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Energy Efficiency Standards for Wireline Communications

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20.1 Introduction

Given the exponential growth of network traffic and increasing network infrastructure for achieving higher speeds and capacity, energy consumption of networks has become a significant concern, from a business as well as environmental perspective. Besides the need for sustainable and interoperable solutions, regulatory initiatives are influencing standardization efforts enforcing energy conservation for network equipment and telecommunication systems. The majority of standardization bodies have nowadays adopted an energy efficiency or green agenda to address energy-saving mechanisms applicable to a wide set of network equipment. Among the most noticeable efforts by Standards Development Organizations (SDO) and consortia for energy efficiency in wireline networks are the ones from International Telecommunication Union Telecommunication Standardization Sector (ITU-T), Institute of Electrical and Electronics Engineers (IEEE), Internet Engineering Task Force (IETF), European Telecommunications Standards Institute (ETSI), Alliance for Telecommunication Industry Solutions (ATIS), and Broadband Forum (BBF).

The Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T, a United Nations Agency) develops international standards, referred to as ITU-T recommendations. In the field of energy efficiency and green communications, ITU-T dedicated the environmental and climate change Study Group 5 (SG5), which investigates

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energy efficiency and the environmental impact of Information Communication Technology (ICT) as well as low-cost sustainable communications, methodologies for assessment and power feeding. ITU-T transport, access and home Study Group 15 (SG15) concentrates on energy-saving mechanisms for metallic and optical access networks covering digital subscriber line (DSL) and passive optical network (PON) technologies. The future networks Study Group 13 (SG13) has introduced energy-saving frameworks for next-generation networks including cloud and data center environments.

IEEE is a professional association for advancing technological innovation, developing also standards. In the field of energy saving for wireline communications, IEEE has developed energy-efficient Ethernet (EEE), which is one of the most significant standards considering the broad industry adoption of Ethernet. EEE is analyzed in Chapter 14, while this chapter considers power over Ethernet (PoE), including IEEE 802.3af and IEEE 802.3at.

IETF and Internet Research Task Force (IRTF) are a part of an open international community of network designers, operators, vendors, and researchers concentrating on the evolution of the Internet architecture and its smooth operation. The IRTF, typically sharing meeting venue with the IETF, focuses on longer term research issues related to the Internet, while the IETF focuses on the shorter term issues of engineering and standards making. Regarding energy efficiency, main activities are carried out within the IETF Energy Management (EMAN) Working Group, the IETF Routing Area Working Group related to network transport and control, and the IRTF. ETSI, a European standards body, which addresses EU regulations regarding energy saving has introduced the Green Agenda that covers several aspects of wireline communication including energy efficiency for broadband and transport equipment as well as measurements and metrics. ATIS, a North American technology and solutions development organization, has launched the Green Initiative that focuses on power consumption measurements and reporting for Ethernet switches and routing equipment as well as metrics. The BBF is an industry organization, driving broadband wireline solutions, empowering converged multi-service packet networks addressing interoperability, architecture and management. Such converged multi-service network architectures can help to reduce the amount of network equipment providing energy saving in the network planning and deployment phase.

Current standardization efforts mainly concentrate on the device, equipment and network level, that is, the way equipment is organized or structured in order to accommodate energy efficiency and performance requirements, on device and equipment energy conservation modes (power saving states), as well as on network-based mechanisms as they need to interoperate across the network [1]. Energy-aware networking is enabled by mechanisms and protocols that support operating the network at a minimum level of aggregate power consumption while satisfying network coverage, robustness and performance, that is, service level agreements (SLAs). As the actual traffic load in a network varies, network elements can be adaptively operated in a mode with lower power consumption during off-peak periods, without causing service degradation or content restriction. Such a fundamental requirement influences the design parameters of certain standards, for example, the transition period that a device needs to take in order to change from a power saving state to a fully operational state, while for particular equipment or network-based standards complementary monitoring and control is recommended to ensure profitable energy saving periods and SLA assurance.

This chapter aims to provide an overview of the main energy saving standardization efforts for wireline communications. Section 20.2 concentrates on energy-efficient equipment considering power states based on the ITU-T framework and the EC code-of-conduct, followed by the IETF/IRFT efforts focusing on energy-aware control planes, routing and traffic engineering in Section 20.3. Section 20.4 analyzes the energy efficiency in network planning based on the converged multi-service broadband architecture of the BBF, while Section 20.5 addresses the ITU-T energy management framework, IETF EMAN and IEEE PoE. Section 20.6 contains energy measurements and metric standards according to ETSI, ATIS and ITU-T, as well as evaluation and testing procedures based on the ECR Initiative. Finally, Section 20.7 provides the concluding remarks.

20.2 Energy-Efficient Network Equipment

A comprehensive analysis of the power consumption for network equipment should consider the complete equipment life cycle. ITU-T [1] identifies the following life-cycle phases in relation with energy efficiency: (i) the production phase, which concentrates on preparing raw materials and individual components, (ii) manufacturing that includes construction and shipping, (iii) usage or equipment operation, and (iv) disposal/recycling. However, ICT and telecommunication standardization efforts concentrate on reducing the energy consumption related to the “always-on” operation via network architecture, equipment capabilities and dynamic operations that reflect the traffic load.

20.2.1 Power Modes/Power Saving States

The performance of networking equipment has evolved considerably over the recent years, similar to the growing dynamics of information technology (IT) systems; still, the efficiency (ratio of performance to consumed energy) has not kept pace, leading to a continued rise in absolute energy consumption. Two main counter-measures are considered: improvements in system design (e.g., improving energy saving considering the thermal design of a node [1]) – addressing the total power consumption of equipment and devices, as well as energy proportionality – addressing the equipment operation. A key enabler for energy-efficient networking is the capability of devices and equipment to support a load-adaptive and energy proportional operation, that is, support adjusting the offered capacities in order to match the actual traffic demand.

Design, engineering and operation have typically focused on service performance, scalability, and availability without taking energy expenses into account; thus, networks have commonly been operated at peak, that is, with full power, even during off-peak hours, where network resources are underutilized. Hence, the power consumption of network equipment remained almost constant at peak level, independent of the actual network traffic demand. As traffic demands vary, elements can be adaptively operated based-on energy conservation modes or states, lowering power consumption during off-peak periods without perceptible impacts on the user service.

ITU-T identifies two levels to address load proportionality in Ref. [1] centered on the device and equipment. On the device level, energy efficiency can be realized by optimizing the operation of large-scale integration (LSI) micro-fabrication, by introducing multi-core CPU. Energy consumption is proportional to clock frequency while dynamic control technologies such as clock gating and sleep mode control can be applied separately to each CPU and via power-aware on-demand virtual or cache memory.

In order to support load-proportional efficiency, allowing adapting energy consumption to variable-load conditions, power states are a prerequisite for the equipment level. In Ref. [1], a sleep mode applied on the equipment or network interface is introduced as a design concept considering the deployment requirements and limitations including the need for delivering control packets even at off-peak times, for example, for routing updates. For link and interface-specific mechanisms, adaptive link rate enables granular control of the bit rate based on the traffic load and dynamic voltage scaling, controlling the voltage of the equipment CPU, hard disk, and network interface cards (NIC) to reflect the expected processing load.

Besides the conceptual analysis of ITU-T, IETF EMAN introduces in Ref. [2] two generic energy saving states: (i) the sleep state or otherwise dosing state where the equipment is not functional but immediately available and (ii) the off state where the equipment requires a significant amount of time to return to the conventional operational state. In principle, equipment may adopt a number of different energy states with diverse properties as documented in Ref. [3]. In the simplest case, the equipment could support two extreme energy states, that is, powered-off state and fully operational state, while certain equipment may also support an additional sleep or dosing state as the main energy saving state. It should be noted that each different technology may support different energy states, which are specified explicitly for the associated standards.

Energy efficiency in network equipment can also be realized via techniques beyond power saving states, as documented in Ref. [1], via packet filtering that blocks inessential data traffic, traffic shaping that controls the output rate or using traffic engineering and multi-layer routing through optical instead of electronic tecnologies. Improvements of the energy efficiency of network equipment can also be achieved by re-engineering on the device or component level, for example, by advancements in chip design or via the use of power-adjustable components, leading to better energy utilization. While internal system design is typically beyond the scope of standardization, regulatory initiatives, such as the EU CoC, aim to promote energy conservation for ICT equipment, facilitating activities in SDOs with influence on the system development and deployment.

20.2.2 EC Code-of-Conduct (CoC)

The EC introduced certain regulations for ICT with the objective of reducing CO_2 emissions. The Commission already recognized early in 1999 that the standby mode of ICT end-use devices is not adequate for minimizing CO_2 emissions. Hence, a Commission Communication proposed actions to promote the efficient use of energy and recommended policies for reducing power consumption of consumer electronic and network equipment in order to reduce CO_2 emissions. As a result, the Commission introduced the instrument of the so-called CoC [4] on voluntary basis. The CoC contains the policy of maximizing energy efficiency of ICT equipment. Service providers, network operators, equipment and component manufacturers may voluntarily commit to the CoC by signing as individual companies. For the time being, five different ICT CoC documents are in force:

- Efficiency of External Power Supplies
- Energy Efficiency of Digital TV Service Systems
- Uninterruptible Power Systems
- Energy Consumption of Broadband Equipment
- Data Centers Energy Efficiency

The EC did not opt for a regulatory instrument, because the CoC is more flexible and can be progressed quicker than regulation. However, if the voluntary agreement is not effective, the CoC may still be transformed to a regulation. The EC Joint Research Center (JRC) is responsible for the development and review of the CoC documents. The targets of the CoC should be realistic and challenging at the same time. The performance of the systems should not be reduced. The CoC will be regularly reviewed and updated in cooperation with all relevant stakeholders including individual companies and fora. The standardization fora BBF, Home Gateway Initiative (HGI) and ETSI TCs EE and ATTM cooperate via liaisons. The industry should be stimulated to optimize the systems and equipment. Procurement specifications should comply with the CoC.

The CoC on Energy Consumption of Broadband Equipment and on Energy Efficiency of Digital TV Service Systems are related to the relevant network equipment, while the CoC on Energy Consumption of Broadband Equipment covers both customer premises equipment (CPE) and network equipment. Covered CPEs are DSL modems, cable modems, optical CPEs, Ethernet routers and wireless user equipment. Types of considered network equipment are digital subscriber line access multiplexers (DSLAMs), multi-service access node (MSAN), optical line terminals (OLTs), base stations, access points, and CMTS. For each type of equipment, power consumption limits depending on the operation state and on the timescale are specified. For CPEs, the operation states “on,” “idle” and “off” are defined. Defined network states are full-load, medium-load, low-load, and standby. In the off state, the CoC on efficiency of external power supplies must be met. The power consumption limits differ depending on the year the equipment is brought to market or purchased or procured or tendered. The definition of the relevant date is still under discussion. Test methods are also defined.

The CoC is regularly reviewed in order to update power consumption targets for future time periods. The actual power consumption of the equipment available in the market is yearly measured in order to monitor the effectiveness of the CoC in achieving the goals. After these activities, a new version of the CoC may be released, which supersedes the old version. Furthermore, targets for future technologies, for example, VDSL vectoring and G.fast, are developed, which will be incorporated into the CoC. A reduction of power consumption of broadband equipment in Europe from 50 to 25 TWh per year is estimated to be achieved by obeying the CoC on Energy Consumption of Broadband Equipment [5].

The CoC on Energy Efficiency of Digital TV Service Systems covers set-top boxes, digital TV sets, computers with digital TV tuners or TV add-in cards, digital receivers with recording function and so on. Values of “Annual Energy Allowance” and “Total Energy Consumption” are given depending on the effective date. Test procedures for different operation modes and types of equipment are specified. A reduction of power consumption of digital TV service systems in Europe from 23 to 15 TWh per year is estimated to be achieved by obeying the CoC on Energy Efficiency of Digital TV Service Systems [5].

20.3 Network-Based Energy Conservation

Network-based energy conservation involves mechanism and protocols that stretch beyond the equipment level combining switches/routers, links, and interfaces as well as data transport and routing protocols. The objective is to achieve low-power consumption operation in a coordinated manner considering a set of equipment, for example, for how long a switch/router and an interface can transmit data or sleep, or which paths and network resources should be used to enable network-wide energy saving. Well-established standardized network-based energy saving protocols concentrate on the network access, such as ITU-T gigabit passive optical network (GPON) [6, 7] and IEEE EEE [8], which are described in detail in chapters 15 and 14, respectively. However, energy efficiency has also become important for wide area networks, including IP core and Internet backbone networks that typically rely on IP packet routing and dynamic control plane protocols. In Ref. [1], ITU-T identifies among the key enablers for achieving network-based energy conservation, energy-aware routing and traffic engineering, transmission scheduling and the use of lightweight protocols.

Energy awareness in network routing and transport is enabled by concepts, mechanisms, and protocols that support operating the network at a minimum level of aggregate power consumption while satisfying the requirement levels for network coverage, robustness, and performance. Overall, energy-efficient network operation depends on the network elements' and the network control's ability in adapting capacities to current demand, and in managing quality of service (QoS), to meet service levels and resilience levels. This relates to the IP networking protocols in scope of the IETF, covering network control, routing, metrics/profiles, and traffic engineering, in order to optimize network resources and operation in terms of energy efficiency. Specific topics currently being addressed include considerations and requirements for energy-aware control plane design, protocol extensions to exchange power ratio metrics, and power-aware networking allowing path selection and traffic steering based on energy profiles.

While research-driven proposals for routing and control adaptations have existed since around 2010, broader activities for energy efficiency in routing and transport have been seen since the IETF84 meeting, including efforts to form a new working group addressing energy-aware networking. The community has elaborated the area of network routing and transport in greater detail over recent years, but it needs to be noted that development and standardization efforts for energy-aware networking within the IETF are still to be considered as being in early stages at the time of this writing. Currently, discussions have been held within the IETF Routing Area Working Group [9], while no new working group has been formed specific to this topic yet.

Regarding the adoption of transmission scheduling, the objective is to minimize buffering on network nodes and provide the means for controlling the amount and timing of packet transmission in order to minimize per packet waiting time at each node. Operating with fewer buffer resources can save energy according to Ref. [1], but no standard has yet been developed to address such an issue, though there is potential for software defined network (SDN) protocols like OpenFlow [10], which can program the use of network resources. Lightweight protocols seek to save energy via simplifying operations or processing data traffic faster at lower layers. Currently IETF is considering the design of new lightweight communication protocols for low power and constraint network environments, for example, battery-powered devices, analyzing also routing, transport, and application layer as well as cross-layer optimization opportunities in Refs. [11].

20.3.1 Energy-Aware Control Planes

Energy-aware control planes are work in progress at the time of this writing in the IETF routing area focusing on network control, closely related to energy conservation and network performance. In large-scale carrier IP and Internet backbone networks, designed for highest availability and resiliency, it is imperative to consider how energy saving procedures, resulting in network resource adaptations, could affect network operation and applications running on the network. The Internet draft [12] provides considerations, use cases, and requirements for energy-aware control planes including operational impacts. Based on high-level business and network application requirements, the document encourages efforts for energy-efficient networking, considering how to balance efficiency and performance in practice, elaborating on effects and trade-offs potentially arising from energy reduction, and giving guidance for energy-aware control plane protocol design. Beyond basic insights on what designers of energy-aware control plane protocols ought to take into consideration, it analyses potential impacts on network QoS metrics.

Considering the main network performance drivers: bandwidth, delay, and jitter, the Internet draft [12] analyzes how these are generally affected by network control operations, related to network stretch and network convergence. Stretch in a network is to be understood as a path extension, resulting in additional hops on the packets' route compared to the shortest path, while network convergence is an effect seen during the distribution of network database updates and re-synchronization of the topology view across all network devices. Currently, Ref. [12] lists the following four ways for energy conservation in a network:

- Removing redundant links from the network topology
- Removing redundant network equipment from the network topology
- Reducing the amount of time equipment or links are operational
- Reducing the link speed or processing rate of equipment

Analyzing use cases and a sample network scenario, [12] elaborates effects potentially resulting from energy conservation actions including bandwidth reduction, increased network stretch, network convergence/recovery, and jitter, revealing to protocol designers the affected operational aspects and limitations. In particular, considering the impact on network performance, that is, bandwidth, jitter, and delay, it proposes to exploit the capability of setting parameters for a minimum expected level of performance, and to enforce it, when selecting elements to be powered down or be removed from the network for achieving energy conservation. As for network stretch, introduced when traffic is steered along a so-called loop-free alternate path for reasons of energy efficiency, it is suggested that developers should include an analysis as part of the protocol design and consider making the maximum allowed additional stretch configurable. In addition, it is suggested to provide the opportunity to maintain a minimum level of redundancy when the network is modified for energy conservation.

Concerning delays induced by the local transition from low-power conservation states to full power states of network equipment or links, Ref. [12] points out that the resulting jitter, subject to accumulation across a longer network path, needs to be considered, as well as options to coordinate the packet transmission considering sleep states or cycle network operations. The aforementioned ways of reducing energy are not dependent on whether the network control is distributed, as it is typically the case in today's Internet backbone networks, or logically centralized, that is, using a path computation engine (PCE) or a network controller. Furthermore, it is assumed that controlling local energy saving mechanisms could be left out of scope unless coordination on the level of the network-wide IP control plane is provided. It should be noted that inter-domain applications are currently not in scope.

Recently, the IETF Internet draft [13] addresses the impact of energy-aware network operation on network performance and, in turn, on the service quality perceived by the user, focusing on mobile, heterogeneous, and hybrid packet access networks. In particular, it elaborates the concept of load-proportional operation and load-adaptive network reconfiguration considering also requirements and basic approaches for network and service management, for managing service quality aspects and for counteracting potential impacts of energy-aware network operation in mobile systems.

20.3.2 Power-Aware Routing and Traffic Engineering

Power-aware routing and traffic engineering is motivated by the Internet draft [14], which provides the problem statement detailing how power awareness can be improved on a network-wide level, that is, beyond a node and link level techniques, and discusses the main technical development and operational practices. In particular, it highlights the components, for example, hardware and software, designs and operational issues, to be considered when developing energy-aware protocols and suggests categorizing potential solutions according to three dimensions: link sleep versus rate adaptation, configured versus adaptive, distributed versus centralized. The proposed problem statement was taken as the basis for a discussion about the problem space and potential solutions, to be in scope of the IETF work on power-aware networking, at the IETF86 meeting [15]. Solutions covered by the discussion concentrated on extensions to Link State Databases (LSDB), enabling layer 3 awareness by a so-called routing adjacency for sleeping links, and allowing component links to enter a sleeping state, while maintaining connectivity of an entire composite link.

As part of the power-aware networking discussion at the IETF86 meeting, proposals for a metric-based approach for reducing power consumption in the Internet routing were analyzed in the Routing Area Working Group [16]. A metric-based hierarchical approach to reduce power consumption in core and edge networks was introduced, covering both the Intra-Autonomous System (Inter-AS) case as well as a collaborative approach between Autonomous Systems (Inter-AS). The main objective concentrated on providing a comprehensive and globally applicable solution beyond powering off resources locally, supporting distributed network environments, and providing operational feasibility and benefits for a fast and widespread industry adoption. While solutions to monitor the network load and to adaptively power down unused network resources can be seen as effective to reduce energy consumption locally, more advanced approaches were recommended to improve energy efficiency in global, large-scale routing systems.

For unicast routing, a metric based on consumed power to available bandwidth was proposed, to determine a low-power path between sources and destinations, while for multicast routing, the proposed metric is based on consumed power to available multicast replication capacity, in order to allow identifying both low-power multicast paths as well as multicast replication points. Beyond energy-efficiency routing metrics, the proposal also covered related modifications to routing topology databases, that is, OSPF/ISIS Link State Database and OSPF/ISIS Traffic Engineering database, routing algorithms, and Traffic Engineering protocols, for example, RSVP-TE, in order to enable energy awareness in intra-domain and inter-domain routing. Furthermore, by introducing the notion of "TCAM power ratio" to tackle the issue of the disproportionately high power consumption of Ternary Content Addressable Memory (TCAM) components – a specialized type of high-speed memory used in network routers – energy efficiency can be achieved by enabling selective use of TCAM, allowing unused TCAM components to be powered down.

Beyond activities for energy-aware routing and transport, proposals have been made to generally investigate IETF protocols with regard to energy efficiency within the IRTF and consider forming an Energy Efficiency Research Group [17]. Particular areas of interest were energy efficiency in cloud networks by optimizing virtual machine (VM) allocations and traffic aggregation/steering in order to power-down network devices, while other topics included higher-layer/application-layer awareness, end users experience and common metrics for energy in network applications. Although aiming to reduce energy consumption from network inactivity is seen as straightforward, two potential major work areas may include: (i) exploring how existing protocols could be made more energy efficient and (ii) ensuring that new protocols support energy saving modes. While characteristics of "traditional" distributed IP control planes are being discussed with regard to energy efficiency, alternative broker-based approaches, for example, based on PCE or based on logically centralized SDN controllers, may more systematically steer traffic based on energy profiles and may be able to resolve routing database update challenges.

20.4 Energy-Aware Network Planning

The initial step toward energy-efficiency networking is network planning, which typically concentrates on performance and reliability issues without considering energy saving until lately. Network planning consists of network design, that is, dimensioning of physical network resources, routing policies and other predetermined network operations. Despite the fact that the actual placement of network resources is simply subject to network operator's service needs, convergent technologies that allow equipment consolidation in the network design phase and the arrangement of interoperable overlay or virtualized networks have been accountable for standardization. Consolidation can be achieved by converging a large number of different access equipment and their associated interfaces, gaining higher energy and space efficiency, which is also typically understood as "removing stovepipes." Network virtualization and overlay technologies allow networking to inherently become more energy efficient due to sharing of network equipment for different services, re-enforcing consolidation by reducing further network physical "boxes" and interfaces.

Consolidation in network design is achieved by standardizing network architecture and transport, an effort that is performed by BBF focusing on broadband infrastructures and services. In particular, BBF [18, 19] has specified the architecture for DSL and GPON-based access with Ethernet aggregation creating broadband loop carriers and multi-service access platforms. Such platforms combine legacy digital loop carriers (DLCs), optical add-drop multiplexers (ADMs), DSLAMs, OLTs, aggregation, and transport elements into single equipment, enhancing energy efficiency [20]. Early standards enabling multi-service overlay networking concentrated on point-to-point protocol (PPP), frame relay and later asynchronous transfer mode (ATM). Nowadays, multi-protocol label switching (MPLS) has been widely adopted to provide overlay networks unifying the priori PPP, frame relay and ATM technologies with the evolving IP and Ethernet, enabling the support of different network services [21]. Such efforts are carried out at the BBF supporting converged packet networks. Specifically BBF has progressed the multi-service broadband network architecture [22], considering the latest infrastructures, topologies and deployment scenarios, while specifying nodal requirements.

BBF has also specified a set of recommendations and best practices for the Mobile Backhaul in Ref. [48], where network planning is particularly challenging due to the diversity of

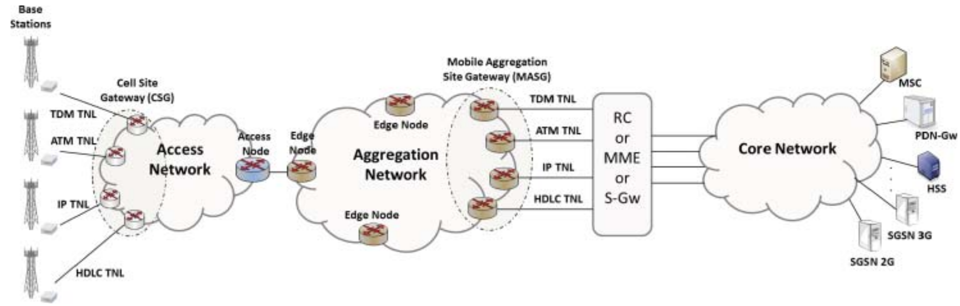

Figure 20.1 An overview of the BBF mobile Backhaul architecture based on Ref. [6]

radio access technologies (RAT) and the progressive development of the network infrastructure using different transport technologies for the access and aggregation networks. Early Mobile Backhaul deployments supporting the 2nd Generation (2G) of mobile systems employed time division multiplexing (TDM) or high-level data link control (HDLC), while later systems adopted ATM and frame relay transport to assure delay and loss for evolving multimedia applications. Nowadays, Mobile Backhaul infrastructures need to support such legacy RATs and transport services, while integrating them with the Long Term Evolution (LTE) and IP/Ethernet transport, which can handle the increasing data traffic growth and application services.

The BBF Mobile Backhaul architecture [23] unifies via the use of converged transport over MPLS diverse transport solutions, enabling a single backhaul access and aggregation network, which combines 2G, with Universal Mobile Telecommunication System (UMTS), High Speed Downlink Packet Access (HSDPA) and LTE, as illustrated in Figure 20.1, allowing a substantial reduction of the number of network elements and communication links, while increasing the network utilization via statistical multiplexing [20]. Consolidating multiple networks does not only save energy but can also ease network sharing/wholesale models, simplify network management, and reduce operational complexity.

Routing and other network policies that address energy efficiency should also be considered in the network planning phase. Beyond energy-aware routing and traffic engineering, which are "on-line" solutions, energy saving may be achieved by defining a policy regarding network equipment that lay within backup paths, which are used for resiliency as introduced in [24] for generalized-MPLS (GMPLS) label switched paths (LSPs) considering examples for 1 + 1 and 1:N protection. In addition, policies regarding content delivery, caching, and content optimization may help avoiding over-provisioning network resources, while reducing the costs of data transfer and, in turn, energy consumption. Such policies may be part of the network planning phase, though the actual mechanisms are typically application-based. IETF application-layer traffic optimization (ALTO) within the Transport Working Group specifies content optimization solutions addressing the problems and key use cases in Ref. [25].

20.5 Energy Saving Management

The energy-efficient operation of network systems requires network management processes, responsible for collecting information regarding the network status, analyzing such information and taking decisions on how to configure and control the network for achieving optimal energy savings. Such network status information and control decisions may correspond into different technology levels according to [1] including device, equipment and network. Network management processes may be distributed, that is, located in every equipment and/or be centralized, that is, performed on a controller or management server, requiring in either case coordination among the devices, equipment and network.

Network status information created on equipment basis is typically forwarded and stored in a database, which offers optimization functions related to performance and service quality profiles as well as energy consumption measures. Traditionally, network management has not included energy monitoring or control processes, but has typically concentrated on fault, configuration, accounting, performance and security management. To address such a need for energy management in a way that provides interoperability for different types of equipment, IETF formed the EMAN working group. For relatively low power edge equipment IEEE 802.3 working group developed PoE, a technology that enables remote monitoring and power control.

20.5.1 ITU-T Energy Control Framework

Managing the energy efficiency in network systems is a process that provisions equipment enabling dynamic control that reflects evolving service demands. Although energy saving management is subject to the operator's needs, certain guidelines from standards bodies provide an insight view of network operations and management principles. ITU-T in [1] documents a network management framework for supporting energy saving on devices, equipment and network systems as illustrated in Figure 20.2, which is composed by the following functions:

- *Energy management function* provides the optimal energy-efficient network state based on information retrieved from the network status information base and issues energy saving decisions toward devices, equipment and network systems. It consists of the Data Collecting sub-function, which interfaces with the status information base, the Optimization sub-function that contains the energy saving algorithms and the Operating sub-function that actuates the energy control decisions and performs potential alternations on the measurement parameters and methods.
- *Energy control and measurement function* is responsible for operating devices, equipment and network systems based on the request of the energy management function, while it also enables feeding measurements related to energy optimization corresponding to the device, equipment and network level toward the network status information base.
- *Status information base* is a database that maintains data traffic, energy consumption, and service quality, information related to the status of different devices, equipment and network systems, and provides the energy management function with the appropriate information in order to perform the corresponding energy optimization.

Such energy management framework can be performed distributed, that is, on local equipment including all described functions, and/or alternatively some of the functions can be performed remotely on a centralized controller or management server as described in Ref. [1]. Distributed arrangements allow self-optimization for network equipment focusing on the device and equipment level, while centralized models execute on a remote controller or server the energy management function, which impacts the network level. Hybrid approaches may

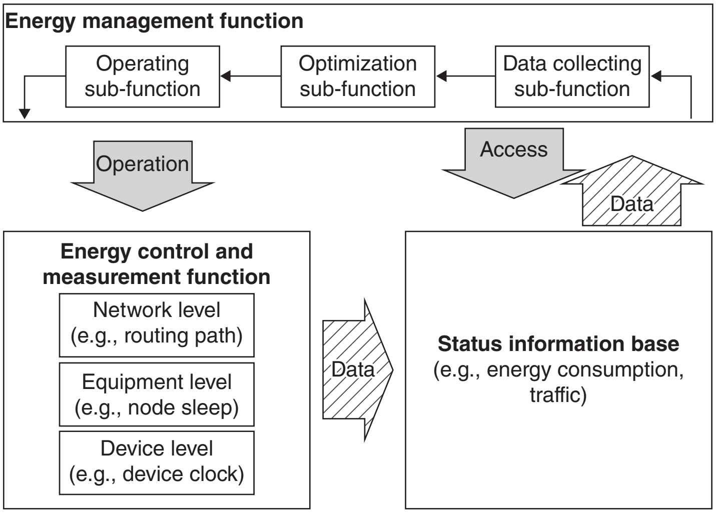

Figure 20.2 ITU-T energy control framework [Y.3021]

combine both distributed and centralized schemes in parallel, optimizing energy consumption in both local and global scale considering the device, equipment, and network level.

20.5.2 IETF Energy Management (EMAN)

There is a long history of managing IT equipment using the simple network management protocol (SNMP) [26] together with management information base (MIB) modules that provide data about and control over a set of manageable device properties. Energy management of IP networks and networked equipment at first seems just like any other network management task. On the monitoring side, instead of reading out things like packet counters, energy-related data is being monitored such as the charging state of a battery. On the control side, instead of setting elements like network protocol parameters, energy-related parameters are being controlled such as a device's power state. If the above were true, the only thing that needs to be done to support energy management using SNMP was to define MIB modules that express energy-related device properties and information.

On a closer look, however, energy management can actually be quite different from "traditional" network management. It is not so much that existing protocols are ill-suited, but the particularities of energy management require special attention. Typical network management tasks require only direct communication with the device to be managed. That might not be enough or possible when managing energy-related properties of a device, for example, many devices do not measure their power consumption simply because they lack the proper instrumentation. That does not necessarily mean that the power consumption of the device is unknown. A power distribution unit (PDU) to which the device is attached might be instrumented to deliver this data. The same applies to control. Switching off a port on a PoE switch will result in shutting down the device powered by that port. In other words, there are intrinsic relationships amongst devices along a power distribution tree that are vital to be understood when managing a network.

For all of this, it is important to note that the power distribution topology and the network topology do not always correlate, for example, when a device is attached to a PDU, that does not imply that the PDU can directly communicate with the device (i.e., there's a link between the two). It could correlate, of course, for example, in the PoE case, but this assumption does not always and generally hold. This makes energy management more complex than traditional network management tasks. Another aspect that makes energy management more complex is that quite a number of non-IP communication networks exist that are already used for energy management, for example, building management systems often use specialized building automation networks to read out energy-related information. It seems wrong to restrict new energy management standards to only IP-enabled devices from the onset as more and more devices will require being energy managed, but not all of them can support an IP stack. Therefore, being able to connect these devices to IP energy management systems is necessary, for example, through a gateway device, while once again a capability to report on other devices is necessary.

The aforementioned issues drove the IETF EMAN working group's [27] effort to define energy management standards using the SNMP. It turned out during the work that existing standards needed to be altered in order to accommodate some of the new requirements. The first standards document – Request For Comment (RFC) – the working group produced was therefore an update to the Entity MIB [28]. The changes to the Entity MIB allow resource-constraint devices to use the Entity MIB (a number of which were assumed to exist in the energy management context), while an Internet Assigned Numbers Authority (IANA) registry was created, so new general hardware types can be registered without having to change the Entity MIB in the future. The latter change was triggered by the EMAN work, because it became evident that the existing types were not sufficient, for example, a power supply type existed, but a battery did not quite fit that definition since at specific times it is a receiver of power rather than a supplier. The new mechanism of an IANA registry now decouples the registration process of new hardware types from the standards document, a process that may also be useful for further standards work.

The working group's priority when chartered was to list the requirements for new standards [2] and to describe a framework [3], where all particularities of network management were captured. A number of documents were also initiated concentrating on defining the actual energy-related managed objects [29], describing the relationships amongst managed devices [30], while batteries were segregated out into a separate document [31] since they are special from an energy management perspective, for example, they age, have a limited capacity, are temperature sensitive, and so on. Since energy management was a new topic to the IETF, it took a considerable amount time to model relationships, to capture a wide range of metrics to make the standard applicable beyond IT equipment and to understand requirements coming from other groups such as the IEEE/ISTO Printer Working Group. What emerged after a number of iterations was a concept quite familiar to IETF participants–power interfaces. A power interface can be an inlet (where a device is supplied with electric power) or an outlet (where a device supplies electric power to other devices); a concept quite similar to network interfaces, which shaped the problem in much easier terms for the EMAN working group. IETF is also working toward a document that contains an applicability statement [32], which describes how the EMAN work can be applied in various scenarios ranging from data centers to industrial automation network.

At the time of this writing, the first implementations of the Internet drafts have been reported, while there is a significant interest in the technology with progress made after a large number of iterations with significant changes. When the set of EMAN documents are finalized, it will be easy to perform energy management with existing IP network management systems as another important aspect of IT management.

20.5.3 IEEE Power over Ethernet (PoE)

IEEE PoE transfers electrical power along with data on a single standard Ethernet cable, empowering remote network equipment, referred to as powered devices (PD), without the need for a conventional alternating current (AC) power supply. Effectively, PoE reduces cabling, eliminating the need for AC outlets, while simplifying installation and maintenance, by using an Ethernet switch, termed as power source equipment (PSE), to provide power for attached equipment. Such a centralized power supply scheme establishes energy efficiency introducing 0.6–2.1 W of power conservation per interface [33], while it also provides the means for "power backup", ensuring a continuous full operation for PDs despite power interruptions.

The original version of PoE, IEEE 802.3af-2003 [34] provides 15.4 W per port; however, only 12.95 W is available at the device as some power is dissipated in the cable. IEEE 802.3af enables PSEs to automatically discover attached PDs and determine their power class. Currently, IEEE 802.3af can be used with 10BASE-T and 100BASE-TX and supports four power classes that correspond to Type 1 PD power levels, as illustrated in Table 20.1. Power originated from a PoE switch is supplied by end-span, that is, directly from the powered port, or by mid-span via another PoE supply. When a PoE connection is initiated, the PD may communicate its power class indicating to the PSE the amount of needed power via a 1-Event Physical Layer Classification. The updated IEEE 802.3at-2009 [35] known as PoE Plus offers up to 25.5 W and it can also be used with 1000BASE-T. The classification scheme of IEEE 802.3at, shown in Table 20.1, is the same as the one defined for IEEE P802.3af, to ensure backwards compatibility, while an additional class is specified for PDs that require more than 12.95 W, referred to as Type 2. PDs can be classified by the IEEE 802.3at PSE by a 2-Event Physical Layer Classification, data link layer classification, for example, Link Layer Discovery Protocol (LLDP) or a combination of both.

PDs may stretch up to 100 m from a PSE, which can empower a wide variety of equipment including Voice over IP (VoIP) phones, wireless access points, Ethernet hubs, security pan-tilt zoom cameras, print servers, and so on. PoE enables remote power management of such PDs,

Table 20.1 PoE PD classification and power supply

Class	PD classification	Power available for PD (W)
0	Default / type 1	0.44–12.95
1	Type 1	0.44–3.84
2	Type 1	3.84–6.49
3	Type 1	6.49–12.95
4	Type 2	12.95–25.5

enabling remote power control of specific ports. Specifically, PoE may enable scheduled, that is, time-based or event-based power-on/off control of particular ports reducing in this way energy consumption related with the attached PDs. PoE may also be combined with the EEE for further energy savings providing a higher reduction on energy per interface.

20.6 Energy-Efficiency Metrics, Measurements, and Testing

Energy-efficiency metrics, measurements and testing procedures are key enablers for providing energy saving in network equipment and telecommunication systems. Metrics can provide a quantified indication of energy efficiency, which once standardized can enable comparisons of different equipment, network of equipment or equipment component s of the same type. Equally, testing procedures and measurements should be performed under identical conditions, which are subject to standardization, to ensure equivalent procedures for assessing the energy efficiency of equipment and networks. Among the different standardization bodies, ETSI, ATIS, ITU-T and the ECR Initiative have produced comprehensive concepts and principles and have specified standards that can be used for measuring, reporting and assessing energy efficiency.

ETSI has introduced energy-efficiency metrics and measurements for broadband equipment, identifying reference models and key performance indicators (KPI) as a part of the Green Agenda. The main Technical Committees (TCs) handling energy efficiency are the environmental engineering (EE) TC, which deals with definitions of energy efficiency, measurement methods and indicators and the access, terminals, transmission and multiplexing (ATTM) TC that focuses on energy-efficiency metrics, KPIs and recommendations. Early efforts on energy efficiency such as [36] have concentrated on defining a power consumption model per line, considering the bit rate and line length, and on specifying measurements and test conditions focusing on digital subscriber line access multiplexer (DSLAM) equipment. An analysis indicating the energy-efficiency factor (EEF), defined as the energy usage to data rates, and KPI figures for access network broadband equipment including metallic loop solutions, for example, asymmetric digital subscriber line (ADSL), and optical fiber access solutions including fiber to the cabinet (FTTC), fiber to the building (FTTB) and fiber to the home (FTTH) is documented in Ref. [37], providing also a summary of power requirement metrics related to each aforementioned technology. Global KPIs in relation to energy efficiency are also specified in Ref. [38] considering broadband infrastructure scalability as well as measurement points and procedures.

ETSI ES 203 215 [39] specifies more advanced measurement methods and test conditions for broadband equipment considering DSLAM, MSAN and GPON OLT, while it also provides, as informative data, power consumption limits corresponding to each priori analyzed technology. Energy-efficiency measurements for IP routers and Ethernet switches are defined in ETSI ES 203 136 [40], which also specifies test suits and the equipment energy efficiency ratio (EEER) that indicates energy efficiency per throughput. ETSI ES 203 184 [41] defines a methodology and test conditions based on EEER considering transport equipment, that is, connected to the network by copper or fiber. It focuses on the physical layer and on equipment running at data link layer, which were not included in Ref. [40], considering switches, multi-service transport platforms, (e.g., combinations of SDH and Ethernet), DWDM multiplexers/demultiplexers, optical amplifiers, transponders, and so on. The ETSI European Standard EN 301.575 [42] provides energy consumption measurement methods for CPE and test conditions concentrating on broadband equipment, LAN and WAN, that is, Ethernet, considering different power modes, including disconnected mode, off mode, standby, idle state and low-power state.

ATIS has also defined energy measurements as a part of its Green Initiative, introducing within the Network Power and Protection (NIPP) Committee the Telecommunications Energy Efficiency Ratio (TEER) standard to measure and report the energy efficiency of telecommunication equipment. ATIS documents a base standard in Ref. [43], which specifies a methodology for deriving TEER, while establishing uniform means for measuring energy consumption and reporting applied to different types of equipment, for example, core, transport, access. Supplementary standards subject to particular types of equipment specify details of measurement configurations and reporting for formulating TEER. In particular, Ref. [44] defines TEER for routers and switches considering fixed and modular equipment, including also the case where power saving is applied on component subsets, while it specifies test procedures, relating energy expenditure with equipment load. In Ref. [45], a set of guidelines for specifying TEER for transport equipment is documented, including testing procedures considering equipment configuration, data rates for typical transport interfaces (TDM/PDH, optical transport, Ethernet packet data, storage area networking and DWDM), and measurements methods.

ITU-T specifies in Ref. [46] the principles and concepts of energy-efficiency metrics and summarizes testing procedures and measurement methodologies for assessing the energy efficiency of network equipment and small networking equipment based on ETSI and ATIS documentation, enabling comparison among equipment that belong within the same class, for example, equipment of the same technology. The network equipment considered includes DSLAM, MSAN, GPON, gigabit Ethernet PON (GEPON), routers, switches, small network devices, WDM/TDM/OTN transport. A framework for approximating energy efficiency as the ratio of power consumption to transmission bandwidth is documented by ECR Initiative in Ref. [47], covering various operation conditions and practical considerations, including peak, variable-load, and idle energy efficiency. Such a framework defines a measurement methodology, which is applicable to many types of packet-oriented networks and equipment, including, but not limited to, core/edge routers, L2/L3 switches, and so on.

20.7 Conclusions

Rising energy costs, environmental policies, as well as equipment scaling and operation issues are driving the need for energy-efficient networking. This chapter overviews the main wireline standardization efforts considering network equipment, network-based mechanisms, planning and management operations, as well as energy metrics, measurements, and evaluation. It summarizes the EC CoC and provides insight views of energy proportionality on network equipment and telecommunication systems. The support of power saving states for network equipment is analyzed, considering functional capabilities, which may vary across different types of equipment. While power states and control mechanisms are typically defined as part of particular technology standards, SDN APIs may provide a generic means to allow more flexibility and control. Network-oriented efforts require coordination to address automated, interoperable ways of adapting network configuration and, in turn, energy consumption considering network performance and service levels. IETF energy-aware routing and control are in early stages where several issues, such as traffic steering, energy profiles, operational overhead, are still open. Logically centralized control and path computation based on SDN paradigms may provide enhancements in terms of flexibility and scalability. For network planning, equipment consolidation and overlay/converged multi-service networking, for example, as specified by BBF, is seen as key enabler for achieving energy efficiency. Considering network management, ITU-T introduces a framework that considers energy saving at different levels of devices, equipments, and networks, while IETF EMAN provides means for energy monitoring, reporting, and control. For small edge equipment, PoE provides installation efficiency and remote power control. In general, energy-saving mechanisms and OAM tools need to be coordinated, aligning the transition into a power saving state with running continuity checks and/or protection mechanisms. Finally, metrics and measurement methodologies introduced by ETSI, ATIS, ITU-T, and the ECR Initiative provide the foundation for comparing and evaluating energy efficiency among network equipment of the same type. Following recent trends toward cloud-centric networking, holistic strategies for energy saving will become more important. While IT/server consolidation is one of the key energy saving approaches in today's data centers, virtual resource optimization and migration in combination with energy-aware, network-wide, interoperable control solutions can become an important topic in data center-centric network architectures.

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