# Power efficiency of optical versus electronic access networks.

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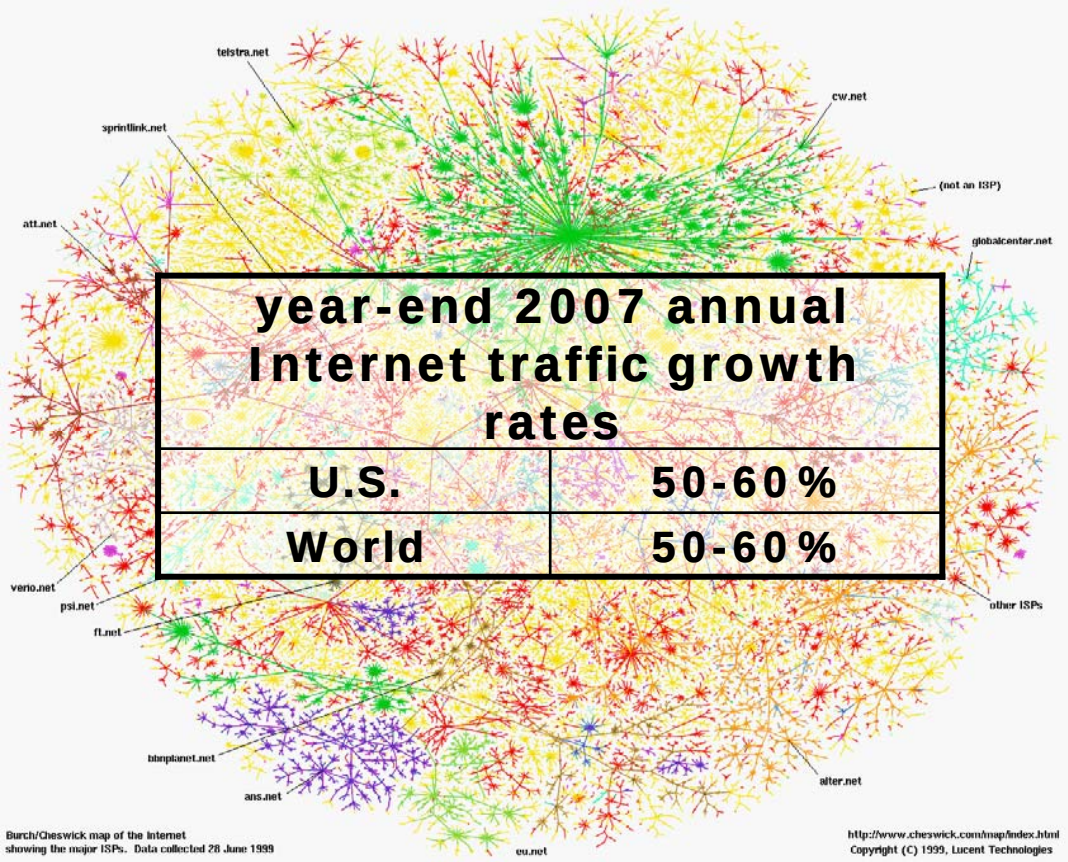
# Outline.

- Introduction and motivation
- Energy consumption of “wired” access networks
- Energy consumption / power consumption in a Multi-Media world
- Increasing network’s energy efficiency
- Conclusion

# Introduction and motivation.

## The Internet traffic growth.




- Current power consumption of the global networks is about 2..4 %* of global electricity consumption.

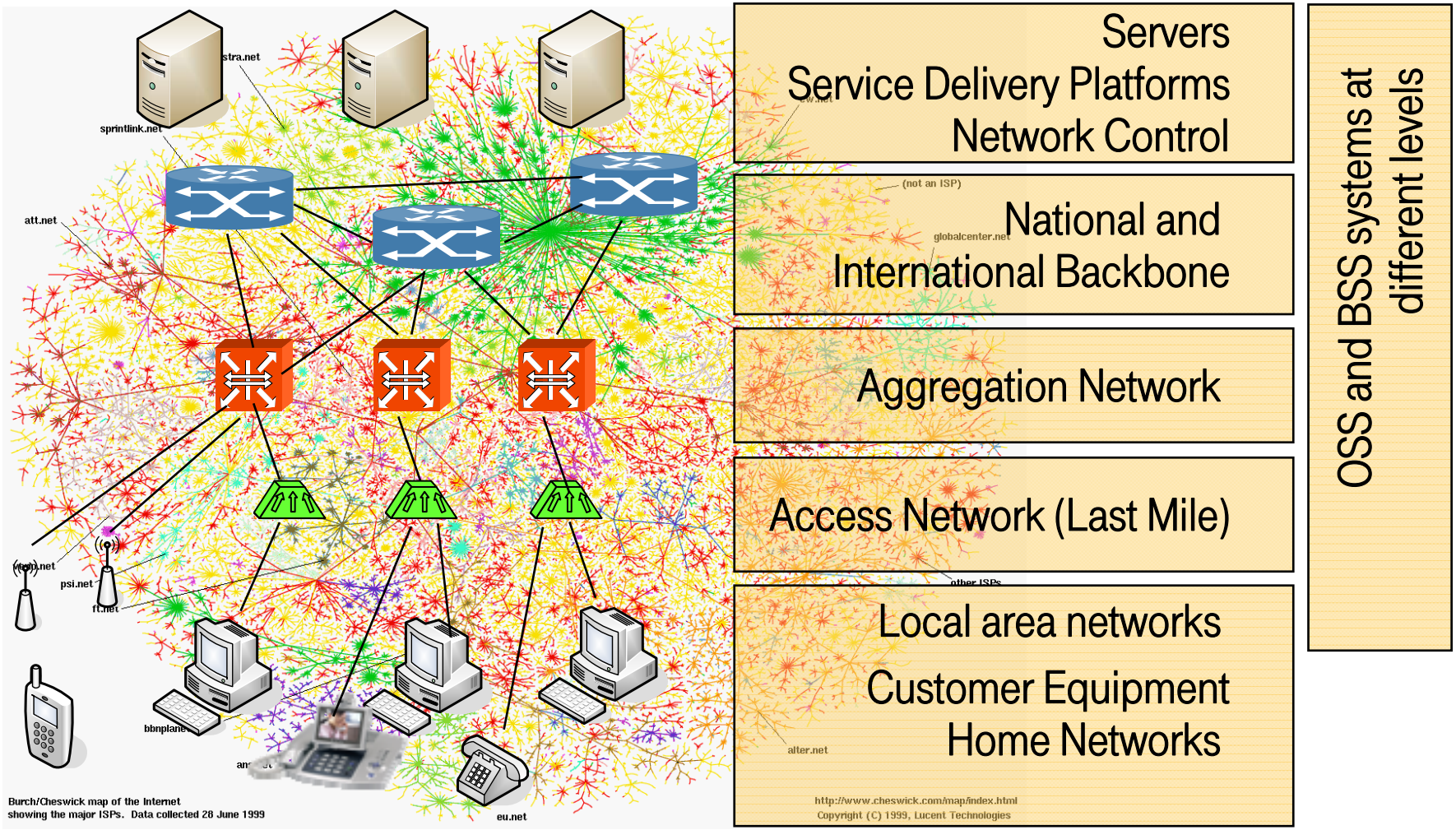
  (* Depending on elements considered in the references)

- Will the power consumption of the Internet grow as fast as the traffic?

Source: Odlyzko et al: http://www.dtc.umn.edu/mints/2002-2008/analysis-2002-2008.html

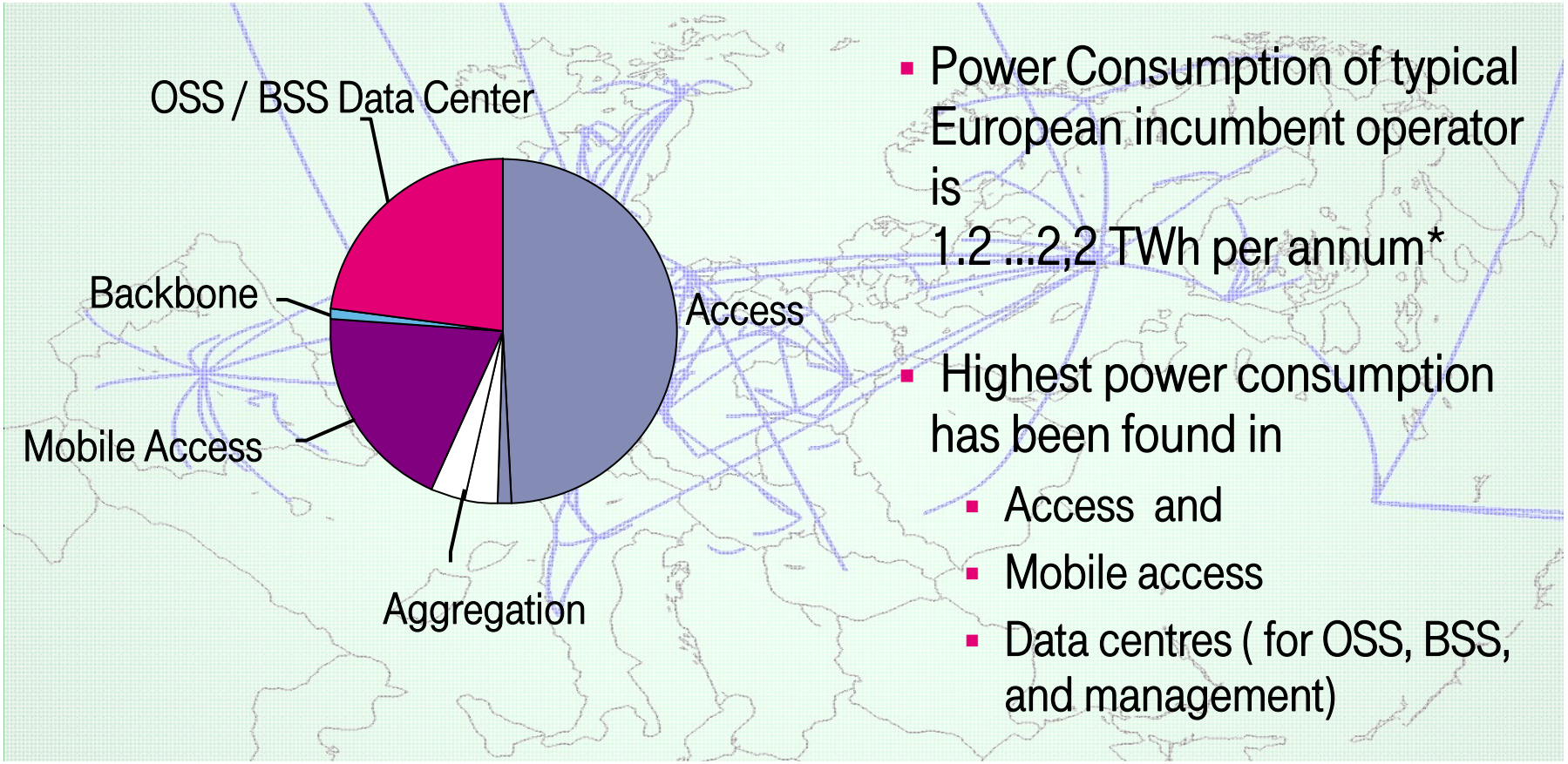
# Introduction and motivation.

## What is the Internet: Network Layers and Functions.



# Introduction and motivation.

## Example: Current Carrier Power Consumption.

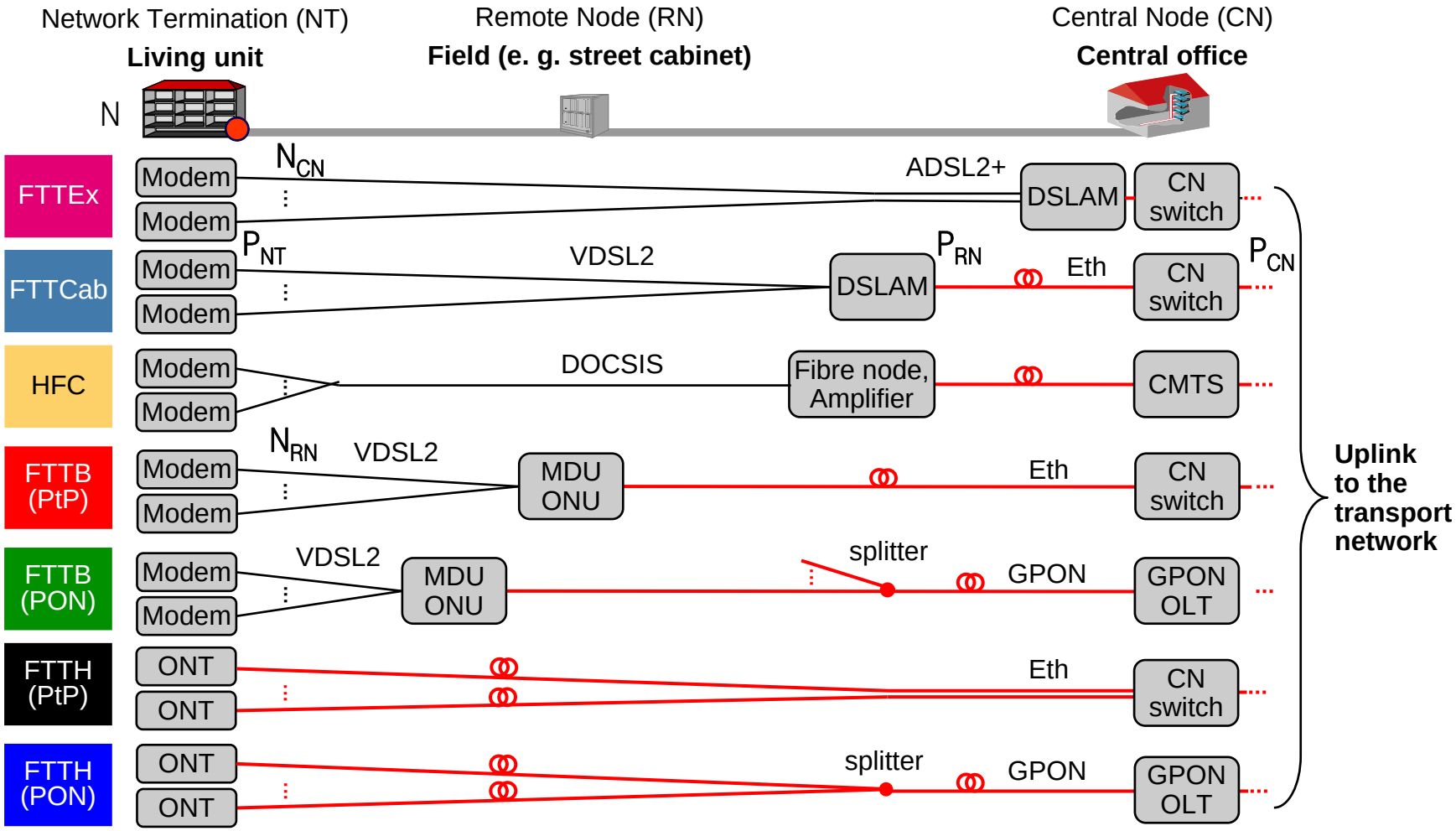



- Power Consumption of typical European incumbent operator is 1.2 ...2,2 TWh per annum*
- Highest power consumption has been found in
  - Access and
  - Mobile access
  - Data centres ( for OSS, BSS, and management)

* Ref.: F.CUCCHIETTI Energy efficiency – an enabler for the Next Generation Network Bruxelles 2006

# Energy consumption of fixed access networks.

## Network model.



# Energy consumption of fixed access networks.

## Exemplary numerical preconditions and study area.

- Preconditions (based on data sheets)

| | $P_{NT}$ (W) | $N_{RN}$ | $P_{RN}$ (W) | $N_{CN}$ | $P_{CN}$ (W) | $r_{max}$ (Gbit/s) |
|---|---|---|---|---|---|---|
| FTTEx | 7 | 960 | 1465 | $\frac{a \cdot R_{CN}}{r \cdot N_{RN} + a \cdot r_p}$ | 3000 | 0.02 |
| FTTCab | 7 | 48 | 240 | $\frac{a \cdot R_{CN}}{r \cdot N_{RN} + a \cdot r_p}$ | 3000 | 0.05 |
| HFC | 30 | 300 | 590 | $16 \frac{r_{max}}{r}$ | 2800 | 0.052 |
| FTTB (PtP) | 7 | 8 | 70 | $\frac{a \cdot R_{CN}}{r \cdot N_{RN} + a \cdot r_p}$ | 3000 | 0.1 |
| FTTB (PON) | 7 | 8 | 70 | $\frac{a \cdot R_{CN}}{r \cdot N_{RN} \cdot (1+a)}$ | 1000 | 0.1 |
| FTTH (PtP) | 4 | N/A | 0 | $\frac{a \cdot R_{CN}}{r + a \cdot r_p}$ | 3000 | 1.0 |
| FTTH (PON) | 5 | N/A | 0 | $\frac{a \cdot R_{CN}}{r \cdot (1+a)}$ | 1000 | 1.0 |

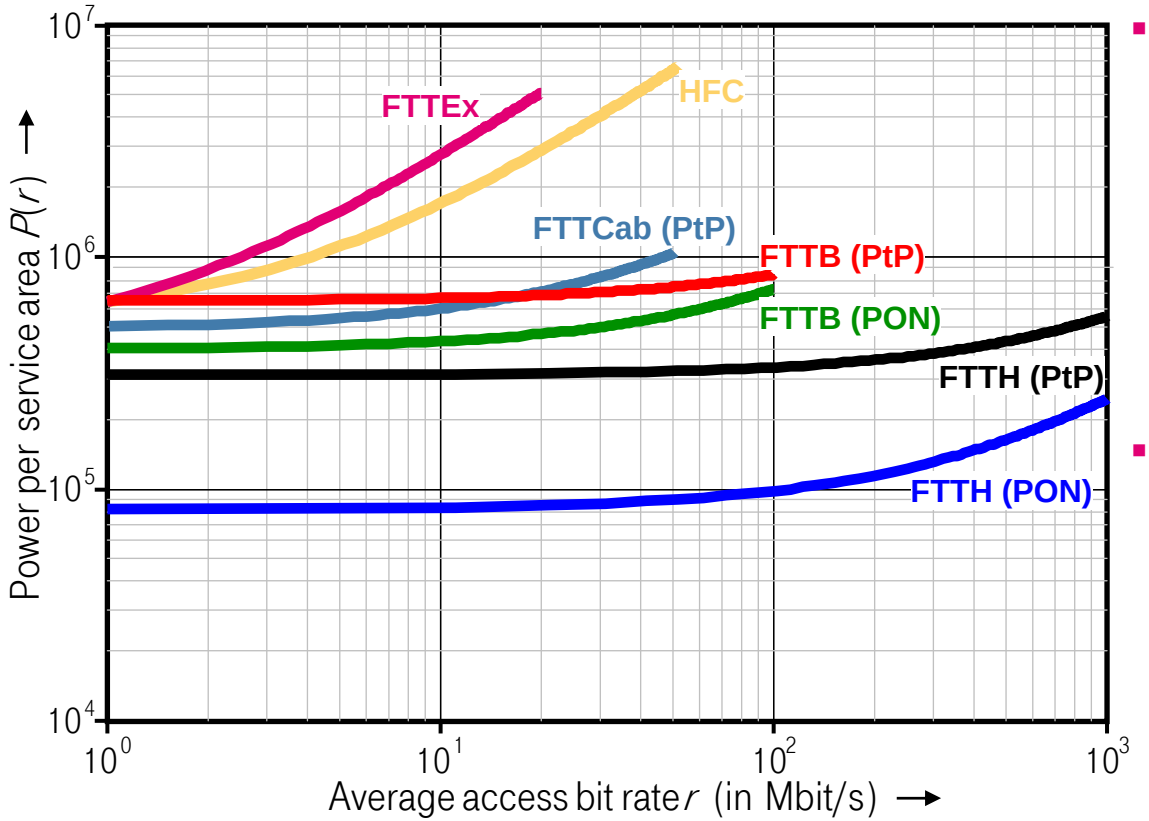
- Power consumption:

$$P = N \cdot \left( P_{NT} + 2 \cdot \frac{P_{RN}}{N_{RN}} + 2 \cdot \frac{P_{CN}}{N_{CN}} \right)$$

- Power consumption directly proportional to the energy consumption
- Factor of two for cooling requirements and additional losses (e. g. external power supplies)
- Exemplary dense urban service area with $N$= 16.384 subscribers
- Upper limit obtained: No bit rate aggregation ($a$ = 1)

# Energy consumption of fixed access networks.

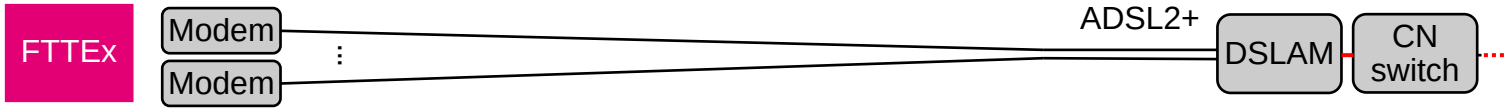
## Results.




- Hybrid optics-copper based networks (FTTEx/Cab/B, HFC):
  - Electro-optic active conversion stage necessary
  - Access bit rates limited by copper infrastructure
- Pure optical access networks (FTTH):
  - High access bit rates at low energy consumption
  - Highest energy efficiency of FTTH PONs due to sharing

# Energy consumption of fixed access networks.

## Measurements: FTTEx ADSL2+ ; FTTCab VDSL2 systems.




| | $P_{NT}$ (W) | $N_{RN}$ | $P_{RN}$ (W) | $N_{CN}$ | $P_{CN}$ (W) | $r_{max}$ (Gbit/s) |
|---|---|---|---|---|---|---|
| FTTEx | 7<br>not tested | 960<br>960 | 1465<br>1268 | $\frac{a \cdot R_{CN}}{r \cdot N_{RN} + a \cdot r_p}$ | 3000<br>not tested | 0.02 |

- Central indoor DSLAM
- Aggregation switches not measured yet


| | $P_{NT}$ (W) | $N_{RN}$ | $P_{RN}$ (W) | $N_{CN}$ | $P_{CN}$ (W) | $r_{max}$ (Gbit/s) |
|---|---|---|---|---|---|---|
| FTTCab | 7<br>3.7 | 48<br>96 | 240<br>351 | $\frac{a \cdot R_{CN}}{r \cdot N_{RN} + a \cdot r_p}$ | 3000<br>not tested | 0.05 |

- Additional energy consumption in the remote node (ventilation, AC-DC converter)
- Aggregation switches not measured yet

# Energy consumption of fixed access networks.

## Measurements: FTTB and FTTH GPON systems.


| | $P_{NT}$ (W) | $N_{RN}$ | $P_{RN}$ (W) | $N_{CN}$ | $P_{CN}$ (W) | $r_{max}$ (Gbit/s) |
|---|---|---|---|---|---|---|
| FTTB (PON) | 7<br>3.7 | 8<br>24 | 70<br>44.5 | $\frac{a \cdot R_{CN}}{r \cdot N_{RN} \cdot (1+a)}$ | 1000<br>1087 | 0.1 |

- Distributed elements in the field
- Different granularities in the remote node


| | $P_{NT}$ (W) | $N_{RN}$ | $P_{RN}$ (W) | $N_{CN}$ | $P_{CN}$ (W) | $r_{max}$ (Gbit/s) |
|---|---|---|---|---|---|---|
| FTTH (PON) | 5<br>5.61 | N/A | 0 | $\frac{a \cdot R_{CN}}{r \cdot (1+a)}$ | 1000<br>968 | 1.0 |

- Pure optical access network
- Good compliance of the values

# Energy consumption of fixed access networks.

## Assumptions and selected measured values.

- Data sheets values (black)
- Selected measured values (magenta)

| | $P_{NT}$ (W) | $N_{RN}$ | $P_{RN}$ (W) | $N_{CN}$ | $P_{CN}$ (W) | $r_{max}$ (Gbit/s) |
|---|---|---|---|---|---|---|
| FTTEx | 7<br>not tested | 960<br>960 | 1465<br>1268 | $\frac{a \cdot R_{CN}}{r \cdot N_{RN} + a \cdot r_p}$ | 3000<br>not tested | 0.02 |
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| HFC | 30 | 300 | 590 | $16\frac{r_{max}}{r}$ | 2800 | 0.052 |
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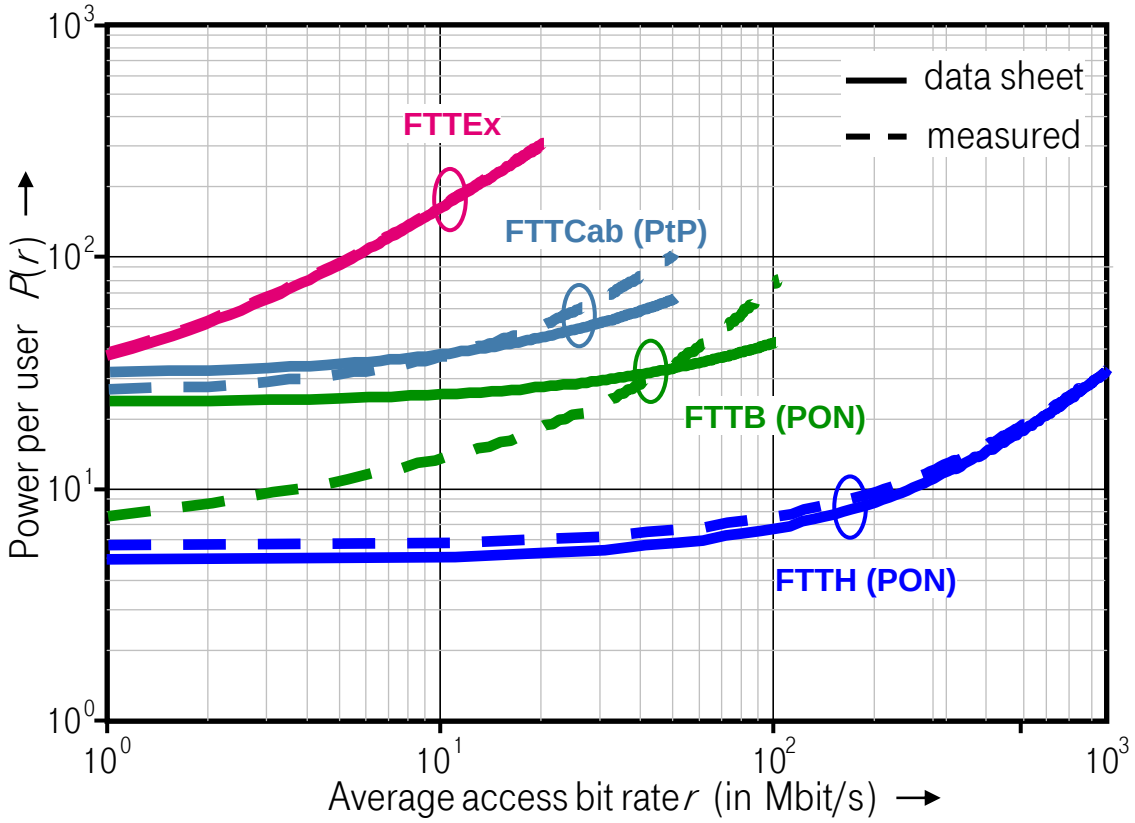
| FTTH (PtP) | 4 | N/A | 0 | $\frac{a \cdot R_{CN}}{r + a \cdot r_p}$ | 3000 | 1.0 |
| FTTH (PON) | 5<br>5.61 | N/A | 0 | $\frac{a \cdot R_{CN}}{r \cdot (1+a)}$ | 1000<br>968 | 1.0 |

- Selected access systems measured in the laboratory until now:
  - FTTEx
  - FTTCab
  - FTTB (PON)
  - FTTH (PON)
- Measurements approximately compliant with numerical values

# Energy consumption of fixed access networks.

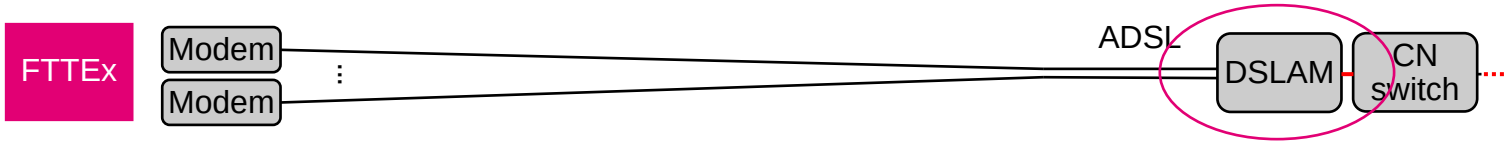
## Selected results with measured values.

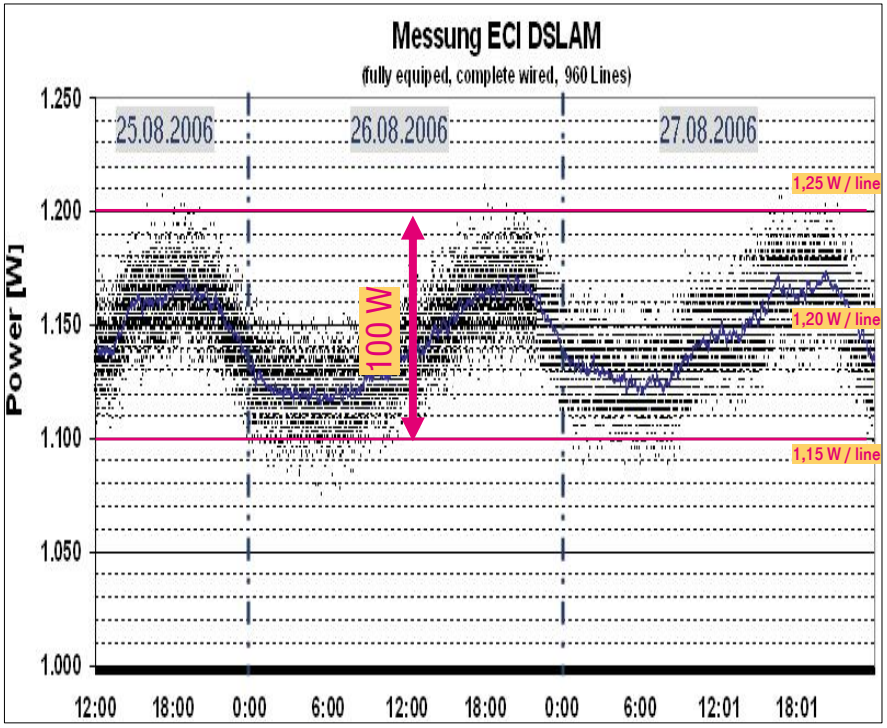



- FTTH: Good compliance
- FTTB: Differences due to different granularities
- FTTCab: Differences due to different granularities
- FTTEx: Good compliance

# Increasing network's energy efficiency.

## Measurement of current DSL systems. FTTEx



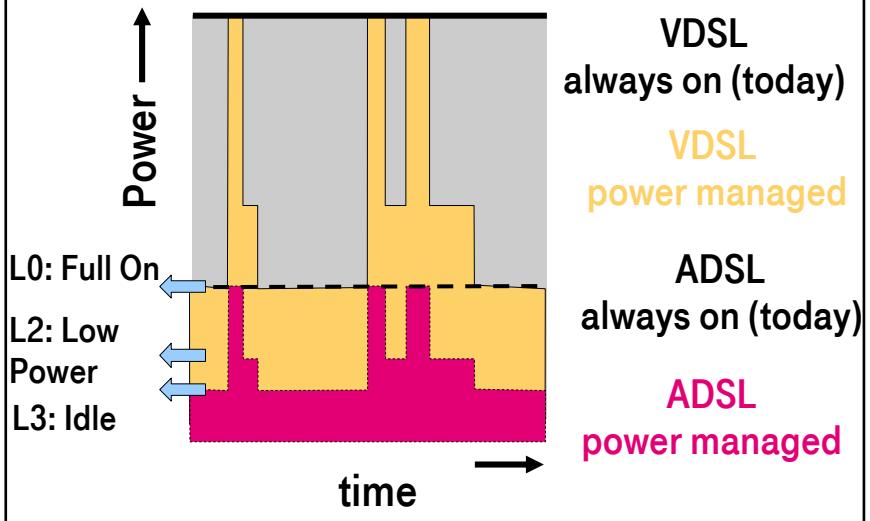

- ADSL indoor DSLAM located in the central office
- Broadband service for 960 subscribers, fully equipped and wired
- Power consumption of several days:
  - Day-night dependency recognizable
  - Small daily power variation due to customer's activities
- But compared to traffic variation the power variation is low
- Probable reason: "Always on" attitude broadly to be found

# Increasing network's energy efficiency.

## Power reduction possibilities on DSL broadband systems.

### DSL power management

Definition of 3 modi, depending on customers communication activities.




*Note: VDSL power management is not standardised today.*

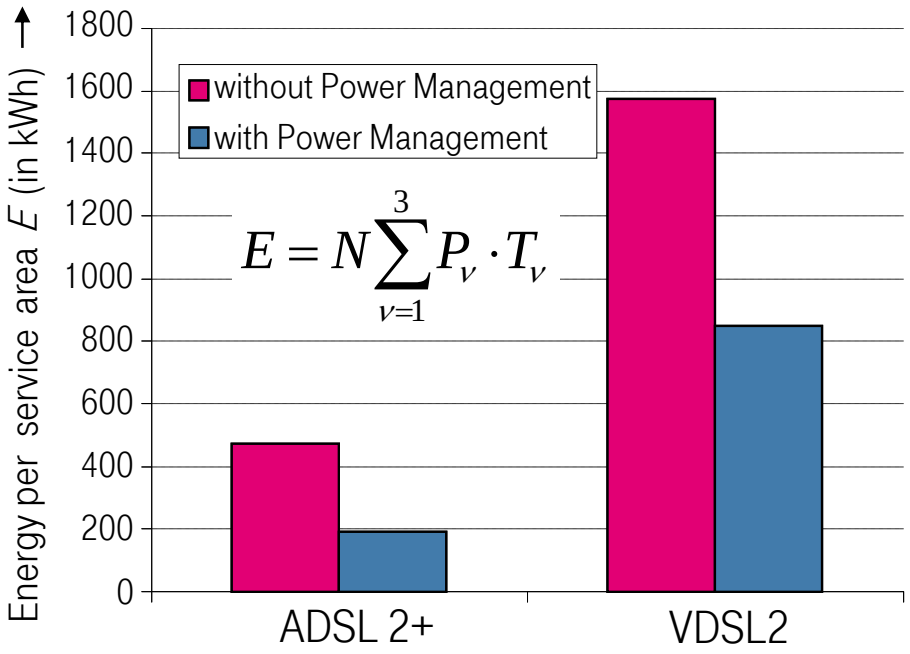
### Code of Conduct (CoC)– Future target values, proposal

| | | ADSL 2+ | VDSL 2 |
|---|---|---|---|
| 2007 | L0 (full power) | 1,5 W | 2,75 W |
| | L2 (low power) | - | - |
| | L3 (idle state) | - | - |
| 2008 | L0 (full power) | 1,4 W | 2,0 W |
| | L2 (low power) | 1,1 W | - |
| | L3 (idle state) | 0,8 W | 1,0 W |
| 2009 | L0 (full power) | 1,2 W | 1,6 W |
| | L2 (low power) | 0,8 W | 1,2 W |
| | L3 (idle state) | 0,4 W | 0,8 W |

[European Commission, Renewable Energies Unit: Code of Conduct on Energy Consumption of Broadband Equipment, Version 2. Ispra, 17 July 2007]

# Increasing network's energy efficiency.

## Power Management in DSL systems.

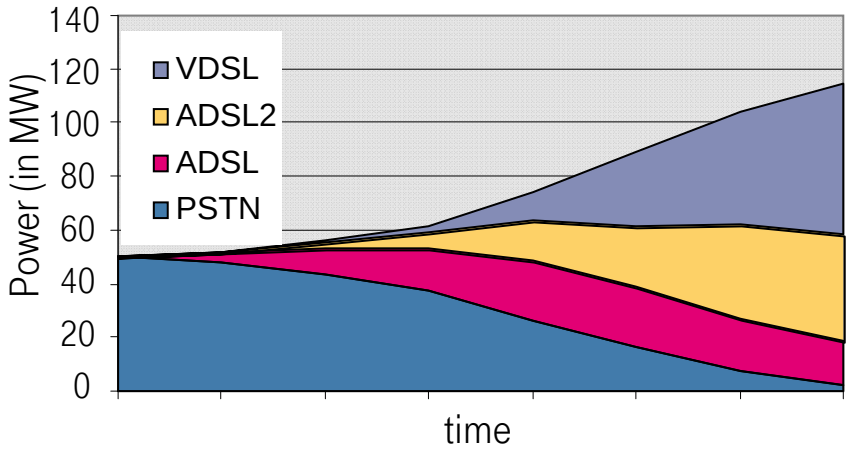



- Energy consumption in the exemplary dense urban service area
- Power values taken from measurements
- Usage scenarios based on public studies
- Significant energy saving potential
- Power management not used due to QoS and line stability issues
- Inter layer effects not fully analysed

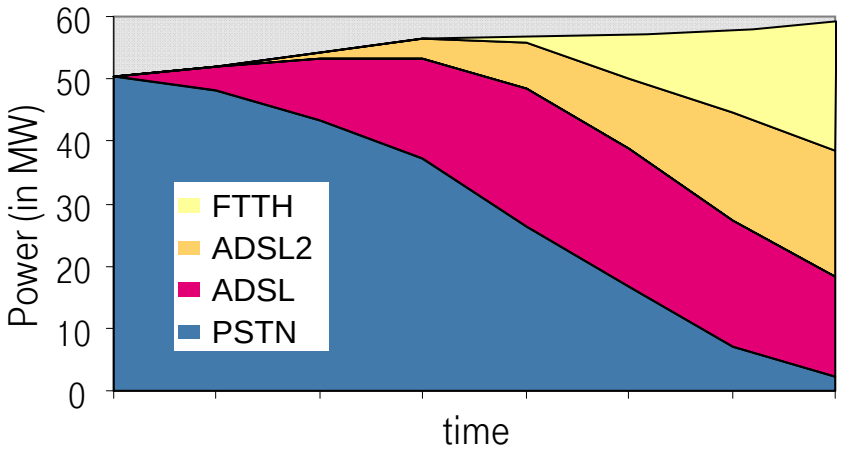
# Energy consumption of fixed access networks.

## Broadband Migration: Extreme scenarios.

- Electronic broadband access network
- Broadband services delivery by DSL systems
- Drastic increase in power consumption



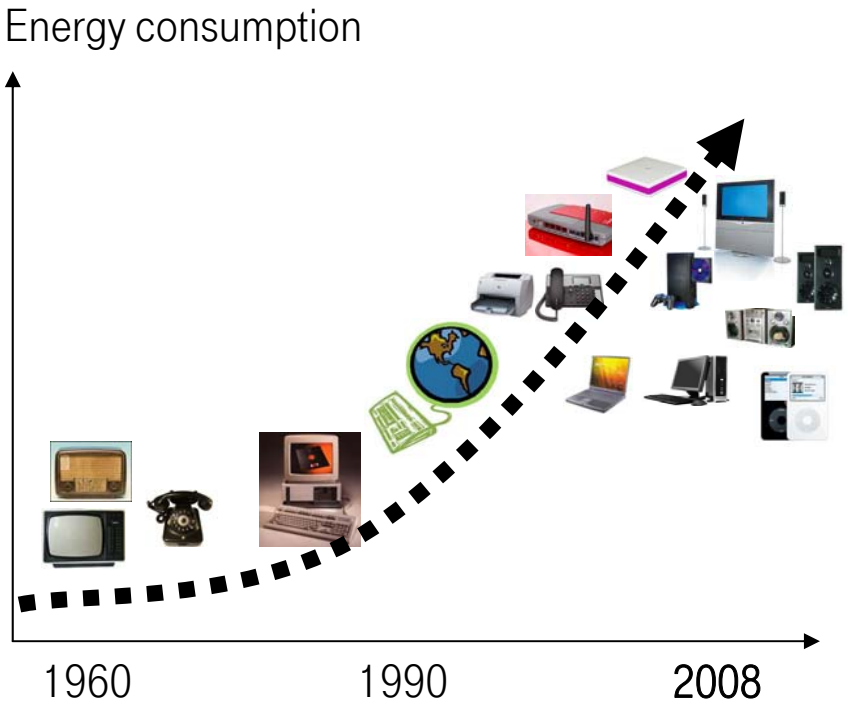

- Optical broadband access network
- FTTH as the target of broadband migration
- Opportunity for decreasing broadband access network‘s power consumption




⇒ High impact of broadband access technology and migration on the power consumption!

# Home networks.

## Increasing number of services and devices.




- A lot of different studies forecast dramatic growth of the internet due to “MultiMedia” traffic
  - Any kind of video (on demand, time shifted , aster than real-time)
  - Broadband Internet
  - Audio
  - Voice
- Broadband services require associated home network components
- Increasing size of home networks with increasing number of devices
- Distributed equipment not fully utilized, e. g. in terms of storage capacity

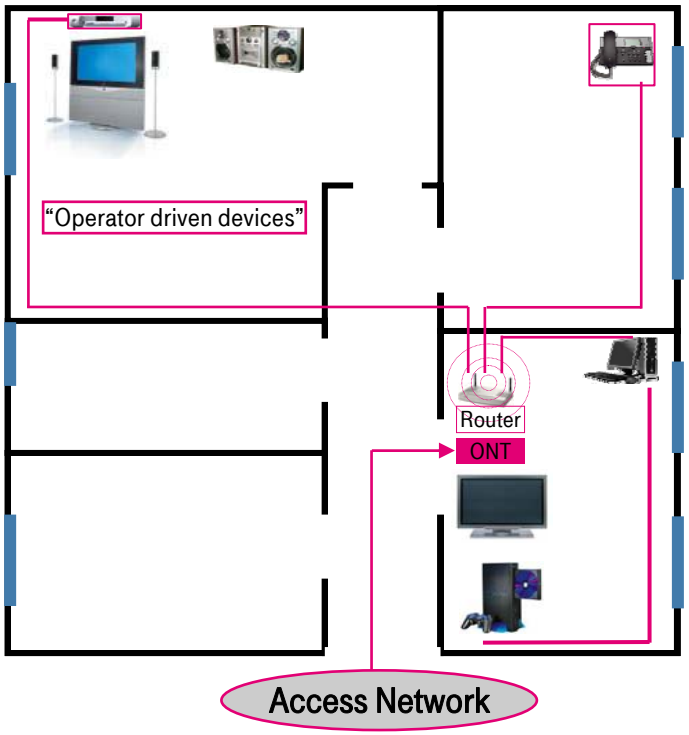
# Home networks

## An extreme  example of multimedia broadband home.

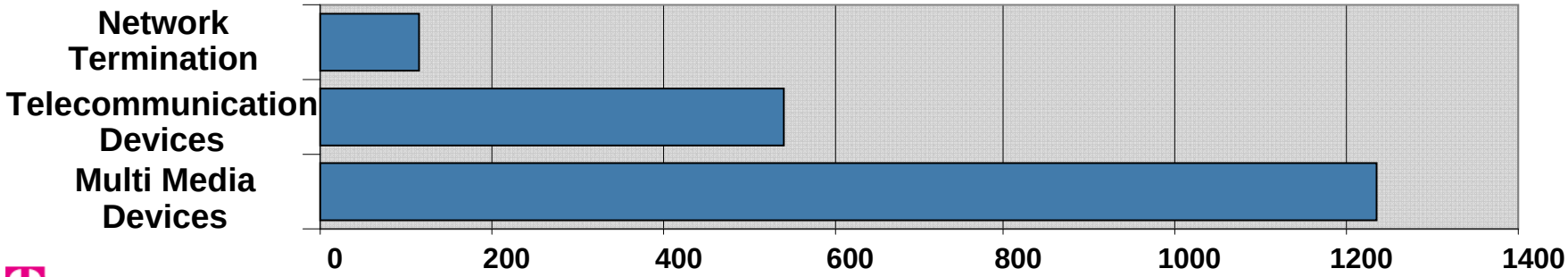

| | Stand By Mode | Operation Mode | Operation Time per day (hour) | Energy per day (Watt Hour) |
|---|---|---|---|---|
| WiFi Radio 1 | 7,3 | 12,2 | 4 | 194,8 |
| WiFi Radio 2 | 2,5 | 4,3 | 4 | 67,2 |
| PC | 2 | 110 | 4 | 480 |
| PC Monitor | 4 | 60 | 4 | 320 |
| Laptop | | 42 | 4 | 168 |
| OptoLan | 1,1 | 1,1 | 4 | 26,4 |
| Settopbox | 15,8 | 17,8 | 4 | 387,2 |
| VDSL - Modem | | 4,8 | 24 | 115,2 |
| TV (Flat) | 1,2 | 95 | 4 | 404 |
| TV (20") | 0,9 | 48 | 4 | 210 |
| Router | | 5,6 | 24 | 134,4 |
| NAS | 0,1 | 12 | 3 | 38,1 |
| ISDN | | 1,4 | 24 | 33,6 |
| DECT | | 0,9 | 24 | 21,6 |
| **Total Energy per Day** | | | | **2600,5** |

Germany ⇒ about 38 Million homes ⇒ scaling up to  4,1 GW.  36 TWh per year.

# Daily power consumption of a reference flat in a Multi Media World




| *Assumptions:* | Standby Mode in W | Operation Mode in W | Operation Time per Day | Energy Wh |
|---|---|---|---|---|
| WLAN Radio 1 | 7 | 12 | 2 | 178 |
| WLAN Radio 2 | 2 | 4 | 2 | 52 |
| VDSL Modem | | 4,8 | 24 | 115,2 |
| PC | 2 | 110 | 2 | 264 |
| PC Monitor | 4 | 60 | 2 | 208 |
| Settopbox | 15,8 | 17,8 | 4 | 387,2 |
| TV (Flat) | 1,2 | 100 | 4 | 424 |
| TV(20´´) | 0,9 | 45 | 2 | 109,8 |
| Router | | 5,6 | 24 | 134,4 |
| IP Phone | | 0,9 | 24 | 21,6 |
| | | | | 1894,2 |




"ONT" provides VOIP functionality 24 h
"Router" provides functionalities for PC, WLAN and Media receiver

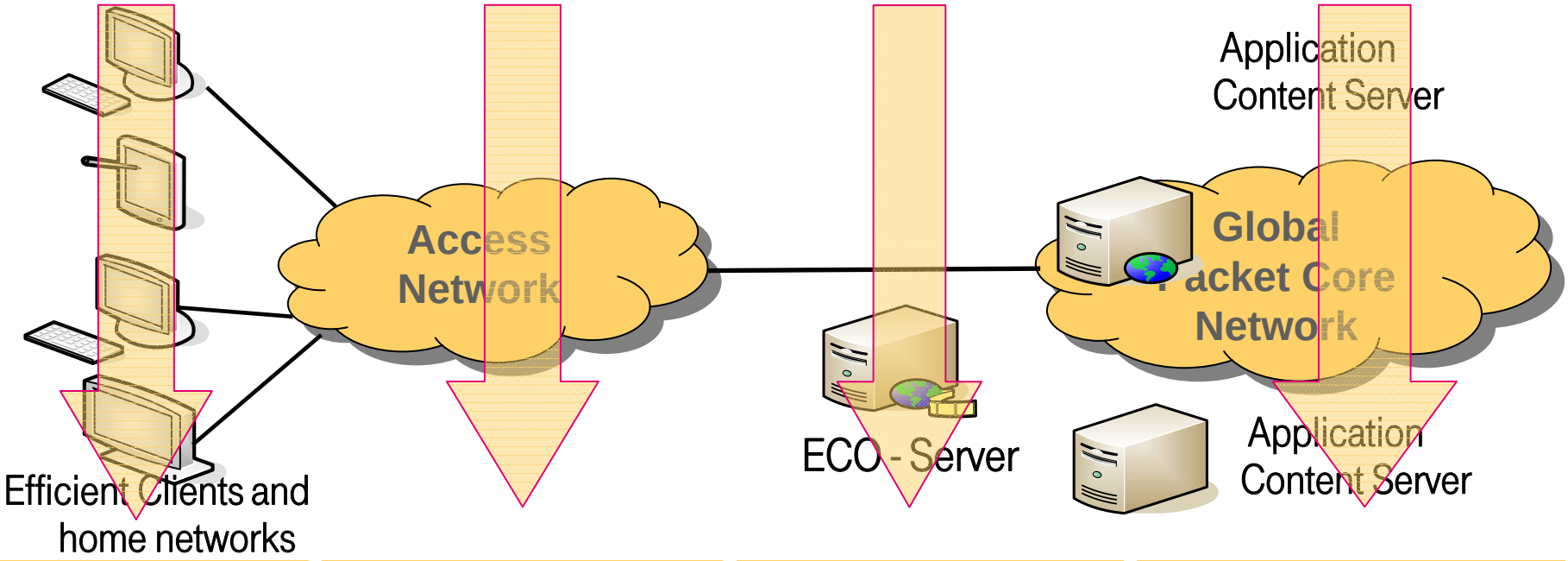
# How do things scale ?

| W per HH | MW | GWh per annum | Part of a power plant |
|---|---|---|---|
| 1 | 38 | 332,88 | 0,10 |
| 2 | 76 | 665,76 | 0,21 |
| 5 | 190 | 1664,4 | 0,52 |
| 10 | 380 | 3328,8 | 1,04 |
| 20 | 760 | 6657,6 | 2,09 |
| 50 | 1900 | 16644 | 5,22 |
| 100 | 3800 | 33288 | 10,43 |
| 200 | 7600 | 66576 | 20,87 |
| 500 | 19000 | 166440 | 52,17 |
| 1000 | 38000 | 332880 | 104,34 |

- Currently 38.000.000 (38 Mio.) households (HH) in Germany
- „Average" power plant in Germany has a capacity of 360 MW*
- 10 W average continuous load per HH is equal to 380 MW
- 10 W average continuous load per HH is equal to 3,3 TWh per annum

Source: Wikipedia, Photo Source; Wikipedia

# Basic Considerations- Energy Efficient Networks




- Investigate alternatives for complex PC
- simple and fast “wake up” and usage adaptive modes of network and clients

- Power adaptive netw.;
- guarantees always basic communication
- adaptive control of components based on communication requirements

- High sharing ratio of servers; Economy of scale & industry based
- Highly efficient power adaptive processing
- Virtualization

- Energy management solutions e.g. controlled link capacity
- NG servers + ECO data centre architecture
- Virtualization

# Conclusion. Energy efficiency of Internet is a big issue.

## But be realistic!

- Big share in operator networks: Access network part
- Things that can help:
  - Optical systems in wired access have the lowest consumption of power
  - Dynamic resource control and management
    - Use of DSL power management in current broadband access systems
    - Making use of day-night utilization curves
- At the level of a national economy
    - Power consumption of multimedia home networks become an issue
- Energy consumption as a network design parameter
  - At architecture level
  - At system level

# Thank you for your attention!

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