Energy efficient broadband infrastructure in mobile and fixed networks and use in the domestic sector

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Abstract

The ever-growing number of Internet users, the introduction of new bandwidth-hungry applications and services as well as the vision of the Internet of Things[1] will set very high requirements on future access networks. Already today there are many different coexisting network technologies and protocols in the access area that have been developed and introduced to fulfill different needs of Internet users and heterogeneous applications. The growing complexity and increasing energy consumption of access networks raise a need for a comprehensive and effective modeling framework that enables a fast projection of energy efficiency of different access network infrastructures. This paper presents a comprehensive framework that joins technological parameters and various configuration options with socio-demographic characteristics and varying user behavior. The modeling framework can be used to evaluate different deployment and migration scenarios for both wireless and wired access networks by means of predicted energy efficiency. Taking into account possible further developments in technology, applications and traffic characteristics, the modeling framework enables predictions on the access related energy demands raised by forecast trends in conjunction with accompanying equipment change options. This modeling framework may serve operators of access networks to select network migration paths that are effective in the short term and efficient in the long term. Beyond that overall options for energy efficient and user oriented ICT[2] solutions have been described and evaluated. Finally policy recommendations have been developed supporting the development of sustainable ICT for the domestic sector on a national level.

I Introduction

Both the number of broadband subscribers and the number of end-user devices have been increasing rapidly in the last decade [1] and this trend is expected to continue in the future. Additionally, introduction and a broad use of high-end applications increasingly drive the need for high capacity in access networks. The most complex part of today's Internet is the access network area, which also contributes mainly to the high total energy consumption of the global network infrastructure. According to the vision of the "Internet of Things", it is expected that in the foreseeable future, additionally to person-used applications also a huge number of intelligent, self-communicating devices will communicate with each other over the Internet. All these trends indicate an urgent need for more efficient access networks. Recently, there has been a lot of research effort to assess and improve the energy efficiency of access networks [2]-[9].

Most of the previous research works either concentrate on energy-efficient devices and structures or consider only a part of the complex and heterogeneous access network infrastructure. In most cases, wired and wireless parts of the network are treated separately. In this study, we evaluate the energy efficiency of the entire access network infrastructure by considering both wired and wireless networks as well as the wireless backhaul that is used to connect base station sites to the backbone network. Additionally, we consider end-user equipment, socio-demographic characteristics and application

[1] Internet of Things (abbrev. IoT): Network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment.

[2] ICT: Abbreviation for „Information and Communication Technologies“

usage to cover all important factors needed to appropriately estimate the energy efficiency of access networks and make projections for future developments.

The paper is organized as follows. The Section II introduces the modeling framework and describes the structures of models used to analyze end-user devices, application usage and access networks. Section III presents some exemplary results of the application of the framework to analyze the energy efficiency of a national-wide access network infrastructure. Finally, Section IV summarizes the paper and draws conclusions.

II Modeling framework

The ultimate aim of the modeling framework presented here is to enable a holistic assessment of access networks and to help understanding complex independencies between socio-demographic trends, technology, applications and usage patterns. It could also serve to indicate potentials and risks of different approaches and to assist policy makers in developing a policy framework towards a sustainable Internet access.

The technical scope of the framework is shown in Fig. 1. The figure illustrates technologies and devices considered in this study. The boundaries of the system under consideration are the interface to the backbone network, i.e. the uplink of the aggregation switch that is usually located in premises of network providers on one side, and users of networked equipment on the other. In the following, we describe three sub models that are used to: i) analyze user behavior and applications ii) predict trends in the end-user equipment sector and iii) evaluate access networks by means of energy efficiency. The three sub models interact with each other to obtain an overall representation of the entire system. For example, development of new end-user devices affects both applications and user behavior, which is also influenced by socio-demographic trends. All these factors influence the bandwidth demand and the traffic pattern at network terminals, which, in addition, have an impact on network design and performance. Similarly, a broad availability of high data rate Internet access and powerful user devices can accelerate the development of new applications and lead to a notable user behavior change.

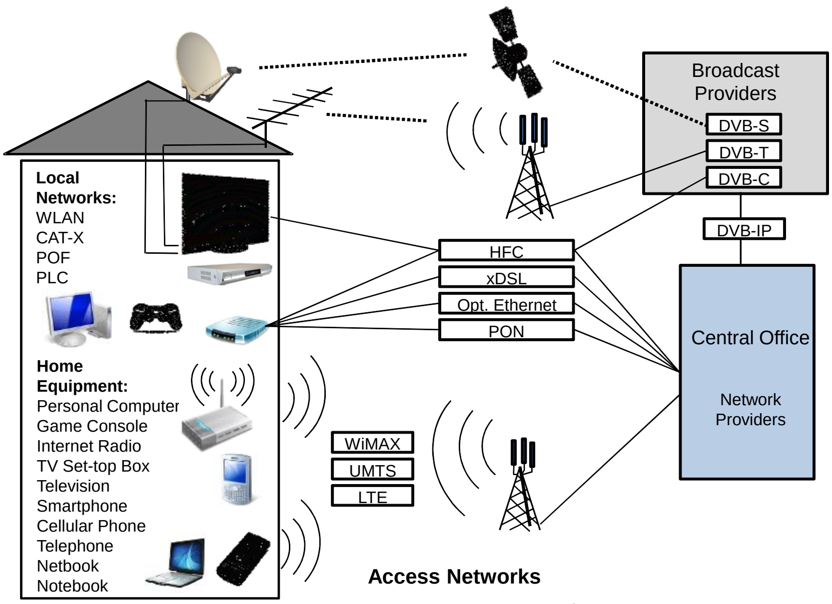


Fig. 1: The scope of the modeling framework[3]

[3] Definitions of used acronyms can be found in the glossary section of this paper.

A. User Behavior, Applications and Traffic

To assess the energy efficiency of different access technologies and deployment scenarios we need to model the traffic that is transported over the provided access capacity. We start with coarse assumptions on the traffic caused by typical applications while in use (Table 1). Next we sketch when and for how long an application is likely used by different user groups. We use five user groups, being children, teenagers, young adults, mature, and the elderly. The usage variation over any day is included by normally distributing the usage likelihood across the day. When doing so, we get usage patterns for each application per user group. Concluding the data base, we rate the popularity of applications for each user group. The application usage (the application mix) can be changed by adjusting the popularity figures, while the application consumption patterns (user behaviors) can be changed by adjusting the usage likelihood curves. The splitting into user groups enables us to flexibly consider diverging trends.

To obtain the utilization of wired and wireless access networks, the traffic caused by an average household and an average mobile customer needs to be calculated, respectively. This is outlined in Fig. 2. Using the socio-demographic distribution we sum up the popularity weighted usage patterns and get the average demand pattern over a day. A tricky challenge results if at certain times of a day the average demand exceeds the capacity provided by a technology, which causes application dependent performance degradation and diminishes the popularity of heavily affected applications. To consider this effect we add a feasibility weighting of applications per access technology. In the end we get a single average utilization curve per technology that can be used to realistically compare the practical energy-efficiency of technologies. The many degrees of freedom preserved are essentially needed to model socio-economic trends.

Table 1: Traffic caused by different applications/services in use

	SERVICES	Downlink [MByte/h]	Uplink [MByte/h]
Voice	Telephone	28,8	28,8
	VoIP (over Internet)	28,8	28,8
	Online Music Streaming (Internet Radio)	72,0	1,5
Video	Video conference	310,5	310,5
	SDTV (Broadcast)	900,0	18,0
	HDTV (Broadcast)	3600,0	75,0
	VoD (Video on demand)	900,0	16,0
	HDoD (HD on Demand)	3600,0	70,0
	Online Video Streaming	720,0	16,0
Data	Classic Internet Services	12,0	3,0
	Online Gaming	28,8	25,2
	File Sharing	52,7	47,7
	Home Office via VPN	41,9	31,4
	Cloud Services	21,1	9,0
	Remote Home Monitoring	0,5	3,0

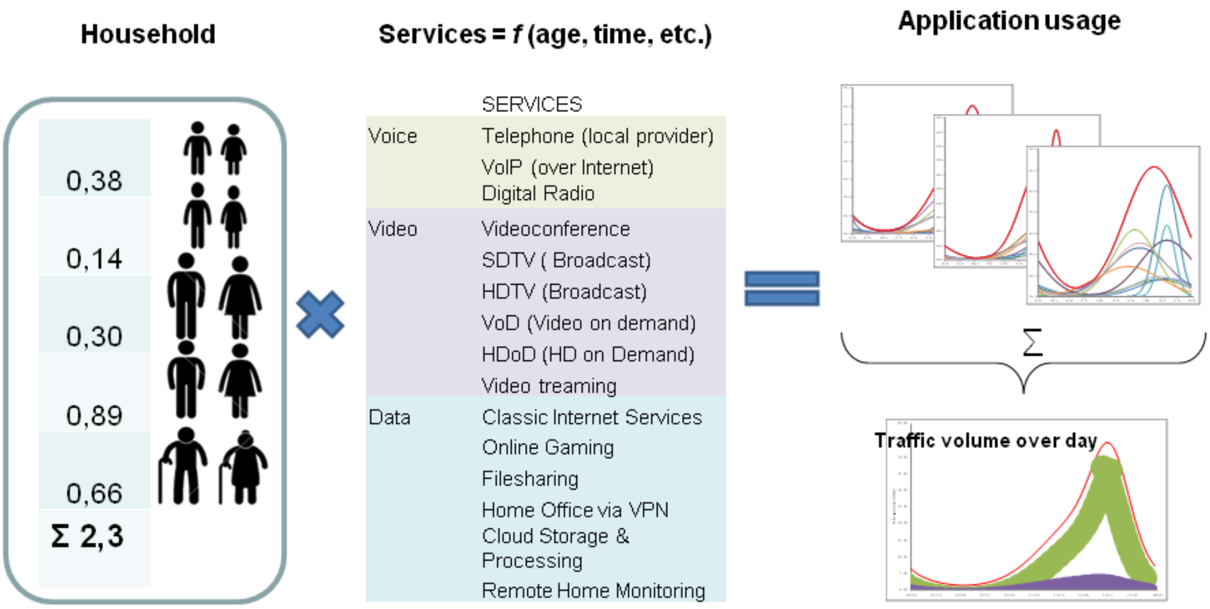


Fig. 2: Access utilization assessment model for an average household

B. Model of Access Networks

The user traffic profiles are determined by the model described in Section II. A. represents an input parameter to the model of access networks. A generic representation of the access network model is shown in Fig 3. The access network is first designed according to the requirements on capacity, coverage, and number of subscribers and the choice of technology. Various technology and application related parameters are taken into account. There are different sub models for wireless and wired parts of the network as well as for the wireless backhaul. The mix of technologies for each sub model is chosen independently, while the input traffic of the wireless backhaul is determined by the traffic aggregated in a base station of the radio access network. The finite capacities of both link and nodes are considered by comparing the actual amount of upstream and downstream traffic to the maximum capacity of each network element. In order to keep the complexity of the model at a reasonable level, the model deals with time-of-day dependent average data rates instead to model the transmission of data packets. Following this approach we are able to perform traffic analysis without using a packet-based, event driven simulator, which would most probably lead to a complex and less scalable implementation. The instantaneous power consumption of the network is determined using the model presented in [7],[10],[11] and according to the characteristics and the number of active network components at each particular time. The results on energy consumption and network performance are combined to obtain the energy efficiency.

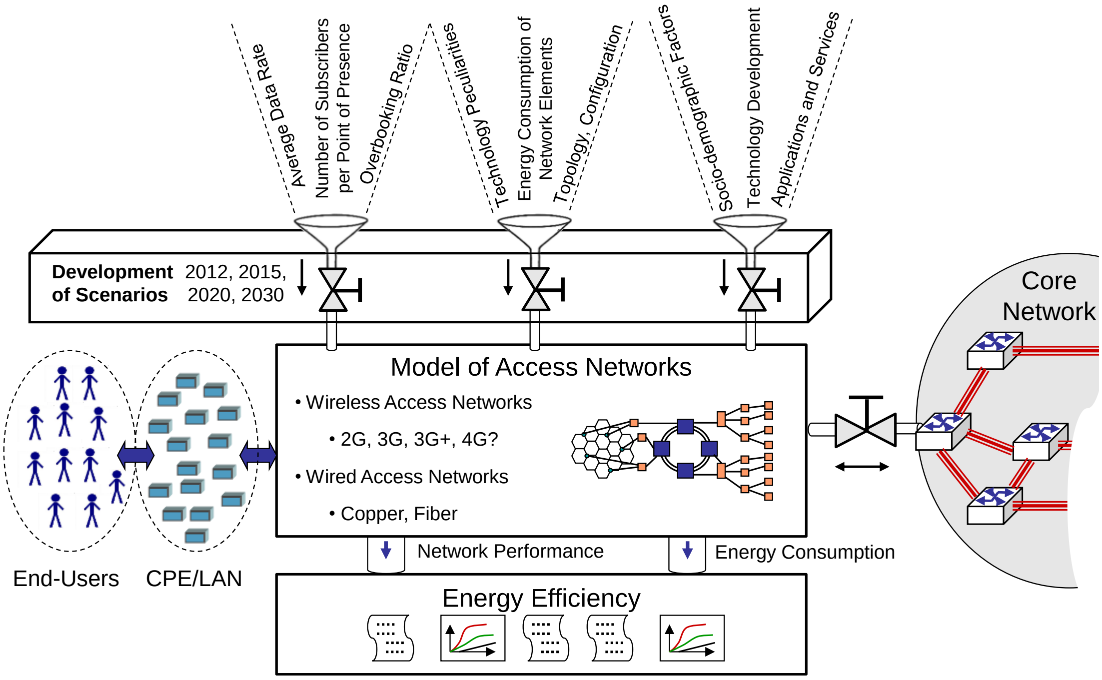


Fig. 3: Generic representation for the access network model

Currently, a typical scenario is to have several network providers acting on the same market. As a consequence, there are usually several networks coexisting and serving their customers within the same region. As a consequence, there are parallel network infrastructures that have to be taken into account. Therefore, an efficient and realistic modeling approach has to be able not only to combine different technologies and network areas but also a number of coexisting networks owned by different network providers as illustrated in Fig. 4.

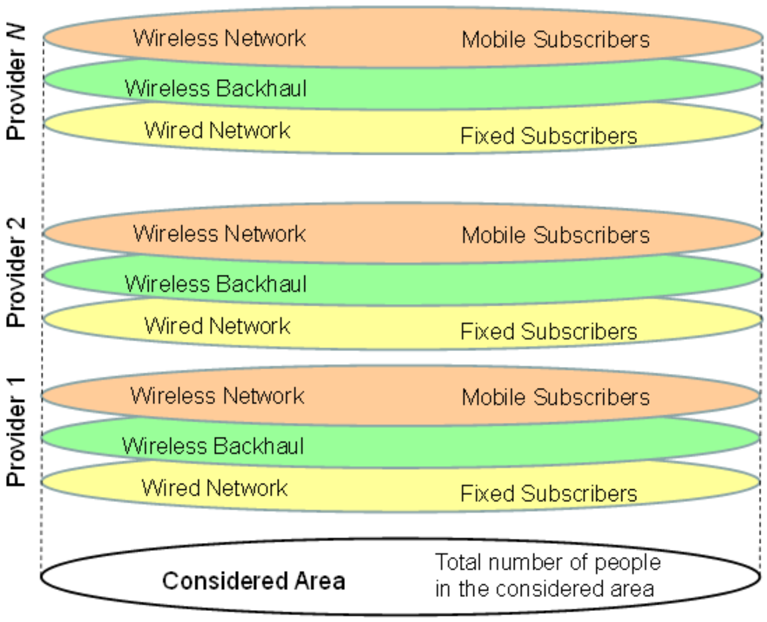
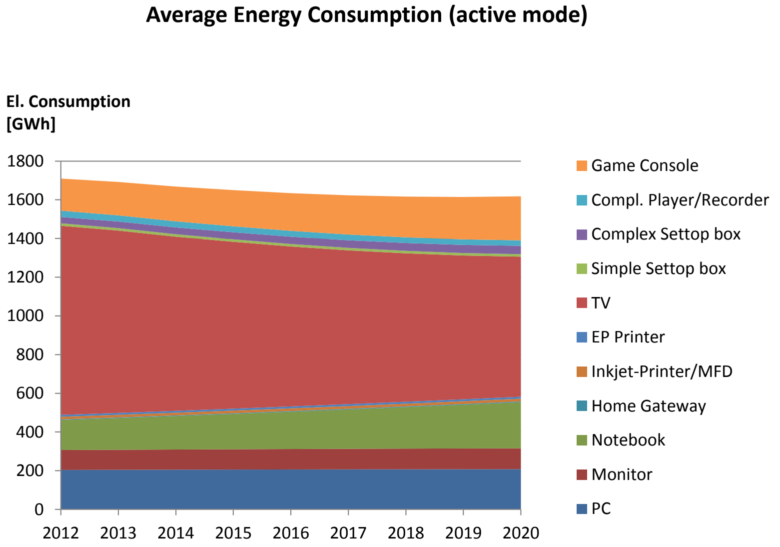


Fig. 4: Multi-provider case

III Case study

In this section, we illustrate the use of the framework for evaluating the energy efficiency of access networks based on a national network infrastructure for Austria. We apply the approach described above to model the region-specific usage patterns for various end-user equipment and applications. An example of a result for energy consumption of different home appliances is shown in Fig. 5. Using a stock flow model and statistical data about usage of electronic devices in Austria, it is possible to determine the current, country-wide energy consumption caused by each type of device and to predict the future trends [12].The results indicate that by far the most energy is consumed by the television set in active mode. The second largest contributor is the personal computer (PC). Thus, the particular attention has to be paid on the methods for improving the energy efficiency of these two devices.

a)



b)

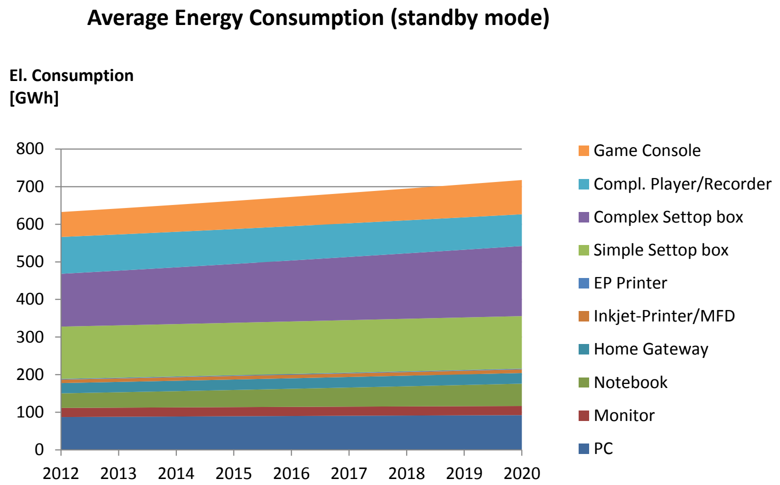


Fig. 5: Projected electricity consumption of various home appliances in a) active and b) standby modes in year 2020 in Austria

According to statistical data of device and application usage as well as the demographic conditions in Austria, we developed traffic profiles for different user types and various combinations of services and technologies. The resulting user traffic profile that describes the time-of-day dependent traffic generated/consumed by a typical user or household is determined following the methodology already briefly described in Section II. A. and illustrated in Fig. 2. Two examples of such traffic profiles for users of UMTS and xDSL networks are shown in Fig. 6. Note that the profiles are different for users of different technologies and are directly influenced by changes in user behavior, applications and their usage patterns as well as by socio-demographic factors. The determination of traffic profiles is an important step in predicting the traffic demand, and thus evaluating network performance for different scenarios.

For the purpose of the evaluation of energy efficiency of Austrian-wide access network, we parameterized the model of access networks according to the data we received from the Austrian Regulatory Authority for Broadcasting and Telecommunications (RTR), Austrian network operators and the Forum Mobilkommunikation (FMK). We also used statistical data about technology penetration, market shares and population densities. The first step was to determine the numbers of mobile base stations required to achieve a desired coverage using the data at the municipality and the federal state levels. There is a very good coverage of both GSM and UMTS networks in Austria, especially in urban and suburban areas. LTE is implemented in some selected areas for test purposes.

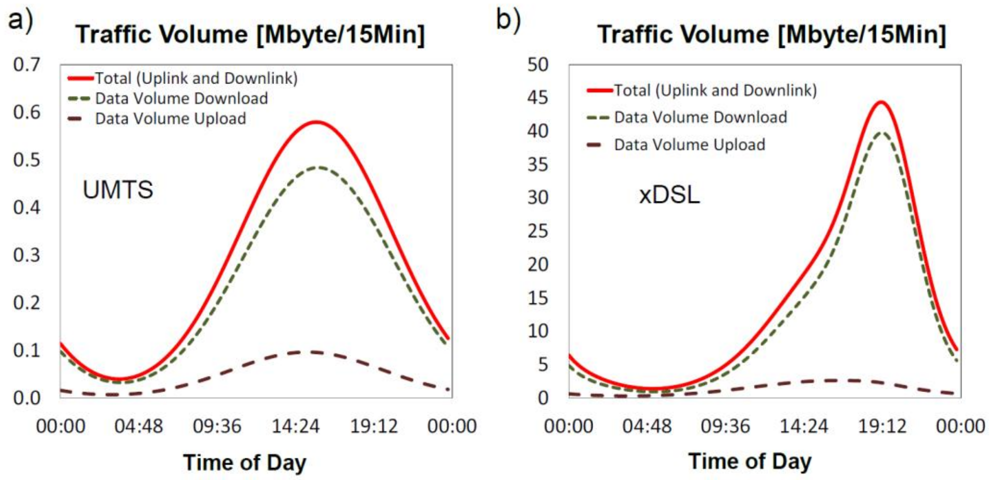


Fig. 6: a) Exemplary user traffic profiles of a) UMTS users and b) xDSL users (households)

An example of the obtained numbers of mobile station sites per federal state is shown in Fig. 7 a). It can be seen from the figure that the numbers of sites obtained by the model are very close to the actual numbers. The difference is mostly below 2% and at most 6.4%. Fig. 7 b) presents the estimated energy consumption of a single-provider radio access network. The unequal energy consumption of radio networks in different states is due to the significant differences in sizes and population densities of the states. The total energy consumption per year of an Austrian-wide radio access network was estimated to be around 270 GWh/a.

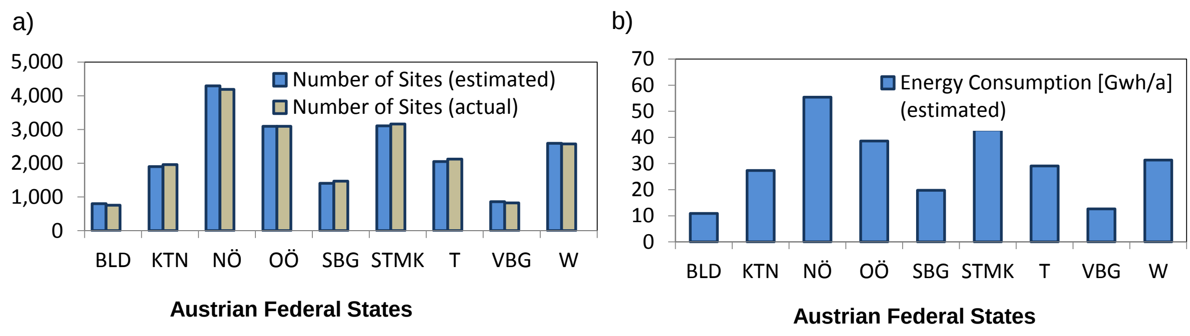


Fig. 7:
a) Comparison of estimated and actual numbers of base station sites in the Austrian federal states. The maximum relative difference is below 6.4 %.
b) Estimated yearly energy consumption of a radio access network in Austria.

Once we have determined the main characteristics of the radio access network, we can model the wireless backhaul. Here we also considered the actual realization of backhaul networks in Austria. The wired access network is designed independently of the requirements for the mobile network. In Austria, the predominant technology for wired access is the digital subscriber line (DSL), while the hybrid fiber coax (HFC) is the second most deployed technology in urban areas. According to our results the entire access network infrastructure in Austria consumes about 1.03 TWh per year. This number includes the consumption of three mobile networks, wireless backhaul and wired networks. In order to assess different access network implementation options with regard to energy consumption we defined three scenarios for future developments. All three scenarios are for the year 2020 and imply an implementation of the goals of the Digital Agenda for Europe [13], which says that the entire European Union (EU) should be covered by broadband above 30 Mbit/s and 50 % of the EU to subscribe to broadband above 100 Mbit/s by 2020.

The business-as-usual (BAU) scenario envisage the use and adoption of currently available technologies for increasing the broadband coverage and limited increase in penetration of the new technologies enabling high-speed Internet access such as LTE and FTTx, predominantly within urban areas. The two other hypothetical scenarios are referred to as “highly energy-efficient” and “energy inefficient”. The highly energy-efficient scenario bases on the assumption that the current network is replaced by a new, high-bandwidth and highly efficient network infrastructure. Thus, LTE becomes the predominant technology for wireless access, while the penetration of FTTH becomes high. The redundancy of network equipment is minimized and the methods for reducing the energy consumption such as alternative energy sources and low-power and standby modes are widely deployed. This scenario provides the minimum possible energy consumption.

The third scenario assumes that new technologies are deployed in a rather energy inefficient manner and the old technologies are kept operating. There are redundancies on the equipment and network levels, which mean that several network providers cover the same area and operate redundant networks. In the energy inefficient scenario, energy-efficient devices and approaches for increasing the network energy efficiency are not used at all.

Fig. 8 presents the estimated energy consumption of the entire Austrian access network infrastructure by 2020. It is evident from the figure that in the BAU scenario the energy consumption increases to 2.9 TWh/a in 2020, which is an increase by a factor of approximately 2.8. In case of an inefficient migration, the energy inefficient scenario, the total energy consumption increases more than 4 times (to 4.4 TWh/a). It is interesting to see that if much attention is paid to energy efficiency and a lot of effort is put into deploying energy efficient components and systems, the high broadband coverage envisaged by the Digital Agenda for Europe could be achieved with almost no increase in energy consumption (at 1.05 TWh/a).

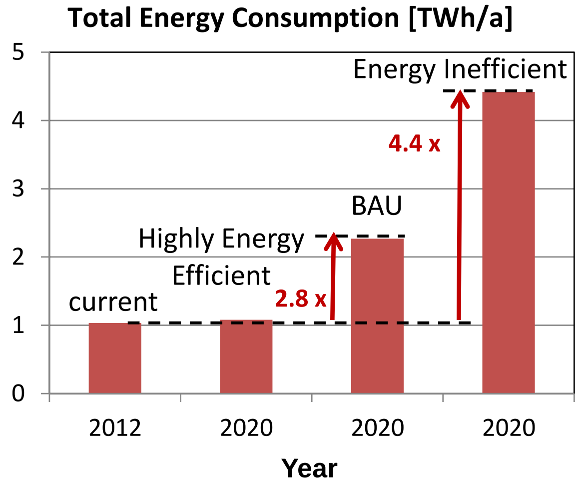


Fig. 8. Prediction of the total energy consumption per year of the overall access network infrastructure in Austria (both wired and wireless networks, multi-provider case).
The curves represent two hypothetical scenarios (highly energy efficient and inefficient) as well as a prediction of the energy consumption in a business-as-usual case.

IV Conclusions and final recommendations

In conclusion, we presented a comprehensive framework for evaluating the energy efficiency of access networks. The framework joins technological parameters and various configuration options with socio-demographic characteristics and varying user behavior. The modeling framework can be used to evaluate different deployment and migration scenarios for both wireless and wired access networks by means of predicted energy efficiency.

In a case study, we applied the framework to evaluate Austria-wide access networks. The results obtained by the model are in a good agreement with the actual data of the network in operation. We assessed different network realization options for achieving a high broadband coverage with at least 30 Mbit/s in 2020. In particular, we considered three scenarios, namely a business-as-usual (BAU) scenario, a highly efficient scenario and an energy inefficient scenario. In the BAU scenario, to cover the most of the populated areas in Austria with a high data rate Internet access one needs to pay with 2.8 times higher energy consumption than it is today. A highly inefficient network planning, deployment and operation could even lead to an increase of energy consumption by a factor of 4.4. However, when concentrating on energy-efficient technologies and approaches and exploiting all their potentials, one could achieve an optimized network infrastructure able to provide both high data rate Internet access to everybody and high energy efficiency. Thus such a high-capacity network would consume approximately the same energy as the current access network infrastructure does.

Aiming at the exploitation of energy efficiency potential a list of recommendations was formulated addressing the policy level as well as telecom network operators. The perspective in elaborating this catalogue reflected the upcoming implementation of Next Generation Access networks even driven by the targets of the EU Digital Agenda:

Area "Network equipment":

- Use of network equipment (for Base stations – BS and point of presences – PoP) with an extended range for operation temperature, aiming at minimizing the average cooling load throughout the year.
- Implementation of efficient cooling concepts (included forced free cooling and efficient cooling systems
- Use of network components which have the capability being operated in low power modes
- Decentralized energy supply based on renewable energy sources

Area "Network operation":

- Wide use of infrastructure sharing for base stations of mobile communication networks
- Dynamic adaption of mobile communication networks for efficient coping with load peaks
- Shut down of a share of base stations in multiple supplied areas by coexisting operators and wide use of national roaming to maintain service for all subscribers

Area "Network planning and next generation access roll out":

- Roll out of publicly financed LTE (4G) network in "white area" (according to definition in Communication of the Commission 2013/C25/01)
- Long term phase out of mature mobile network infrastructure (GSM, possibly UMTS) in the situation of a full scale LTE roll out
- System of incentives or obligations for laying of dark fiber or ductwork

V Acknowledgment

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VI Glossary

DVB-X Digital Video Broadcasting (DVB) is a suite of internationally accepted open standards for digital television. Suffix X represents the generic placeholder, as DVB systems distribute data using a variety of approaches, including: Satellite (DVB-S, DVB-S2 and DVB-SH), Cable (DVB-C, DVB-C2), Terrestrial television (DVB-T, DVB-T2).

FTTx Fibre to the x (FTTX) is a generic term for any broadband network architecture using optical fibre to replace all or part of the usual wired local loop used for last-mile telecommunications. The term is a generalization for several configurations of fiber deployment, ranging from FTTN (fibre to the neighborhood) to FTTD (fibre to the desk). Common types are FTTB (*fibre-to-the-building)* where fibre reaches the boundary of the building with the final connection to the individual living space being made via alternative means, similar to the curb or pole technologies as well as FTTH (*fibre-to-the-home*) where fibre reaches the boundary of the living space, such as a box on the outside wall of a home.

GPRS General Packet Radio Service (GPRS) is a packet-switched technology that enables data communications over GSM network, often described as 2.5G (second and a half generation).

GSM Global System for Mobile Communications (GSM) is a standard set developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second generation (2G) digital cellular networks used by mobile phones.

HFC Hybrid fiber-coaxial (HFC) is a telecommunications industry term for a broadband network that combines optical fibre and coaxial cable. It has been commonly employed globally by cable television operators since the early 1990s.

HSPA High Speed Packet Access (HSPA) is the most widely deployed mobile broadband technology in the world today. HSPA is the terminology used when both HSDPA (D stands for download) and HSUPA (U stands for upload) technologies are deployed on a network. HSPA builds on third generation (3G) UMTS/WCDMA.

LTE LTE, an initialism of long-term evolution, marketed as 4G LTE, represents the fourth generation standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements.

PLC Power line communication (PLC) carries data on a conductor that is also used simultaneously for AC electric power transmission or electric power distribution to consumers. It is also known as power line carrier, power line digital subscriber line (PDSL), mains communication, power line telecom (PLT), power line networking (PLN), and broadband over power lines (BPL).

POF Plastic optical fibre (POF) (or Polymer optical fibre) is an optical fibre which is made out of plastic. POF has been called the "consumer" optical fiber because the fiber and associated optical links, connectors, and installation are all inexpensive.

PON Passive optical network (PON) is a point-to-multipoint, fibre to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises, typically 16 – 128. A PON consists of an optical line terminal (OLT) at the service provider's central office and a number of optical network units (ONUs) near end users. A PON reduces the amount of fiber and central office equipment required compared with point-to-point architectures. A passive optical network is a form of fiber-optic access network.

UMTS Universal Mobile Telecommunications System (UMTS) is a third generation mobile cellular system for networks based on the GSM standard. UMTS uses wideband code division multiple access (WCDMA) radio access technology to offer greater spectral efficiency and bandwidth to mobile network operators.

WLAN Wireless local area network (WLAN) links two or more devices using some wireless distribution method, and usually providing a connection through an access point to the wider Internet. This gives users the mobility to move around within a local coverage area and still be connected to the network. Most modern WLANs are based on IEEE 802.11 standards, marketed under the Wi-Fi brand name.

xDSL Digital subscriber line (DSL, originally digital subscriber loop) is a family of technologies that provide Internet access by transmitting digital data over the wires of a local telephone network. The x is a variable that, in context, is replaced according to the appropriate variety of DSL (such as ADSL, VDSL, etc.).In telecommunications marketing, DSL is widely understood to mean asymmetric digital subscriber line (ADSL), the most commonly installed DSL technology.

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