International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

L.1360

(12/2016)

SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Energy control for the software-defined networking architecture

Recommendation ITU-T L.1360

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Recommendation ITU-T L.1360

Energy control for the software-defined networking architecture

Summary

Energy efficiency has become one of the most important aspects for both current and future telecommunications infrastructures. Taking energy into account induces a new constraint when managing a network. To tackle the integration of the energy constraint into the networks, the European Telecommunications Standards Institute (ETSI) has recently standardized the green abstraction layer (ETSI ES 203 237) which is an interface between the resource and the control planes of a network that enables control plane processes to manage the power management capabilities of fixed network nodes to effectively adapt the energy consumption of the network nodes with respect to the load variations.

Recommendation ITU-T L.1360 defines the integration of the green abstraction layer into a software-defined networking (SDN) architecture (see Recommendation ITU-T Y.3302) in which the connections between a set of network resources are on demand and are managed by one or more software-defined networking controllers.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L.1360	2016-12-14	5	11.1002/1000/13148

Keywords

Energy control, green abstraction layer, software-defined networking.

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[*] To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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1 Scope

This Recommendation defines the integration of green abstraction layer [ETSI ES 203 237] into a software-defined networking (SDN) architecture [ITU-T Y.3302].

Four basic SDN elements are defined within the SDN architecture [ITU-T Y.3302]: the SDN application layer, the SDN control layer, the northbound interface between the SDN application layer and the SDN control layer and the southbound interface between the SDN control layer and the SDN resource layer. The green abstraction layer adds a further dimension which requires integration and is the subject of this Recommendation.

Since the green abstraction layer allows applications to access to the power management capabilities of network nodes in the resource layer to effectively adapt the energy consumption of the network nodes with respect to the load variations, it can be said that all the SDN elements are impacted.

In this respect, this Recommendation focuses on:

– The definition of an energy-efficient SDN general architecture;

– The definition of an energy states model.

Appendix I provides an example of an energy-efficient SDN based on the Open Networking Foundation (ONF) specification [b-ONF-SDN].

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.3302]	Recommendation ITU-T Y.3302 (2017), *Functional architecture of software-defined networking.*
[ETSI ES 203 237]	ETSI ES 203 237 (2014), *Environmental Engineering (EE); Green Abstraction Layer (GAL); Power management capabilities of the future energy telecommunication fixed network nodes.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 convergence layer interface [ETSI ES 203 237]: GAL interface designed to map the GAL commands and data into low-level configuration registers/APIs, which are often manufacturer/HW specific.

3.1.2 energy-aware entity [ETSI ES 203 237]: Entity that can trade its power consumption and its available functionalities and responsiveness.

3.1.3 energy-aware state [ETSI ES 203 237]: Entity power setting managed through the GAL that impact on the power consumption, the performance, the available functionalities, and the responsiveness of the entity.

NOTE – An EAS can be considered as an operational power profile mode implemented by the entity that can be configured by control plane processes. To assure the correct exchange of information between the entity and control plane processes, the EAS should be represented as a complex data type, which contains indications on the power consumption, the power saving, the performance, the available functionalities, and the responsiveness of the entity when working in such configuration.

3.1.4 entity [ETSI ES 203 237]: Device or a sub-part of it, of which the GAL constitutes the energy-aware interface

NOTE – At the lowest hierarchical levels, an entity can correspond to a chip, a network processor, a link interface. At medium hierarchical levels, it can correspond to line-cards, chassis, etc. At the highest level the entire device corresponds to an entity. Higher level entities can include one or more entities at lower levels. This hierarchical architecture is optional and the relative depth should depend on the specific internal architecture of the network device. The terms "entity" and "resource" are used interchangeably in the present document.

3.1.5 green abstraction layer [ETSI ES 203 237]: Interface between resource and control planes for exchanging data regarding the power status of a device.

3.1.6 green standard interface [ETSI ES 203 237]: GAL interface designed to exchange power management data in a simplified way among data-plane elements and processes realizing control plane strategies.

3.1.7 local control policy [ETSI ES 203 237]: Control process optimizing the configuration at the device level in order to achieve the desired trade-off between energy consumption and network performance according to the incoming traffic load.

3.1.8 network control policy [ETSI ES 203 237]: Control process trading-off between power consumption and performance of a network.

3.1.9 software-defined networking [b-ITU-T Y.3300]: A set of techniques that enables to directly program, orchestrate, control and manage network resources, which facilitates the design, delivery and operation of network services in a dynamic and scalable manner.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 abstraction: A representation of an entity in terms of selected characteristics, while hiding characteristics irrelevant to the selection criteria.

3.2.2 network element: A group of resources that manipulates or stores user data and is managed as a single entity.

3.2.3 virtualisation: An abstraction whose function is to dedicate resources to a particular client.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ACI	Application-Control Interface
API	Application Programming Interface
CLI	Convergence Layer Interface
DPCF	Data Plane Control Function
EAE	Energy Aware Entity

EAS	Energy Aware State
GAL	Green Abstraction Layer
GSI	Green Standard Interface
HW	Hardware
LCP	Local Control Policy
NCP	Network Control Policy
NE	Network Element
NFV	Network Function Virtualization
OAM	Operations Administration and Management
ONF	Open Networking Foundation
OSS	Operations Support System
PMP	Power Management Primitive
QoS	Quality of Service
RCI	Resource-Control Interface
SDN	Software-Defined Networking
TCP	Transmission Control Protocol

5 Conventions

None.

6 Introduction

Energy efficiency has become one of the most important aspects for both current and future telecommunications infrastructures. Taking energy into account induces a new constraint when managing a network. This constraint is added to the three already existing constraints, namely quality of service (QoS), resilience and security. Network operators need to define the order in which the four constraints are taken into account in order to set-up the optimal set of hardware resources.

When dealing with quality of service, resilience and security, there are six possible combinations: {QoS, security, resilience}, {QoS, resilience, security}, {security, QoS, resilience}, {security, resilience, QoS}, {resilience, QoS, security} and {resilience, security, QoS}. Bearing in mind that the reputation of an operator can be ruined by a malicious user, security is the requirement to be firstly chosen. In addition, since resilience depends on QoS, the only possible combination is {security, QoS, resilience}.

Adding energy to those three constraints induces four combinations: {energy, security, QoS, resilience}, {security, energy, QoS, resilience}, {security, QoS, energy, resilience} and {security, QoS, resilience, energy}. Among these four possible combinations, two combinations are relevant: {security, QoS, resilience, energy} and {security, energy, QoS, resilience}. The first combination, in which energy is the last constraint taken into account when defining the optimal set of hardware resources, means that the transition toward energy-efficient networks is done smoothly. The second combination, in which the energy constraint is before QoS and resilience, means that energy is more important than QoS. This case is possible in best-effort networks.

To tackle the integration of the energy constraint into the networks, ETSI has recently standardized the green abstraction layer (GAL) [ETSI ES 203 237] which is an interface between the data and the control planes of a network that enables control plane processes to manage the power management capabilities of fixed network nodes to effectively adapt the energy consumption of the network nodes with respect to the load variations.

One of the challenges is to now define the integration of GAL into a software-defined networking (SDN) architecture [ITU-T Y.3302] in which the connections between a set of network resources are managed by one or more SDN controllers.

7 Green SDN architecture

A way to define a green SDN architecture, i.e., an energy-efficient SDN, is to implement the green abstraction layer standard in the SDN architecture.

7.1 SDN architecture

The SDN functional architecture [ITU-T Y.3302] allocates virtualised network resources to customers' applications. The virtualisation concept in SDN differs from the one used in network functions virtualisation (NFV) [b-NFV] in which virtualisation is used to abstract network functions away from dedicated hardware.

The basic SDN components are introduced in Figure 1. The SDN resource layer incorporates network elements (NEs) that deal with customers' traffic along with the necessary supporting resources to ensure proper quality of service (QoS), security and resilience. Each network element exposes their capabilities toward the SDN control layer via the southbound interface, also called the resource-control interface (RCI).

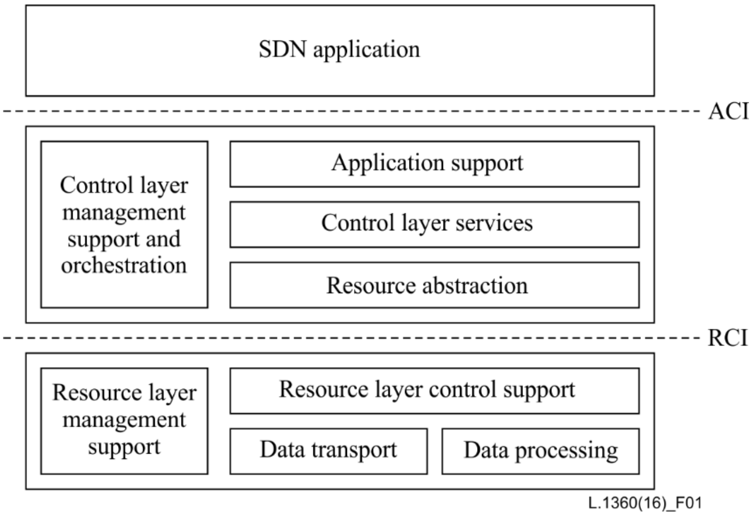

Figure 1 – SDN components

In the SDN application layer, while customers' systems have historically interfaced the network indirectly by way of the provider's operations support system (OSS), customers' applications may have dynamic control of network resources exposed by the SDN control layer. They communicate their network requirements toward the SDN control layer via the northbound interface, also called the application-control interface (ACI).

In the middle, the SDN control layer translates the customers' applications requirements and exerts low-level control over the network elements while providing relevant information up to the customers' applications. The SDN control layer may orchestrate competing demands for limited network resources according to policies.

In the SDN architecture, the SDN control layer (see Figure 2) offers services to customers' applications by way of an information model instance derived from the underlying resources. The resource abstraction functional component of the SDN control layer hides the configuration details. Information and data models, that are means to provide an abstracted view of the underlying network resources to the SDN control layer, are stored in the topology repository in the resource abstraction functional component.

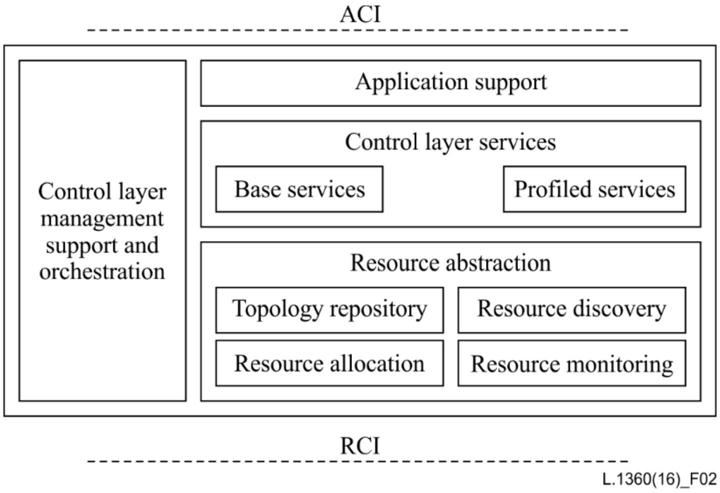

Figure 2 – SDN control layer

The control layer services functional component provides a set of programmable control and optionally, management functions covering e.g., physical and virtual network topologies, network elements configuration and traffic flows forwarding management. It includes base control layer services that are obligatory in all SDN instantiations and profile-dependent control layer services that are use case specific services.

The control layer application support functional component provides an ACI reference point to the SDN application layer for accessing network information and requesting application-specific network behaviours. The information exposed to the SDN application layer is abstracted by means of information and data models. The abstracted network view is provided to SDN application layer functional components via the application-control interface (ACI) reference point.

7.2 Green abstraction layer

The green abstraction layer (GAL) [ETSI ES 203 237] is a multi-layer hierarchical interface that allows intercommunication among the control plane and the data plane of a network with the aim of managing the trade-off between the power consumption of the entities composing a network and the performances of the network.

The different layers of the GAL multi-layer hierarchical interface are meant to represent various abstraction levels of the power consumption of the devices. At the lowest hierarchical level, an entity can correspond to a link interface, a processor, or a fan. At the medium hierarchical levels, an entity can correspond to line cards, chassis, etc. At the higher hierarchical level, an entity can correspond to one or more items of network equipment. Only the top layer of the multi-layer hierarchical interface is mandatory in order to allow communication between the data plane entities and the control plane processes managing their energy consumption.

According to GAL [ETSI ES 203 237], an energy-aware entity (EAE) is an entity that can trade its power consumption and its available functionalities and responsiveness. Its possible energy consumption states are defined in an energy-aware state (EAS) that can be managed by processes in the control plane.

This management is possible through two interfaces, the green standard interface (GSI) and the convergence layer interface (CLI). The first one, the GSI, which represents the standard part of the

GAL, allows the communication between the control plane processes, whereas the latter, the CLI, may map GAL commands and data onto low-level application programming interfaces (APIs), which are hardware specific. Regarding the control plane processes, there exist three main sets of processes:

– Local control policy (LCP) which optimizes the configuration at the device level in order to achieve the desired trade-off between energy consumption and network performance according to the incoming traffic load. For this purpose, such processes need to know in detail the internal architecture of the device (or parts thereof), the number, the typology and the capability of energy-aware elements, as well as have access to network performance indexes;

– Network control policy (NCP) to control and optimize the behaviour of a network. Typical examples of these kinds of processes are traffic engineering, routing and signalling protocols with "green" extensions;

– Monitoring and operation administration and management (OAM) for the operator to control and optimize the trade-off between energy consumption and network performance through a network management system with "green" capabilities.

Figure 3 shows an example of a GAL architecture composed of four layers.

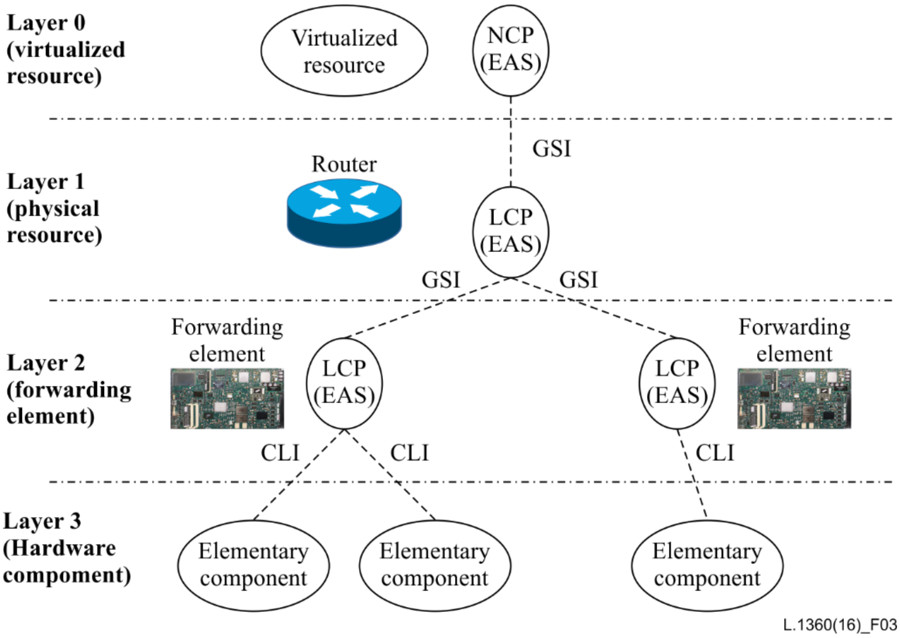

Figure 3 – Example of a four-layer green abstraction layer hierarchy

To summarise, the green abstraction layer synthetizes the data related to power management settings into sorts of standard data objects, namely energy-aware states (EASs). The GAL manages the EASs by means of two interfaces:

– Green standard interface (GSI) to exchange power management data among processes realizing control plane strategies;

– Convergence layer interface (CLI) to map the green abstraction layer commands and data into low-level APIs.

7.3 Energy control in the SDN architecture

Providing energy control in the SDN architecture implies piloting the convergence layer interface that manages the power management primitive (PMP) of the hardware from the SDN control layer.

According to the green abstraction layer, the hardware CLI can be piloted through a hierarchy of LCPs and the SDN control layer communicates with the top-level LCP of each resource it manages.

To effectively manage the hardware power consumption, the SDN control layer may host an optimizer which is built on the following elements (see Figure 4):

- Periodically, an optimizer computes the set of network elements that consume the minimum power for a given traffic load subject to the satisfaction of some constraints. The constraints may include Security, Resilience and Quality of Service.
- The input of the optimizer is fed by network statistics that includes the power used by each component of the virtual network and its associated performance.
- The outputs of the optimizer are twofold: the first one feeds a power control module, which task is to interact with the LCPs, and the second one feeds a forwarding control module which task is to push forwarding rules.

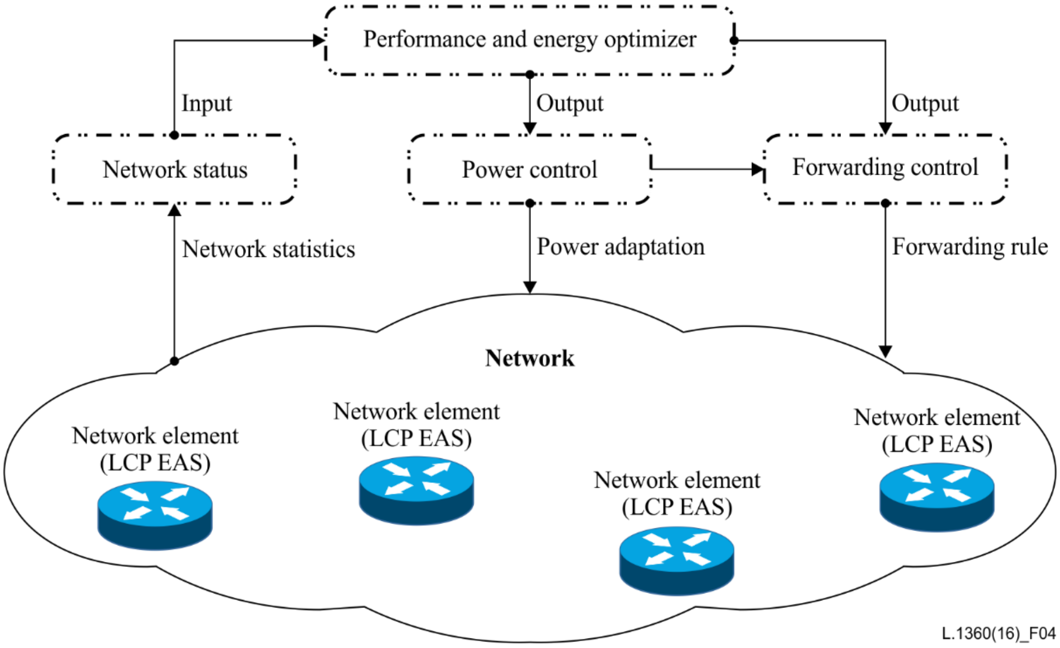

Figure 4 – Power optimisation elements

Figure 5 shows the mapping between the performance and energy optimizer, the network status, the power control and the components of the SDN functional architecture.

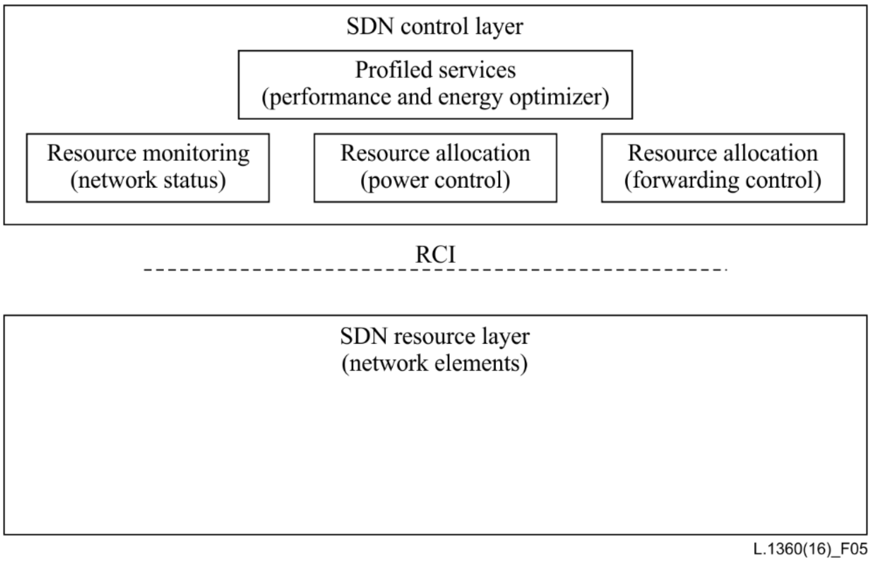

Figure 5 – Mapping with the SDN components

The mapping is as follows:

- The performance and energy optimizer is mapped with an energy dedicated profiled services functional component;
- The network status is mapped with the resource monitoring;
- The power control is mapped with the resource allocation;
- The forwarding control is mapped with the resource allocation;
- The network elements are part of the SDN resource layer.

7.4 Implementation issues

An implementation issue may appear for bursty communications, for example with transmission control protocol (TCP) connections which are self-clocking connections [b-JIANG]. In this case, the scheduler that extracts packets out of the buffer in which the burst arrives may not have enough energy to perform its tasks and could induce packets losses. With TCP, packet losses involve retransmissions at TCP level, which in turn increase the traffic load. In the worst case scenario, the TCP protocol shuts down the connection. [b-SAKELLARI] has shown that the average power increases as the delay-bound requirement becomes stringent. Further study on this point shall be done in the future.

Another implementation issue may also appear when constraints are put on resilience and security. A study [b-PENHOAT] examining the relation between energy consumption and security, resilience and quality of service has shown that energy consumption is higher when resilience and security constraints are taken into account than when they are not taken into account.

8 Energy states model

Each network element can have several energy states and this Recommendation relies on the energy states model defined in the energy management framework [b-IETF RFC 7326].This framework allows network elements' energy states to be managed by an energy management system according to three energy management schemes (see Figure 6). The three schemes involve an energy management system that monitors and controls devices and power sources. It can be noted that in the three schemes, the energy management system monitors and controls the power sources besides the devices. Controlling and monitoring power sources make sense when the power sources have limited energy storage capacities because the energy management system can select the most suitable power sources according to the quantity of energy they can store.

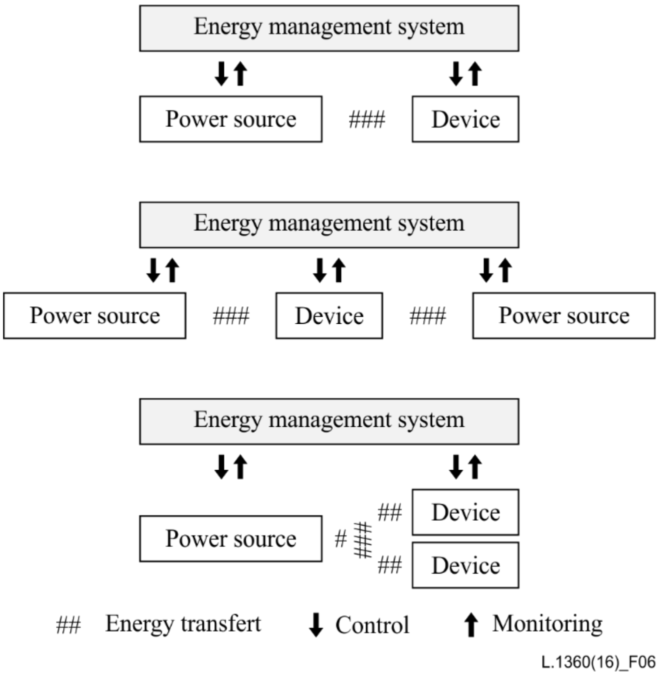

Figure 6 – IETF energy management schemes

The energy states defined in [b-IETF RFC 7326] are shown in Table 1. When dealing with the SDN architecture [ITU-T Y.3302], these energy states should be stored in the topology repository in the resource abstraction functional component.

Table 1 – IETF energy states

Non-operational states	Operational states
mechoff: an off state where no energy object features are available. The energy object is unavailable. No energy is being consumed and the power connector can be removed.	**lowminus**: indicates that some energy object features may not be available and the energy object has taken measures or selected options to use less energy than low.
softoff: similar to mechoff, but some components remain powered or receive trace power so that the energy object can be awakened from its off state. In softoff, no context is saved and the device typically requires a complete boot when awakened.	**low**: indicates that some energy object features may not be available and the energy object has taken measures or selected options to use less energy than mediumminus.
hibernate: no energy object features are available. The energy object may be awakened without requiring a complete boot but the time for availability is longer than sleep.	**mediumminus**: indicates that some energy object features may not be available and the energy object has taken measures or selected options to use less energy than medium.
sleep: no energy object features are available, except for out-of-band management, such as wake-up mechanisms. The time for availability is longer than standby.	**medium**: indicates that some energy object features may not be available and the energy object has taken measures or selected options to use less energy than medium.

Table 1 – IETF energy states

Non-operational states	Operational states
standby: no energy object features are available, except for out-of-band management, such as wake-up mechanisms. The time for availability is longer than ready.	**highminus**: indicates that some energy object features may not be available and the energy object has taken measures or selected options to use less energy than high.
ready: no energy object features are available, except for out-of-band management, such as wake-up mechanisms. The energy object can be quickly transitioned into an operational state.	**high**: indicates that all energy object features are available and the energy object may use the maximum energy as indicated by the nameplate Power.

Appendix I

Example of energy control in a SDN architecture

(This appendix does not form an integral part of this Recommendation.)

The goal of this appendix is to present an implementation of the power optimizer in the ONF architecture [b-ONF-SDN].

The power optimizer can be hosted in the data plane control function (DPCF) of the SDN controller as shown in Figure I.1:

- The network status feeds the optimizer with inputs. These inputs consist in the resources energy-aware state, security, resilience, or quality of service levels. The GAL_Discovery, the GAL_Monitor_State and the GAL_Monitor_History, permit to retrieve and monitor information related to the resources. Moreover, the GAL_Monitor_Sensor allows retrieving of energy consumption information. The sensor resources may be fed by the [b-ETSI ES 202 336-12] standard.
- The GAL control concerns the EAS management of the resources. The GAL_Provisioning, GAL_Release, GAL_commit, and GAL_Rollback, permit the resource to be put in a given configuration. The optimizer feeds the GAL control with the energy-aware states of the resources it manages.
- The optimizer finds the minimum set of resources according to their power consumption. The constraints taken by the optimizer may be the security constraint, the resilience or the QoS constraint. That is to say, the minimum set is selected in such a way that the constraints are satisfied.

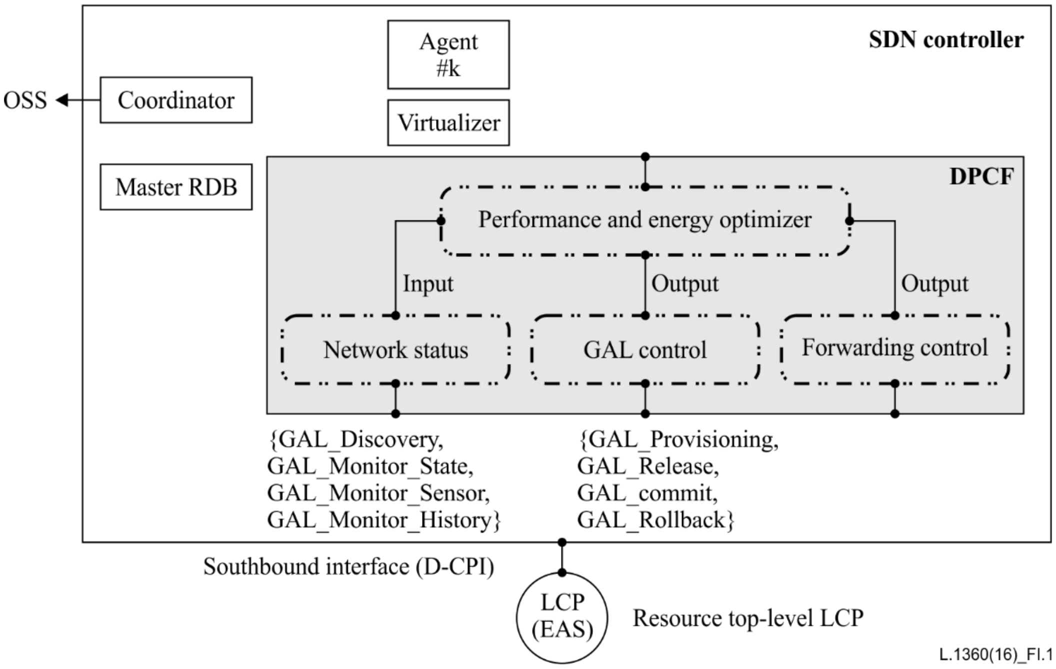

Figure I.1 – Energy control in a SDN controller

An example given in Figure I.2 shows how the optimizer may work. As the traffic load can suddenly vary, the optimizer cannot track the traffic variations in real time. It may reorganize the network topology in a time scale greater than the traffic variations.

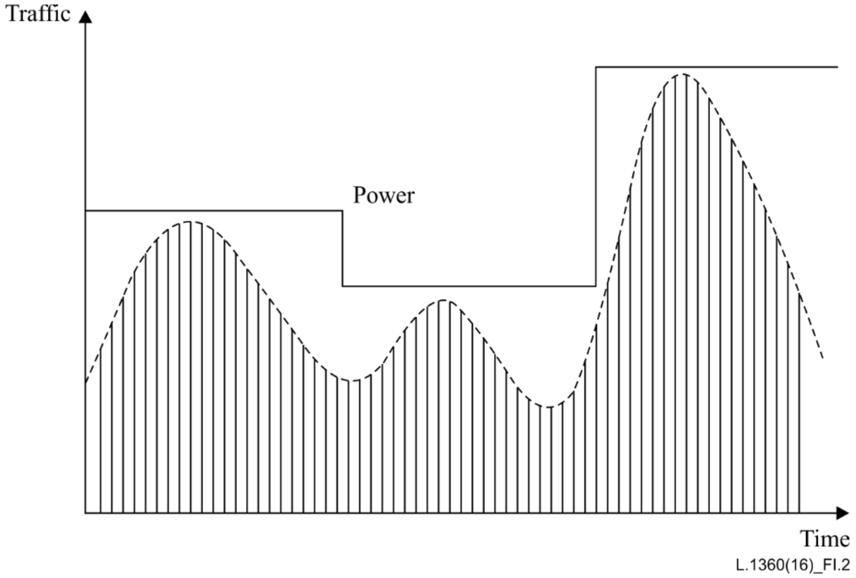

Figure I.2 – An example of power adaptation

An example of a heuristic which optimizes the energy consumed by a network composed of Ethernet switches and Ethernet links is provided in [b-BOLLA].

As the role of the optimizer is to find the configuration of the network that minimizes the power consumption according to the traffic load and several constraints such as security and QoS, it must periodically acquire an estimation of the traffic load and the power consumed by the network elements.

The polling mechanism is not well suited to accomplish this task because it is not possible to define the right polling frequency as mentioned in [ETSI ES 203 237]. Indeed, if the frequency is high, the network status of the SDN controller might be overloaded by too many polling requests and responses; on the other hand, if the frequency is low, the network status might not be able to track the traffic variations.

An alternative to the polling mechanism is to define a local decision-maker inside each element composing the network. When the traffic flows increase or decrease, the local decision-maker adapts the power of the element accordingly and the network status may be informed of the new values of the traffic load and the power consumed. This alternative mechanism introduces two levels of control:

– The first is a local control performed in each network element. It allows quick reaction to traffic variations;

– The second is a global control performed in the optimizer. It allows periodical reorganisation of the network to adapt the energy consumption to the traffic load.

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Printed in Switzerland
Geneva, 2017