Company A
c	Digital video UNI#M.	NA.	Mains failure, and shutdown of downstream possible till an IGMP report command requires a stream.	When present: Mains failure – 15 second support and/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 till an IGMP report command requires a stream.	x
d	Data UNI#N.	Port disconnected. 1 hour to low traffic status.		NA.	No traffic for X minutes.	x
e	Data UNI #1 to move to power-saving low data rate mode.	We have 4 ports all to be treated the same.		Low data rate detected – Operator-configured timer to low data rate and/or power saving mode. Inactivity detected – Operator-configured timer to power saving mode and/or port power down. Port disconnected – Port power down.	All data ports to be treated the same.	x
f	Data UNI #N in power saving mode to shut down.	When battery is exhausted, all ports are the same.	x	NA	After a stand-by of Y minutes.	x
g	Data UNI #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/power saving mode, and then port power down. Battery exhaust – Port power down. Port disconnected – Port power down.	After a stand-by of Y minutes.	x
h	POTS or VoIP UNI #P.	NA.	x	NA.	Not clear.	

Question#		BT	FT	VZ	TI	Company A
i	POTS UNI #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. Last 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 on the 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
19	Data rate.	Not determined yet.	320 kbit/s for voice.	http://ec.europa.eu/energyefficiency/ 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/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/ beneficial.	User and access network provider.	Operator.	User and access network provider.	Customer.
c	Time delay on first install.	Less than 40 s.	Cold start value from ITU-T G.984.3.	Less than 40 s.	TDB.	Not clear.

Question#		BT	FT	VZ	TI	Company A
d	Time delay is acceptable when AC power returns.	Less than 5 s assuming battery still alive.	Less than 1 s.	Less than 5 s.	Less than 5 s.	Less than several seconds.
e	Delay as ONU/T moves from low power mode to higher power.	2 s or less.	Less than 1 s.	AC present – as soon as return to normal trigger/condition is detected. Battery operation/no AC – immediate for POTS upon off-hook or incoming call acknowledged.	1 s or less.	Much faster than (e.g., 40 s).
2.3 Power Targets						
22	Maximum power consumption on battery.	Less than 2 W.	The one required in question 25.	Unknown at this time.	The NT power consumption must be compliant to the European Code of Conduct for broadband devices [European Commission "Code of Conduct on Energy Consumption of Broadband Equipment (version 2)", 17th July 2007, http://re.jrc.ec.europa.eu/energyefficiency/], defining specific values to be applicable from 2009 to an ONT comprising 1 GPON interface; 1 10/100/1000 Ethernet UNI port and 1 USB device; 12 W max in operation.	Not clear.
23	Maximum power consumption in energy saving mode.	Less than 3 W.	The one enabling a reasonable wake up incoming data/signal (ANI chips might be always on if no satisfactory TC solution is available).	Unknown at this time.	0.3 W Off position max consumption. TBD (to be defined) 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 x POTS, Ethernet, RF Video.	Unassigned and disconnected ports are not powered.	1 x telephony (via VoIP) and 1 x Ethernet (GigE or FE).

Question#		BT	FT	VZ	TI	Company A
24b	Full power consumption Watts.	5 W today, 3 W target.		Unknown at this time.	See CoC 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 insure 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 telco-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;

– a user who would like to maintain an automatic medical monitoring/alert service utilizing either phone or data service continuously throughout the outage;

– a user who would like to be able to receive incoming well-check calls from family members;

– a user who has the PC and router running off the battery/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;

– a user who 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 defined. 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. Four hours is a minimum value for maintaining a remote POTS line, optionally an 8 hours 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 hours for all CPs. Telephony service can be offered by CPs who would use Ethernet terminal adapters to derive the service, as shown in Figure I.1.

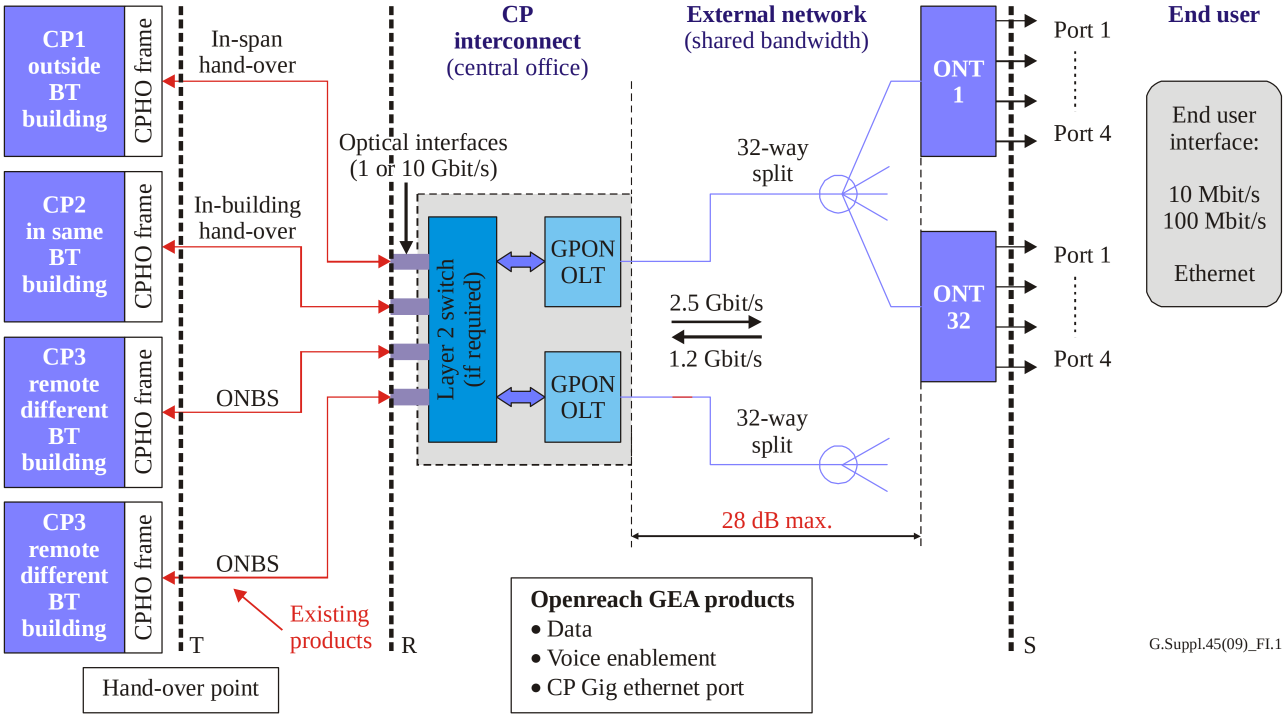

Figure I.1 – FTTP GEA architecture

– 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/FCC 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 U.S. have targeted 8 hours of POTS support during outages via central office and remote terminal back-up systems. Customers are responsible for providing a handset capable of functioning during outages, e.g., traditional analogue POTS handset, UPS powered handsets, etc. For FTTH applications, Verizon provides an ONT back-up battery during initial install. The battery then becomes the customers' responsibility for on-going maintenance/replacement. Verizon FTTH systems currently support POTS for 7 hours continuous, and an additional 1 hour 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 else to be defined. Second application beyond human care will of course be the intrusion detection/home monitoring type service that is in no way imposed by regulation.

Duration should nominally be of 4 hours, and longer duration options should be developed. Another major question within the scope is if a single interface has to be considered or if several simultaneous ones need to be considered (case of an MDU ONU).

– BT Openreach: N/A (covered by 1.1)

– Company A: Premium grade voice-over-IP 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/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/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/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 hours is considered reasonable.

– Company A: No provision about the 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 at OLT side the operator should match the best compromise between its service bundle requirement and the power saving concern, but at the ONU the access network operator can only suggest a best practice default configuration, that the user should be able to override since providing 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 in 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 in Openreach control. Any CP in UK could be asked the question.

– Company A: No.

– VZ: Yes, the capability for a customer to select options/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 and/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/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 in Openreach control.

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

– VZ: POTS service is expected to perform for at least 7 hours without degradation and an additional 1 hour for outgoing only. Some trade-offs may be acceptable if a significant increase in battery duration can be gained through creative alternatives/mechanisms. An acceptable trade-off might include a slight dial tone and/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/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 define 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 in case of any user mishandling of 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/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 to 10 minutes at least should be targeted for full diagnostic report to emergency authorities.

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

– Company A: In our experience to provide POTS services via STM-PON, power outage is assumed as 3-hours long 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. Typical average may be 1-2 calls per hour, 1 to 10 minutes 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 in 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/message is generated?

– FT: Must remain compatible with POTS/Z interface specifications and timeouts to place the call. For instance, in 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 in Openreach control. Any CP in UK could be asked.

– Company A: Not sure.

– VZ: Possible trade-offs need to be explored. Up to a 2-3 second delay 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 dial tone. In this way, the dial tone delay could possibly be extended beyond 3 seconds to as much as 12 seconds. Greater delays may also be considered.

3.4 Which other aspects/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 in 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.

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