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Please don't change the structure of this table, just insert the necessary information.

1. Introduction

As a result of discussions in Shanghai, this contribution offers a compromise regarding the G.987.3 ONU power management section. This proposal achieves the goal to include updates for Watchful sleep mode while maintaining backward compatibility with current power saving modes contained in the standard. The resulting revised standard will allow implementers to use power saving modes as appropriate.

The following text revisions are proposed to the ONU power management now defined in G.987.3, to add Watchful sleep mode to the existing sleep modes.

2. Proposed Revision to G.987.3

2.1 Proposed change on SR message

Sleep_Request message

However, it used to be as following:

Octet	Content	Description
1-2	ONU-ID	
3	0x10	Message type ID "Sleep_Request".
4	SeqNo	Always 0.

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5	Activity_level	0- Sleep_Request (awake). 1- Sleep_Request (doze). Doze request, ONU receiver active – During low-power periods of doze mode, the ONU can receive downstream traffic. 2- Sleep_Request (sleep). Cyclic sleep request, ONU receiver inactive – During low-power periods of cyclic sleep mode, the ONU cannot receive downstream traffic. Other values reserved. 3 –Sleep_Request (WSleep). Request to initiate Watchful Sleep power management mode: ONU alternates between the Aware state, when the ONU receives and transmits traffic, and the LowPower state, when the ONU does not transmit upstream; when in the LowPower state, the ONU periodically checks the downstream traffic for wakeup indications from the OLT.
6-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check

2.2 Proposed revision to section 8.1.2.5 FWI

8.1.2.5 Forced wake-up indication (FWI) bit

When addressing an ONU that supports the protocol-based power management, the OLT sets the FWI bit to expedite waking up an ONU that has been in **any of the low power modes** ~~watchful sleep mode~~. See clause 16 for the details of the ONU power management. When required by the OLT power management state machine, the FWI bit is set in the first allocation structure of each burst allocation series to a given ONU. The value of the FWI bit in the subsequent allocations structures of a burst allocation series is not controlled and is ignored by the ONU.

2.3 Proposed revision to section 16 ONU power management

For a variety of reasons, it is desirable to reduce the power consumed by an ONU as much as possible:

Over time, the natural evolution of technology tends toward more efficient realizations of given functions, a tendency that is offset, at least to some extent, by increasing levels of functionality and speed.

If there is a way for the ONU to determine that a subscriber interface is idle, it is desirable for the ONU to power down the circuitry associated with that interface, while retaining the capability to detect subscriber activity on that interface. The details vary as a function of the interface type.

The extent of feasible power reduction depends on the acceptable effect on service. The maximum possible savings occurs when a subscriber intentionally switches off an ONU, for example, overnight or during a vacation.

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During failures of AC power, some degradation of service is generally acceptable. To conserve backup battery lifetime, it is desirable for the ONU to power down circuitry associated with all interfaces, except those considered to provide essential services. Different operators and customers may have different definitions of essential services, and may wish to prioritize the time when the interfaces are powered down. This feature, which is known as power shedding, is described in [ITU-T G.988].

The preceding techniques for power management are a matter of ONU design and subscriber and operator practice, and are beyond the scope of this Recommendation.

This clause addresses ~~an~~ **three** additional means of power management, which does require TC layer support.

One is called doze mode; **another** is referred to as cyclic sleep mode; **the third is referred to as** ~~This power management means, which is referred to as~~ watchful sleep mode, **which** combines the semantic features of the doze and cyclic sleep modes of G.987.3-2010 ~~(and, therefore, also known as unified power management mode)~~ while reusing the states and transitions if the doze mode only ~~(which was defined as mandatory by G.987.3-2010)~~. ~~By deprecating the alternative subset of states and transitions associated with the cyclic sleep mode, the watchful sleep simplifies the power management signalling and achieves better power saving at the same time.~~

A compliant G.987.3 implementation may either:

- **Implement the Watchful sleep mode (which is reducible to either Doze or Cyclic sleep behavior through parameter configuration); or**
- **Implement Doze mode; or**
- **Implement Doze and Cyclic sleep mode.**

The specific power management capabilities are subject to operators' system requirements, and for each ONU are negotiated over OMCI upon ONU activation.

16.1 Power management configuration and signalling

The OLT uses OMCI to discover the ONU's power management capabilities and to configure its power management attributes and modes. To control the power management behaviour of a given ONU, the ONU and the OLT maintain a pair of power management state machines. The ONU state machine and the corresponding OLT state machine operate in partial state alignment. The primary signalling mechanism used to coordinate the ONU and OLT state machines is based on the PLOAM messages. The output PLOAM messages are generated and queued for transmission at the time of state transitions. The states of both ONU and OLT state machines can be classified into two mutually exclusive subsets: the full power states and the low power states. Only the state transitions between the full power and low power state subsets generate an output PLOAM message. If the sojourn in the target state of a transition is controlled by a timer, the timer is not started until the actual transmission of the message. As a secondary signalling

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mechanism used to speed up or wake up a sleeping ONU, the forced wake-up indication bit is carried within a BWmap allocation structure.

16.2 Power management parameter definitions

Table 16-1 defines the essential intervals, timers and counters. Parameters known to both ONU and OLT are exchanged via OMCI [ITU-T G.988]. Parameters local to the ONU or the OLT are defined only for use in the description below.

Table 16-1 – Power management parameters

Parameter	Description	Defined by	Known to
Ilowpower	Ilowpower is the maximum time the ONU spends in its Asleep or Listen or LowPower state, as a count of 125 microsecond frames. Local wake-up indications (LWIs) or remote events, if detected, state may truncate the ONU's sojourn in these states.	OLT	ONU, OLT
Tlowpower	Local timer at ONU. Upon entry to the Asleep or Listen or LowPower state, the ONU initializes Tlowpower to a value equal to or less than Ilowpower. Secondary internal timers may be required to guarantee that the ONU will be fully operational when it enters the Aware state after an interval not to exceed Ilowpower.	ONU	ONU
Iaware	Iaware is the minimum time the ONU spends in its Asleep or Listen or Aware state before transitioning to the Asleep or Listen or LowPower state, as a count of 125 microsecond frames. During the Iaware interval, local or remote events may independently cause the ONU to enter the ActiveHeld state rather than returning to any low power ~~the LowPower~~ state.	OLT	ONU, OLT
Taware	Local timer at ONU, initialized to a value equal to or greater than Iaware once downstream synchronization is obtained upon entry to the Aware state. Taware controls the dwell time in the aware ~~the Aware~~ state before the ONU re-enters one of the low power ~~LowPower~~ state.	ONU	ONU
Itransinit	The worst-case transceiver initialization time: The time required for the ONU to gain full functionality when leaving the LowPower state, measured in units of 125 μs PHY frames, and known by design. The value of zero indicates that the sleeping ONU can respond to a bandwidth grant without delay.	ONU	ONU, OLT
Itxinit	Transmitter initialization time: the time required for the ONU to gain full functionality when leaving the Listen state (i.e., turning on the transmitter while the receiver has remained on), measured in units of 125 μs PHY frames. The value of zero indicates that the dozing ONU can respond to a bandwidth grant without delay.	ONU	ONU, OLT

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Table 16-1 – Power management parameters

Parameter	Description	Defined by	Known to
Irxoff	Irxoff is the maximum time the OLT can afford to wait from the moment it decides to wake up an ONU in one of the low power ~~the LowPower~~ states until the ONU is fully operational, specified as a count of 125 microsecond frames. The ONU timer Trxoff and the OLT timer Talerted are initialized based on Irxoff,	OLT	ONU, OLT
Trxoff	Local timer at ONU. The ONU uses this timer in one of the low power ~~the LowPower~~ states while checking the downstream signal for the remote wakeup indications to ensure that the time between two consecutive checks does not exceed the provisioned Irxoff interval.	ONU	ONU
Talerted	Local timer to bound the time that the OLT state machine remains in an alerted state before entering the AwakeForced state. Talerted should be initialized to at least Itroff + Itransinit + round-trip delay + tolerances for Rx synchronization, bandwidth grant irregularities, and processing time.	OLT	OLT
Ter _i	Local handshake timer at the OLT that defines the latest instant at which an upstream burst is expected from ONU <i>i</i> when it is in one of the low power ~~LowPower~~ states. The OLT reinitializes and starts this timer when the OLT's state machine for the given ONU transition into the LowPowerWatch state and each time an upstream burst is received from the ONU while in that state. If Ter _i expires, the OLT declares a handshake violation and attempts to force the ONU awake. To determine the initial value of Ter _i , the OLT is responsible to consider the provisioned llowpower interval and any possible effects of transceiver initialization, synchronization, and irregularities in the bandwidth grant cycle.	OLT	OLT
Ihold	Minimum sojourn in the ActiveHeld state.	OLT	ONU, OLT
Thold	Local timer at the ONU that is initialized to Ihold upon transmission of SR(Awake) after entry into ActiveHeld state and that enforces the minimum sojourn in the ActiveHeld state.	ONU	ONU

16.3 Power management state machine specifications

The power management behaviour of a given ONU is controlled by a pair of state machines residing at the OLT and the ONU. While the state nomenclature of the OLT machine is similar to that of the ONU machine, the two state machines operate in just partial state alignment. The lock-step state tracking is not an objective of the protocol.

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16.3.1 ONU state machine

The ONU power management states along with their corresponding semantic description are listed in Table 16-2. The set of input events is represented in Table 16-3. The state transition diagram is illustrated in Figure 16-1. The normative specification of the state transitions and outputs are given in Table 16-4.

Table 16-2 – ONU power management states

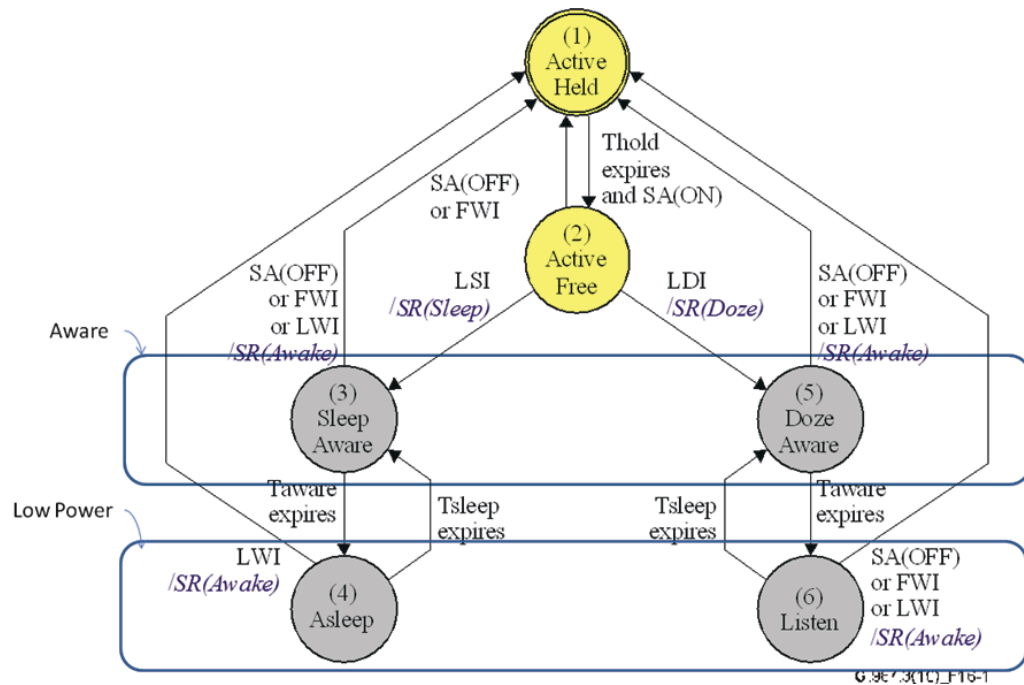
State	Semantics
ActiveHeld	The ONU is fully responsive, forwarding downstream traffic and responding to all bandwidth allocations. Power management state transitions do not occur. The minimum sojourn in this state is enforced by the Thold timer. Upon entrance to this state, the ONU sends a Sleep_Request (Awake) PLOAM message. On the state diagrams, this is abbreviated as SR(Awake).
ActiveFree	The ONU is fully responsive, forwarding downstream traffic and responding to all bandwidth allocations. Power management state transition requests are a local decision.
Asleep	The ONU shuts down both its receiver and transmitter, retaining the ability to wake up on local stimulus. This state persists for a specified duration Isleep if not truncated by the arrival of a local stimulus LWI. Before exiting this state, the ONU ensures that it is fully powered up, synchronized, and capable of responding to both upstream and downstream traffic and control.
Listen	The ONU receiver is on; the transmitter is off. The ONU listens to the downstream signal and forwards downstream traffic, while retaining the ability to reactivate the transmitter on local stimulus or receipt of SA(OFF) from the OLT. This state persists for a specified duration Isleep if not truncated by the arrival of a local stimulus LWI or receipt of SA(OFF) or FWI from the OLT. Before exiting this state, the ONU ensures that it is fully powered up and capable of responding to both upstream and downstream traffic and control.
LowPower (the state is renamed with the adjusted semantics)	The ONU transmitter is off. The ONU periodically checks the downstream signal for remote wakeup indications. When the downstream signal is checked, the ONU does not respond to grant allocations and does not forward downstream traffic. This state persists for a specified duration llowpower if not truncated by the arrival of a local stimulus LWI or receipt of SA(OFF) or FWI from the OLT. Before exiting this state, the ONU ensures that it is fully powered up and capable of responding to both upstream and downstream traffic and control.
DozeAware SleepAware watchfulsleepAware	Both ONU receiver and transmitter remain on. This state persists for a specified duration laware if not truncated by the arrival of a local stimulus LWI or receipt of SA(OFF) from the OLT. The ONU forwards downstream traffic and responds to all grant allocations. It is the responsibility of the OLT to transmit bandwidth allocations containing the PLOAMu flag with frequency sufficient to ensure that an aware ONU sees at least one.

Table 16-3 – ONU state machine inputs

Input categories	Input	Semantics
PLOAM events	Sleep_Allow(ON)	The OLT grants permission to the ONU to exercise ~~watchful sleep~~ any power management mode, and leaves the selection of doze or cyclic sleep or watchful sleep mode to the ONU's discretion
	Sleep_Allow(OFF)	The OLT withholds consent to exercise a power management mode.
Bit-indication event	Forced wake-up indication (FWI)	Transmitting FWI as a flag of an allocation structure, the OLT requires immediate ONU wake-up and its transition to ~~the ActiveHeld~~ a full power state.
Timer events	Thold expiration	The event applies in the ActiveHeld state, controlling the minimum sojourn in that state.
	Taware expiration	The event applies in the Aware, DozeAware and SleepAware states, controlling the sojourn in that state.
	Tlowpower expiration	The event applies in the Asleep, Listen and LowPower states, controlling the sojourn in that state.
Local events	Local sleep indication (LSI)	The ONU has no local reason to remain at full power and is willing to exercise the watchful sleep power management mode or the cyclic sleep power management mode.
	Local doze indication (LDI)	The ONU has no local reason to remain at full power and is willing to exercise the doze power management mode or the watchful sleep power management mode.
	Local wake-up indication (LWI)	A local stimulus prevents the ONU from exercising any power management mode.
NOTE – The LSI, LDI and LWI events are conceptually derived from the ONU's binary stimulus status level (Awake/Sleep/Doze) and correspond to the events of the level change or, in case of ActiveFree state, to the sampled value at the time of the transition. The specific criteria for the local stimulus definition remain out of scope of this Recommendation.		

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Figure 16-1 – ONU state transition diagram (initial state circled)

Note: The vertices on the state diagram graph can be qualified as either “tense” or “relaxed” forming the yellow and grey subgraphs, respectively. As a rule, an output PLOAM message is generated only on a state transition that crosses the subgraph boundary.

Table 16-4 – ONU state transition and output table

Inputs	ONU power management states					
	(1) ActiveHeld	(2) ActiveFree	(3) SleepAware/Aware	(4) Asleep/lowpower	(5) DozeAware/Aware	(6) Listen/lowpower
FWI	*	→ (1)	→ (1) /SR(Awake)		→ (1) /SR(Awake)	→ (1) /SR(Awake)
SA (OFF)	*	→ (1)	→ (1) /SR(Awake)		→ (1) /SR(Awake)	→ (1) /SR(Awake)
SA (ON)	→ (2) Upon Thold exp. (Note)	*	*		*	*

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LWI	*	*	→ (1) /SR(Awake)	→ (1) /SR(Awake)	→ (1) /SR(Awake)	→ (1) /SR(Awake)
LSI		→ (3) /SR(Sleep/ WSleep)	*	*		
LDI		→ (5) /SR(Doze/ WSleep)			*	*
Tsleep exp.				→ (3)		→ (5)
Taware exp.			→ (4)		→ (6)	
* Indicates a self-transition. ■ A shaded cell means that the input is not applicable in the given state. NOTE – An ONU remains in the ActiveHeld state for at least Ihold upon entry into that state regardless of the SA message parameter value indicated by the OLT. The minimum sojourn in the ActiveHeld state is controlled by timer Thold that is initiated to Ihold upon ONU's entry into the ActiveHeld state. When Thold expires, the ONU executes a transition into to the ActiveFree state if the latched value of SA message parameter is ON or as soon as SA (ON) message is received.						

16.3.2 OLT state machine

The OLT power management states along with their corresponding semantic description are listed in Table 16-5. The set of input events is represented in Table 16-6. The state transition diagram is illustrated in Figure 16-2. The normative specification of the state transitions and outputs is given in Table 16-7.

6 Table 16-5 – OLT power management states

State	Semantics
AwakeForced	The OLT provides normal allocations to ONU i , forwards downstream traffic, and expects a response to every bandwidth grant. The OLT declares the LOB _{i} defect on detection of the specified number of missed allocations. On transition into this state, the OLT sends a Sleep_Allow (OFF) PLOAM message, thus revoking its permission to the ONU to enter any low power mode the LowPower state.

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State	Semantics
AwakeFree	The OLT provides normal allocations to the ONU, forwards downstream traffic, and is ready to accept a power management transition indication from the ONU. On transition into this state, the OLT sends a Sleep_Allow (ON) PLOAM message, thus granting the ONU a permission to enter any low power state ~~the LowPower state~~ at its own discretion. The OLT expects a response to every bandwidth grant, and in case of missed allocation transitions to the AwakeForced state, where LOB_i condition can be eventually declared. There are two stable state combinations involving the AwakeFree state of the OLT state machine: the ONU state machine can be either in the ActiveFree state or in the ActiveHeld state.
Doze LowPowerSleep LowPowerWatch	The OLT supports the ONU in a low power state. The OLT provides normal allocations to the ONU but expects only intermittent responses from the ONU to bandwidth grants, as defined by various timers. In the low power doze state, the OLT forwards downstream traffic; in the low power sleep/ LowPowerWatch state, the OLT may ~~either discard or~~ buffer the downstream traffic. If timer Ter_i expires before the OLT receives a burst from ONU <i>i</i>, the OLT recognizes a handshake violation and goes to the AwakeForced state.
Doze AlertedSleep Alerted	The OLT attempts to wake up the ONU. Having sent Sleep_Allow (OFF) message on transition to the state, the OLT sets the FWI bit in every allocation to the ONU along with the PLOAMu flag. The OLT forwards, discards or buffers downstream traffic for the ONU, just as it did during the immediately preceding Doze or LowPowerSleep or LowPowerWatch state. The OLT goes to the AwakeForced state if it receives a burst from the ONU that includes a Sleep_Request (Awake) PLOAM message or if timer Talerted expires.

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Table 16-6 – OLT state machine inputs

Input categories	Input	Semantics
PLOAM events	SleepRequest(Doze)	The ONU informs the OLT of its intent to exercise the doze power management mode.
	SleepRequest(Sleep)	The ONU informs the OLT of its intent to exercise the cyclic sleep power management mode.
	Sleep_Request(WSleep)	The ONU informs the OLT of its intent to exercise the watchful sleep power management mode.
	Sleep_Request(Awake)	The ONU informs the OLT of its intent to remain at full power.

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Table 16-6 – OLT state machine inputs

Input categories	Input	Semantics
Timer events	Ter _i expiration	The event occurs only in the LowPowerDoze, LowPowerCyclic Sleep, and LowPowerWatch states indicating the violation by the ONU of the provisioned low power timing parameters.
	Talerted expiration	The event occurs only in AlertedDoze, AlertedSleep and Alerted states indicating the ONU's failure to wake-up upon OLT's demand.
Local events	Local wake-up indication, OLT-LWI	Local wake-up indication and its inverse indicate, respectively, the presence and the absence of a local stimulus to maintain the ONU at full power.

NOTE – The OLT-LWI event and its inverse are conceptually derived from the OLT's binary stimulus status level and correspond to the stimulus level change. The specific criteria for the local stimulus definition remain out of scope of this Recommendation.

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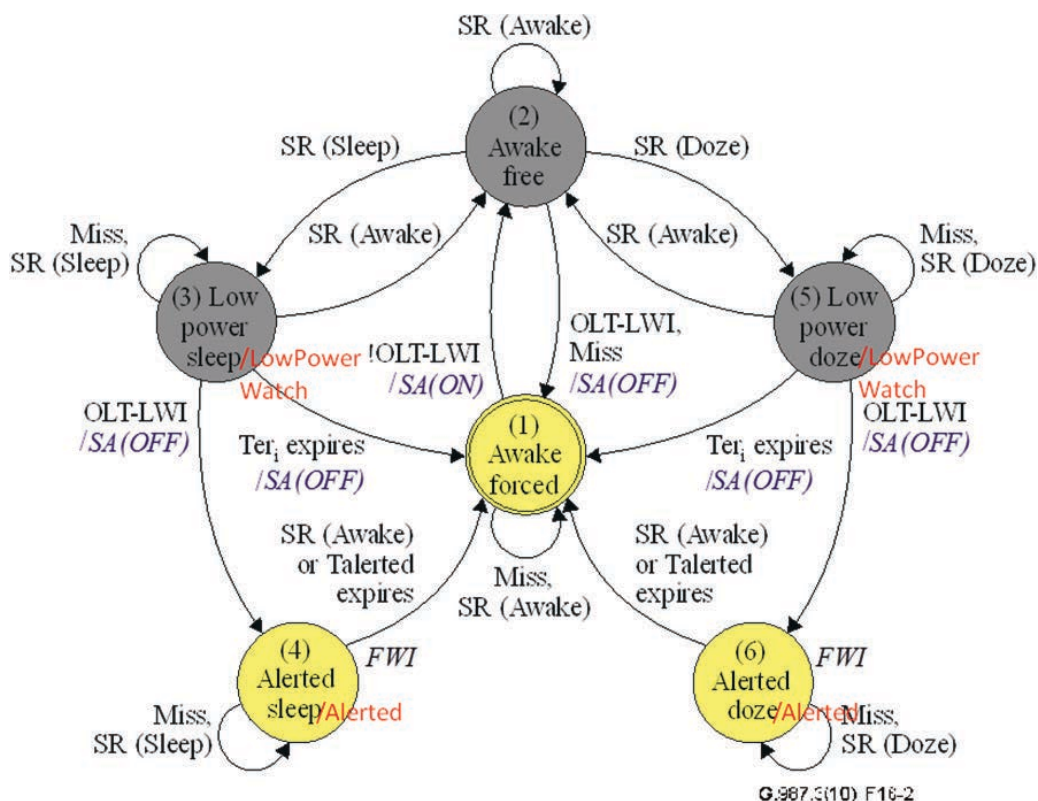


Figure 16-2 – OLT state transition diagram (initial state circled)

Note: The vertices on the state diagram graph can be qualified as either “tense” or “relaxed”

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forming the yellow and grey subgraphs, respectively. As a rule, an output PLOAM message is generated only on a state transition that crosses the subgraph boundary.

Table 16-7 – OLT state transition and output table

Inputs	OLT power management states					
	(1) AwakeForced	(2) AwakeFree	(3) LowPower Sleep/LowPowerWatch	(4) Alerted Sleep / FWI/Alerted	(5) LowPower Doze LowPowerWatch	(6) Alerted Doze / FWI/Alerted
SR (Awake)	*	*	→ (2)	→ (1)	→ (2)	→ (1)
SR (Sleep)	* /SA(OFF) (Note 1)	→ (3)	*	*	→ (1) /SA(OFF) (Note 2)	→ (1) /SA(OFF) (Note 2)
SR (Doze)	* /SA(OFF) (Note 1)	→ (5)	→ (1) /SA(OFF) (Note 2)	→ (1) /SA(OFF) (Note 2)	*	*
Allocation miss	*	→ (1) /SA(OFF)	*	*	*	*
OLT-LWI ON	*	→ (1) /SA(OFF)	→ (4) /SA(OFF)	*	→ (6) /SA(OFF)	*
OLT-LWI OFF	→ (2) /SA(ON)	*	*	* (Note 3)	*	* (Note 3)
Talerted exp.				→ (1)		→ (1)
Ter _i exp.			→ (1) /SA(OFF)		→ (1) /SA(OFF)	

NOTE 1 – An exception from the subgraph rule; an output may help to stabilize the state machine in case the condition is caused by a lost SA(OFF) message. The output is not shown on the FSM diagram.

NOTE 2 – Direct transitions between Doze mode and Cyclic Sleep mode are disallowed. When the OLT receives a request to execute such a transition, it attempts to regain state machine synchronization by waking up the ONU. The transitions are not shown on the diagram for the sake of compactness.

NOTE 3 – This is a situation when the OLT initiates a wake-up, but the OLT-LWI is cleared before the ONU is awoken. In this case, the OLT, instead of cancelling the wake-up process and attempting to immediately revert to a low power state, insists on waking the ONU up with the intent to re-enter a low power state via states AwakeForced and AwakeFree.

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16.4 Management transactions during low power mode

The ONU can receive and act on downstream management traffic at any of the three channels described in clause 6.3, except when it is in its LowPower state and has its receiver turned off. The OLT is responsible for understanding when the ONU can be expected to receive downstream management traffic, or to deal with the possibility that the ONU does not receive such traffic.

If the ONU receives embedded OAM commands such as DBRu or PLOAMu when it cannot respond immediately, i.e., when it is in its LowPower state, it ignores the commands. It is the OLT's responsibility to allow for extra response delays if it sends PLOAM or OMCI commands to an ONU that may be incapable of responding within the normal time.

It is prudent for the OLT to force the ONU awake before conducting management transactions.

The OLT is permitted to send unidirectional management transmissions at any time, including Profile, Deactivate_ONU-ID, Disable_Serial_Number, and Sleep_Allow PLOAM messages. The OLT must be prepared for the possibility that a sleeping ONU does not receive the transmission.

For the purposes of this clause, an ONU sleeps only when it is in state O5. When the OLT understands that the ONU is not in state O5, for example, because the ONU is only newly discovered or has not yet registered, the normal ranging and assignment transactions occur without regard to the power saving state model.

NOTE – It is possible that an ONU in states O1 or O2 might also wish to doze or sleep, as a way of conserving power while waiting for turn-up. This would involve a much simpler state model, and would require no exchange of information between OLT and ONU, externally visible merely as delayed discovery. Such a possibility is beyond the scope of this Recommendation.

3. Proposals

It is recommended that the power management section in G.987.3 be updated per this proposal to achieve standardized power savings modes that reflect industry requirements.

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