TECHNICAL REPORT

TR-293
Energy Efficient Mobile Backhaul

Issue: 1
Issue Date: September 2014

Notice

Issue History

Issue Number	Approval Date	Publication Date	Issue Editor	Changes
1	8 September 2014	24 September 2014	Konstantinos Samdanis, NEC Manuel Paul, DT	Original

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Executive Summary

The steady rise of power cost in combination with regulatory initiatives and government policies that introduce environmental consciousness are driving the industry towards energy efficiency solutions. As mobile networks progressively handle bigger portions of the traffic this increases the needs for network infrastructure and energy demand for the Mobile Backhaul.

This document provides a conceptual framework for Energy Efficient Mobile Backhaul, based on the Mobile Backhaul architecture layed out by BBF TR-221[1], which enhances energy efficiency by supporting different radio access technologies (2G, 3G, LTE) and Mobile Backhaul services (TDM, ATM, Ethernet and IP) on a common, converged network infrastructure.

This document covers four energy efficiency mechanisms including Energy Efficient Ethernet (EEE), Power over Ethernet (PoE), ITU-T PON power management and Ethernet Link Aggregation (LAG) with EEE. It examines the applicability and external behavior with respect to Mobile Backhaul and defines related nodal requirements.

Purpose and Scope

1.1 Purpose

Due to the increasing impact (e.g., in terms of expense, carbon footprint, supply) of energy consumption in combination with regulatory initiatives, government policies and industry efforts are driving standardization activities for energy efficiency. In this document, the term “energy efficiency” follows the convention of ITU-T L.1310 [2] , i.e. *the ability of a telecommunication system to minimize energy waste*.

To date, network design, engineering and operation typically have focused on service performance, scalability and availability without prioritizing energy expense, thus, networks have commonly been operated providing full capacity with practically full power, even during non-busy hours, where network resources are not fully utilized. However, given the exponential growth of network traffic, energy consumption of networks has become a significant concern, from a business as well as regulatory perspective, hence, energy efficiency and energy awareness are to be addressed.

A key enabler for energy efficiency in networking is the capability to provide operation of the network at an energy consumption level below full power. This can be based on different approaches such as e.g., ITU-T L.1310 load-adaptive [2]. Other operational models and schemes may be used to drive lower network power consumption depending on the individual deployment scenario.

Energy-awareness in networking is enabled by concepts, mechanisms, and protocols that support operating the network a minimum practical level of aggregate power consumption while satisfying the requirement levels for network coverage, robustness, availability and performance.

TR-221 [1] specifies end to end architecture for the Mobile Backhaul and does not cover detailed energy efficiency considerations. This work would leverage the current work of other Standards Developing Organizations (SDOs) on energy efficiency.

The purpose of this document is to provide a set of mechanisms and protocols that enable operating the network at an energy consumption level below full power covering the TR-221[1] architecture, i.e. mobile access and aggregation networks from CSG to MASG.

1.2 Scope

The TR-221 [1] architecture provides network infrastructure resource efficiency (e.g. reducing the number of nodes, links) obtained through network convergence and emerging backhaul technologies.

In addition, this document covers mechanisms for energy efficient network operation, targeting the energy efficient networking of mobile access and aggregation networks from CSG to MASG.

This document specifies nodal requirements for energy efficiency focusing on the TR-221[1] architecture, addressing Ethernet, TDM, ATM and IP Services for Mobile Backhaul.

While TR-221[1] has focused on IP/MPLS-based Mobile Backhaul architectures and solutions, this document is applicable to packet-based Mobile Backhaul networks in general.

It should be noted that defining energy specific requirements for RAN equipment is out of scope. The intention of this work is the energy efficiency provision in the Mobile Backhaul without compromising its Service Level Agreement (SLA).

Applicability of energy efficiency can be discussed at different levels of a network. According to ITU-T Y.3021 [3], energy saving in networks can be achieved at three levels:

- Device-level: e.g. load-adaptive and power-adjustable components
- Equipment-level: e.g. through low-power states and dynamic adaptation of operational parameters (sleep mode control);
  Example mechanisms for such an equipment-level sleep mode control are Energy Efficient Ethernet and GPON power saving modes.
- Network-level: e.g. resource consolidation, energy consumption-based routing/traffic engineering

This document discussed energy efficiency at the equipment-level described above. It is not the intent of this project to define internal system design or system architecture.

Energy efficiency and energy consumption of networking equipment has been assessed by several industry and standardization organizations, including for example: ATIS, Broadband Forum, ETSI, IEC, IETF and ITU-T, and activities have been performed in order to define common energy efficiency reference values for telecommunication equipment and infrastructure. ITU-T L.1310 [2] and European Commission Joint Research Center (EU JRC) CoC [4] assess energy consumption values for different types of equipment for broadband services. These values are related to energy efficiency metrics, test procedures, methodologies and measurement profiles.

This document makes no assessment or definitions of values for equipment and infrastructure energy consumption.

2 References and Terminology

2.1 Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found be in RFC 2119 [5] .

MUST	This word, or the term "REQUIRED", means that the definition is an absolute requirement of the specification.
MUST NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the term "RECOMMENDED", means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the term "OPTIONAL", means that this item is one of an allowed set of alternatives. An implementation that does not include this option MUST be prepared to inter-operate with another implementation that does include the option.

2.2 References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.
A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

2.2.1 Normative References

Document		Title	Source	Year
[1]	TR-221	*Technical Specification for MPLS in Mobile Backhaul Networks*	BBF	2011
[2]	L.1310	*Energy Efficiency Metrics and Measurements for Telecommunication Equipment*	ITU-T	2012

[3]	Y.3021	*Framework of Energy Saving for Future Networks*	ITU-T	2011
[4]	CoCv5.0	*Code of Conduct on Energy Consumption of Broadband Equipment*	EU	2013
[5]	RFC2119	*Key words for use in RFCs to Indicate Requirement Levels*	IETF	1997
[6]	802.3az	*Energy Efficient Ethernet*	IEEE	2010
[7]	802.3af	*Power over Ethernet*	IEEE	2003
[8]	802.3at	*Power over Ethernet*	IEEE	2009
[9]	G.987.3	*10-Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) layer specification*	ITU-T	2014
[10]	G.984.3	*Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification*	ITU-T	2014
[11]	802.3ax	*Link Aggregation*	IEEE	2008
[12]	TR-223	*Requirements for MPLS over Aggregated Interfaces (MPLSoAI)*	BBF	2012
[13]	TR 32.826	*Telecommunication Management; Study on Energy Saving Management (ESM), Rel.10*	3GPP	2010
[14]	TS 32.551	*Telecommunication Management; Energy Saving Management (ESM); Concepts and Requirements, Rel.11*	3GPP	2013
[15]	RFC 7326	*Energy Management Framework*	IETF	2014

2.2.2 Informative References

[16]	TS 23.002	*Network Architecture*	3GPP	2014

2.3 Definitions

The following terminology is used throughout this Technical Report.

Abis	Interface between the BTS and BSC (TNL is TDM).
ATM TNL	The Transport Network Layer defined in TR-221[1] as the transport bearer for 3G ATM traffic.
CSG	Cell Site Gateway – Node at the cell site that presents the transport network interface to the Base Station equipment.

Energy	Per ITU-T L.1310 "The capacity for doing work". In the telecommunication systems, where the primary source of energy is electricity, energy is measured in Joules.
Iub	Interface between the NB and RNC (TNL is ATM or IP)
IP TNL	The Transport Network Layer defined in TR-221 [1] as the transport bearer for LTE and 3G IP traffic.
MASG	Mobile Aggregation Site Gateway - Node at the radio controller, MME or serving gateway site that presents the transport network interface to the mobile equipment.
Power	Time rate of doing work or delivering energy. Power is commonly measured in Watts.
S1 interface	Interface between the eNB and the MME or S-GW
TDM TNL	The Transport Network Layer defined in TR-221 [1] as the transport bearer for 2G TDM traffic.
X2 interface	Interface between two neighboring eNBs

2.4 Abbreviations

This Technical Report uses the following abbreviations:

2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
AC	Alternating Current
AC/DC	Alternating Current/Direct Current
ATM	Asynchronous Transfer Mode
AN	Access Node
BS	Base Station
CSG	Cell Site Gateway
DSL	Digital Subscriber Line
EEE	Energy Efficient Ethernet
EN	Edge Node
eNB	Evolved Node B
ESaving	Energy Saving
ES-Compensation	Energy Saving Compensation
E-UTRAN	evolved-UMTS Terrestrial Radio Access Network
GPON	Gigabit Passive Optical Network
GSM	Global System for Mobile Communication
HSDPA	High-Speed Downlink Packet Access
HDLC	High-Level Data Link Control

HSS	Home Subscriber Server
IP	Internet Protocol
L2VPN	Layer 2 Virtual Private Network
L3VPN	Layer 3 Virtual Private Network
LAG	Link Aggregation
LSP	Label Switch Path
LTE	Long Term Evolution
MASG	Mobility Aggregation Site Gateway
MME	Mobility Management Entity
MPLS	Multi Protocol Label Switching
MSC	Mobile Switching Center
MS-PW	Multi-Segment Pseudowire
No-ES	No Energy Saving
OAM	Operations, Administration and Management
ODN.	Optical Distribution Network
OLT	Optical Line Terminal
OMCI	ONT Management and Control Interface
ONT	Optical Network Terminal
ONU	Optical Network Unit
P	Provider
PE	Provider Edge
P-GW	PDN (Packet Data Network) Gateway
PHY	Physical Layer
PoE	Power over Ethernet
PON	Passive Optical Network
PW	Pseudowire
RAN	Radio Access Network
RAT	Radio Access Technology
RC	Radio Controller
SGSN	Serving GPRS (General Packet Radio Service) Support Node
S-GW	Serving Gateway
SLA	Single-Segment Pseudowire
SS-PW	Service Level Agreement
TC Layer	Transmission Convergence Layer
TDM	Time Division Multiplexing
TNL	Transport Network Layer
UMTS	Universal Mobile Telecommunication System

3 Technical Report Impact

3.1 Energy Efficiency

TR-293 specifies energy efficiency nodal requirements for the Mobile Backhaul.

3.2 IPv6

TR-293 has no impact on IPv6.

3.3 Security

TR-293 impacts security in the sense that energy saving mechanisms, (e.g. powering down interfaces), on network equipment and controlling mechanisms in theory may introduce potential opportunities for network attacks. These risks must be addressed through node hardening and other security mechanisms, which are out of scope of this specification.

3.4 Privacy

TR-293 has no impact on privacy.

4 Energy Efficiency within the BBF Reference Architecture

The architecture of converged transport over MPLS as described in TR-221 [1] and illustrated in figure 1 enables to unify, via network virtualization, diverse backhaul technologies into a single network bringing together 2G, with UMTS, HSDPA and LTE. Such architecture permits functionalities related to different mobile technologies to be combined, minimizing network equipment e.g., routers/switches and communication links and in turn minimizing energy consumption in converged backhaul networks.

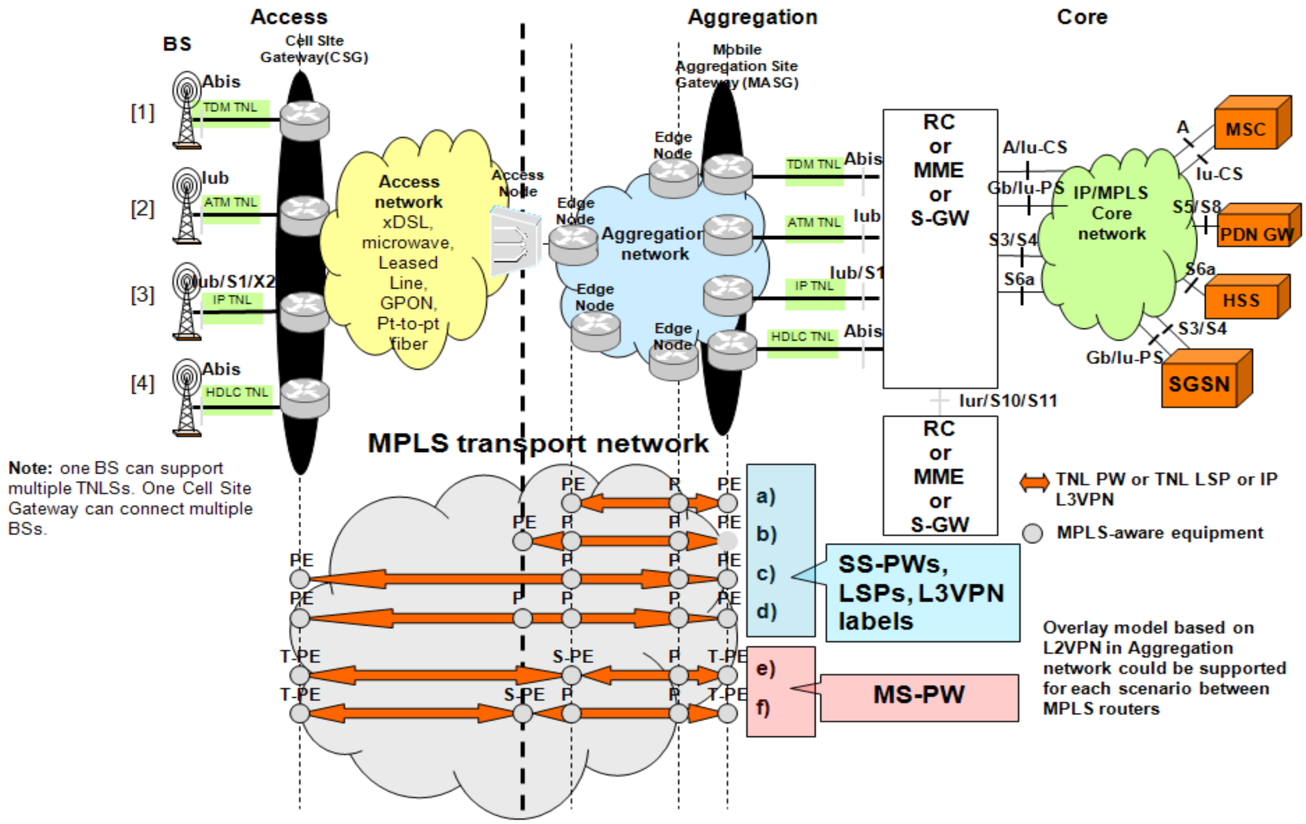

Figure 1: Reference Architecture for Mobile Backhaul network using MPLS Transport in the Access, Aggregation, and Core Networks [1]

Going beyond network infrastructure resource efficiency (e.g. number of nodes, links) obtained through network convergence and emerging backhaul technologies as covered by the TR-221[1] architecture, this document considers principles, technologies and mechanisms for energy efficient network operation, targeting the energy efficient networking of mobile access and aggregation networks from CSG to MASG.

While energy efficiency is important in most segments of the network, it is particularly important in the access network segment, due to the high number of network interfaces, links, and nodes. For example this is the case in broadband access networks, and Mobile Backhaul networks, including small cell deployments.

5 Energy Efficiency Mechanisms

The following sections address specific energy saving equipment mechanisms and their nodal requirements.

Some of the mechanisms use the concept of a "power state". Energy consumption varies, depending on equipment type, and equipment components. As the network equipment covered by this document differs in type, size, scalability, energy consumption pattern, and applicability of energy saving mechanisms, this document provides no power state definition but references the applicable power state terminology specified per energy efficiency mechanism.

5.1 IEEE 802.3az Energy Efficient Ethernet (EEE)

5.1.1 Mechanism Summary (INFORMATIVE)

For 100Mb/s and higher rates, Ethernet transmitters continuously forward, even when there is no data an auxiliary signal called IDLE to keep transmitters and receivers aligned, keeping interfaces active at all times.

EEE defines an additional **Low Idle** link state when no data packets are sent and a protocol that enables Ethernet PHYs in low idle to maintain up-to-date operational parameters. EEE defines a way of signaling once the physical link is about to be used in order to allow fast link activation. For more details refer to IEEE 802.3az [6].

5.1.2 Mobile Backhaul Applicability (INFORMATIVE)

Ethernet is relevant to Mobile Backhaul and commonly used for LTE base stations in the access as well as in aggregation networks. Hence, the adoption of energy efficient mechanisms, i.e. IEEE EEE, may help to conserve energy during periods of low utilization.

An interface with EEE support that provides connectivity to base stations may enter a low idle link state. The EEE mechanism may be applicable for use with those base stations that are capable of entering an energy saving state (see Appendix I).

5.1.3 External Behavior (INFORMATIVE)

The use of the low idle state mechanism may have the following effects on the external behavior:

- **Increases delay:** In such a state the link (transmitter and receiver) is non-operational when a new packet arrives and requires a short time to recover.
- **Potential of packet loss:** To increase the energy savings, packet coalescing (packets sent as larger blocks) is recommended (though not explicitly specified) but this may further increase delay with potential of packet loss due to buffer overflow.
- **Low Idle link state management**
    - Transiting from an active to low idle state and back is managed by the transmitter
    - During low power periods the transmitter, transmits a short signal periodically to maintain synchronization with the receiver, while checking for faults.

Note: The effectiveness of EEE in terms of performance vs energy saving is a function of incoming traffic, i.e. link utilization, packet transmission time and the distribution of packet inter-arrival times.

5.1.4 Mechanism Requirements (NORMATIVE)

IEEE 802.3az section 78.1.4 lists the applicable physical interfaces for Energy Efficient Ethernet (EEE).

[R1] If the implementation supports EEE 100Base-TX the normative requirements for the EEE capabilities corresponding clauses listed in IEEE 802.3az table 78-1 MUST be supported.

[R2] If the implementation supports EEE 1000Base-T the normative requirements for the EEE capabilities corresponding clause listed in IEEE 802.3az table 78-1 MUST be supported.

[R3] If the implementation supports auto negotiation then IEEE 802.3az clauses 45.5.3.8 and 45.5.3.9 MUST be supported

5.2 IEEE 802.3af and IEEE 802.3at Power over Ethernet (PoE)

5.2.1 Mechanism Summary (INFORMATIVE)

PoE permits data and electrical power to be provided on a single standard Ethernet cable to empower remotely network equipment avoiding the use of conventional AC supply. Hence, PoE reduces cable installation and eliminates the use of AC outlets by supplying power from a centralized location to distant devices. Such centralized power management paradigm also provides means for “power backup” ensuring continuous operation during local power interruptions. PoE also enables remote power management of devices providing control, i.e. powering-off/on.

The current version of PoE, IEEE 802.3af -2003 [7] provides 15.4W, while IEEE 802.3at-2009 [8] 25.5W. PoE offers an energy efficient way to supply power eliminating additional AC/DC transformation, which account for extra energy saving per link. This is applicable to equipment that can run within the range of PoE power supply. Currently, power is supplied either by an end-span technology directly from a powered port or by a mid-span technology via another PoE supply (see IEEE 802.3at-2009 [8] for details).

5.2.2 Mobile Backhaul Applicability (INFORMATIVE)

PoE is relevant to Mobile Backhaul for devices with modest power demands, e.g. small cells. PoE may power-off backhaul links associated with powered-off small cells, e.g. as described in the overlaid network use case (see Appendix I).

Network equipment without a power supply are the ones that may benefit from the use of PoE.

5.2.3 External Behavior (INFORMATIVE)

PoE, besides powering network equipment, can provide network management features enabling remote power control of specific ports. Specifically, PoE may enable a management system to perform scheduled, i.e. time based, or event based power-on/off control of particular ports reducing in this way energy consumption related with the attached network devices. For the Mobile Backhaul PoE could be particularly useful for managing the energy consumption of small cell arrangements.

Using PoE to perform scheduled power-on/off control may result in network management alarms. These alarms may be suppressed. In particular this should be considered and coordinated if the radio equipment is on a separate network management system than the backhaul network.

Note: PoE may also be combined with EEE for further energy savings.

5.2.4 Mechanism Requirements (NORMATIVE)

[R4] If the implementation supports PoE 10Base-TX the normative requirements for the PoE capabilities corresponding clauses listed in IEEE 802.3af-2003 and IEEE 802.3at-2009 MUST be supported.

[R5] If the implementation supports PoE 100Base-T the normative requirements for the PoE capabilities corresponding clause listed in IEEE 802.3af-2003 and IEEE 802.3at-2009 MUST be supported.

[R6] If the implementation supports PoE 1000Base-T the normative requirements for the PoE capabilities corresponding clause listed in IEEE 802.3at-2009 MUST be supported.

5.3 ONU Power Management in ITU-T PON

5.3.1 Mechanism Summary (INFORMATIVE)

Power conservation for ITU-T PON concentrates on energy efficiency of the ONU. Power management techniques are a matter of ONU design as well as subscriber and customer practice. That means it is beyond scope of ITU-T Recommendation. Following three additional means of power management, which do require TC layer support, are addressed in ITU-T Recommendation G.987.3 [9] and G.984.3 [10]:

- **Doze mode** introduces an ONU transmitter power-off for substantial time periods provided that the receiver remains continuously on. (Transmitter is Off/Receiver is On)
- **Cyclic sleep mode** where both ONU transmitter and ONU receiver are powered off, in a sequence composed by a sleep and active period. (Transmitter-Receiver are in cyclic On/Off)
- **Watchful sleep mode** combines the semantic features of the Doze and Cyclic sleep modes while reusing the states and transition of the Doze mode on the ONU side, and those of the

Cyclic sleep mode on the OLT side. Watchful sleep mode is reducible to either Doze or Cyclic sleep behavior through parameter configuration.

Upon ONU activation, the OLT discovers the ONU's power management capabilities via OMCI and configures the necessary attributes and nodes.

5.3.2 Applicability (INFORMATIVE)

ITU PON offers a high bandwidth and reliable backhaul medium, which can be applied for aggregation and last mile Mobile Backhaul access.

5.3.3 External Behavior (INFORMATIVE)

The ONU power management as described in ITU-T G.987.3 [9] is an internal protocol-based feature of the ITU PON system and takes mainly effect in the Optical Distribution Network (ODN) between OLT PON port and ONU. Nevertheless it may have effects in external behavior depending on used settings for different attributes and modes, like Tlowpower timer for Asleep power state. There is a tight relation between power reduction in ITU PON system and degradation of service. The requirement of significant power reduction may lead to noticeable effects on service integrity. That means additional delay or packet loss may occur in power saving states. Also limited processing of downstream management traffic occurs in low power states.

The ONU power management states (e.g. Listen state, Asleep state, Watch state, DozeAware/SleepAware/WSleepAware) are described in detail in table 16-2 in ITU-T G.987.3 [9] chapter 16.3.1. The bullets below are a summary of ITU-T G.987.3 [9] table 16-2. If there is a discrepancy between the bullets and the ITU text, the ITU text takes precedence.

- **Listen state:**
  - ONU receiver is on; the transmitter is off.
  - ONU listens to downstream signal and forwards downstream traffic
  - This state persists for a specified duration
  - 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.
- **Asleep state:**
  - ONU shuts down both its receiver and transmitter
  - This state persists for a specified duration
- **Watch state:**
  - ONU transmitter is off.
  - ONU periodically turns on the receiver for a brief time to check the downstream signal for remote wakeup indication. When the downstream signal is checked, the ONU does not respond to bandwidth allocations and does not forward downstream traffic.
  - This state persists for a specified duration
- **DozeAware / SleepAware / WSleepAware:**
  - Both ONU receiver and transmitter remain on.
  - This state persists for a specified duration
  - ONU forwards downstream traffic and responds to all bandwidth allocations

5.3.4 Mechanism Requirements (NORMATIVE)

[R7] For GPON, the implementation MUST support the normative requirements for the power management capabilities of ONU and OLT as per ITU-T G.984.3.

[R8] For XG-PON1, the implementation MUST support the normative requirements for the XG-PON1 power management capabilities of ONU and OLT as per ITU-T G.987.3.

[R9] A compliant G.984.3 implementation SHOULD 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.

[R10] A compliant G.987.3 implementation MUST 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 modes.

5.4 Link Aggregation (LAG) used with EEE for Energy Efficiency

5.4.1 Mechanism Summary (INFORMATIVE)

Link Aggregation (LAG), based on IEEE 802.1AX [11] and further qualified for carrier-grade application in multi-vendor IP/MPLS environments through BBF TR-223 [12], allows one or more links to be bundled together to form a Link Aggregation. In normal operation, to ensure frame ordering, the Link Aggregation distribution algorithm selects the port used to transmit a given frame, such that the same port will be chosen for subsequent frames that form part of the same flow.

EEE mechanism defines a low idle link state as described in section 5.1, which can be used for each link of the bundle provided that it supports EEE.

During periods of low utilization, energy-wise it is inefficient to keep all member links of the bundle active. IEEE 802.1AX [11] provides the mechanism to add and delete component links. During low utilization times traffic could be aggregated onto a subset of member links, providing the opportunity for member links to be removed from the bundle and then apply low idle state using EEE, thus improving the energy efficiency of the overall bundle.

5.4.2 Applicability (INFORMATIVE)

IEEE802.1AX [11] Link Aggregation is relevant to Mobile Backhaul since it is commonly used in access and aggregation networks to enhance the link capacity. Hence, energy efficient mechanisms during periods of low utilization would be beneficial.

The energy efficiency for IEEE 802.1AX [11] Link Aggregation can be improved by supporting removal of member links within the LAG bundle according to the traffic load, so that the number of active links is reduced under low load conditions.

The decision to remove member links within the LAG bundle can be based on observed load. How the decision is represented within network management and implemented is outside the scope of this specification. Nodal requirements for adding and deleting links from the bundle are given in TR-223 [12]. Links that are removed from the bundle may be put into an EEE low idle link state for energy efficiency.

5.4.3 External Behavior (INFORMATIVE)

The external behavior of IEEE802.1AX Link Aggregation is described in TR-223 section 4.1.

The external behavior of the EEE low idle link state is described in section 5.1.3 of this document.

5.4.4 Mechanism Requirements (NORMATIVE)

[R11] The router MUST support LAG as per TR-223 section 5.

[R12] The router MUST support EEE described in section 5.1.4 for links used in TR-223 bundles.

[R13] The router MUST support application of the EEE requirements described in section 5.1.4 of this document to links removed from the IEEE802.1AX bundle as per TR-223 section 5.1 Req-1a.

Appendix I. 3GPP Use Cases on Energy Saving Management

Energy saving management for Radio Access Network (RANs) aims to match the capacity offered by operators to the actual traffic demand at off-peak times when the network resources are under-utilized.

To provide a beneficial energy saving management solution, 3GPP introduces the notion of *energy saving activation* and *energy saving de-activation*, which refers to time periods where the following energy saving mechanisms are enabled/disabled. Energy saving activation and de-activation is identified based-on measurements of the overall network load, with the time periods of low load forming energy saving activation/de-activation limits.

The 3GPP Service Architecture Group 5 (SA5) has specified in [13][14] the following use cases centered for the RAN:

(i) **Carrier frequency restricted** in where a multi-carrier eNB restricts the use of certain carriers while always keeping a primary carrier operating; a common scenario in where an eNB operates on multiple carrier frequencies.

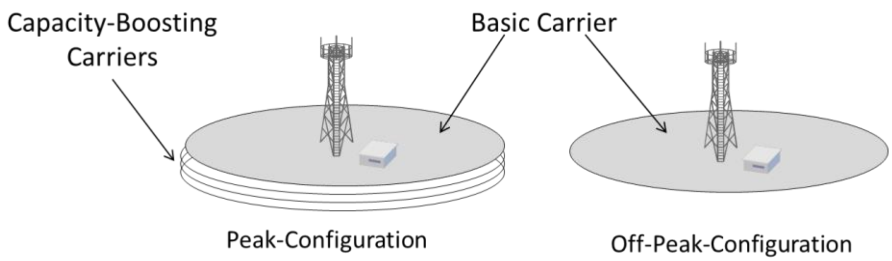

Figure 2 – Carrier frequency restricted use case

(ii) **Schedule driven strategies (eNB restricted)**, in where an eNB is powered-off/on according to a predetermined operating schedule. Such a mechanism targets special deployment areas in where the variation of eNB service traffic is regular or associated with pre-determined events.

(iii) **Overlaid networks**, in where capacity-boosting cells are powered-off, i.e. cells are in Energy Saving (ESaving) state, provided that an overlaid cell assures basic coverage at all times. For the overlaid network use case the following scenarios are considered by 3GPP, including:

- two E-UTRAN cells, i.e. cell type A (macro-cell) and cell type B (micro/pico-cell) with separate frequency bands, which covers the same geographical area
- two E-UTRAN cells, i.e. cell type A, (macro-cell) and cell type B (femto-cell – indoor hotspot), with different cell types covering the same geographical
- an E-UTRAN cell type B mainly used as a capacity-boost access, is totally covered by a different Radio Access Technology (RAT) cell type A, i.e. inter-RAT such as legacy system UMTS or GSM, which provides basic coverage

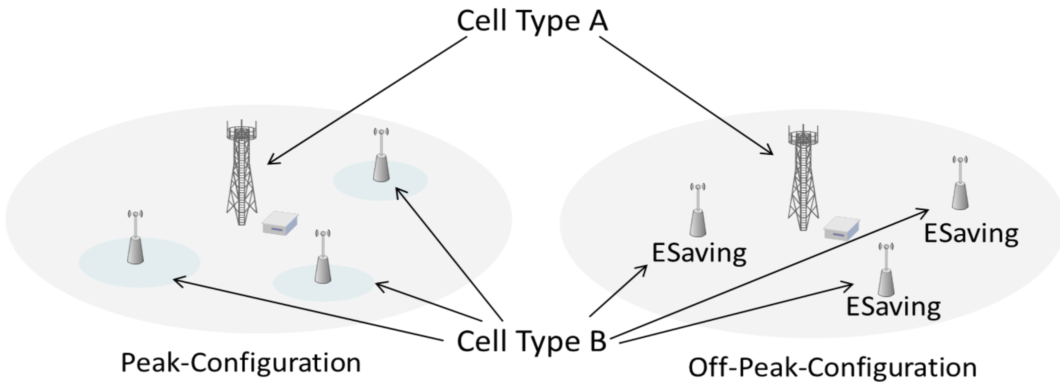

Figure 3 – Overlaid networks use case

(iv) **Capacity limited,** in where specified eNBs may extend their coverage to provide access service on behalf of neighbor eNBs (i.e. eNBs in Energy Saving Compensation (ES-Compensation) state), which are powered-off (i.e. are in Energy Saving (ESaving) state). The goal is to concentrate the load into a few selected cells that remain active during low traffic demand periods with increased coverage area and to de-activate the remaining less loaded cells

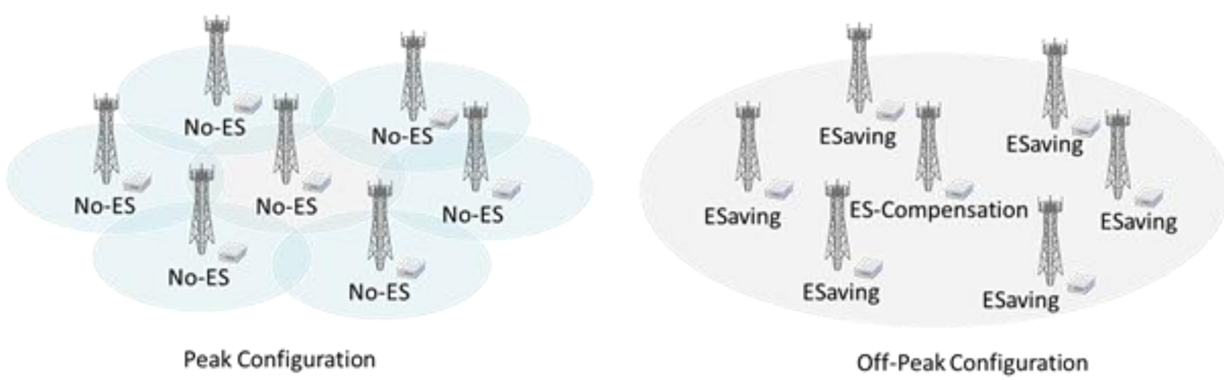

Figure 4 – Capacity limited use case

Note: The No-ES refers to the conventional operating state, i.e. with No-Energy Saving.

Appendix II. Discussion on Energy Control and Management

Energy management refers to the activities, methods, procedures and tools that pertain to measuring, modeling, planning, controlling and optimizing the use of energy in networked systems, as being described in the IETF Energy Management Framework [15]

On a network-wide basis, energy management can be performed through policies enforced by a network management system that centrally controls power states of managed entities. Central management can be beneficial if power consumption of a large number of managed entities is to be controlled and aligned. Monitoring and OAM measures are applied to acquire information about energy provisions and conditions, as well as their effect on the network and service performance.

Energy saving functions of a device can be executed locally. Local and de-centralized energy saving management is often used for energy saving mechanisms that are based on observations about the load of a local entity, e.g. as it is the case with GPON power saving.

Related policies and functions can be managed either locally, centrally or both, according to the energy efficiency mechanism that is applied. Both, local or network-wide management of energy saving functions, as well as combinations, are possible.

Energy Monitoring is a part of Energy Management that deals with collecting or reading information about energy consumption parameters in order to aid in Energy Management. Performance monitoring and OAM mechanisms, as defined in e.g. TR-221 [1], available at the node and through the network management, are used to monitor SLA attributes to ensure that any power saving mechanisms do not have an adverse impact the service.

In addition, monitoring mechanisms may be used to collect traffic data regarding the network resource utilization in order to identify low load activity periods. The information regarding these periods can be applied to ensure effective and efficient power management.

End of Broadband Forum Technical Report TR-293

