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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS AND NEXT-GENERATION NETWORKS

Next Generation Networks – Future networks

Framework of energy saving for future networks

Recommendation ITU-T Y.3021

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Recommendation ITU-T Y.3021

Framework of energy saving for future networks

Summary

Recommendation ITU-T Y.3021 describes the framework of energy saving for future networks (FNs). It first describes the need for energy saving within networks themselves, and reviews potential energy-saving technologies. The Recommendation then identifies major functions and their cyclic interactions, analyses the possible impact of introducing certain energy-saving technologies and itemizes the high-level requirements for introducing such technologies.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T Y.3021	2012-01-13	13

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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1 Scope

This Recommendation:

– describes the necessity for energy saving,
– reviews potential technologies,
– identifies multiple viewpoints to be considered,
– identifies major functions and their cyclic interactions,
– analyses any possible impact caused by introducing the technologies, and
– itemizes high-level requirements;

to achieve energy saving within and due to future networks (FNs).

The framework and ideas described in this Recommendation may also be applicable and useful for networks which are not categorized as future networks, although the description is produced through full recognition of the objectives and design goals of future networks [ITU-T Y.3001].

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 L.1400] Recommendation ITU-T L.1400 (2011), *Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies*.

[ITU-T Y.3001] Recommendation ITU-T Y.3001 (2011), *Future networks: Objectives and design goals*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following term defined elsewhere:

3.1.1 future network (FN) [ITU-T Y.3001]: A network able to provide services, capabilities, and facilities difficult to provide using existing network technologies.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 device: This is the material element or assembly of such elements intended to perform a required function.

3.2.2 energy saving within networks: This is where network capabilities and their operations are set up in a way that allows the total energy for network equipment to be systematically used in an efficient manner, resulting in reduced energy consumption, compared with networks that lack these capabilities and operations.

NOTE – Network equipment includes routers, switches, equipment at the terminating point e.g., optical network units (ONUs), home gateways, and network servers such as load balancers and firewalls. Network equipment is typically composed of various components such as switching fabric, line cards, power supply, and cooling.

3.2.3 equipment: A set of devices assembled together to form a physical entity to perform a specific task.

3.2.4 network energy efficiency: Throughput of the network divided by the power consumed.

NOTE – It is usually expressed in bps/W.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ALR	Adaptive Link Rate
BTS	Base Transceiver Station
CAM	Content Addressable Memory
CAPWAP	Control and Provisioning of Wireless Access Points
CDN	Content Delivery Network
CPU	Central Processing Unit
DDoS	Distributed Denial-of-Service
DPD	Digital Pre-Distortion
DVS	Dynamic Voltage Scaling
FN	Future Network
GHG	Greenhouse Gas
HVHBT	High Voltage Heterojunction Bipolar Transistor
ICT	Information and Communication Technology
LSI	Large Scale Integration
MIMO	Multiple Input Multiple Output
MPLS	Multi-Protocol Label Switching
NIC	Network Interface Card
ONU	Optical Network Unit
PA	Power Amplifier
PC	Personal Computer
SINR	Signal to Interference and Noise Ratio
SISO	Single-Input Single-Output
SLA	Service Level Agreement
SRAM	Static Random Access Memory

UE User Equipment

WLAN Wireless Local Area Network

5 Conventions

None.

6 Introduction

6.1 Background and motivation

Energy saving in the information and communication technology (ICT) field is an important issue, as has been identified in designing future networks [ITU-T Y.3001]. One of the basic objectives of the development of future networks is demonstrating environmental awareness, which may be realized via energy-saving technologies. Historically, energy saving has been studied for increasing benefits to the user or company, such as reduced energy costs and temperature management for stable machine operation.

The importance of these issues is increasing due to the more widespread implementation of network equipment and the greater energy consumption that this requires. It is also becoming increasingly important from a social aspect to support the reduction of greenhouse gas (GHG) emissions. These issues will gain more importance in the future. This Recommendation therefore studies potential technologies and their coordinated operation, which will contribute to saving energy and to various other objectives.

The contribution of ICTs to reduce the negative impact on the environment is often categorized into "Green by ICT" and "Green ICT". "Green by ICT" refers to reducing the environmental impact of non-ICT sectors by using ICTs. "Green ICT" refers to reducing the environmental impact of the ICT itself such as the reduction of electric power consumption of personal computers (PCs), servers, and routers. The contribution of future networks to reducing environmental impact can therefore be categorized as shown below.

– Green by future networks

  A challenge to reduce the environmental impact in non-ICT sectors by using future networks.

  Future networks must become a useful tool for reducing the environmental impact of other sectors. Network architecture designed for smart grids for electric power distribution, or ubiquitous sensor networks that monitor environmental changes of the Earth are a few examples of how "Green by Future Networks" may be interpreted.

– Green future networks

  A challenge to reduce the environmental impact of future networks.

  The fundamental principle for future networks is that they must have a minimum impact on the environment. As described above, the use of networks may provide the means to reduce the environmental impact of other sectors. Yet by doing so, it increases the volume of traffic flowing into networks, increases energy consumption of the networks accordingly, which then increases the environmental impact. Reducing the energy consumption of network facilities such as routers, switches and servers is a direct example of contributions of "Green Future Networks".

Each issue is important, but this Recommendation focuses on "Green Future Networks", which means energy saving within the networks themselves, because energy consumption by networks is rapidly increasing as the number of applications on the networks increases.

6.2 Lifecycle stages and levels to be considered

To reduce energy consumption, it is important to analyse energy consumption at each stage of the lifecycle. In life-cycle management, the following stages are typically used for analysis (for example in [ITU-T L.1400]):

– Production (preparing raw materials and components for the target);
– manufacturing;
– use;
– disposal/recycling.

In the case of networks, the first stage, production, is the preparation of raw materials for small electronic devices and the composition of the equipment that is included. The second stage, manufacturing, includes constructing a network by means of the equipment. For network construction, relevant pieces of equipment are transported from a manufacturer's site to the construction location. The third stage, use, refers to operating the equipment. At the end of the service life of the network, the network including all the equipment would be disposed of and/or recycled in the fourth stage, disposal/recycling. Life-cycle management considers all of these stages. In the case of networks, however, the third stage, use, is primarily considered because energy consumption in the "use" stage is usually the major issue for always-on network equipment, and the energy consumption of this stage can be controlled by network architecture, capabilities and operations.

Energy saving within networks includes a variety of technologies. It is unrealistic to rely on a single technology. At the use stage, three levels can be considered along with their relevant technologies, i.e., device-level, equipment-level and network-level.

– Device-level

  Technologies which are applied to electronic devices, such as large scale integration (LSI) and memory.

– Equipment-level

  Technologies which are applied to one piece of equipment (a set of devices) such as a router or switch.

– Network-level

  Technologies which are applied to equipment within the whole network (e.g., a routing protocol applied to multiple routers).

Technologies categorized into each level and their combination will change and evolve. Future networks should incorporate these technologies and flexibly adopt their development and evolutions enhance their energy-saving effects.

7 Review of energy-saving technologies

7.1 List of technologies and their levels

Based on the three levels described in clause 6, various potential technologies can be categorized as follows:

– Device-level technology

  LSI microfabrication, multi-core central processing unit (CPU), clock gating, power-aware virtual memory, advanced power amplifier (PA).

– Equipment-level technology

  Optical network node, sleep mode control, ALR/DVS, thermal design, cache server, filtering, sorry server, shaping, compact base transceiver stations (BTSs), smart antenna technologies, relay stations

– Network-level technology

  Circuit/burst switching, energy consumption-based routing/traffic engineering, lightweight protocol, transmission scheduling, content delivery network (CDN), traffic peak shifting, small-cell design, energy consumption-aware network planning.

In clauses 7.2 to 7.4, an outline of each technology of the device, equipment and network-levels is described. This categorization may change in the future due to the improvement of implementation technologies.

7.2 Device-level technologies

7.2.1 LSI microfabrication

With a given function and/or performance, the thinner the LSI process becomes, the smaller the size of the LSI. Because LSI microfabrication enables reduced driving voltage, it reduces power consumption that is proportional to the square of the driving voltage. Up to now, the ratio of improvement has progressed by 30% per year, but this has slowed down recently owing to the increased leakage current. Some LSI manufacturers are tackling this slow-down in various ways to increase the improvement percentage.

7.2.2 Multi-core CPU

This is a technology for implementing multiple CPU cores in a single processor package. For a given task, using multiple low-spec CPUs can generally save more energy than using a single high-spec CPU because of the hardware characteristics of electronic devices. It means that energy consumption is generally proportional to clock frequency cubed, and that multiple CPUs generally have more advantages in terms of energy consumption. In addition, if the required performance is very high and cannot be achieved with a single CPU, there is no choice other than to use multiple CPUs.

In addition, the multi-core CPU can run together with dynamic control technologies such as clock gating (see clause 7.2.3) and sleep mode control (see clause 7.3.2). They control the power supply and the clock rate across multiple core CPUs, so that the minimum required number of CPUs can operate at the minimum clock rate. If these two CPU parameters, i.e., the number of active CPUs and their clock rate, are controlled adequately according to the load, then energy can be saved.

7.2.3 Clock gating

This is a technology that stops supplying the clock to LSIs and circuits when there are no necessary tasks. The longer the duration without explicit clock supply, the more energy can be saved. The issue is that if the transition between ON and OFF states of the clock occurs frequently, less energy is saved because additional energy is needed for that transition.

7.2.4 Power-aware virtual memory

This is a technology to optimize the energy consumption of memory by controlling an active piece of memory depending on actual demand and use [b-Huang]. From the viewpoint of energy saving, this technology is introduced to buffer memory and cache memory in a network node.

7.2.5 Advanced power amplifier (PA)

This is a power amplifier that is applied to base stations in wireless networks and realizes highly-improved efficiency, which is difficult to achieve using existing commercial technologies. As the power amplifier alone counts for a major percentage of the total power consumption of base stations in wireless networks, using high-efficiency power amplifiers can reduce power consumption [b-ATIS]. Advanced PA should take into account circuit application, component selection, and process innovation. Examples of this technology include digital pre-distortion (DPD) and high-voltage heterojunction bipolar transistor (HVHBT). When there is distortion in the power amplifier, DPD inputs distortion into the opposite direction to the power amplifier distortion, thus cancelling the distortion. HVHBT is an advanced chip device to improve efficiency.

7.3 Equipment-level technologies

7.3.1 Optical network node

This technology aims at introducing energy-efficient optical technologies for transmission interfaces and/or switching fabrics to a network node. An optical network node has a very large capacity compared with the electronic network node, with speeds of Tbps or more. This can drastically improve network energy efficiency [b-Klein]. The improvement is based on a large amount of traffic aggregation along with the node or outside the node. The issue is that, if traffic flows sparsely, sufficient energy efficiency cannot be achieved.

All-optical packet switching can improve the network energy efficiency because it does not need optical to electric and electric to optical translation, which usually consumes a large amount of energy, in a network node. But it is still difficult to realize on a large and practical scale. The main difficulty is to memorize the optical signal as it is.

7.3.2 Sleep mode control

This is a technology that puts equipment and functions to "sleep mode" when they are not used, conserving energy. At the equipment-level such as for routers and switches in wired networks, and radio base stations and mobile devices in wireless networks, sleep mode control is typically implemented on equipment and network interfaces. The effect of energy saving depends on traffic dynamics. The larger the difference between maximum and minimum traffic, the larger the energy-saving effect that can be achieved. The reason is as follows: energy consumption of equipment without sleep mode control is almost constant, and depends on the maximum traffic to be accommodated. With sleep mode control, if the traffic across parallel paths in a particular period is smaller than the maximum, some flows can be aggregated dynamically into one path, and equipment irrelevant to the path can move into sleep mode. Energy consumption can be reduced depending on the minimum traffic.

In wired networks, the obstacle to using this technology is the small-sized, routine and yet important control traffic to be delivered, such as routing information, even if there is no data traffic. So the method for treating control traffic is an issue. One solution is to have a "proxy" which maintains a network presence during sleep mode operation for any network node, and responds to routine network traffic instead of the network node itself. The details of this technology are described in ENERGY STAR computer specification Version 5.0 [b-ESTAR1]. One example of sleep mode control is energy efficient Ethernet protocol developed by the Energy Efficient Ethernet Task Force [b-IEEE P802.3az]. Another example is the L2 power saving mode (e.g., low power mode) combined with existing ADSL2 and ADSL2plus technologies.

On the other hand, in wireless networks, sleep mode control software and sleep mode operation are implemented for energy-saving radio base stations and mobile devices, respectively. In radio base station systems, the sleep control software shuts down (turns off) a band that is observing low traffic patterns on that cell, or the whole radio base station. During sleep mode operation, mobile devices change state between sleep state and listening state. In the sleep state, mobile devices do not communicate with their corresponding radio base stations by powering down their batteries. In the listening state, mobile devices check for an awakening message from their serving radio base station.

7.3.3 Adaptive link rate (ALR) and dynamic voltage scaling (DVS)

This is an energy-saving operation mode for network equipment. ALR controls the link speed (i.e., bit rate) of the interface according to the amount of traffic to be processed. DVS controls the driving voltage of the CPU, hard disc, network interface card (NIC), and so on, according to the amount of traffic to be processed. The issue of this technology is how to treat burst traffic (e.g., how quick in terms of response time and how efficient in the case of frequent change).

7.3.4 Thermal design

In a network node, the cooling system consumes a considerable amount of energy, which means that energy saving can be achieved by the improvement of thermal design of the node. This topic also applies to the case where multiple nodes exist in the floor of a data centre.

7.3.5 Cache server

With this technology, contents are cached to reduce duplicate and inessential traffic considering that multiple users consume the same content, or that a single user consumes a single content multiple times. The benefit of the technology corresponds to the reduction of bandwidth. This technology becomes effective if the copy of the content exists at high probability in the cache server. The issue with this technology is that, if the probability is low, the server needs to perform a task to check the availability of the content and then access the original server frequently. Because of the extra task and extra servers, it may use more energy. It is therefore necessary to control the operation of the server considering its hit rate to reduce energy consumption.

7.3.6 Filtering

This technology blocks inessential or invalid data to be transmitted, such as excessive keep-alive messages or duplicate user messages. Another example of this technology includes intrusion prevention systems, also known as intrusion detection and prevention systems. It is able to actively prevent/block detected intrusions such as distributed denial-of-service (DDoS) attacks by monitoring network traffic and/or activities for malicious activity. They reduce the traffic, and reduce the corresponding energy consumption that was originally needed.

7.3.7 Sorry server

This is a server that returns an alternative response or "an excuse" to inform that the requested service is not available due to a reason such as temporal traffic congestion. According to the response, some users may shift peaked traffic on the time axis or may give up on their demands, thus reducing maximum traffic and saving energy.

To complete the picture, actions taken by the entity that receives the message should also be specified. For example, the entity may not resend the request for a specified time.

7.3.8 Shaping

This is a technology that controls the output rate of packets lower than the potential link rate. As it controls and reduces the maximum data rate, it can save the energy of other subsequent nodes, which are being operated according to the maximum data rate. The main issue of this technology is that it may increase the delay caused by the waiting queue.

7.3.9 Compact base transceiver stations (BTSs)

This is a base station system for saving power consumption and reducing costs. Unlike the existing ground-based BTSs and distributed BTSs, compact BTSs do not require ground shelters and cooling equipment, so they consume less energy, are cheaper, and incur lower installation costs. In addition, they are able to support high performance features such as multiple antennas per sector with multiple input, multiple output (MIMO), and beamforming [b-Fili].

7.3.10 Smart antenna technologies

Smart antenna technologies, such as MIMO, are smart signal processing algorithms using antenna arrays with multiple antennas at both the transmitter and receiver that improve wireless communication performance. Since they can control the directionality of the reception or transmission of a signal and reduce the interference of other signals, they can support higher data rates under the same transmit power budget and bit-error-rate performance requirements compared with a single-input single-output (SISO) system. For example, cooperative transmission technologies, where multiple base stations cooperate with each other and transmit single or multiple MIMO streams to the terminal using the same frequency band, promise the potential gain of better spectral efficiencies by increasing the signal to interference and noise ratio (SINR). In particular, distributed antenna systems can enlarge the available network coverage near or in overlapped cell coverage areas. These smart antenna-based technologies can achieve energy saving in wireless networks [b-ATIS][b-Cui].

7.3.11 Relay station

A relay station is a transmitter which relays or repeats another base station's signal to an area not covered by the signal of the originating station. The relay station in wireless networks improves performance and also saves energy potentially because more connections between the source node and the destination node are established and data can be delivered through multiple wireless links due to the relay nodes. It means each link has independent fading channels, so diversity gains and spectral efficiency can be improved. Therefore, the time to transmit a fixed amount of data is reduced thus saving energy consumption.

7.4 Network-level technologies

7.4.1 Circuit switching and burst switching

Circuit switching consumes less energy than packet switching in general because its mechanism is simple and does not need energy-consuming memory devices such as SRAM and CAM, which are mainly used for packet routing. Even now, a case has been reported in which packet routing accounts for 37% of all power consumption of routers [b-Baliga]. It means that circuit switching can save the power because circuit switching does not need packet routing functions. Circuit switching is especially efficient for continuous traffic such as video streaming, which is expected to increase drastically in the future. The issue with this technology is that it cannot realize packet-level statistical multiplexing, which may degrade link utilization and thus network energy efficiency. It is well known that each connection in circuit switching occupies the line. Even if traffic flows sparsely in a connection, other connections cannot use the remaining resource.

Burst switching is also able to save energy consumption in core routers. The feature of this technology is that packets are aggregated into data bursts at edge routers. Therefore, by using bursts, its mechanism reduces the operations at core routers for computing each packet header [b-Kim]. A variant of burst switching used in optical networks is optical burst switching. It aims at improving the network utilization by statistical multiplexing. The feature of this technology is that by control packet, reserved bandwidth is used for the bursts in advance of transmission. It is more efficient with respect to bandwidth utilization than optical circuit switching because set-up times are significantly reduced compared to optical circuit switching. Moreover, compared to an optical packet switching network, it significantly reduces the amount of processing operations and core network energy consumption [b-Peng]. The issue with this technology is that its network performance is affected by the burst assembly mechanism.

7.4.2 Energy consumption-based routing and traffic engineering

This is a routing/traffic engineering technology which intentionally controls the traffic route to minimize network-wide energy consumption. This technology may include some traffic processing such as traffic aggregation, multiple path routing, and network coding. This technology assumes that the sleep mode or ALR/DVS functions described in clause 7.3 is available in network nodes. When the sleep mode function is available, this technology aggregates the traffic into a limited set of routes, and allows unused nodes or links to operate in sleep mode so that unnecessary energy can be saved. When the ALR/DVS function is available, this technology distributes the traffic into multiple routes so that each node treats the minimum traffic, and makes the link rate or voltage the adequate level so that unnecessary energy can be saved. The issue with this technology is how to treat the dynamics of traffic.

When the network coding function is available, this technology reduces the amount of packet transmission by encoding individual packets into a coded packet at intermediate network nodes. Therefore, it can save power consumption [b-Nagajothy]. This technology can be crucial in a wireless sensor network.

7.4.3 Lightweight protocol

This technology examines the use of a protocol in conjunction with protocols in other layers and optimises its use to make the total protocol processing in a network lightweight. It includes the simplification procedure of a particular network protocol. Typically, there are two approaches. One is to transfer the data traffic by lower layers, which is generally simpler and lightweight. This may be applicable to a dedicated area such as a core network. The other is to make the protocol or its use simple. The former includes label switching, such as multi-protocol label switching (MPLS), performed under the IP layer. The latter includes convergence by extending the IP capability from an access network to its backhaul to utilise full IP networking as a common platform [b-ATIS], a modified TCP that improves the retransmission algorithm, and the control and provisioning of wireless access points (CAPWAP) protocol that reduces the signalling overhead for the wireless local area network (WLAN) [b-IETF CAPWAP]. This technology can reduce the unnecessary functions of the network nodes, which in turn saves energy.

7.4.4 Transmission scheduling

This technology aims to reduce the buffers that need to be operated or implemented at the network nodes. It controls the amount and timing of packet transmission so that it can minimize the output waiting time at each node and, thus operate with fewer buffers and save energy. The issue with this technology is that the packet loss ratio deteriorates if the control fails to meet the designed buffer capacity. If scheduling fails, multiple packets will arrive at a node, some of which may be beyond the designed buffer capability. To avoid packet loss, extra network resources for transmission scheduling may consequently be required outside of the target node. The difference with shaping (clause 7.3.8) is that shaping operates as stand-alone in a node to reduce the maximum traffic which flows in, and that transmission scheduling operates cooperatively among multiple nodes to control the timing of each node's packet transmission in order to avoid congestion inside the network.

7.4.5 Content delivery network (CDN)

This is an optimized network specifically designed for the delivery of contents. An optimized CDN can save energy because it can access a server that is nearer than the original one, so it can save resources in terms of bandwidth and distance, and thus save energy [b-Klein]. The issue with this technology is the same as that for the cache server; that is, if the hit rate is small, this technology is not so effective.

7.4.6 Traffic peak shifting

This technology shifts as much transmission of the traffic peak as possible onto the time axis. It reduces the maximum traffic to be accommodated, and then reduces the total power consumption, which depends on the maximum traffic. One specific method is to distribute popular content to major cache servers in advance, during off-peak hours.

7.4.7 Small-cell design

This technology introduces smaller cells (microcell, picocell, and femtocell) to places where mobile demand is high such as city downtowns, shopping malls, airports, campuses, and large offices to off-load macro-cell traffic. As for each cell, it is obvious that a small cell needs less power to transmit the data traffic compared to a macro cell because the power loss over a wireless channel is proportional to the propagation distance d^{α}, where α is the path loss exponent, so it can save energy for transmitting a radio signal. However, if static power, circuit power, and site cooling power as well as transmitting power are also considered, small-cell design is not always energy efficient [b-Chen-a], so the combination of macro and micro cells considering a realistic measurement of power consumption for optimal cell planning makes it the most energy efficient. Also, small-cell design technologies are typically implemented in the compact BTSs described in clause 7.3.9 with macro BTSs, establishing the overlay cellular networks [b-SCELL][b-INST].

Furthermore, the small-cell design has a potential advantage in allowing the base station to adjust the operation to its environment more precisely and dynamically than large cells. For the adjustment, small-cell design can exploit energy-efficient algorithms such as coverage-aware switch-off, which allows a base station to detect existing spatial coverage by other stations and switch off its activity, and traffic-aware sleep mode which detects user equipment (UE) activity via carrier sniffing, and temporarily switch off the idle small cells [b-Claussen]. One example is femtocells, which are low-power, low-cost and small home area base stations. Due to their short distance, femtocells can get better indoor voice and data coverage, greatly lower the transmit power, prolong handset battery life, and achieve a higher signal to interference noise ratio [b-Badic]. The reduction of energy consumption is explained in [b-Grant] in more detail.

7.4.8 Energy consumption-aware network planning

This technology deals with the network-wide design and planning which are applied to both wired and wireless networks. Until now, network planning has usually considered performance and reliability without paying much attention to the improvement of energy efficiency and the reduction of the environmental impact. These need to be taken into account in network planning. For this purpose, various types of information such as an energy consumption report should be collected, as well as traditional information such as network outage reports (e.g., number of losses, duration of outage).

Energy consumption-aware network planning has two parts: static and dynamic. The static part is effective in the pre-operation (network design) phase. This is to construct a physical network and establish routing policy to minimize total energy consumption, on the condition that it should accommodate the pre-defined estimation of maximum traffic. On the other hand, the dynamic part is effective in the operation phase. It is to reroute the existing traffic flow or to dispatch new additional traffic flow to minimize total energy consumption, on the condition that it should accommodate the existing traffic measured and the new traffic requested. Both approaches are important for saving the energy consumed in a network. According to [b-Chabarek], energy consumption-aware network planning can result in significant energy saving. One of the examples of dynamic network planning in wireless networks is cell zooming, which adaptively adjusts the cell size according to the traffic load fluctuation and user requirements. It can be used for load balancing by transferring load from a cell with a heavy load to cells with a light load and it can be used for energy saving by zooming into the cell to zero when the traffic load is light enough [b-Zhisheng].

8 Considerations for energy saving

First, the target area considered for energy saving is described in clause 8.1. Then, under these preconditions, some considerations are made regarding the direction to be taken to achieve energy saving from the essence of the technologies listed in the previous clauses.

8.1 Target area of this Recommendation

– "Green Future Networks" or "Green by Future Networks"

  This Recommendation focuses on "Green Future Networks" (clause 6.1).

– Stages in a lifecycle

  This Recommendation focuses on the use stage (clause 6.2).

  This stage includes the pre-operation and operation phases. The pre-operation phase treats the static issue of how to minimize the amount of network resources prepared for the given traffic demand in the network design. The operation phase treats the dynamic issue of how a smaller amount of network resources could be used according to the traffic at a given moment in the network operation.

– Levels of technologies

  This Recommendation considers three levels of technologies (device, equipment, and network level).

  Each technology does not stand alone, but cooperates with others at different levels. The objective is to find an all-encompassing solution, which incorporates each level of the technologies.

– Type of methods for energy saving

  This Recommendation focuses on technical methods.

  There are various methods, each with a different approach. Some are technical, and some are non-technical. A typical example of non-technical methods is regulation by law, which assigns individual usage time of networks to each pre-defined user group. Both the technical and non-technical methods are important, but since this Recommendation is a technical one, it focuses on the technical methods.

8.2 Approaches to energy saving

Approaches to energy saving are extracted as follows from the essence of technologies listed in previous clauses. These approaches, which are described in clauses 8.2.1 and 8.2.2, will help when considering the appropriate combination of technologies to obtain increased benefits.

• Reduction of required network capacity (clause 8.2.1)
  – Reduce the volume of traffic across the whole network (clause 8.2.1.1).
  – Shift the traffic at peak time, which reduces the maximum capacity (clause 8.2.1.2).

• Improvement in network energy efficiency (clause 8.2.2).
  – Control device and/or equipment operation according to traffic dynamics (clause 8.2.2.1).
  – Forward traffic with less power (clause 8.2.2.2).

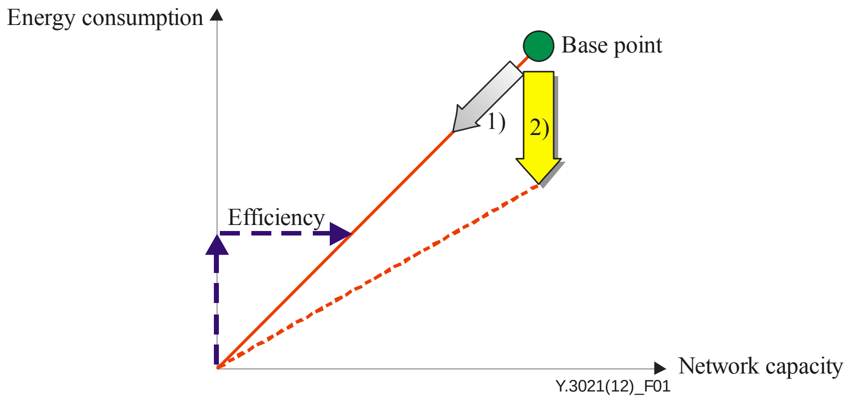

Figure 1 – Energy consumption vs network capacity

8.2.1 Reduction of the required network capacity

This is an approach based on the amount of traffic. When traffic is reduced, the required network resources and capacity are reduced, and consequently energy consumption is reduced. This effect is shown in Figure 1 as an approach towards the origin.

8.2.1.1 Reducing the volume of traffic across the whole network

This is a static approach. It aims to reduce the volume of traffic to be forwarded by devices or equipment. One example is by providing a cache at the entrance of the networks (making it closer to the user) so as to reduce the corresponding network resource for the frequently accessed content.

8.2.1.2 Shifting the traffic at peak time

Shifting the traffic at peak time reduces the maximum capacity. This is a dynamic approach. Part of the energy consumption of devices or equipment is primarily dependent on the maximum amount of traffic that can be accommodated. So, if the maximum traffic to be accommodated could be reduced, energy consumption would also be reduced accordingly. It aims to move the data on the time axis and to put down the peak traffic. One example is job scheduling, which allows popular contents to be distributed to cache servers close to the users in advance during off-peak hours.

8.2.2 Improvement of network energy efficiency

This approach focuses on network energy efficiency, assuming that the required network capacity is intact. The effect is shown in Figure 1 as the approach toward the reduction of energy consumption. This approach needs architectural consideration at various levels. Network energy efficiency can usually be defined by the throughput of the network divided by the power consumed, that is, bits-per-second/Watt, and it is expressed here for a network capacity that is equivalent to the maximum throughput. So, if network energy efficiency could be improved in some ways such as device evolution, e.g., LSI microfabrication based on Moore's Law, total energy consumption would be reduced according to this evolution.

8.2.2.1 Controlling device and/or equipment operation according to traffic dynamics

This is a dynamic approach. Existing network devices or equipment usually operate at full capability and full speed regardless of traffic fluctuations. This approach controls the operation of devices or equipment according to the fluctuation. One example is sleep mode control.

8.2.2.2 Forwarding traffic with less power

This is a static approach. Existing data transmission is usually carried out on complex layered protocols. It aims to transmit data on a simplified mechanism, using lower layers, light protocols, and so on. One example is an optical network with less electrical intervention.

One issue that requires careful consideration is the target (i.e., service, equipment) and the period to measure network energy efficiency. As described in clause 3.2.2, efficiency is defined as data throughput of the network divided by the power consumed (usually bps/W). The issue is that bps has a strong relationship with the nature of the service(s) which varies with time, leading to different values of bps/W. It is therefore necessary to select the target and the period to measure the efficiency in an appropriate manner considering the property of the service, user (e.g., end-to-end or a particular sub-network), and such.

Clauses 8.3 and 8.4 discuss approaches described in clauses 8.2.1 and 8.2.2 in more detail and show useful practices of the different technologies.

8.3 Controlling device and/or equipment operation according to traffic dynamics

Technologies focusing on traffic dynamics include sleep mode control and dynamic voltage scaling (DVS). Sleep mode control saves energy by putting a device to "sleep mode" when it is not in use, and DVS works by reducing the traffic forwarding capacity of devices such as CPUs, line cards and network interface cards (NICs) when the traffic volume is low. These technologies can save more energy when networks have many nodes in sleep mode or scaled down in terms of voltage. For this reason, sleep mode control and DVS are effective when they are applied to networks which characteristically have a large number of devices probably for wide coverage, high peak traffic demand but low volume of traffic on average, and consequently, low device operating ratios. One issue with sleep mode control is, as shown in clause 7.3.1, how to treat small control traffic such as routing information. Having a "proxy" is one possible approach. On the other hand, one issue with DVS is, as shown in clause 7.3.2, how to treat burst traffic.

From the viewpoint of traffic dynamics, Internet traffic is characterized by dynamic time and spatial variability. Energy consumption of routers, on the other hand, is almost independent of the instantaneous volume of traffic forwarded. Accordingly, putting routers to sleep mode when traffic does not flow into them provides a possible energy-saving capability. In the present situation, however, traffic is distributed for forwarding on a network according to the paths predefined by routing protocols or other methods, which means that traffic flows into each router even when the overall volume of traffic is low, resulting in the need to keep each router running all the time. This clarifies a technical challenge of how to control traffic paths in entire networks in such a way that it allows routers to enter sleep mode.

8.4 Forwarding traffic with less power

Technologies aiming at less power consumption include the use of LSI microfabrication and an optical network node. The use of LSI microfabrication reduces driving voltage and offers prospects for energy saving. The use of an optical network node greatly increases the transport capacity and drastically improves network energy efficiency, though it requires traffic aggregation as a prerequisite to maximize the potentially high capacity. These are device-level technologies, and have been tackled directly for energy saving up to now. Meanwhile, equipment- and network-level technologies were usually not identified for that purpose, but they have the potential for energy saving in future.

From the viewpoint of forwarding technology, IP networks, such as the Internet, use packet switching, which achieves efficient accommodation of multiple applications by the statistical multiplexing effect. The other side of the coin is that further increases in the speed and capacity of transmission lines in the future will require improved performance of special types of memory that are high-speed, high-capacity, and consequently, high-power-consumption (such as static random access memory (SRAM) and content addressable memory (CAM) for buffering and routing. However, video traffic, which is expected to increase in the future, is characterized by a continuous generation of information in one direction while a session associated with video traffic does not change and routing decisions are required only on a session-by-session basis. This characteristic can eliminate the need for CAM, which was originally intended for packet-by-packet routing and suitable for heterogeneous traffic. If we get rid of such a device that consumes high power, it is a great technical opportunity to save energy. Accordingly, one technological challenge is to build a new forwarding mechanism that does not require these types of costly memory to be used.

8.5 Classification of individual technologies

Individual technologies are classified in terms of their applicable level and approach, as shown in Table 1.

Table 1 – Classification of technologies

Technology level	Reduction of capacity (Clause 8.2.1)		Improvement of energy efficiency (Clause 8.2.2)	
	Reduce traffic (Clause 8.2.1.1)	**Peak-shift (Clause 8.2.1.2)**	**Dynamic control (Clause 8.2.2.1)**	**Less power (Clause 8.2.2.2)**
Device			– Multi-core CPU – Clock gating – Power aware virtual memory	– LSI fabrication – Advanced power amplifier
Equipment	– Cache server – Filtering	– Sorry server – Shaping	– Sleep mode control – ALR/DVS	– Optical node – Thermal design – Compact BTSs – Smart antenna technologies – Relay station
Network	– CDN	– Traffic peak shifting	– Routing/traffic engineering – Energy-aware network planning (dynamic)	– Circuit/burst switching – Light protocol – Transmission scheduling – Small-cell design – Energy-aware network planning (static)

Although these are all useful energy-saving technologies and demonstrate the possibilities of energy saving that networks would support, there is a wide degree of difference between the difficulty to achieve this and energy reduction. Further studies are needed for deciding which technologies should be mandatory, and which should be optional for future networks. This Recommendation does not specify the above and assumes that these technologies are all optional.

9 Possible functions and their interactions

9.1 Possible functions

From the considerations of clause 8, "Considerations for energy saving", energy saving within networks has both a static and dynamic nature. Regarding the static nature, energy saving within networks considers how to construct the network with low power device, equipment, and network-level technologies in the pre-operation (network design) phase, and minimizes the total energy consumption for the pre-assumed maximum traffic. Regarding the dynamic nature, energy saving within networks considers how to adopt the operation of device, equipment, and network-level technologies to the varied actual traffic in the operation phase and minimizes the total energy consumption according to these dynamics.

To reflect the static nature, energy saving should involve technologies of the three levels described as energy control processes during the construction of the network. To reflect the dynamic nature, energy saving in general should involve the management process, which collects the current statuses, analyses them, and conducts better procedures targeted at optimized operation. Management processes can be identified at each technology level: device, equipment, and network levels. Management processes may exist in each network node, or in a network management server which oversees the individual equipment of the network. Obviously, cooperation between different levels of management is required to achieve network-wide energy saving. In addition to management processes, a database that includes energy-related information is necessary for the management.

Below are possible functions which can be generally applicable to any energy-saving technology. Figure 2 shows these functions, including a database and their interactions.

– The energy control and measurement function performs control actions to reduce energy consumption, as specified by the energy management function, and obtains measured status information. It is subdivided into device-, equipment-, and network-level technologies.

– The energy management function collects basic information, calculates the optimum case of operation and issues operation commands to the energy control function and the energy measurement function. It includes three subfunctions: DataCollecting subfunction, Optimization subfunction, and Operating subfunction.

– The status information base is a database that gathers basic information of the current mode from the energy control and measurement function. It gives a set of status information such as energy consumption and traffic.

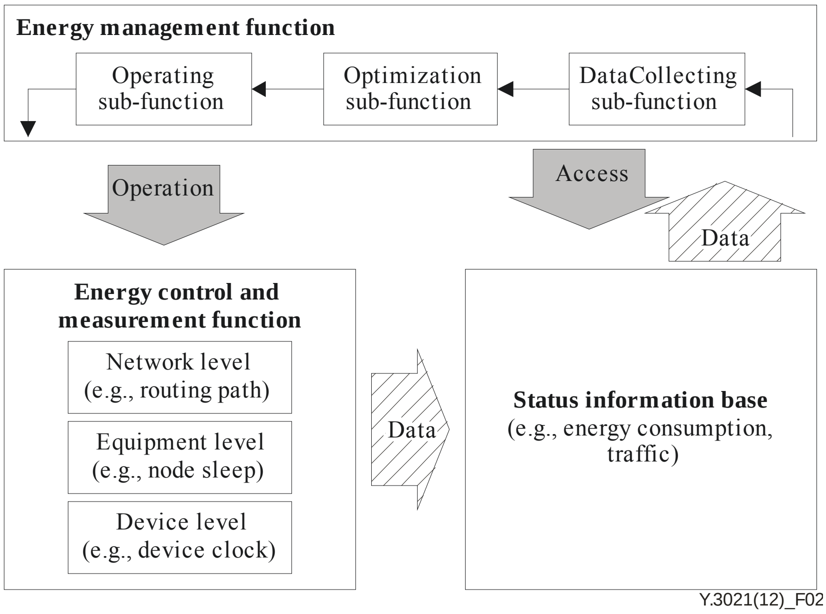

Figure 2 – Possible functions

Figure 2 is a logical figure. The location of the functions and database is basically independent of the specific equipment.

9.1.1 Energy control and measurement function

The energy control and measurement function has a control process and a measurement process.

As a control process, the energy control and measurement function includes a set of various energy-saving technologies, which are described in clause 7. They are subdivided into device-, equipment-, and network-level technologies. Examples for each level are device clock change, node sleep operation, and routing path change, as shown in Figure 2. This function is directly related to power consumption, and is managed by the energy management function.

In addition, each level has both static and dynamic technologies. Static technology is itself a stand-alone technology for saving energy, and is not affected by inputs from outside, such as LSI microfabrication and thermal design. Dynamic technology is controlled by inputs from the outside, such as node sleep and energy-based routing. Energy consumption for static technologies is decided in the pre-operation (network design) phase of the network, and is constant. Contrary to this, energy consumption for dynamic technologies is controlled and optimized in the operation phase. In the framework depicted in Figure 2, the energy control and measurement function is used for both the static and dynamic phase. In the static (pre-operation) phase, the energy control and measurement function is constructed using the three-level technologies without interacting with other functions. In the dynamic (operation) phase, the energy control and measurement function has interactions with other functions.

As a measurement process, the energy control and measurement function includes a set of various energy-measurement technologies, which can be related to energy-control technologies in each layer. These are also subdivided into device-, equipment-, and network-level technologies. Examples for measurement in each level are frequency, sleep period and link utilization.

In addition, if a change of the measurement parameters and method is required following a decision by the energy management function, the energy control and measurement function is operated by the energy management function. It stores the measured status information to the status information base. The measurement parameters and method are different according to the type of energy control technologies used in the node or network.

9.1.2 Energy management function

The energy management function accesses the status information base and manages the energy control and measurement function in order to minimize total energy consumption. It includes the following three subfunctions:

DataCollecting subfunction: collects the necessary status information about network nodes from the status information base.

Optimization subfunction: decides which management operation should be performed on which network node to minimize total power consumption.

Operating subfunction: sends an operation request to the energy control and measurement function of a network node.

9.1.3 Status information base

The status information base is a database which includes a set of status information for defining network node characteristics, such as energy consumption and traffic.

9.2 Combination models of functions

Combination models of several functions identified by the above framework are shown in Figure 3. In this figure, three models are shown. The more the applied model expands, the more benefits are expected by achieving global optimization and combination with local optimization. Here, the solid line shows the signalling flow (operation/monitor/access) and the dotted line shows data flow.

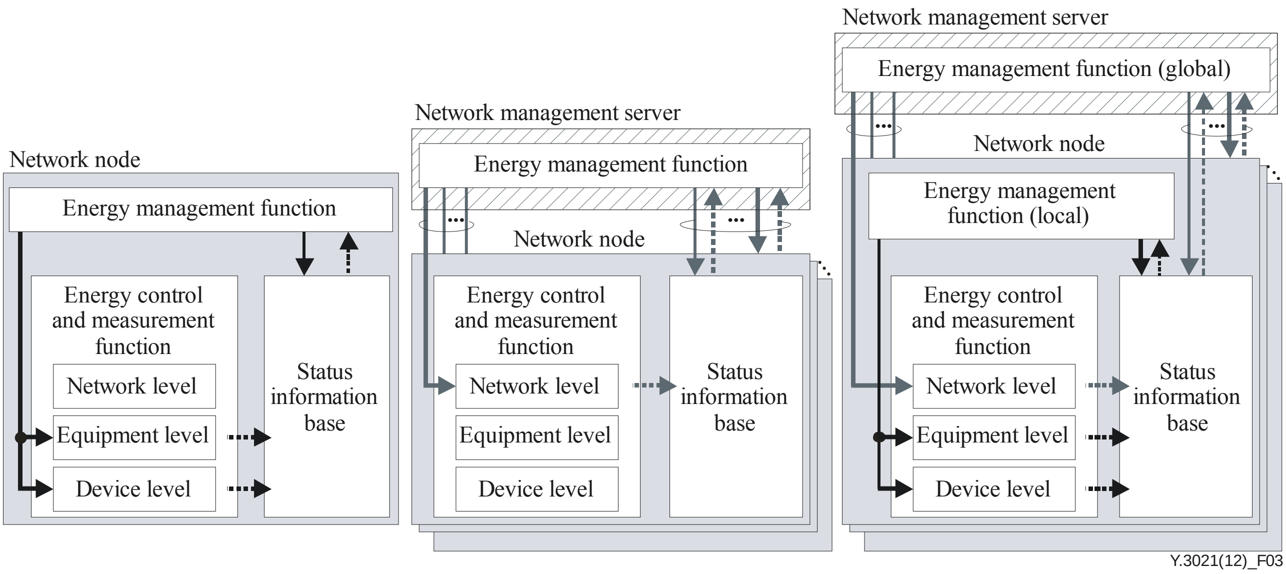

Figure 3 – Combination models of energy-saving functions

(A) Local-loop model: This is usually deployed on a single network node, such as a router or a switch. Two principal functions and a database all exist in one node. A local control loop is closed in the node. The energy management function issues operation commands to the equipment and device-level of the energy control and measurement function, because these levels are executed in a single node. This loop is for self-optimization in each node.

A typical example of this case is controlling the device clock according to the traffic.

(B) Global-loop model: This is usually deployed on multiple network nodes and a single network management server. The energy control and measurement function and the status information base exist in each network node, and the energy management function exists in a network management server. The global control loop extends to the relevant nodes and the server. The energy management function issues operation commands to the network level of the energy control and measurement function, because this level is executed among multiple nodes. For this loop it is assumed that a network management server accesses and operates multiple nodes in a centralized manner.

A typical example of this loop is the intentional routing which assigns the least power consumption route.

(C) Combined-loop model: This is usually deployed on multiple network nodes and a single network management server. The energy control and measurement function and the status information base exist in each network node, and the energy management function exists in the network node and network management server. The two kinds of energy management functions, global and local, constitute two combined control loops. A combined control loop, that includes a local loop and a global loop, circulates among them. The local energy management function issues operation commands to the equipment and device-level of the energy control and measurement function, because these levels are executed in a single node. The global energy management function issues control commands to the network-level of the energy control and measurement function, because this level is executed among multiple nodes. In this model, the network management server accesses and operates multiple nodes in a centralized manner, and each node performs self-optimization in a distributed manner.

A typical example of this case is energy-based routing, where the global loop aggregates the traffic routes, and the local loop puts the node to sleep when there is no traffic.

10 Impact analysis of energy saving

This clause analyses the impact of energy saving within networks, especially on the performance aspects. First, analyses are conducted regarding the influence on network performance where energy-saving technologies are solely introduced (clause 10.1). Then, analysis are conducted regarding the influence on service provisioning via energy consumption where energy-saving technologies are introduced with new service provisioning (clause 10.2).

10.1 Influence on network performance

Introducing energy-saving technologies may alter aspects of network performance such as the QoS, and may also influence security.

On the one hand, energy-saving technologies may use additional resources or processes. On the other hand, energy-saving technologies may reduce the use of unnecessary resources on the time and space axis so that minimum resources are used, e.g., the minimum amount of equipment or minimum bandwidth. In both cases, network performance could be degraded, and could cause increased delays, congestion, connection hang-ups, and so on. For example, sleep mode technology can reduce energy consumption. But, if the wake-up time from sleep mode takes long, the communication delay may be increased. Accordingly, it is necessary to avoid performance degradation, or to make the degradation fall within the acceptable range, which is usually defined by the SLA (service level agreement). It means that energy-saving technologies are realized as the trade-off between energy saving and performance degradation. However, it depends on the application services or network systems as to how much degradation can be acceptable. For example, a usual e-mail service can tolerate a delay of several seconds. So, the influences on network performance should be identified, and monitored to see whether the degradation to the service is tolerable and falls within the acceptable range.

Consequently, energy-saving technologies should be applied where the degradation of network performance, which is caused by the introduction of energy-saving technologies, falls within the acceptable range for specific services.

These influences can be clarified using Shannon's capacity relation such as:

- Deployment efficiency versus energy efficiency.
- Bandwidth versus power, only in a given data rate.
- Delay versus power.
- Spectral efficiency versus energy efficiency, only in a given available bandwidth.

These relationships are inversely proportional in phases of network planning, operation, and management [b-Chen-b] [b-Li]. These trade-off relationships should be considered when aiming to achieve energy saving with a guaranteed QoS.

10.2 Influence on service provisioning

The provisioning of a new service, which usually requires extra capabilities and resources, could result in increased energy consumption. Introducing energy-saving technologies along with the service provisioning can mitigate these consumption increases.

With service provisioning, traffic increases for the service and additional resources are required. Accordingly, the total energy consumption naturally increases. But, if energy-saving technologies are also introduced at the same time with the service provisioning, the total energy consumed would be less than the energy originally required without the technologies. For example, in the conventional cellular network with a macro cell, the compact base station with the small cell or relay station are feasible to be established at the place of the urban area, so that the number of users traffic demands can be achieved with less power. This means that energy-saving technologies can mitigate the increase in energy consumption and improve efficiency. Therefore, the benefits from energy-saving technologies should be evaluated carefully when new services are provisioned. If even more sophisticated energy-saving technologies are introduced, it may be possible to reduce energy consumption to a point where it the reduction is greater than the amount of increase due to additional traffic and resources, and the total energy consumption could even decrease. In any case, service provisioning should be made while ensuring the increase of energy consumption remains within the acceptable range.

Consequently, on service provisioning, energy-saving technologies should be applied so that the increased consumption, which is caused by multiple simultaneous service provisioning, would fall within the acceptable range in order that individual service requirements are maintained (e.g., delay, loss, etc.).

11 High-level requirements

Energy saving within networks allows network capabilities and their operations to reduce the energy consumption of the network compared with existing networks. It is recommended that the following items are supported:

1) Approaches (clause 8.2)
   - Energy saving within networks is recommended to reduce the volume of traffic to be forwarded by devices or equipment.
   - Energy saving within networks is recommended to shift the traffic at peak time, which reduces the maximum capacity.
   - Energy saving within networks is recommended to control device/equipment operation according to traffic fluctuations.

- Energy saving within networks is recommended to forward traffic with less power by transmitting data on a simplified mechanism.

2) Functions (clause 9.1)

- Energy saving within networks is recommended to support the energy control and measurement function, energy management function, and the status information base.
- The energy control and measurement function is recommended to perform control actions to reduce the energy consumption specified by the energy management function, and to perform the measurement of energy consumption. It is recommended that device, equipment, and network-level technologies are included.
- The energy management function is recommended to collect basic information, calculate the optimum case of operation, and issue operation commands to the energy control and measurement function. It is recommended that the DataCollecting subfunction, Optimization subfunction, and Operating subfunction are included.
- The status information base is recommended to gather basic information of the current mode from the energy control and measurement function, such as energy consumption and traffic.

3) Influence on network performance (clause 10)

- When introducing energy-saving technologies, it is recommended that they are applied so that the degradation of network performance (caused by their introduction), falls within the acceptable range for the services.
- On service provisioning, it is recommended that energy-saving technologies are applied so that the increased consumption, which is caused by multiple simultaneous service provisioning, would fall within the acceptable range in order that individual service requirements are maintained (e.g., delay, loss, etc.).

12 Environmental considerations

This Recommendation reviews future network-related energy-saving technologies and analyses their impact, which contribute to energy saving within networks in the future.

13 Security considerations

In this Recommendation, energy-saving technologies are discussed at multiple levels such as the device, equipment, and network levels. The cyclic interactions among key functionalities are identified to define the framework for energy saving when building and operating networks.

As for static technologies, they should not reveal any additional security risks because they do not have any interaction with the outside. But, as for dynamic technologies, security issues can be raised because they are managed by outside functions. These security risks should be considered in order to mitigate potential security risks when introducing energy-saving technologies.

The cyclic interactions among key functionalities should consider how to sustain stable operation, which is a general issue for mechanisms relying on the feedback loop. As this risk depends on operation parameters of the cyclic interactions, the parameters should be carefully selected. Further considerations should be made for introducing each specific system.

Since some technologies introduce the suspension of procedures such as sleep mode, response time to user demand may be different from those during normal operation. This Recommendation remarks that performance degradation should be within an acceptable range, especially for public safety and emergency telecommunications.

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