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Unified Power Management in PON systems

1 Introduction

ITU-T Recommendation G.987.3 introduced the TC-based ONU power management in XG-PON1, addressing the topic in the PON context for the first time. The Recommendation defines two power management techniques that require TC layer support. One is called doze mode; the other, cyclic sleep mode. Both modes are parametrically controlled and the control parameters are statically provisioned through OMCI. ITU-T Recommendation G.987.3 specifies the static control parameters, OLT and ONU state machines, transition diagrams (Clause 16) as well as the real-time signalling mechanism (Clause 8.1 and Clause 11).

The real-time signalling transaction between the OLT and the ONU is required only to initiate a low-power mode cycle and to terminate a low-power cycle. Within each cycle the behaviour of the parties is controlled with statically provisioned parameters. A dozing ONU continuously maintains its receiver ON (thus retaining the capability to detect an external wakeup stimulus), and has to perform relatively infrequent bi-directional keep-alive handshakes. A sleeping ONU periodically turns off both the receiver and the transmitter (thus achieving the deepest power saving), but has to perform more frequent bi-directional handshakes to ensure timely reaction to an external stimulus. In a system supporting both doze mode and cyclic sleep mode, each low-power cycle is nevertheless characterized by either doze or sleep behaviour, but not both. At the start of each cycle, the parties negotiate whether the ONU will doze or sleep.

The present specification can be extended by allowing a unified power management mode, in which an ONU periodically turns off both the receiver and the transmitter, as in the cyclic sleep mode, and performs infrequent bi-directional handshakes, as in doze mode. The timely reaction to an external stimulus is ensured by periodic uni-directional handshakes when only the ONU receiver is turned on. The unified power management mode thus combines the advantages of the two power saving modes.

2 Discussion

2.1 Depth of power saving

In both doze mode and cyclic sleep mode, an ONU in a low-power cycle alternates between **two power consumption levels**: a full power level and a low power level (see Fig. 1). In a pure doze mode, the ONU's latency in detecting an external wakeup stimulus is comparable to a round trip propagation delay, and the configured sojourn in a state with the low power level (Listen state) primarily depends on how long the OLT can afford to keep the ONU out-of touch. This value can be quite large and limited, for example, by the need to periodically adjust the equalization delay. In the cyclic sleep mode, the ONU's latency in detecting an external wakeup stimulus includes the sojourn in the low power state (Asleep state) and, therefore, the configured sojourn in a state with the low power level is substantially shorter – perhaps, by several orders of magnitude, compared with the doze case (Fig. 2).

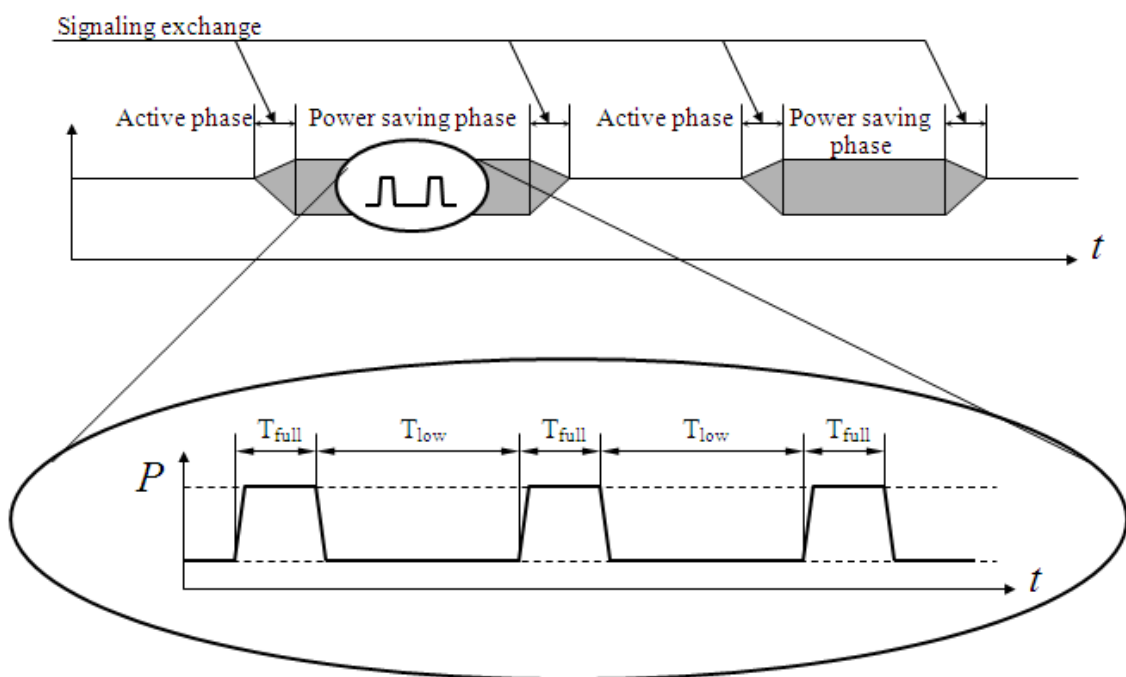


Figure 1: Conventional approach to power management

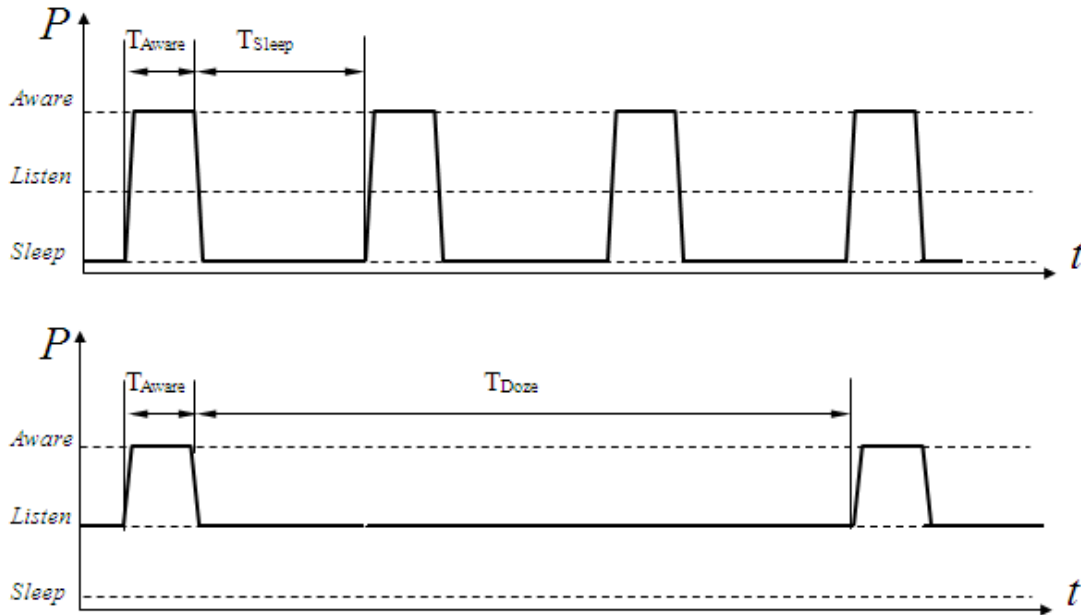


Figure 2: Typical power consumption profiles: Sleep mode (above) and Doze mode (below).

In the unified mode, an ONU in a low-power cycle alternates between **three power consumption levels**: a full power level, a low power level, roughly corresponding to the cycle sleep low power level, and intermediate level roughly corresponding to the doze low power level (see Fig. 3). The configured sojourn in the low power level is determined by the same factors as in case of the cyclic sleep mode. The combined sojourn in the combined low and intermediate power level states is determined by the same factors as in case of the doze mode. Importantly, the configured sojourn in the intermediate power level state in-between the adjacent stays in the low power level state (unidirectional handshake) is substantially shorter than the sojourn in the full-power state in case of either doze or cyclic sleep (bi-directional handshake).

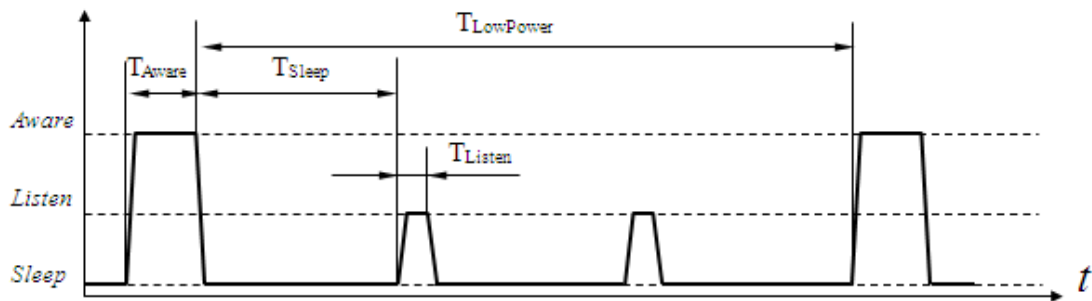


Figure 3: ONU power consumption profiles in unified mode.

To get the feeling of the efficiency of the unified power management mode, compare the average power consumption during a low-power cycle. Consider the following example, where the parameter values are taken to the first order of approximation:

P_{High}	P_{Low}	P_{Interm}	T_{LowPower}	T_{Sleep}	T_{Aware}	T_{Listen}
10W	0W	2W	1 hour	1 sec	0.1 sec	0.01 sec

Then the average power consumption in a low power cycle can be estimated as follows:

Doze mode	Cyclic sleep mode	Unified mode
2W	1 W	0.02W

2.2 Properties

Performing qualitative comparison among the available and newly specified power management modes, observe that:

- the power management signalling mechanism required for the unified mode remains identical to that of doze mode and cyclic sleep mode: the existing embedded and PLOAM management channels means are needed.
- One of the three codepoints of the Sleep_Request message becomes obsolete.
- Mode negotiation at the start of a low power cycle is eliminated
- The state machines become simplified as only one branch needs to be retained
- One extra state is added to the retained branch of the ONU state machine
- The set of OMCI-configured parameters is extended to accommodate additional controlled timing parameters.
- The unified power management mode can be reduced to either doze mode or cyclic sleep mode through parameter configuration thus ensuring full backward compatibility.

3 Simulation

The simulation model has been implemented in OMNeT++ using the self-similar traffic generator adapted from:

http://glenkramer.com/ucdavis/code/trf_gen3.html

The measure of network load is the ratio of the mean arrival rate to the link service rate. The packet size is uniformly distributed between 64 and 1518 bytes.

The following table represents the parameter combinations that have been studied.

Parameter	Case 1	Case 2	Case 3	Case 4
Tsleep	100 ms	1 s	1 s	5 ms
Tlowpower	100 s	1 h	10 s	1 s
Taware	50 ms	0.1 s	0.1 s	2 ms
Tlisten	0.5 ms	10 ms	0.5 ms	2 ms
Plisten	40.0 %	20.0 %	30.0 %	60.0 %
Psleep	5.0 %	0.0 %	20.0 %	20.0 %
Pdoze	40.0 %	20.0 %	30.7 %	60.3 %
Psleep	37.1 %	9.1 %	27.3 %	66.7 %
Punified	5.4 %	0.2 %	20.8 %	43.7 %

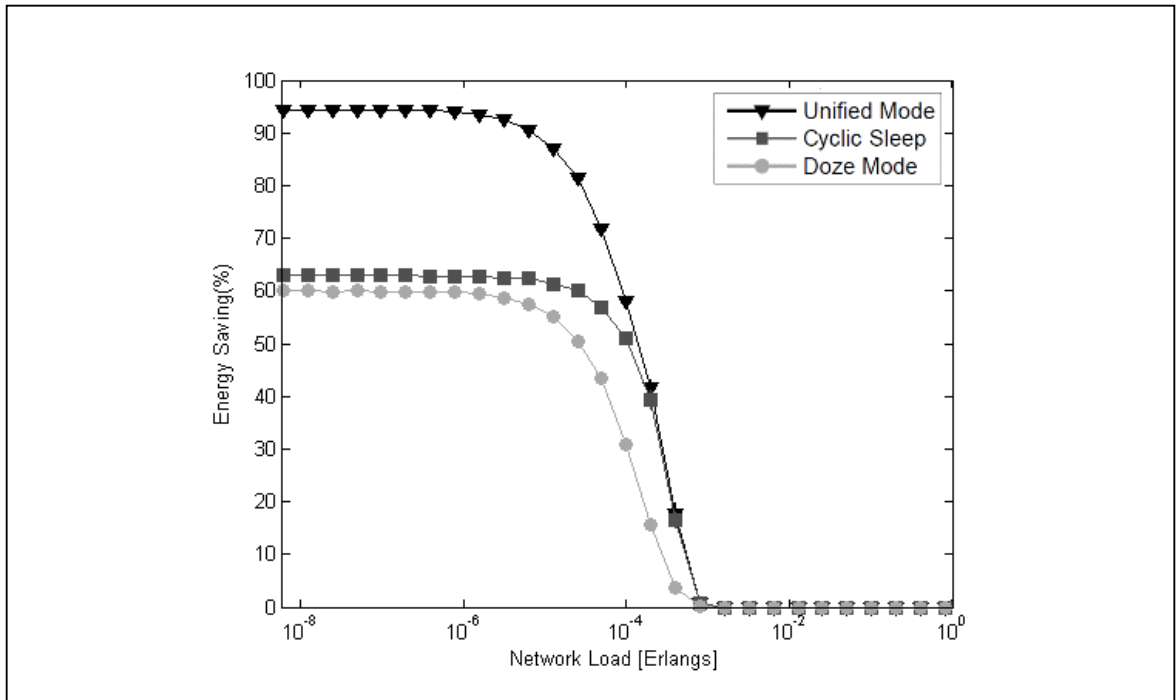


Figure 4: Simulation results: Case 1.

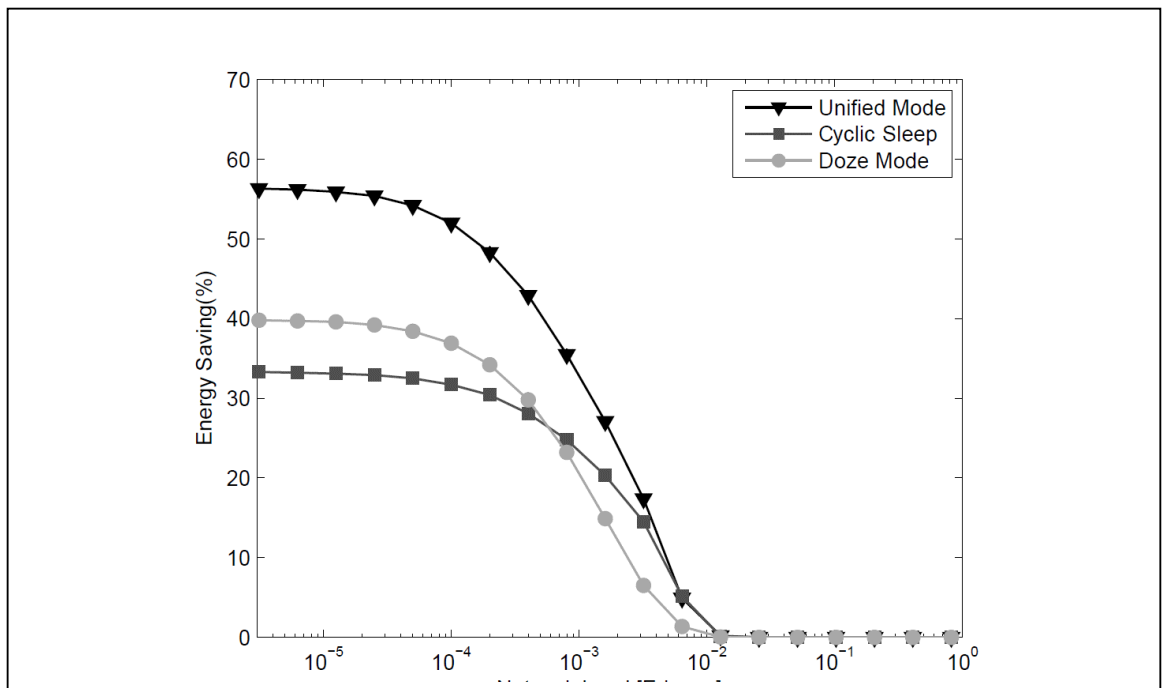


Figure 5: Simulation results: Case 4

4 Specification

4.1 Impact on the state machines

As the Unified mode of ONU power management brings two previously defined power management modes under a single parametric framework, it naturally simplified the implementation. Furthermore, the Mode state machines can be derived as a reduction of the two-mode state machines currently specified in G.987.3. In both the OLT and ONU cases, one of the branches can be eliminated, and the number of codepoints to distinguish between two modes, reduced.

4.1.1 ONU state machine

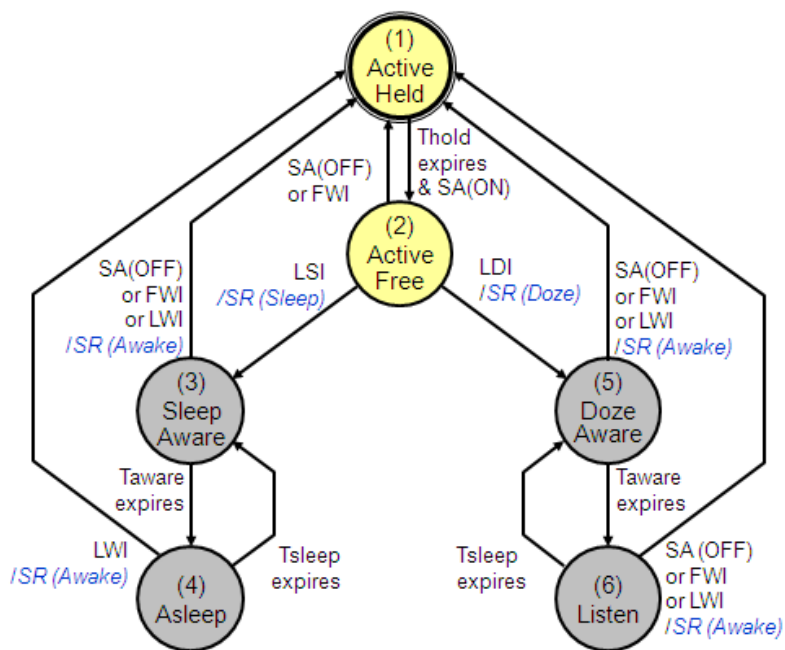


Figure 6: Original ONU state machine per G.987.3, Fig. 16-1.

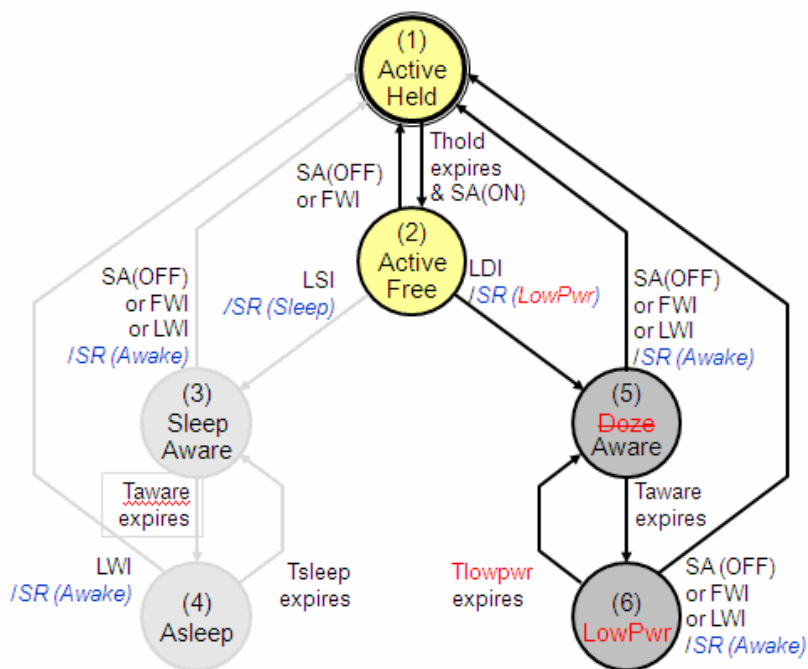


Figure 7: Unified mode ONU state machine.

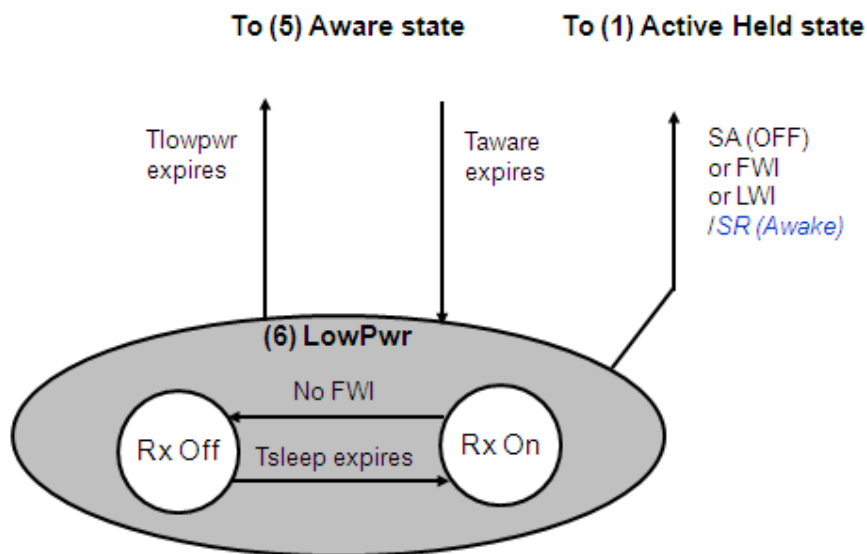


Figure 8: Internal semantics of the new Low Power state.

4.1.2 OLT state machine

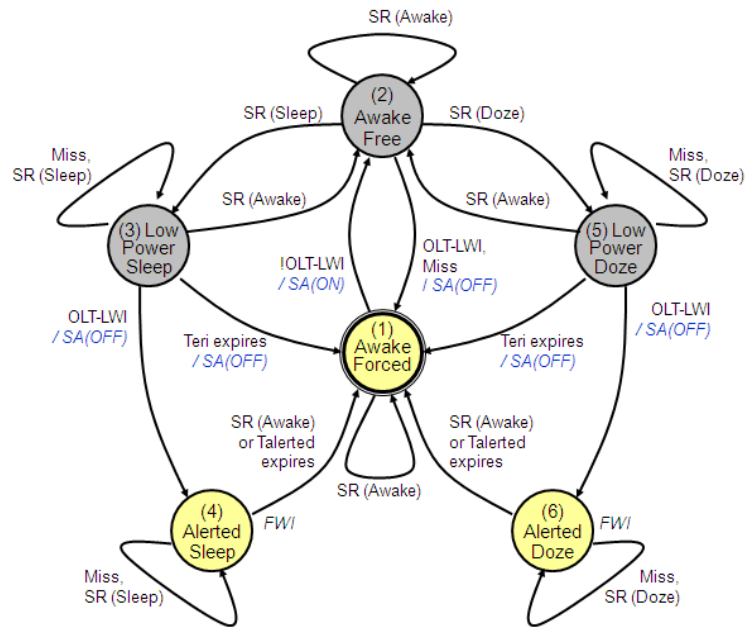


Figure 9: Original OLT state machine per G.987.3, Fig. 16-2.

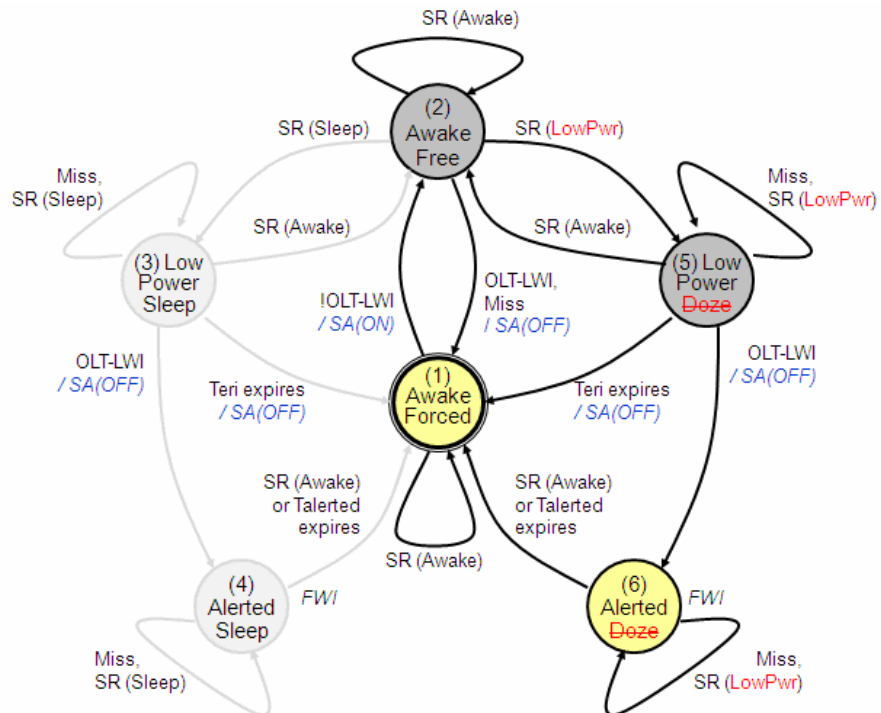


Figure 10: Unified mode OLT state machine.

4.2 Parameter definitions

The Table below contains the essential configurable timing parameters for the Unified mode of the ONU power management, emphasizing the differences with the base G.987.3 specification.

Parameter	Description	Defined by	Known to
Ilowpower	Ilowpower is the maximum time the ONU spends away from the Aware state, as a count of 125 microsecond frames. Local wake-up indications (LWIs) or remote events may truncate the ONU's sojourn in these states.	OLT	ONU, OLT
Tlowpower	Local timer at ONU. Upon leaving the Aware state the ONU initializes Tlowpower to a value equal to or less than Ilowpower.	ONU	ONU
Isleep	Isleep is the maximum time the ONU spends in its Asleep ~~or Listen states~~ , as a count of 125 microsecond frames. Local wake-up indications (LWIs) ~~in both Asleep and Listen states or remote events in Listen state~~ may truncate the ONU's sojourn in these states.	OLT	ONU, OLT
Tsleep	Local timer at ONU. Upon entry to Asleep state, the ONU initializes Tsleep to a value equal to or less than Isleep. Secondary internal timers may be required to guarantee that the ONU will be fully operational when it enters aware state after an interval not to exceed Isleep.	ONU	ONU
Iaware	Iaware is the minimum time the ONU spends in its Aware state before transitioning to a low power state (~~Asleep or Listen~~), 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 a low power 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 Aware state. Taware controls the dwell time in aware state before the ONU re-enters one of the low power states.	ONU	ONU
Itransinit	Complete transceiver initialization time: The time required for the ONU to gain full functionality when leaving the Asleep state (i.e., turning on both receiver and transmitter), measured in units of 125 us 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 Obsolete	~~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 us PHY frames. The value of zero indicates that the dozing ONU can respond to a bandwidth grant without delay.~~	~~ONU~~	~~ONU, OLT~~

Talerted	Local timer to bound the time that the OLT state machine remains in an alerted state before entering the AwakeForced state. If the ONU that the OLT attempts to wake up has been sleeping, Talerted should be initialized to at least Isleep + Itransinit + round-trip delay + tolerances for Rx synchronization, bandwidth grant irregularities, and processing time. ~~If the ONU that the OLT attempts to wake up has been dozing, Talerted should be initialized to at least Itxinit + round trip delay + tolerances for bandwidth grant irregularities and processing time.~~	OLT	OLT
Clobi	Counter of missing upstream bursts in OLTs AwakeForced(i) state for loss of signal defect for ONU i. If Clobi expires, the OLT declares LOBi against ONU i.	OLT	OLT
Teri	Local handshake timer at the OLT that defines the latest instant at which an upstream burst is expected from sleeping or dozing ONU i. The OLT reinitializes and starts this timer when the OLT's state machine for the given ONU transition into the LowPower state and each time an upstream burst is received from the ONU while in that state. If Teri expires, the OLT declares a handshake violation and attempts to force the ONU awake. To determine the initial value of Teri, the OLT is responsible to consider the provisioned Isleep 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

Acknowledgement

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<http://www.cin.ufpe.br/~dcampelo>

https://dl.dropboxusercontent.com/u/10069284/Tech_Report_final.pdf