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Access, Terminals, Transmission and Multiplexing (ATTM); Broadband Deployment - Energy Efficiency and Key Performance Indicators; Part 4: Access networks

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

The present document is part 4 of a multi-part deliverable. Full details of the entire series can be found in part 1 [i.22].

Introduction

The increasing interaction between the different elements of the Information Communication Technology (ICT) sector (hardware, middleware, software, services, etc.) supports the concept of convergence in which:

- a variety of multi-service packages can be delivered over a common infrastructure;
- a variety of infrastructures is able to deliver these packages.
- a single multi-service-package may be delivered over several different infrastructures.

As a result of this convergence, the development of new services, applications and content there is an increasing demand for bandwidth, reliability, quality and performance. The consequent increase in the demand for energy which implications for cost and, in some cases, availability. It is therefore important to maximize the energy efficiency of network equipment at all levels.

New technologies and infrastructure strategies are expected to enable operators to decrease the energy consumption, for a given level of service, of their existing and future infrastructures thus decreasing their costs. This requires a common understanding among market participants that only standards can produce.

The present document is Part 4 of a multi-part set which has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM) in close collaboration with CENELEC via the Co-ordination Group on Installations and Cabling (CGIC). The document set offers a contribution to the required standardization process by establishing an initial basis for work on ICT networks and transmission engineering, with active collaboration from a number of other ETSI and CENELEC Technical Bodies. When complete, the documents will contain information that has been jointly evolved to present developments in installations and transmission implementation, and describing their progress towards energy efficiency in next generation networks (NGN).

The present document analyses the work on Access Networks whilst details of each of the other parts of the document set can be found in Part 1. Clearly the energy efficiencies of Operator Sites, Data Centres, the Core Networks and Customer Network Infrastructures are also important in maximizing the end-to-end energy efficiency of broadband communications and these issues will be covered in other parts of the document set. However, Access Networks differ from the other network components in that they are likely to include a very large number of locations each consuming a relatively low amount of energy. Not only do such small installations tend to be inefficient in their power utilization but when multiplied by their number, their total energy usage becomes considerable. Thus any energy saving which can be achieved becomes significant when the number of sites is taken into account. At the same time, it is likely that the energy consumption of the customer-owned equipment connected to the access network is likely to have an energy demand far in excess of that of the network equipment. This is completely outside the scope of any possible standardization initiative and can only be influenced by manufacturers minimizing the power requirements of their products, perhaps under a Code of Conduct.

In order to monitor the implementation and operation of energy efficient broadband deployment, the documents will also discuss Key Performance Indicators (KPI) for energy efficiency and focus on the possible consequences of standardization of installations, cabling techniques and equipment. In particular, the study will investigate possibilities and suggest solutions for development of processes for optimization in installation techniques and energy consumption.

1 Scope

The present document details measures which may be taken to improve the energy efficiency the access networks for broadband deployment. Clauses 2 and 3 contain references, definitions and abbreviations which relate to this part; similar information will be included in the corresponding clauses of the other parts, thus ensuring that each document can be used on a "stand-alone" basis.

Clause 4 of the present document:

- identifies the standardization bodies working on interfaces to, cabling within, installation of, and other aspects of the communication infrastructures of, access networks;
- outlines some of the principal access network topographies and their differences in respect of energy consumption;
- provides strategic analysis of energy consumption trends within access networks;
- develops the concept of Key Performance Indicators (KPI), introduced in Part 1 of this multi-part set of documents, to enable consistent monitoring of energy efficiency;
- outlines further work needed to ensure the improvement of energy efficiency in communication networks.

This will enable the proper implementation of services, applications and content on an energy efficient infrastructure, though it is not the goal of the present document to provide detailed standardized solutions for network architecture.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

- For a specific reference, subsequent revisions do not apply.
- Non-specific reference may be made only to a complete document or a part thereof and only in the following cases:
  - if it is accepted that it will be possible to use all future changes of the referenced document for the purposes of the referring document;
  - for informative references.

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2.1 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

Not applicable.

2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area**.** For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] ETSI TR 102 530: "Environmental Engineering (EE); The reduction of energy consumption in telecommunications equipment and related infrastructure".

[i.2] ETSI TS 102 533: "Environmental Engineering (EE); Measurement Methods and limits for Energy Consumption in Broadband Telecommunication Networks Equipment".

[i.3] "EC Code of Conduct on Energy Consumption of Broadband Equipment".

[i.4] IEEE Standard 802.11: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.5] IEEE Standard 802.15.1: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPAN)".

[i.6] IEEE Standard 802.15.4: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs)".

[i.7] IEEE Standard 802.16: "IEEE Standard for Local and metropolitan area networks - Part 16: Air Interface for Broadband Wireless Access Systems".

[i.8] ITU-T Recommendation G.983.1 (05/2005): "Broadband optical access systems based on Passive Optical Networks (PON)".

[i.9] ITU-T Recommendation G.983.2 (01/2007): "ONT management and control interface specification for B-PON".

[i.10] ITU-T Recommendation G.983.3 (07/2005): "A broadband optical access system with increased service capability by wavelength allocation".

[i.11] ITU-T Recommendation G.983.4 (01/2005): "A broadband optical access system with increased service capability using dynamic bandwidth assignment".

[i.12] ITU-T Recommendation G.983.5 (01/2002): "A broadband optical access system with enhanced survivability".

[i.13] ITU-T Recommendation G.984.1 (03/2008): "Gigabit-capable passive optical networks (GPON): General characteristics".

[i.14] ITU-T Recommendation G.984.2 (03/2008): "Gigabit-capable passive optical networks (GPON): Physical Media Dependent (PMD) layer specification".

[i.15] ITU-T Recommendation G.984.3 (01/2002): "Gigabit-capable passive optical networks (GPON): Transmission convergence layer specification".

[i.16] ITU-T Recommendation G.984.4 (01/2002): "Gigabit-capable passive optical networks (GPON): ONT management and control interface specification".

[i.17] ITU-T Recommendation G.984.5 (01/2002): "Enhancement band for gigabit capable optical access networks".

[i.18] ITU-T Recommendation G.984.6 (01/2002): "Gigabit-capable passive optical networks (GPON): Reach extension".

[i.19] ITU-T Recommendation G.992.1 (03/2003): "Asymmetric digital subscriber line (ADSL) transceivers - Annex A: Specific requirements for an ADSL system operating in the frequency band above POTS".

[i.20] ITU-T Recommendation G.992.3 (06/2008): "Asymmetric digital subscriber line transceivers 2 (ADSL2) - Annex J: All digital mode ADSL with improved spectral compatibility with ADSL over ISDN".

[i.21] ITU-T Recommendation G.992.5 (01/2009): "Asymmetric digital subscriber line (ADSL) transceivers - Extended bandwidth ADSL2 (ADSL2plus)".

[i.22] ETSI TS 105 174-1: "Access, Terminals, Transmission and Multiplexing (ATTM); Broadband Deployment - Energy Efficiency and Key Performance Indicators; Part 1: Overview, common and generic aspects".

[i.23] ETSI TR 105 174-5-1: "Access, Terminals, Transmission and Multiplexing (ATTM); Broadband Deployment - Energy Efficiency and Key Performance Indicators; Part 5: Customer network infrastructures; Sub-part 1: Homes (single-tenant)".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

access circuit: telecommunications circuit connecting the operator site to the subscriber's premises

access network: part of the network that is deemed to include the last active component at the relevant operator site and the first active element at the subscriber's premises

access point: termination point on a telecommunications network allowing access by nomadic devices to obtain telecommunications services to which they have subscribed elsewhere

active element: network component that requires externally supplied electric power to enable it to perform its network function

Bluetooth: short range wireless network defined by IEEE Standard 802.15 and usually considered to be part of a Personal Area Network (PAN)

community network: communications network, usually wireless, established by and for a local community often to compensate for lack of publicly available access to relevant facilities

customer: person or entity using a telecommunications service and who may or may not be the subscriber

Digital Access Carrier System (DACS): 0+2 pair gain system providing two separate telephone lines over one copper pair using digital technology

digital radio: any wireless link system in which the information carried is encoded in any one of a variety of digital formats

Digital Subscribers Line (xDSL): access circuit over which information is carried in a digital format and where the upstream and downstream transmission rates may be the symmetrical (SDSL) or asymmetrical (ADSL)

energy consumption: measure of the energy consumed by the operation of the electronic devices necessary to provide a specific communications service

enterprise network: network established by a large company or similar enterprise to serve its internal telecommunications needs with connectivity to one or more public networks

Ethernet: frame-based local area networking technology standardized as IEEE 802.3

fibre to the cabinet: optical fibre distribution network providing connectivity from the network operator's site to a shared distribution node close to the end-user's premises

firewall: security measure designed to prevent unauthorized electronic access to a networked computer system

flexibility point: device in the access network where access circuits can be configured to their intended destination by cross connecting metallic pairs

games console: electronic device on which one or more games may be played and which is often capable of being connected to a communications network

home network: network that supports and distributes within the home, those services to which a customer subscribes

hotspot: location that offers publicly accessible internet access over a wireless connection

Industrial, Scientific and Medical (ISM) band: band of radio frequencies allocated for use for industrial, scientific and medical purposes

intrusion detection system: mechanism by which any attempt by an unauthorized user or terminal to gain access to a communications network is detected

meshed network: communications network, usually wireless, in which every node has connectivity with a number of other nodes thus enabling a variety of possible communication paths between nodes

mobile phone: terminal device capable of voice (and often data) communications which operates using one or more types of publicly available wireless communications systems

network gateway: device which will enable the interconnecting of two networks which inherently use different and incompatible protocols

packet: information block identified by a label at layer 3 of the OSI reference model

peripheral: peripheral is a device attached to a host computer whose primary functionality is dependent upon the host, and which expands the host's capabilities, but is not part of the core architecture of the system

point-to-multi-point: communications link operating between a network operator's site and a number of other locations

point-to-point: communications link operating between two, usually fixed, locations

service: provision of a defined functionality in a computer systems or telecommunications environment

sub-loop: secondary access circuit from a street cabinet or similar access node used to deliver one or more services to a customer

subscriber: person or entity responsible for paying for a telecommunications service

Subscribers Loop Carrier (SLC): equipment providing multiple telephone circuits over one or two standard subscriber's telephone lines (see also DACS)

triple play (telecommunications): provision of cable TV, telephony and broadband data as a combined service offering, possibly using a single bearer medium

Watt (W): unit of power, the rate at which work is done; in electrical terms it is the product of the supply voltage (volts) and the current passed (amps)

Watt-hour (Wh): unit of energy used or work done; the product of the rate at which work is done and the time for which it done

NOTE: The terms "Watt" and "Watt-hour" are frequently confused.

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3G	3rd Generation (mobile networks)
3GPP	3G (mobile) Partnership Project
4G	4th Generation (mobile networks)

ADSL Asymmetrical Digital Subscribers Line

NOTE: See ITU-T Recommendation G.992.1 [i.19].

ADSL2 Second generation ADSL with extended upstream bandwidth

NOTE: See ITU-T Recommendation G.992.3 [i.20].

ADSL2+ Second generation ADSL with extended downstream bandwidth

NOTE: See ITU-T Recommendation G.992.5 [i.21].

BBF	Broadband Forum
BEF	Building Entrance Facility
BSC	Base Station Control site
BSS	(Mobile) Base Station
CATV	Cable Television
CMTS	Cable modem termination system
CoC	Code of Conduct
CPE	Customer Premises Equipment
DACS	Digital Access Carrier System - see also SLC
DECT	Digital Enhanced Cordless Telecommunications
DHCP	Dynamic Host Configuration Protocol
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
EC	European Commission
EE	Environmental Engineering
EEF	(broadband service) Energy Efficiency Factor
ENTI	External Network Test Interface
FDM	Frequency Division Multiplex
FSO	Free Space Optics
FTTB	Fibre To The Building
FTTC	Fibre to the Cabinet
FTTH	Fibre To The Home
GPON	Gigabit Passive Optical Network
GPRS	General Packet Radio Service
GSM	General System for Mobile communication/Global Mobile System
HEF	Home Entrance Facility
HFC	Hybrid Fibre Coaxial
HGI	Home Gateway Initiative
IEEE	Institution of Electrical and Electronics Engineers (USA)
ISDN	Integrated Services Digital Network
ISM	Industrial, Scientific and Medical (frequency band)
ISP	Internet Service Provider
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LAN	Local Area Network
LBL	Lawrence Berkley Laboratories
NGN	Next Generation Network
NPC	Normalized Power Consumption (per line)
NTP	Network Termination Point
OIE	Operator Independent Equipment
OLT	Optical Line Terminal
ONT	Optical Network Termination
ONU	Optical Network Unit
OSE	Operator Specific Equipment
PAN	Personal Area Network
PC	Personal Computer
PLC	Power Line Carrier
PON	Passive Optical Network
POTS	Plain Old Telephone Service
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation

RF Radio Frequency
SDSL Symmetric Digital Subscriber Line
SLC Subscribers Line Carrier (system)

NOTE: See also DACS.

TDM Time Division Multiplex
UMTS Universal Mobile Telecommunication System
USB Universal Serial Bus
VDSL Very high-speed Digital Subscriber Line
VoIP Voice over Internet Protocol
W Watt
WAN Wide Area Network
WDM Wavelength Division Multiplex
Wh Watt hour
WiFi Wireless Fidelity

NOTE: Technology using IEEE 802.11 standards.

WiMax Worldwide Interoperability for Microwave Access
xDSL Digital Subscriber Line (generic title)

4 Overview of access network solutions

4.1 Customer access point

For the purposes of the present document, the access network is deemed to include the last active component at the relevant operator site and the first active element at the subscriber's premises. The connection between the operator's access network and the home distributor as shown in figure 1 (or the equivalent in non-generic cabling) is provided by network access cabling and some type of network telecommunication equipment as shown.

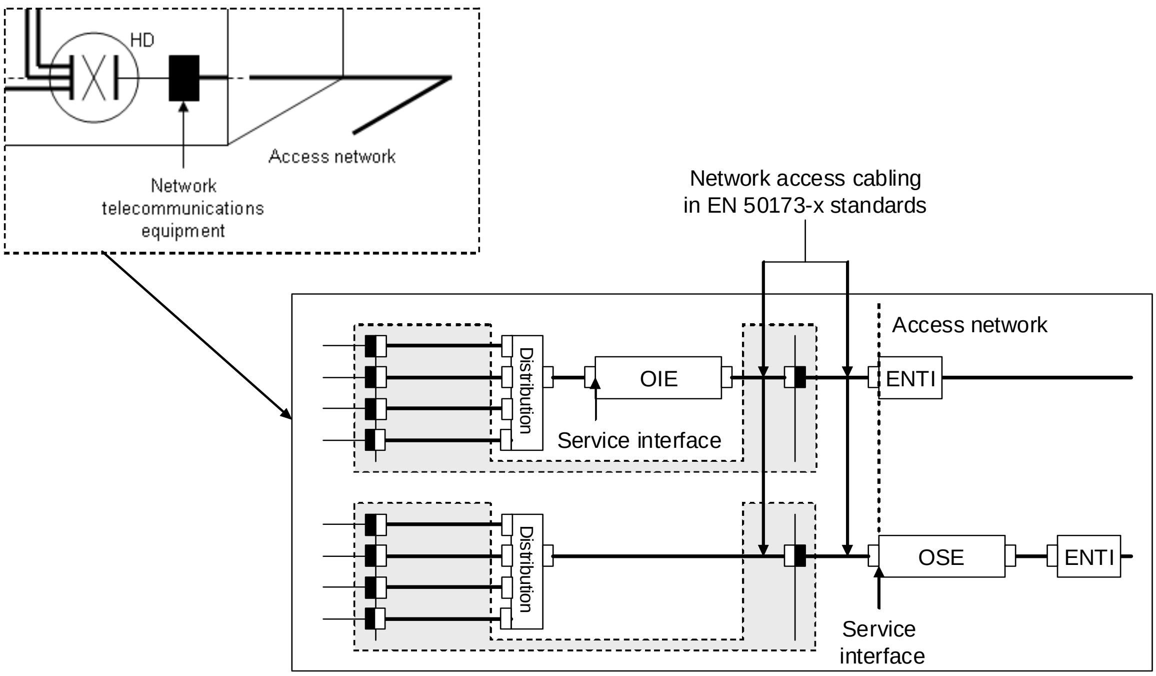


Figure 1: Network access cabling and equipment

The access network normally includes a Network Termination Point (NTP) at the customer's premises. In the case of a broadband connection this typically comprises a passive interface (ENTI) and an optional item of apparatus. The apparatus may either be specific to the network operator (OSE) or may be operator independent (OIE) as described in the following examples:

- OSE: CATV modem, FTTH modem (if no standardization is achieved);
- OIE: DSL modem, FTTH modem (if standardization is achieved).

The OSE is regarded as part of the access network whereas the OIE is part of the customer premises infrastructure.

In some cases the OIE, or some part of it, may be powered from the access network and the OSE may be powered from the customer premises. For this reason, calculations of the energy efficiency of the access network should take into account any energy required to maintain the functionality at the service interface, irrespective of the source of that energy.

Some OIE or OSE may have functionality beyond that which is strictly necessary to provide adequate service termination. For example, a DSL or cable modem may have an inbuilt router or WiFi terminal. When determining the energy efficiency in these cases, a judgement should be made as to what proportion of the total power requirement of the device should be taken into account for the purposes of the calculation.

This clause will examine the principal access network topographies used for the delivery of NGN services and describe them in sufficient detail to define their typical power requirements. It should be appreciated that each of the topographies to be described will have a number of variants; no attempt will be made to describe all of these or their implications on energy consumption.

In some cases, proprietary systems or those having a specific application may be described. It is not intended that these are definitive but only that they serve to describe an access network mechanism. Legacy applications will only be described insofar as is necessary to present a substantially complete picture.

4.2 Principal access technologies

4.2.1 Metallic Loop

The traditional access network or local distribution network has comprised a copper based network with each subscriber or in some cases, each service, having a dedicated copper twisted pair from the operator site ("telephone exchange") to the customer's premises. Such connections are normally made via a number of "flexibility points" in the external distribution network allowing the pairs to be routed appropriately; discussion of this is outside the scope of the present document. Some networks incorporate conductors made from other metals (typically aluminium or bronze) but these are very much in the minority.

This network technology was originally conceived for voice telephony and has remained virtually unchanged for more than a hundred years apart from improvements having been made in its physical construction and the materials used. The network is essentially passive, no power normally being required between the operator site and the customer premises. Its application has been extended to include multiple channel telephony (for example, ISDN2 and DACS based services); although these are not seen as core services, they are expected to exist for a considerable time, thus necessitating the continued existence of the metallic network.

These networks have been and will continue to be used for broadband services using xDSL in support of the NGN. These have typically operated up to approximately 8 Mbit/s using older DSL technology, this being principally dependent upon the line length, but up to a few tens of Mbit/s using ADSL2+ and VDSL, though only relatively short subscriber lines can support the download speeds recommended by ITU-T as the equipment capability, thus limiting the usefulness of the more advanced DSL technologies. Lines carrying xDSL services usually serve a single terminal, or a small home or enterprise network for a single subscriber.

4.2.2 Other metallic-based solutions

There are several variants of the copper based local access network, some based on similar copper pairs to those described above and others on co-axial cable. These are mostly suited to short access circuits and are more frequently used in customer networks.

Coaxial copper cables are sometimes been used in the access network for circuits serving business premises requiring substantial communications capacity and/or a resilient network connection. Such connections have typically carried multi-channel TDM or FDM systems or Ethernet-based services and were usually arranged on a "point-to-point" basis, duplicated when resilience was required. Ethernet services were normally carried on ring-configured circuits, sometimes extending into the customer premises network.

Such solutions are now considered to be obsolescent and not expected to play a part in NGN access networks, except possibly as subscriber drop circuits from street-located facilities. For example, coaxial cables are frequently used for this application in CATV networks using a variety of Hybrid Fibre Coaxial (HFC) architectures.

4.2.3 Wireless access

4.2.3.1 General

A number of wireless systems have been proposed for NGN access networks, some providing network connections for fixed users and others for roaming and nomadic users. The crossover point between systems intended for use in home or enterprise and those intended for access networks is not clear-cut, some products being appropriate in both applications. These systems are summarized in the following clauses but none can be regarded as a broadband access solution, either because of their limited range or bandwidth or both.

4.2.3.2 Bluetooth

Bluetooth is a wireless protocol which facilitates data transmission over short distances from fixed, portable and mobile devices. The protocol is standardized in IEEE 802.15.1[i.5] and it was originally intended for creating wireless Personal Area Networks (PANs) to provide secure connectivity between devices such as telephones, personal computers, digital cameras, game consoles, etc. using unlicensed radio frequencies in the industrial, scientific and medical (ISM) bands.

Bluetooth technology has been used for access network applications, most commonly in customer networks over very short distances. The technology was designed for, and is more suited to, "in-house" and PAN applications. It is not generally regarded as a commercial access product, therefore will not be discussed further in the present document.

4.2.3.3 ZigBee

ZigBee is a low-power digital radio standard (IEEE 802.15.4 [i.6]) for wireless PANs as a simpler and less expensive alternative to Bluetooth. ZigBee is targeted at Radio-Frequency (RF) applications requiring a low data rate, long battery life and secure networking, more suited to "in-house" applications such as building automation ("domotics"). Thus, it is more commonly found in customer network applications than in access networks. It is not regarded as a commercial access product, therefore will not be discussed further in the present document.

4.2.3.4 WiFi

WiFi is a popular wireless technology standardized in IEEE 802.11 [i.4], originally intended to be used in home networks, mobile phones, video games and other electronic devices requiring some form of in-house wireless networking capability but now partially superseded in these applications by the Bluetooth and ZigBee technologies.

WiFi technology is supported by most modern PC operating systems, game consoles and computer peripherals, thus providing point to multi-point wireless internet connectivity for such devices. It is also widely used for in-house distribution of audio and video media or other data. WiFi has found many applications in home and enterprise networks and has become widespread in corporate infrastructures.

The latest draft of the WiFi specification allows for operation at 2,4 GHz or 5 GHz, with network data rates of up to 108 Mbits/s with a potential for further increases up to several hundred Mbit/s using frame aggregation and sophisticated modulation techniques. Channel bonding may also be used to increase data rates, though it application in the 2,4 GHz band is limited due to overlapping channel allocations. At 5 GHz, the range of WiFi is reduced due to increase atmospheric attenuation.

It should be noted, however, that the available bandwidth is shared between all devices connected to the wireless access point and that the use of channel bonding will usually block a substantial proportion of the available RF channels. The available external bandwidth is dependent on the access technology employed to connect the local access point to the access network operator's site and this may in itself limit the user experience.

More recent developments have enabled the interconnection of WiFi access points to form meshed networks, thus providing seamless access across large areas, potentially ranging up to many square kilometres. Both the point to multi-point and meshed topologies can operate together in such community networks, providing wide-area network access for both fixed and nomadic users.

WiFi is thus both an access network and customer premises network technology. As well as providing "permanent" access connectivity, WiFi systems can also support publicly available hotspots, either without charge or on a subscription basis. Businesses, hotels and restaurants may provide free WiFi access to hotspots to attract customers. Such "public" networks require the addition of a secure network gateway, firewall, DHCP server, intrusion detection system, accounting and other functions thus increasing their overall energy consumption.

4.2.3.5 WiMax

WiMax (an abbreviation of *Worldwide Interoperability for Microwave Access*) is a telecommunications technology that provides for the wireless transmission of data using a variety of transmission modes, from point-to-point links to portable internet access. It is based on IEEE standard 802.16 [i.7] (also referred to as Broadband Wireless Access). WiMax has been described by its proponents as "a standards-based technology enabling the delivery of "last mile" wireless broadband access as an alternative to cable, xDSL and High Speed Packet Access. It is also a useful tool for the connection of WiFi hotspots to the main access network and for business continuity applications. The original standard IEEE 802.16d which had no provision for terminal mobility has largely been superseded by IEEE 802.16e which introduced support for mobility and is otherwise known as "mobile WiMax".

WiMax has a theoretical maximum bit rate of about 70 Mbit/s and operating over a range of up to 50 km - but not simultaneously. Bit error rate increases with range which results in a much lower net data rate. Conversely, reducing the range allows a device to operate at speeds closer to 70 Mbit/s.

WiMax stations in fixed networks usually have an omnidirectional antenna at the operator site but may have a higher-gain directional antenna installed at the customer premises to improve the range and data throughput.

Mobile WiMax networks usually include devices such as desktop modems, laptops with integrated WiMax or other mobile WiMax devices and may include fixed stations. Mobile WiMax devices typically have lower gain, omnidirectional antennae to improve nomadicity.

In practice, this means that in a line-of-sight environment a portable WiMax terminal may be capable of operating up to approximately 10 Mbit/s over 10 km. In urban environments, where there may not be line-of-sight and where there a greater likelihood of interference from other systems using the same RF spectrum, the actual throughput and range of such systems may be considerably reduced.

It should be noted that although the base station capacity may be up to 72 Mbit/s, this bandwidth is shared on a random access (contention) basis between all users. The total useful bandwidth at a node will be very much less than 72 Mbit/s if many customers are contending for access. In current deployments, a realistic throughput of closer to 2 Mbit/s symmetrical for around twenty users may be expected. In practice, additional radio channels may be added to the base station to increase its capacity but like all wireless systems, available RF spectrum is shared in a given radio sector, limiting the total data capacity. Because of these problems, various granular and distributed network architectures are being incorporated into WiMax including wireless meshed networks and remote repeaters, thus making WiMax a promising solution to the digital divide in sparsely populated areas.

4.2.3.6 GSM, GPRS, UMTS and 4G

Although the overall network architectures of all these cellular wireless access systems vary considerably, the access parts of the networks are all very similar and designed to serve mobile and nomadic customers. The access network is outlined in figure 2.

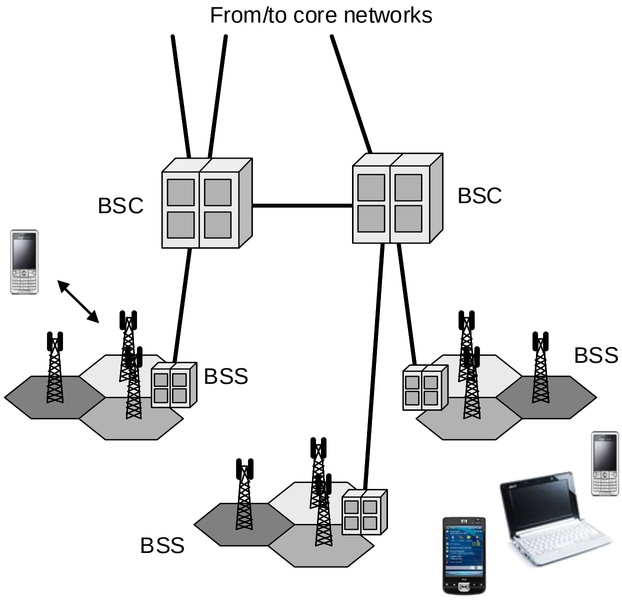


Figure 2: GSM, GPRS, UMTS and 4G network implementations

At the access network level, we can consider a typical "basic area" containing three base stations (BSS), each of which will have redundant transmission links between it and the related Base Station Control sites (BSC). In calculating energy efficiency of the access network, we need to take into account the power requirements of the six transmission links, the BSC equipment and the three base stations each of which will have several transmitters and receivers.

Since the actual useful traffic carried on these links will vary greatly depending upon the time of day, day of the week, occurrence of local events, user population and other unpredictable factors, it may seem more reasonable in this case to calculate efficiency in terms of the area covered or even the population of that area (though this may also be greatly variable form time to time).

For the present purpose, it is proposed that the metric used should be different from that suggested for fixed links. It will be related to the *energy required* to provide a given *capability* to the network to serve customers with a given *data rate* within a specified *coverage area.* As such, this will not allow the direct comparison of the energy efficiency of such systems with networks having a physical infrastructure connecting customers in fixed locations.

4.2.3.7 Fixed wireless links

Fixed wireless links are point-to-point connections between two defined end-points. When used in access networks, they are distinct from the solutions described in clauses 4.2.3.2, 4.2.3.3, 4.2.3.4 and 4.2.3.5. Such links are often used to serve single, isolated business customers when other access technologies are not technically or economically suitable. Simple fixed wireless links may serve purely as conduits for information flow undertaking no data or packet formatting. More complex radio terminals may include data processing or concentration capabilities and in such cases the power requirements of such functions are not properly included in access network efficiency calculations. Fixed wireless links are usually bi-directional capable of carrying the required data protocols in either public or private networks. Such wireless connections may operate in any of a number of authorized frequency bands, generally in the gigahertz range and can accommodate very high data rates (for example, from ≈100 Mbit/s to ≈1 Gbit/s). They usually require line of sight between the end-points for satisfactory operation and may be duplicated for availability reasons. This definition may be extended to include technologies such as laser communications such as Free Space Optical (FSO) systems. High gain directional antennas are used in all cases, both to minimize path loss and maximize spectral re-use.

There is a wide range of point-to-point wireless systems available for application in private networks and to provide commercial access connectivity. Since no single system has a wide application it is not considered appropriate that these systems should be discussed further in the present document but KPIs similar to those postulated for other fixed links may be applied to specific applications.

4.2.4 Optical Fibre

4.2.4.1 General discussion

Optical fibre is undoubtedly the medium of choice for NGN broadband transmission. It is inherently secure and has a very wide transmission bandwidth with low signal loss. Hence it is capable of carrying prodigious amounts of data over long distances without intermediate active (power consuming) equipment. It is essentially a transparent conduit for information flow and can support a wide range of protocols, dependent only on the connected terminal equipment.

Optical fibres may be employed in pairs (go and return) with each optical fibre also being capable of illumination at a number of discrete wavelengths or frequencies ("colours') using Wavelength Division Multiplexing (WDM). Alternatively a single optical fibre may be used, with different go and return wavelengths, though this may limit the total bandwidth carried on that optical; fibre. Each wavelength can carry traffic independently of the others and may be likened to one of many radio stations in a broadcast band, except that each wavelength can also carry numerous independent communications channels multiplexed together in one of a number of different ways.

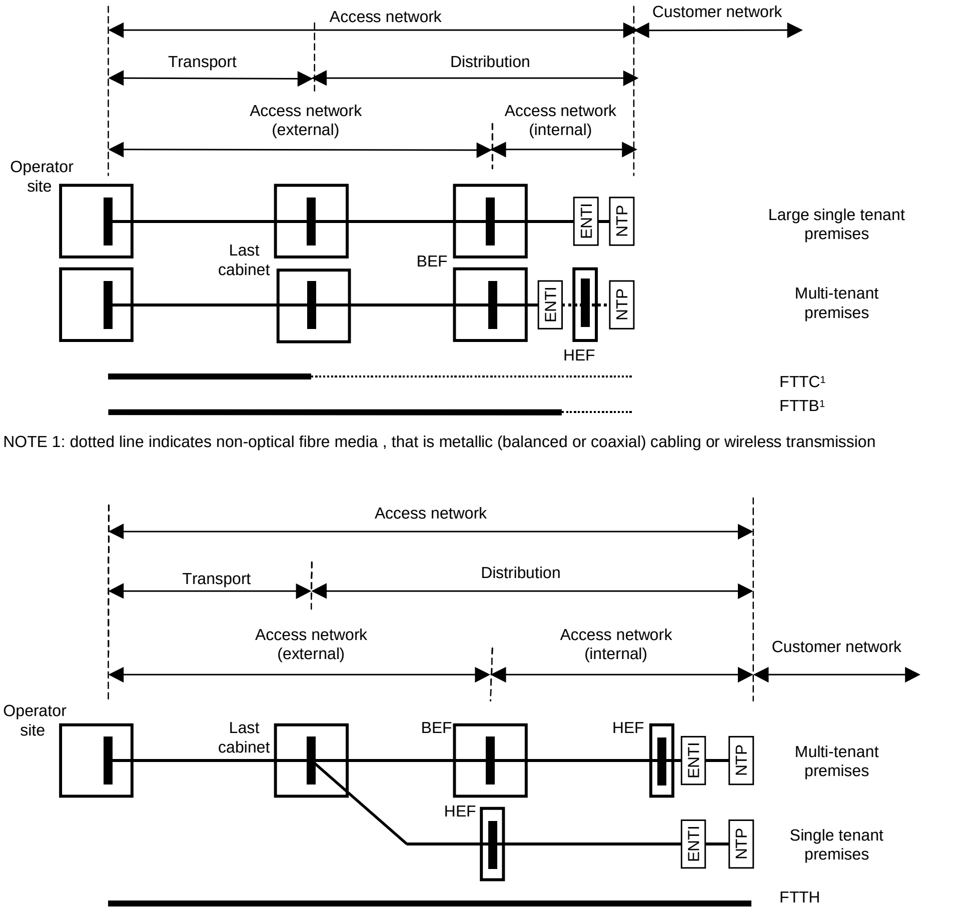
Optical fibre systems can also be deployed in point-to-point or point-to-multi-point configurations. The former provides a dedicated connection between the access network operator's site and a single location, usually a building or street cabinet. A point-to-multi-point configuration provides connectivity between the access network operator's site and a number of buildings or street cabinets, using WDM and/or passive optical splitting techniques to separate the relevant traffic.

A Passive Optical Network (PON) is a point-to-multi-point, fibre to the premises network architecture in which passive (unpowered) optical splitters are used to enable a single optical fibre to serve multiple premises. A PON consists of an Optical Line Terminal (OLT) at the operator site and a number of Optical Network Units (ONUs) near or within customer premises. A PON configuration greatly reduces the amount of optical fibre and operator site equipment, thus the power consumption, compared with point-to-point architectures. Systems using WDM and capable of carrying up to 622 Mbit/s and 2.5 Gbit/s are described in ITU-T Recommendations G.983 [i.8], [i.9], [i.10], [i.11], [i.12] and G.984 [i.13], [i.14], [i.15], [i.16], [i.17] and [i.18] respectively.

4.2.4.2 Fibre To The Cabinet (FTTC)

The enormous bandwidth available from optical fibre transmission systems makes them ideal as a shared medium to carry the traffic of a very large number of customers between the operator's site and the customer premises. As a shared medium, it becomes necessary to separate those traffic streams for delivery to their respective customers without being dependent on any one subscriber's facilities (accommodation, power, etc.), in accommodation provided by the access network operator. This usually takes the form of an equipment cabinet located in the street and maintained by the network operator (described as the last cabinet in figure 3) which marks the boundary between the transport and distribution parts of the access network. The distribution of the individual customer services comprises secondary transmission systems or sub-loops. These "last-mile" connections (usually up to a few hundred metres) may be optical fibre, wireless or copper-based and the descriptions elsewhere in the present document under these headings are equally applicable.

Where optical fibre is used within the distribution part of the access network, this may be delivered to buildings accommodating multiple subscribers or larger commercial subscribers (fibre to the building) or individual domestic subscribers (fibre to the home).



NOTE 1: dotted line indicates non-optical fibre media , that is metallic (balanced or coaxial) cabling or wireless transmission

NOTE: an ENTI for an operator network may be connected to more than one NTP, within the premises, each of which is service-specific

Figure 3: FTTx access network implementations

Fibre To The Cabinet (FTTC) systems may be connected on a point-to-point basis between the operator site and the street cabinet adjacent to customers" premises but in view of the enormous capacity of such systems customers often require a more resilient solution, if only to protect their traffic against mechanical disruption. Thus, one or more additional optical fibre connections may be made between the operator site and each street cabinet using a different cable routing. More commonly, several street cabinets may be connected to a ring over which traffic can be carried in either direction to and from the operator site. Other resilient solutions may also be implemented depending on the access network operator's policies and the customers" requirements. Such resilient solutions will always have a greater total energy requirement than a simple point-to-point configuration but this is easily justified on grounds of the need for high levels of system integrity.

Fibre switching is an interesting technology which potentially has a number of applications in the broadband access network. It could, for instance, allow bandwidth sharing and bandwidth-on-demand but both these applications imply some form of "time-shared" service whereas true broadband service is usually expected to be "always-on". A more likely application of fibre switching is that of providing access network resilience, perhaps by re-routing of customer traffic in the event of a network fault or (most likely at the operator site) by re-routing traffic as part of a customer disaster recovery scenario. Whilst fibre switching is not yet widely used, the technology is proven and likely to become an important element in access network implementation as speeds increase, resulting in the need for enhanced traffic security. Any such applications will result in some increase in the overall energy consumption of the access network but this is likely to be very small in the overall network context and unquantifiable except by reference to a specific network design.

Whatever the physical arrangement of the optical fibre network, the optical fibres may be illuminated at a number of different wavelengths using WDM, each providing an independent transmission path though each wavelength will require some additional energy at the operator's site. In order to connect individual traffic streams to their respective customers, filtering is required. This is normally a passive process requiring no power source and the separated wavelengths can be extended via separate fibres to their respective destination without the necessity for power. WDM therefore has the potential to vastly increase the bandwidth available in the distribution network, with a relatively modest increase in the energy consumption, thus resulting in improved overall energy efficiency.

4.2.4.3 Fibre to the Building (FTTB)

The enormous bandwidth available from optical fibre transmission systems makes them a very cost-effective medium to carry the traffic of subscribers requiring considerable capacity between their access network operator's site and the premises served.

However, where the building accommodates multiple domestic or small commercial organizations, the service delivered to individual subscribers within the building is restricted by the transmission medium between the FTTB interface and the subscriber. There is generally no requirement for resilient solutions between individual subscribers and the operator's site since although certain subscribers may have significant demands for data throughput, primarily for entertainment purposes, the criticality of those services is comparatively low.

Where the building accommodates more demanding commercial entities it may be necessary to provide a resilient solution to ensure service continuity. Thus, in a similar manner to that noted for the FTTC case, two or more optical fibre connections may be needed to such premises using different cable routings. These diverse routings may even be connected to different operator sites, and possibly even to different operator networks where extreme reliability is a business necessity. Other resilient solutions may also be implemented depending on the access network operator's policies and the customer's particular requirements. Any such resilient solutions will invariably have a greater total energy requirement than the single point-to-point configuration, and may well approach twice the figure applicable in an unprotected access network.

There are many variants on Fibre To The Building (FTTB); for example, circuits such as those described for FTTC may be used either from the access network operators" sites directly to large subscriber sites or simply from local street cabinets served by resilient circuits having even greater capacity. The latter is a cost effective solution which has the added advantage of providing a network flexibility point close to the subscriber's premises. This may in some cases remove the need to provide dedicated resilience for customer access circuits and have the further potential benefit in the present context of reducing overall network power requirements.

4.2.4.4 Fibre to the Home (FTTH)

The enormous bandwidth available from optical fibre transmission systems makes them a very cost-effective medium to carry the traffic of subscribers requiring considerable capacity between their access network operator's site and the individual subscribers served.

There is generally no requirement for resilient solutions between the subscriber and the operator site since although certain subscribers may have significant demands for data throughput, primarily for entertainment purposes, the criticality of those services is comparatively low.

4.2.5 Other access technologies

A number of other telecommunications access technologies are available including power line transmission systems, point to point laser-based links and satellite access systems, Each of these suffers from one or more of a variety of disadvantages (low bandwidth, poor reliability, high cost, etc.) and whilst they are all valuable in certain niche markets, none is generally suitable for high-bandwidth, high-reliability, low-cost, mass-market communications systems.

Such applications are not expected to be significant consumers of energy in the access network and thus will not be discussed further in the present document.

5 Energy efficiency standards and metrics

5.1 Summary of pre-existing work

The EU Code of Conduct on Energy Consumption of Broadband Equipment [i.3] provides a framework for ensuring operational energy efficiency consumption of network telecommunication equipment.

Previous ETSI work resulted in the publication of TR 102 530 [i.1] and TS 102 533 [i.2] which proposed a metric entitled Normalized Power Consumption (NPC).

TR 102 530 [i.1] described various potential methods of increasing the efficiency of telecommunications systems by controlling or reducing the energy consumption. It is essentially an accumulation of ideas from operators and manufacturers on methods of increasing the energy efficiency of telecommunication systems to reduce operational energy costs. It addresses energy usage by both the telecommunications and infrastructure equipments (power conversion, cooling, environmental, etc.) in telecommunication centres. The energy efficiency of end-user equipment is not considered.

TS 102 533 [i.2] recognized the EU CoC and used the quoted power requirements figures in defining the methodology and the test conditions to be used in measuring the power requirements of broadband fixed telecommunication networks equipment. The published document only considers DSLAM DSL equipment, with future versions planned to include MSAN equipment. Other access technologies (WiMAX, PLC, optical, etc.) were not yet considered because they were in an early stage of development at the time the work was undertaken. In addition to the full power state, power-saving states as defined in DSL standards are also included. The document focused on network equipment and did not include details of end-user equipment. It proposed a metric entitled Normalized Power Consumption (NPC) which is introduced in clause 5.2.2 of the present document.

5.2 Power requirement metrics and KPI

5.2.1 Background

A logical comparison figure for energy efficiency in the access network may be one which relates the power requirements related to the bandwidth capable of being transmitted over the medium, and the distance over which it can be sent. In the case of a service for which the power requirement varies according to the usage of the service, it is also logical to include a time parameter, thus bringing the concept of service state into the calculation and allowing valid comparisons to be made between services having one or more "sleep" modes.

In the case of an access point serving mobile or nomadic customers, it is more appropriate to use a metric relating the *energy required* to provide a given *capability* to the network to serve customers with a given *data rate* within a specified *coverage area* since the actual traffic requirements are extremely variable and unpredictable. In many cases the available bandwidth will greatly exceed the normal usage.

5.2.2 Suggested metrics

The present document begins by suggesting a power requirements metric for fixed networks relating the *transmission speed*, and the *line length* to the *power requirement.* In the case of a service which is discontinuous or where the power requirement is variable from time to time (for example a POTS telephone) it may be appropriate to make an allowance for the time for which the service is operational or the average power requirement over the relevant period.

Energy Efficiency Factor (EEF) = (transmission speed x line length)/(power requirement)

where the transmission speed measured in Mbit/s, the (average) power requirement is in Watts and the line length is in kilometres.

EEF is therefore expressed in Mbit/s-km per W

An alternative power requirement metric, NPC, is proposed in TR 102 530 [i.1] and TS 102 533 [i.2] and defined as:

$$NPC = 1\,000 \times P_{BBline} /(\text{bitrate} \times \text{line length}),$$

where P_{BBline} is the power requirement of the broadband connection in Watts, the bit rate is in Mbit/s and the line length is in km.

NPC is therefore expressed in mW/Mbit/s per km.

Neither of the metrics described above is easily applied or altogether appropriate for networks serving mobile and nomadic customers, where one or more access points provide a variety of services to a varying number of customers in a given, potentially large, area. It is therefore suggested that an alternative metric be used, although this does not allow comparison with those for networks serving fixed customers.

The energy efficiency of such systems may be defined as follows:

$$EE_i = \frac{V_i * S_i}{P_i}, \ i = 1,2.3....n$$

$$EE = \frac{1}{n}\sum_{i=1}^{n} EE_i$$

Where V is the available Data Speed (Mbit/s) at Distance S from the base station (kilometres), P is the Power Requirement of base station in Watts and EE is the calculated Energy Efficiency Factor of the base station.

It should be noted that this formula is not dependent upon any knowledge of the customer distribution within the coverage area, their numbers or their service capabilities. However, detailed calculations or measurements will be needed to determine the available data speeds at various distances from each base station before its energy efficiency can be determined.

5.2.3 KPI figures

Any KPI should ideally be a ratio and therefore dimensionless, which the suggested metrics are not. However, since there is no measure of the "useful power" against the "total power" consumed by access networks it is not possible to determine any such ratio.

In order to have any meaningful KPI, historical data needs to be readily available with which the current performance can be compared. There appears to be little, if any, such data available for energy consumption in the access network. In the absence of such information, all that can be done is to compare the expected performance of newly commissioned installations with their immediate predecessors in the expectation of a continuing improvement in the specified metric.

5.3 Power requirements metrics applied to access network solutions

5.3.1 Metallic loop

Traditionally the metallic loop was used for the basic telephone service. With older exchange technologies the energy requirement attributable to each service was very low with the power requirements for a POTS service in the order of one to two Watts when in use and negligible when idle (often more than 95 % of the time).

As a comparison only, it is worth examining the case of a POTS telephone service. Whilst present day data services are "always-on" and consume power accordingly, a typical residential telephone is used for around only two percent of the time, making any comparison of the energy efficiency dependent on the duration of the service. It is estimated that a modern telephone exchange consumes about two Watts per equipped line continuously and that a call in progress requires an additional 1,5 W, mainly for the line current. This comes to about 50 W-hours per day and is virtually independent of the length of the access circuit. A voice call is generally reckoned to be the equivalent of 64 kbit/s and the length of the local loop is typically about 3 km. Thus the time-related EEF of a POTS telephone service may be calculated as being about 0,096 Mbit/s-km per W - a very low figure indeed!

Many of the more recent exchange technologies have been much less energy efficient per line; in some cases the average energy usage in the exchange has been as much as three Watts per line, almost irrespective of whether or not the line was either provisioned or in use. Metallic pairs used for xDSL services have an even higher energy requirement per line due to the additional electronics required both at the operator site and the customers" premises. Each line to a customer's premises is terminated by a DSL modem which is an "always on" device, with a typical energy requirement of 5 W; this does not include the energy used by other components (routers, WiFi terminals, etc.) that are essential elements of the customer premises network. At the operator site, a single DSLAM termination card provides a modularity of DSL services. Multiple termination cards can be accommodated in a single equipment shelf, as and when required. A typical 64-port DSLAM card has an energy requirement of 130 W (including uplinks), that is approximately 2 W (continuous) per port. Thus with the advancement of technology, it can be seen that the power requirement of the metallic access loop and its associated terminating equipment is significantly greater.

Based on an average line length of 3 kilometres and a typical transmission speed of 3,5 Mbit/s, for an "always-on" ADSL service the EEF = 3,5 × 3 / (2 + 5) = 1,5 Mbit/s-km per W.

In comparison, a voice service, assuming a data equivalent of 64 kbit/s, a power requirement of 2 W (plus 1,5 W only whilst in use) and typical residential usage of 30 min per day, over a similar line produces a corresponding EEF of approximately 0,096 Mbit/s-km per W. Whilst this may seem anomalous in comparison with the ADSL case, the alternative to the inclusion of the time parameter is to include the total data transmitted over each of the services. This actually has the effect of bringing time back into the equation.

Based on the figures used above, the NPC for the referenced ADSL service becomes about 667 mW/Mbit/s per km and for the voice service the NPC is 10 400 mW/Mbit/s per km.

5.3.2 Other metallic-based access solutions

The energy consumptions of the other metallic-based access services described above are difficult to quantify due to their diverse nature. In any case, such systems are not likely to play a significant part in NGN and are therefore not relevant in the present context.

5.3.3 Wireless access

5.3.3.1 General discussion

Compared with the metallic loop access circuit both wireless and optical fibre are relatively new access technologies and their present energy efficiency performance cannot be directly related to historical figures. In both cases, the logical comparison is one of the energy consumption related to the bandwidth capable of being transmitted over the medium, and the distance over which it can be sent.

5.3.3.2 Bluetooth and Zigbee

Bluetooth and Zigbee are by definition low power, low bandwidth, non-resilient and short range systems. A Class 1 Bluetooth device (100mW output, assuming 50 % RF efficiency) using protocol version 2 (effective speed assumed to be 2,1 Mbits/s per the specification) communicating over 100 metres produces an EEF of
$2,1 \times 0,1 / 0,2 = 1,05$ Mbit/s-km per W, which corresponds to an NPC value of 952 mW/Mbit/s per km.

5.3.3.3 WiFi

Based on the figures given in the EC Code of Conduct on Energy Consumption of Broadband Equipment [i.3], a similar calculation for a WiFi (802.11n) hotspot gives an EEF of (108 Mbits/s) × (0,3 km) / (13 W) = 2,5 Mbit/s-km per W and an NPC of 400 mW/Mbit/s per km . This relates only to the WiFi device in a public hot-spot and does not include any ancillary equipment such as DSL modems, DHCP servers, routers, etc.

In the home environment, most WiFi access devices have other built-in functionality, including modems, routers, etc. and thus are not directly comparable. Whilst this makes it difficult to define the access network energy consumption, it expected that the overall energy consumption of these composite devices will normally be substantially less than that required by separate devices having similar overall functionality.

5.3.3.4 WiMax

According to figures from an equipment manufacturer, a typical WiMax transmitter-receiver consumes between 10 W and 14 W per channel. Devices are usually configured in clusters of three or six, each serving a 120 or 60 degree sector respectively, thus providing all-round coverage.

WiMax is said to be capable of delivering 70 Mbit/s over 50 km, normally requiring line of sight between end points. In reality, the system can deliver one extreme or the other. Operating over a long range or over an obstructed radio path increases the bit error rate whilst reducing the range allows operation at higher bitrates. A typical compromise might be the delivery of 10Mbit/s over 10 km. This produces an EEF of ≈7 Mbit/s-km per W in each sector (equal to NPC of 1,4 mW/Mbit/s per km).

5.3.3.5 Fixed wireless links

The power needs for these systems depend on a number of factors, including the operating frequency, the carried data rate, the spectral efficiency (modulation formats up to 256 QAM are commonly used), the power output needed for addressed typical link length (from few hundred meters up to tens of km). Some equipment types have integrated data processing and monitoring capabilities or ancillary equipment; the power requirements of these components should not be included as access network power.

Figures, per link/end, range from 30 W (for simple, low power) up to a typical 40 W and beyond for special cases. It should be noted that this does include any ancillary equipment for baseband connectivity or performance monitoring. Constraints related to operating frequency, data rates, spectral efficiency and link length apply, thus it is estimated that the EEF may approach 10 Mbit/s× km per W in some cases (for example, a typical 38 GHz, 256 QAM, 200 Mbit/s system over a distance of 2 km).

5.3.4 GSM, GPRS, UMTS and 4G

In order to produce a direct comparison with the figures given above for other access network technologies, we cannot simply take into account the bandwidth of the transmission links and their length, since this does not include the energy consumption of the broadcast equipment towards the mobile users.

Since the actual useful traffic carried on these links will vary greatly depending upon the time of day, day of the week, occurrence of local events and other unpredictable factors, it may seem more reasonable in this case to calculate efficiency in terms of the area covered or even the population of that area (though this may also be greatly variable form time to time).

In clause 5.2.3, it is postulated that a KPI based on the area covered and the maximum data rates available to users at various ranges should be used. This does, however, require detailed calculations of the performance of the base station, either based on actual or laboratory measurements, making the KPI relatively difficult to use. It will not be directly comparable with the KPI for systems having fixed connectivity to static customers.

5.3.5 Optical fibre solutions

5.3.5.1 FTTC

It has proved extremely difficult to obtain reliable and comparative figures for power requirement in this area. Based on a typical CATV network, it is estimated that a typical Cable Modem Termination System (CMTS) consumes about 100 W including its optical uplink and downlink interfaces. Each of the cabinet-located equipments at perhaps four to eight locations, depending on the network architecture, has similar energy consumption. Each of perhaps 800 customer located cable modems uses about 15 W.

The actual transmission distance of such a network tends to determined by customer requirements rather than the theoretical maximum, but it seems reasonable to assume a capability in the region of 80 km. Based on the maximum data throughput of such a network, this produces an EEF significantly in excess of 1 000 Mbit/s-km per W, coupled with the ability to equip multiple optical fibres or use several wavelengths, thus further increasing the energy efficiency of the overall system.

Since the use of multiple wavelengths on a single optical fibre (or pair of fibres) does not result in a linear increase in the energy requirement of the system, it seems logical to compare the EEF of a system having N wavelengths with that of a system using N optical fibres each carrying only one wavelength.

5.3.5.2 FTTB

It is extremely difficult to obtain reliable and comparative figures for power requirements for fibre to the premises access networks due to the many differing network configurations that may be employed. Based on a point-to-point connection, it may be reckoned that each of the two OLTs required will require a power input of about 20 W. The actual transmission distance of such a link tends to determined by customer requirements rather than the theoretical maximum capability which may be more than 80km. Based on the maximum data throughput of such a network, this produces an EEF figure significantly in excess of 1 000 Mbit/s-km per W, coupled with the ability to illuminate the fibre at several wavelengths, thus further increasing the energy efficiency of the overall system.

5.3.5.3 FTTH

The general comments expressed in clause 5.3.5.2 also apply to FTTH access circuits, the main difference being that FTTH circuits are more likely to be connected as point to multi-point.

The table of EEF and NPC values attached as annex B is indicative of the values that might be achieved in a typical access network and those obtainable for a circuit exploiting FTTB or FTTH as it approaches its maximum usable range.

5.3.6 Summary of power requirement metrics

5.3.6.1 Determination of parameters

5.3.6.1.1 Transmission rate/bitrate

An ADSL service described as "up to 8 Mbit/s", will typically have an actual downstream line rate of around 6 Mbit/s (this is highly dependent upon line length) and be configured by the ISP for a maximum throughput of 5,5 Mbit/s (to provide a "safety margin"). The ISP's measurement of the actual throughput of such a circuit will usually be between 4,5 Mbit/s and 5 Mbit/s based on an unconstrained source of test data. The end-user's experience of receiving "real data" from a distant source will almost invariably be somewhat less than this due to network routing, error correction, congestion and far-end server constraints.

It therefore has to be asked which of these FIVE possible data rates is to be used in the calculation, particularly as most of them may be affected from time to time by external influences, totally unconnected with energy efficiency! Depending on the protocols in use, some proportion of the so-called "real data" will consist of system overheads, further reducing the useful throughput; should this loss also be taken into account? A further issue arises regarding measurement of energy efficiency in the upstream directions since the speed is normally constrained by the ISP to 448 kbit/s, making the upstream efficiency only 10 % to 15 % of the downstream figure. Similar issues will arise in access networks using other technologies. This asymmetry issue may be resolved by calculating separately the "up" and "down" efficiency figures and adding them together, though this might further confuse any comparisons between efficiency figures for differing technologies.

These figures quoted above relate to a single ADSL access network service. If compared with an optical fibre access network circuit having the potential to serve many hundreds of customers, further complications arise in making such calculations, not least that in a practical network, even if network requirements are such that an optical fibre access circuit is used at near its maximum bandwidth, in many cases it is likely to be used at less than its maximum range, simply due to the location of the customer premises being relatively close to the operator site.

The difference between the actual bandwidth in use and that equipped may make a considerable difference to the KPI figure calculated using the parameters suggested, particularly in complex networks where individual links may have differing utilizations and/or shared capacity. It seems sensible to use the net throughput of the link as the KPI reference parameter, rather than any higher, claimed figure.

5.3.6.1.2 Distance

The "distance" parameter may be the actual length of a specific access circuit or the maximum range achievable using the particular technology. To avoid problems in this respect, it may be desirable to fix one or more reference distances for each specific technology. However, this may become a critical issue since it could significantly affect any attempt to compare the energy efficiencies of differing technologies in the access network.

The choice of this reference distance can also be a critical issue in technologies such as xDSL, which show a peculiar variation of their capabilities depending on the loop length. This would result in different energy efficiency figures depending on the loop length chosen.

As a guide it has been proposed to fix the reference distances as follows:

- ADSL/ADSL 2+ 3 000 m
- VDSL2 (8-12-17) 700 m
- VDSL2 (30) 150 m

These figures were chosen by reference to typical system performance over 0,4 mm copper pairs. These distances would clearly need modification where network operators used pairs of other sizes but this can be left to the operator since it is only necessary to be consistent within a given network.

5.3.6.1.3 Power requirements

For a service where the power demands change depending upon the service state, the period over which the power requirement is averaged needs to be considered.

A number of energy-saving states for broadband equipment have been defined, for instance in the DSL standards ITU-T Recommendations G.992.3 [i.20] and G.992.5 [i.21]). These low-power states are intended to be automatically implemented during periods of low traffic needs. If such energy-saving states are implemented in the network equipment and/or the equipment deployed at the user premises (OSE or OIE) the total energy consumption may be further reduced.

Using the NPC to compare the energy usage during different working states is not recommended in TS 102 533 [i.2] due to the uncertainty caused by user behaviour. TS 102 533 [i.2] suggests that other, unspecified parameters should be used to compare power requirement at service level, particularly for service types where the energy requirement is fundamentally related to user behaviour (for example, when comparing VoIP with PSTN).

5.3.6.2 Network Configuration Issues

There are further complication created by the configuration of the network and the methods of implementation. Consider the case of an optical fibre based broadband cable television network at least 40 channels (or carriers) at 8 MHz spacing, each modulated using 256 QAM (in which the binary data is sampled in blocks of eight bits). Such a system would have a throughput (including overheads) of about 2 200 Mbit/s on each of the several wavelengths at which the fibre might be illuminated! In calculating the energy efficiency of such a system, this figure would have to be divided by the number of customers being served. Unlike DSL services, where access equipment at the operator site is such that it can be provided in relatively small modules as customer demand arises, much of the access network equipment in a CATV operator site (head-end), whilst capable of serving a large number of customers, has to be provided from the outset. It follows therefore, that a large proportion of the energy requirement arises at "day one" and that the energy efficiency of the access network as a whole will steadily improve as the customer base grows.

This is only one example; it is possible to envisage other network scenarios where similar situations might arise, circumstances where the power requirement of the operator site equipment is disproportionate to the number of customers being served. In these cases, calculation of the overall KPI figure may become a complex process and the result will vary from time to time depending on the effective "fill" of the available network capacity.

5.3.6.3 Applicability

Clearly, either the EEF metric proposed in the current study or NPC can be used to compare the performance of various telecommunications technologies as indicated in clause 5.3. Other formulae could be envisaged, some possibly taking into account other parameters of the service, though the results of doing this would inevitably result in their calculation becoming more complex.

Whilst this has some logic when discussing a single access network technology, it is less useful when comparing different access network technologies such as a copper loop carrying an ADSL circuit compared to an optical fibre pair serving multiple customers.

The methodology is applicable when comparing a series of point-to-point implementations with complex networks using a similar technology and designed to deliver the same service capability in terms of the total energy used.

Previous work undertaken by ETSI and published as TS 102 533 [i.2] examined the question of the power requirements of broadband equipment and suggested the using the NPC concept. This uses the same basic parameters as in the present document, although in a slightly different way. That work concluded that the NPC can be satisfactorily used for comparing different products with the same technology or different generations of the same technologies. NPC might also be used with caution to compare different products in different technologies using their maximum capabilities as the input parameters.

It is clear that a single KPI cannot be used to directly compare the performance of different access network technologies (metallic loop, optical fibre, wireless, etc.). Although the same basic parameters can be used in all cases the resultant figure will differ considerably between different technologies. A value calculated in this way can be used to compare differing network topologies using a similar technology but intended to provide the same service capability but it cannot properly be used to compare differing technologies.

It is concluded, therefore, that it is not possible to have a single, comparative indicator applicable to all access technologies. A general KPI based on the stated parameters (and, where applicable, the duration for which the connection is active) for access networks might be feasible but it would have to be recognized that the reference value would necessarily be different for each different network technology.

Consequently, two methods of calculation are proposed, one for networks having subscribers in a fixed location relative to the operator site and the second for networks having nomadic or mobile subscribers. These have been detailed in clause 5.2.2.

5.3.6.4 Further development

It seems logical that the "benefits" of the service (speed and distance) should be divided by the "cost" (power requirements) and that the resultant figure should increase as the service becomes more energy efficient. It is also important for ease of use that the value of the metric should remain within reasonable bounds, irrespective of the technology being considered. NPC for a 100Mbit/s service over a 150 km optical fibre link using 10 W would be 0,667 mW/Mbit/s per km, whereas the EEF would be 1 500 Mbit/s-km per W. Ideally, the metric used to monitor energy efficiency should be dimensionless, a condition not satisfied by either of the proposals, though this is not considered to be a significant problem (see also clause 5.2.3).

It seems likely that in the "real world" implementation of access network circuits that complex networks are likely to prove more cost effective and flexible than the provision of dedicated point-to-point services for each end-user. Energy efficiency of such arrangements is also an important parameter and some standardized basis of measuring this is clearly necessary.

5.4 Energy Efficiency Key Performance Indicators (KPIs)

Following the success of deregulation, the rapid growth in telecommunications networks, particularly the competition in the provision of access network services put considerable pressure on network deployment. Consequently, operators were concerned only with network growth, concentrating on capacity management and planning without giving sufficient consideration to the management of network energy consumption. A recent and substantial increase in the cost of energy, coupled with the greater emphasis on "green" issues, now necessitates a review.

In addition, the design of new access networks has been largely a matter for equipment suppliers who were given no brief and had no particular standards relating to energy efficiency. In order to better manage energy efficiency in the future it is desirable to formulate a performance measure which can be specified to equipment suppliers as part of the procurement and design validation processes. This parameter could also be used to bench-mark new build and to monitor the longer term performance of installed systems.

Since measurement of energy performance is a relatively new concept, there is very little valid data available on KPIs as measured on existing access networks. The very simplest of KPIs might be a straightforward division of the total power consumed in a given access network by the number of customers connected to that network, producing a figure for "Watts per home". However, this fails to take into consideration the differing traffic needs of the customers. Likewise, it ignores the length of the customer access circuits, whereas length might have an important influence on the energy consumption when the access technology requires active elements between the operator site and the customer's premises. Perhaps more importantly, this measure takes no account of equipped but unused capacity at the operator site, meaning that any new or growing site would fail to meet such KPIs simply due to equipment having been provided for planned growth!

It has been shown in clause 5.3 that KPIs based on information transfer, distance and energy consumption of an access circuit are widely variable depending on the technology being considered. In the case of services or devices which have one or more "sleep" states it is also necessary to take into account the energy saving this achieves. The simplest way of doing this is to estimate the proportions of time for which each state exists and to average the energy usage over an appropriate period.

Clause 5.3.6.1.1 discusses the various measures of data speed applicable to a particular network type. Similar problems arise with other network technologies, adding to the complications of comparing their energy efficiency. The only practicable way of dealing with this problem is for the "useful" speed to be consistently defined within a given technology.

There is also a need for the KPI calculation to be relatively simple, based on similar data for all existing network types, and easily applied to new network types. It is therefore concluded that such an approach is justified. This would allow valid comparison between two access networks using the same technology (say DSL) but would not allow straightforward comparison between the energy efficiencies of (say) a DSL network and (say) a network based on WiFi access.

In any case, it is probable that in most cases a "cross-technology" comparison is not relevant or required, only comparisons between different networks of the same type being necessary, since energy efficiency alone is unlikely to be a major factor in deciding what technology is appropriate in a particular network application. In those cases where cross technology comparisons are necessary results obtained by calculation of the EEF or NPC should be treated with caution, bearing in mind that they are necessarily technology dependent, therefore making valid comparison difficult.

It should also be borne in mind that any network configuration and utilization differences will also potentially affect KPI calculations. It is also possible that KPI might be affected by user behaviour, for example, watching TV, available content and applications, or customer churn (which might be due to network operator behaviour, for example after tariff increases).

It can be argued that revenue produced might be a factor in any KPI on energy consumption but that is considered to be beyond the scope of the present work and is, in any case, highly dependent upon the network operators" commercial policies. A figure calculated in this way might, in practice, become solely dependent on operator tariffs thus negating its fundamental purpose as a measure of energy efficiency.

Another measure that has been discussed is that of the total access network bandwidth provided divided by the area served and/or the number of customer premises passed. This approach potentially produces anomalies due to the differing demographics in residential, commercial and industrial areas and again, the inclusion of such a parameter might overwhelm the intended purpose of the KPI.

It is also clear that the energy usage in a typical broadband access network connection is very substantially less than the power requirements of the Customer Premises Equipment (CPE) which is dependent upon it. A fractional reduction in the energy used by the CPE is likely to exceed the total energy used by the access network (see clause 5.5).

Whilst the present document has largely focussed on the *measurement and comparison* of energy usage, there are other indicators that may be used to monitor the *overall environmental performance* of broadband access services. For instance, in some jurisdictions network operators are already required to report on such issues as their usage of renewable energy, the number and nature of the sources of their energy and the proportion of total energy used in their access network which is generated from renewable sources.

Generally speaking, the levels of monitoring of the performance of access networks are much lower than that at the core network level. It might be considered appropriate in some networks to enhance the supervisory systems (which would increase the energy requirement) to provide near real-time information on the data throughput and energy usage from the network and possibly from the connected CPE as well.

5.5 Customer premises networks

Although energy consumption in home networks is to some extent related to the network state, it is completely outside the control of access network operators and is almost impossible to regulate, although work is being undertaken by the EC, IEEE, Home Gateway Initiative (HGI) and the Broadband Forum (BBF) in this field, the principal objective being to reduce the power requirement when the service is quiescent. Some work has also taken place at Lawrence Berkley Laboratories (LBL) under their Energy Efficient Networks programme (see http://efficientnetworks.lbl.gov/enet.html). In many cases, even the terminating device (for example, the DSL modem) is outside the network operator's control and such devices may or may not include additional functionality such as routing, firewall provision, USB, LAN and WAN interfaces, WiFi capability, DECT or VoIP telephony, print servers and other user interfaces. These factors make the definition of any consistently applicable KPI almost impossible.

In addition to these issues there will inevitably be a rich variety of usage, ranging from the home with a single computer to those having a complex network of computers and home entertainment equipment, further contributing to the impossibility of controlling energy usage.

The only practicable mechanisms for managing energy consumption in home networks seem to be the encouragement of equipment manufacturers to follow established mechanisms, such as the EC Code of Conduct on Energy Consumption of Broadband Equipment [i.3], when designing component parts of such networks and for end-users to construct their networks so as to minimize the use of those component parts.

6 Increasing the energy efficiency of access networks

6.1 Network Architecture and deployment

Four specific types of access network deployment are likely, due to varying customer population densities in different localities. Each of the following situations will result in a different energy efficiency figure:

- City centre networks with many direct optical fibre systems to businesses and homes.
- Suburban networks fed by optical fibre systems (FTTC) and using remote DSLAM equipment using the existing metallic pairs for the distribution part of the access network.
- Villages with lower population density will be served by optical systems to an operator site within the village and use DSL distribution circuits over the existing metallic access network.
- Rural areas will mostly use FTTC technologies using remote DSLAM equipment over existing metallic pairs for the distribution part of the access network. Wireless technologies will provide a "last resort" solution for "last-mile" links to isolated properties or in difficult terrain as an alternative to metallic pairs.

6.2 Technology overview

The various available technologies present a wide range of possible access networks solutions and although the present work has focussed on the study of energy efficiency of access networks, it cannot completely ignore the need for a practicable solution in terms of being able to provide the total telecommunications access needs of a given area. For instance, even if DSL solutions proved to be the most energy efficient, it is unlikely that sufficient bandwidth could be provided and almost certain that a substantial number of potential customers would not be able to receive the speed of service they required. Equally, radio spectrum is simply not available to accommodate all its potential users.

It is generally accepted that optical fibre solutions are the most energy efficient access network delivery mechanisms when used at or near the total bandwidth they are capable of delivering.

Optical fibre is the ultimate transmission medium for high bandwidth services and implementation of the physical infrastructure for FTTC, FTTB and FTTH access network solutions represents an enormous and long-term investment by network operators. Decisions on component choice within the physical infrastructure should reflect the predicted energy efficiency of future services. Nevertheless, there are other factors to be considered; such bandwidth should be used efficiently and there is a need to reduce the energy consumption of access network systems when their capacity is not being fully used.

Even more importantly, the energy consumption of access network is insignificant compared to that of the customer premises networks, over which the network operator has no control (see TR 105 174-5-1 [i.23]). The EC Code of Conduct on Energy Consumption of Broadband Equipment [i.3] is only addresses a small part of this topic but further work is underway both by the EC and elsewhere (see also clause 5.5).

It has to be realized that with the increasing use of technology, especially in the telecommunications arena, we cannot realistically expect reduce the overall power requirements. Instead efforts should be concentrated on improving energy efficiency, increasing the benefits by more that we increase consumption of energy.

6.3 Targets and actions needed

Following the principles outlined above, some preliminary targets and actions are required but first there should be studies by equipment suppliers of what is realistically possible. This will allow network designers to think in terms of energy management. A set of "guiding principles" needs to be established to evaluate existing and future network technologies in terms of their energy efficiency, including a study of the existing power requirements of network elements.

These principles might include:

- the delivery of more capacity in the access network;
- the delivery of more and better services;
- provision more cost effective services; and
- the use of a greater proportion of green energy, all with the same or lower energy consumption.

Actions required to improve the design of networks from an energy efficiency point of view include ensuring that:

- no device on a network should cause any other device to stay awake when it might otherwise go into a quiescent mode without affecting network performance;
- no legacy or incompatible device should prevent the rest of the network from effectively using its energy management capabilities;
- all network devices will expose their own power state to the rest of the network and be able to report their energy usage levels.

To achieve this:

- standards are required for the way in which products that influence energy consumption should behave and communicate with other network elements;
- network elements should have the ability to modulate their energy use according to short-term service requirements;
- network elements should have the ability to quickly return to a full power state to meet service requests;
- all network technologies should be the target for efficiency efforts;
- standards intended to improve energy efficiency should not favour any particular hardware or software technology;
- harmonization of the basic principles of design for energy efficient network devices should be global in their application.

To assist in the achievement of these objectives equipment suppliers might be reasonably expected to accelerate the development of equipments having the facilities noted above and in the early provision of "last-mile" optical interfaces having advanced energy-saving features. Network operators might be expected to co-operate by sharing whatever KPIs and other relevant information they have to assist in the design of energy efficient networks. National regulatory authorities should co-operate in the production of realistic energy performance targets for broadband deployment, possibly based on the existing EC Code of Conduct [i.3].

Priorities need to be set for these actions and whilst it may seem difficult in the short term achieve some of these objectives, the only way to improve energy efficiency in our ever-growing communications networks is to tackle all of these problems and others, with the utmost vigour.

One mechanism by which it may be possible to progress these issues is to undertake research among existing access network operators to determine what (if any) KPIs are currently used by them in each in each of their main network access technologies.

6.4 Energy saving measures

Some specific measures applicable to optical fibre based access networks which may be considered are summarized below. This is by no means an exhaustive list but is intended to suggest some of the ways in which access network energy efficiency might be improved, the emphasis being on a *network-based* approach.

6.4.1 FTTC

There is a need to increase the emphasis on energy efficiency by adding appropriate constraints within access network engineering software. Thus we can achieve an optimized network solution taking into account the length of transmissions systems, the density of network in terms of customers (or more specifically, traffic opportunities) passed and ensuring the minimum necessary number of network sites.

Network operators should work with equipment suppliers to study and improve the design of power supply solutions and ensure that a range of optimized, rather than standardized, solutions is available, with flexibility to accommodate future changes at access network sites. Thus specifications can be written in terms of more flexible and efficient power distribution systems.

An extension of the temperature range over which reliable operation of cabinet-located equipment can operate satisfactorily and/or the use of more efficient cooling methods will also lead to a reduction in the total network energy consumption.

6.4.2 FTTB

Access networks provided over fibre to the building essentially use similar "building blocks" as those provided to the cabinet. Hence the same recommendations apply at those listed in clause 6.3.1.

In addition, we need to consider the provision of means by which access network power requirements can be reduced when there is no requirement for communications from the building. Additionally, monitoring of network traffic could be used to control some or all of the CPE, thus further reducing energy consumption.

Although not strictly relevant to the present study, it should be mentioned that the output of such monitors might also control the building's power, temperature regulation and safety management systems when nobody is present in the affected areas.

6.4.3 CPE and Home equipment

As noted in the Introduction to the present document, convergence can enable the merging several functions or services onto a common network infrastructure or CPE "black box". This has the potential to increase the overall end-to-end power consumption. Any such converged solutions should be more power efficient than the provision of similar facilities using non-converged hardware. It is therefore necessary that any multi-functional network or end-user device should provide the capability for activation of only the functionality required in a specific application, using logical provisioning, that is, not activating any interfaces not required for the end users" subscribed services. CPE devices should have their functionality and service interfaces disabled by default and enabled only when a service is logically provisioned.

A specific management system associated with the access network in the network operator's control centre could be programmed to automatically switch off and on of the customers" equipment by the according to a set of predetermined rules or where some services are not required on a continuous basis. Automatic alerts and best practice messages could be sent to customers, encouraging them to switch off other unused equipment when it is not required.

7 Overall Conclusions

It is clear that historically, little or no account was taken of the need for energy efficiency during the design of access networks. Whilst is likely that in some specialized cases there has been some consideration of the power requirement of terminal devices, this was limited to battery powered, portable equipment. Whilst batteries have been used as a standby power source at operator sites for many years it is only relatively recently that they have been used in street cabinets in which their charging, size and capacity has been more of an issue.

During the last few years, the cost of energy, the ever increasing need for energy and the environmental consequences of its excessive use have become more significant factors in attempting to limit its consumption, not least in the ever more demanding telecommunications arena.

We now have to establish means by which this usage can be properly monitored. We need to have a clear intent to improve the energy efficiency of such networks and to do so, we need a reference metric against which systems and networks can be evaluated. There has to be a continuing improvement in the "value for money" we get from the use of energy in telecommunications networks. To monitor this we need Key Performance Indicators, against which all new equipment developments, new technologies and new network plans should be evaluated.

There is no value in trying to use these new KPIs in legacy networks and systems. The equipment was not designed with energy efficiency in mind, nor was it a consideration in the design of the systems.

A new range of KPIs is required for broadband deployment. Not only are such systems becoming ever more ubiquitous and using more power in doing so, but we are increasingly reliant upon them. These KPIs should be a clear measure, using easily measured parameters and simple calculations, by which improvement can be demonstrated. Ideally, KPIs should be a ratio, therefore dimensionless, and applicable to all relevant technologies, but most importantly, they should be simple numbers and easily understood.

The present work has demonstrated that it is not possible to use a single KPI for all network types. We have therefore postulated one measure for networks in which the customer location is fixed and known, and a second measure for networks in which the customers are mobile or nomadic. These are detailed in Clause 5 of the present document. An older measure, Normalized Power Consumption (NPC) has been suggested for fixed networks, but the new Energy Efficiency Factor (EEF) is preferred since it produces more easily handled numbers when calculated for "real" networks, though it does not allow easy comparison between differing technologies. The KPI for energy efficiency in networks having nomadic customers is capable of being determined without knowledge of the customer distribution within the service area, their numbers or their service capabilities. However, it will require detailed calculations or measurements determine the available data speeds at various distances from each base station before its energy efficiency can be determined.

Future network technology choices should take full account of the relevant KPI within the framework of overall systems deployment though it also has to be recognized that in some scenarios, energy efficiency may not be the ultimate determining factor in the equipment choice. Such factors as customer requirements and service feasibility will also play their part in such decisions.

In terms of systems development, such factors as scalability of data rate and system flexibility in terms of customer and operator needs should all be factors as well as striving for a constant improvement of energy efficiency KPI . Above all, we should avoid technological solutions that address only short term improvements in KPI without considering the long term implications.

Annex A:
Table of EEF and NPC values

In table A.1, EEF and NPC calculations have been made as described in clause 5.2.2 using figures, where available, from the "EC Code of Conduct on Energy Consumption of Broadband Equipment [i.3]". Elsewhere other sources have been used in order to obtain figures typical of those to be expected in "real" networks, rounded as appropriate. Due to the variety of sources for the base data, the results may not be entirely consistent. The values in table A.1 for EEF and NPC should not be used to compare the energy performance of systems using different technologies.

Table A.1: Typical values of EEF and NPC for various telecommunications technologies

	ADSL	ADSL2	VDSL2 (Profile 17)	CATV	FTTC	FTTB/H	POTS	Fixed W/L	WiFi	WiMax	Zigbee/ B-tooth
Figures for typical range applicable to relevant technology											
Range (km)	3,0	3,0	0,7	5,0	5,0	5,0	5,0	2,0	0,3	10	0,002
EEF	1,50	6,00	1,87	330	200	25	0,15	10	2,50	14	0,02
NPC	670	170	535	3,00	5,00	40	6 500	100	400	70	47 600
Figures for range = 3 km (where applicable)											
EEF	1,50	6,00	n/a	200	120	15	0,09	11	n/a	11	n/a
NPC	670	170	n/a	5,00	8,00	67	10 800	89	n/a	93	n/a
Figures for range = 10 km (where applicable)											
EEF	0,71	3,00	n/a	670	400	50	0,31	3,75	n/a	14	n/a
NPC	1 400	330	n/a	1,50	2,50	20	3 250	270	n/a	70	n/a
Figures for maximum range applicable to relevant technology											
Range (km)	10	10	1,5	75	20	20	20	20	0,3	70	0,002
EEF	0,71	3,00	0,40	5 000	800	1 000	0,62	7,50	2,50	25	0,02
NPC	1 400	330	2 500	0,20	1,25	1,00	1 600	130	40	40	47 600

History

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