Universität Stuttgart

INSTITUT FÜR
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UND RECHNERSYSTEME
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The Seven Deadly Sins of ICT

- Green Computing and Communication -

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Overview

1 Observations on Power Consumption in IT

2 The "7 Deadly Sins" of IT

3 Causes and Development Options

1. Device Technology
2. "Green Computing"
3. Sleeping - The Benefits of Doing Nothing
4. Power Control - Positive Results from Negative Feedback

4 Towards an Optimized Power Management

1. Observations on Power Consumption in IT(1)

Moore's Law **Doubling of Device Performance every 18 Months**

by

Integration Density: Microtechnology $\rightarrow$ Nanotechnology
Switching Speed: Microseconds $\rightarrow$ Nanoseconds $\rightarrow$ Picoseconds
Semiconductor Technology: Si $\rightarrow$ Ge/Si $\rightarrow$ GaAs
Bipolar $\rightarrow$ CMOS

Power Consumption

$$P \sim C_S \times V_{DD}^{2.3\ldots2.6} \times f$$

clock frequency
power voltage
switch capacitance

Consequences **Cooling Systems (Air $\rightarrow$ Water)**
Massive Parallelization
Performance Limitations by Power Constraints

1. Observations on Power Consumption in IT(2)

Measurements (Annual Electricity Consumption)

- **US year 2000:**

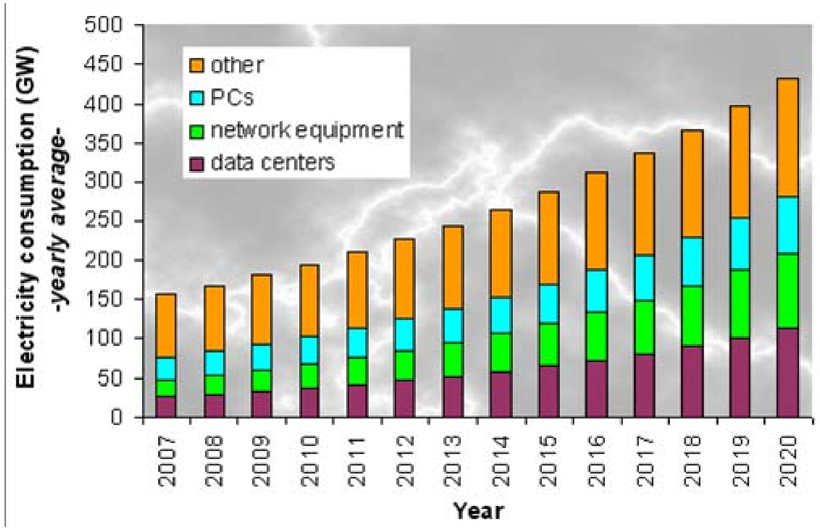
Device	Est. Numbers	Cons. TWh	Costs	Equiv.
Hubs	93.5 Mio	1.6		
LAN-Sw.	95.000	3.2		
WAN-Sw.	50.000	0.2		
Router	3.257	1.1		
Total (US)		6.1	10^9 US $	1 Nucl. Reactor
Total (World)		144		

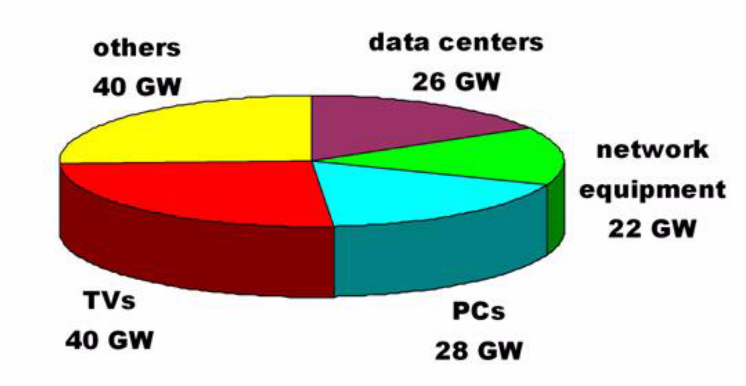
➥ Annual increase in networking power consumption in this decade (estimated) US: 1 TWh

- **Total power consumption of IT $\approx$ 10% of all power consumption!**

1. Observations on Power Consumption in IT(3)

- **Annual Electricity Consumption in IT in Germany (2007-2020; 2010)**





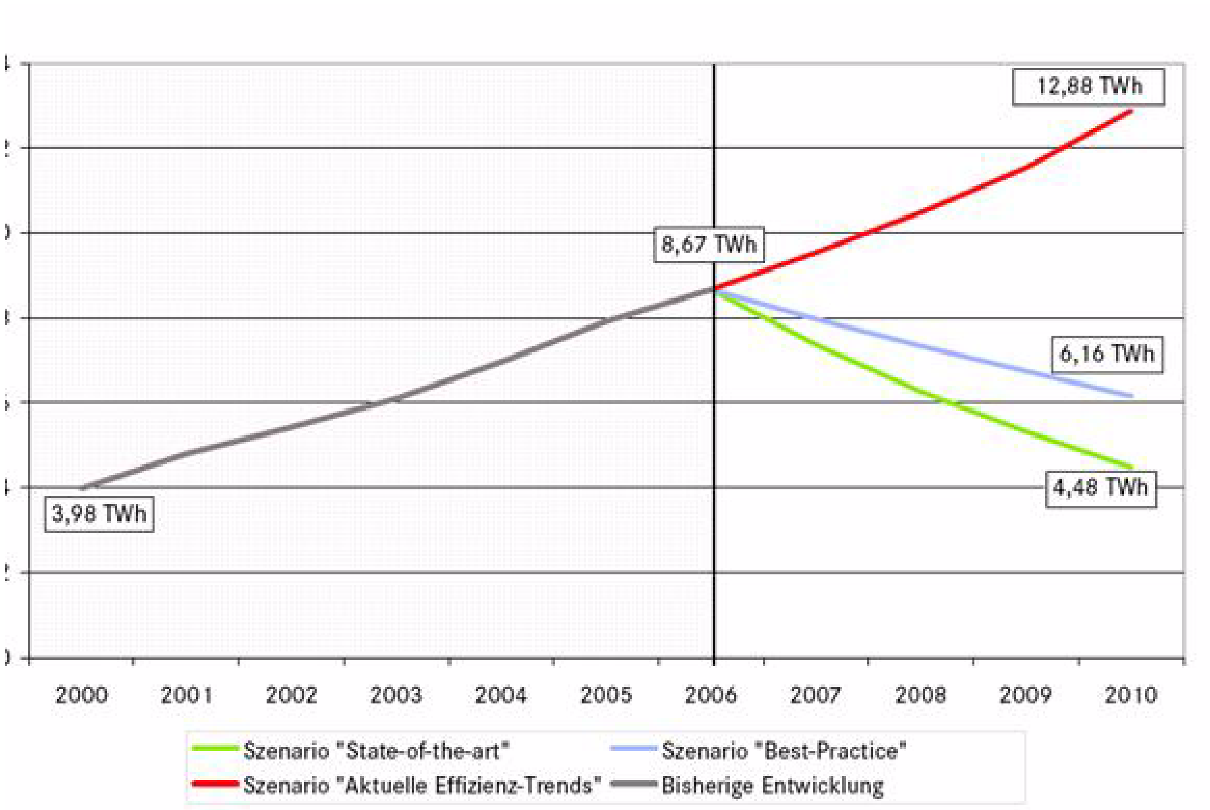
Note: **P (Power Consumption) in Gigawatts (= 10^9 Watts)**

Annual Energy Consumption = P · $\frac{8760h}{a}$ = 8.760 x P $\frac{TWh}{a}$

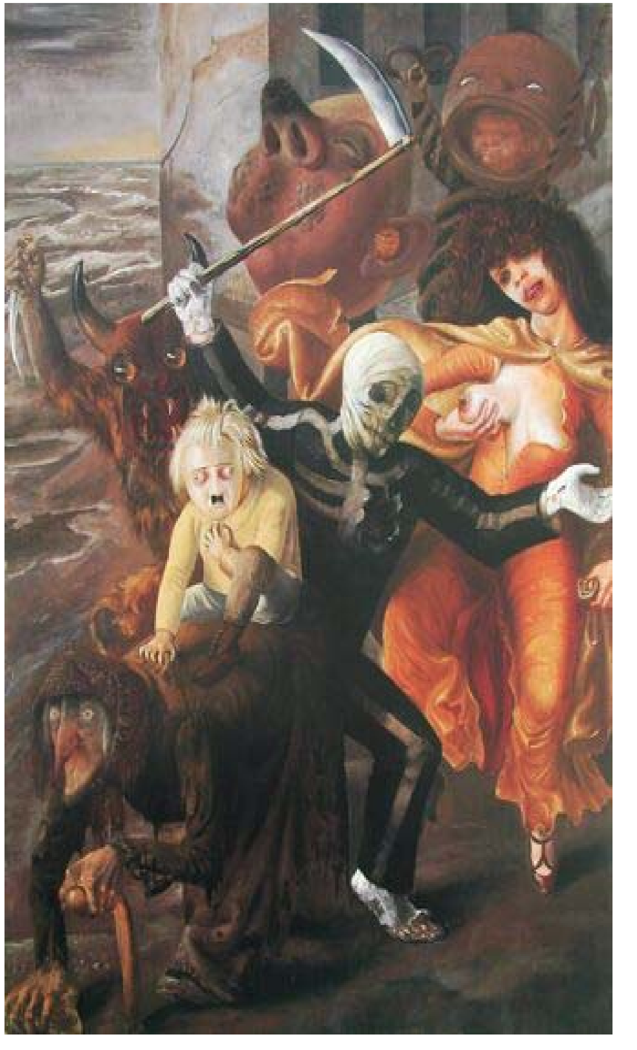
1 Nuclear Reactor Provides Typically 6 TWh

1. Observations on Power Consumption in IT(4)

- **Annual Electricity Consumption in Computing Centers in Germany**



2. The "Seven Deadly Sins" of IT (1)



Arts: The 7 Deadly Sins
(Otto Dix, 1933, Staatl. Kunsthalle KA / Galerie der Stadt Stuttgart)

2. The "Seven Deadly Sins" of IT (2)

	Type	Examples
(1)	Device Power Consumption	Current Leakage
(2)	Inefficient Operation	Design for Maximum Performance
(3)	Cooling Systems	Power Consumption of Cooling, Waste of Heat
(4)	Ineffective Power Management	No Systemwide Power Control
(5)	Wasted Power Consumption ("Always-On")	Permanent Activation
(6)	Massively Redundant Data Storage	Useless Data Replications
(7)	Highly Redundant Network Traffic	CC, Exploders, Provisional Downloads

3. Causes and Development Options (1)

3.1 Device Technology

- Device Power Consumption

Example: IBM Blades

Power Supply	20%
Processing and Caching	55%
Memory	10%
I/O Subsystems	5%

- End of Moore's Law $\rightarrow$ New Technologies

Reduction of Leakage

➥ Replacement of Silicon Oxyde by Carbon Nanotubes

➥ Nanowire Devices

➥ Molecular Electronics

➥ Spin Devices (Quantum Computing)

3. Causes and Development Options (2)

3.2 "Green Computing" - Set of activities to reduce power consumption

- **IBM Announcement "Big Green":**
  (2007) 1 Billion US $/a reallocated
  Long-term strategy committment
  CO_2 reduction and computer power increase
  Effective cooling and waste heat usage
  Operational changes
  Virtualization
- **NSN Announcement:**
  (11-20-2007) Design for Environment (DfE)
  Environmental Management System (EMS)
  Recycling of devices and products
  Energy-efficient telecom solutions
  see: *www.nokiasiemensnetworks.com/*
- **EU:**
  (7-17-2007) Code of conduct on energy consumption of broadband equipment (version 2)
  see: *EU Document Renewable Energies Unit*
  Broadband Equipment Code of Conduct

3. Causes and Development Options (3)

Power Limitations for Broadband Terminal Equipment (as of 12-31-2009)

Source: EU Document Renewable Energies Unit, Broadband Equipment Code of Conduct (7-17-2007)

Terminal Equipment	**Off State**	**Low Power State**	**On State**
ADSL/VDLS Modem	0 W	0.8 W	1.5 W
VDLS Modem einschl. Ethernet Port, Router und Firewall	0.3 W	2.0 W	6.0 W
Optical Network Termination	0.3 W	(offen)	12.0 W
WLAN Access Point 802.11	0.3 W	2.0 W	6.0 W
VoIP Device	0.3 W	2.0 W	5.0 W
Network Equipment/Port			
ADSL 2+	-	0.8 W	1.2 W
VDSL 2	-	1.2 W	1.6 W
Wakeup Time	-	$\leq$ 1 s	$\leq$ 1 s

3.3 Coordinated Sleeping - The Benefits of Doing Nothing

Example 1: System Power Management Support IBM POWER6 MP
see: *IBM J. Res. & Dev., Vol. 51, No 6, November 2007, pp. 733-745*

- On-Chip Support by Sensors, Actuators, Thermistors (Energy Scale^{TM}-Architecture)
- Thermal and Power Management Device
- Principle: Make use of application dependent power consumption
- Measures:
  - Pipeline Trottling (run/hold, instruction)
  - Multiple voltage domains
  - Voltage and frequency scaling
  - Processor idle modes
  - Dynamic memory modes
  - Overheat protection by sensor technology (on-the-chip)

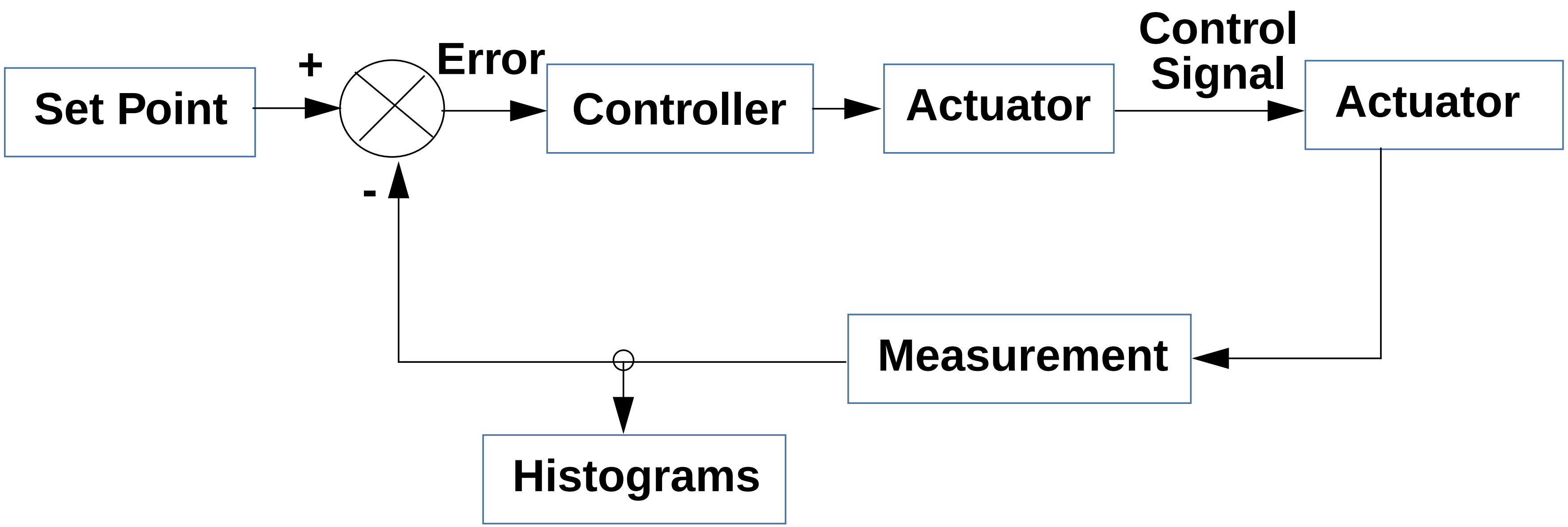
3. Causes and Development Options (5)

Example 2: Sleep Mode of Telecommunication Equipment

IP-Phone:	5-10 W Continuous Power Consumption
Analog Phone:	≈ 0 W Silence Period 6 W Connection Period
PC Online:	100s W Always-On Mode
Router:	40 kW
***Question*:**	When and how to sleep? Coordinated Sleeping
see:	*"Greening of the Internet"* *ACM SIGCOMM'03, Aug. 25-29, 2003, Karlsruhe*
Measure:	Dynamic Control of Low Power Mode

3.4 Power Control - Positive Results from Negative Feedback

Example: EnergyScale™ for IBM POWER6 Microprocessor
see: *IBM J. Res. & Dev., Vol. 51, No 6, Nov. 2007, pp. 775-785*



3. Causes and Development Options (7)

3.5 Virtualization

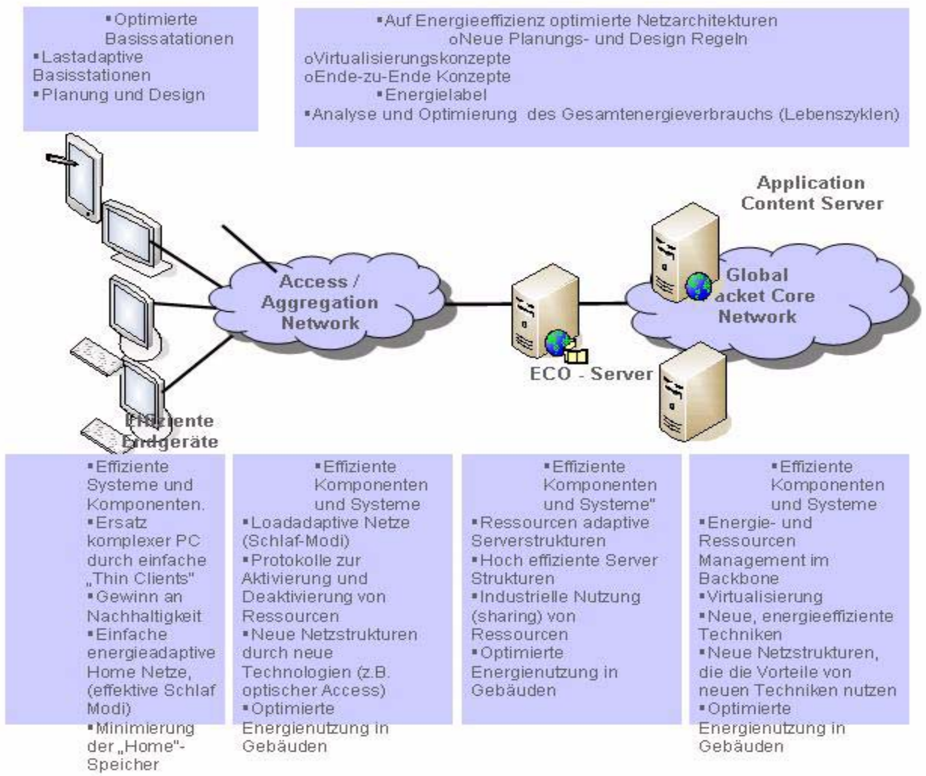
- Dynamic Workload Assignment to Active Resources
- Multiprocessing Systems
- Network Level Multiprocessing
- Workload-Dependent Activation
  Adaptive Scheduling Algorithms

3.6 Redundancy Reduction (Storage, Transmission)

- Much Information is Stored on Different Memories / Databases
- Much Information is Distributed to Multiple Destinations
  (Exploders, Copy Operations, ...)
- Distribution of Reference Links Rather Than Distribution of Data
- Trade-Off Between Storage / Transmission Costs

4. Towards an Optimized Power Management (1)

- **IT Scenario and Challenges**



4. Towards an Optimized Power Management (2)

Research and Development Challenges

- Micro-, Nano- and Optoelectronic Technologies
  - CMOS and III/V Semiconductors
  - New Technologies (Nanotubes, Molecular Electronics, Quantum Computing)
- Protocols for the Activation/Deactivation of Network Elements
  - Components, Systems, Network Level Consideration (Multi-Scale Consid.)
  - Power Monitoring on Chip, Device, Computer/Router/Base Station Equipment, Network
  - Power Control
  - Protocols and Standardization
  - Thin Clients and Virtualization
- Modelling, Performance Analysis and Optimization
  - Power Consumption, Economic and Cost Models
  - System and Network Models
  - Placement of Resources
  - Dynamic Load Models and Scheduling for Resource Sharing (Virtualization)
  - Reliability and Availability of Resources and Services
  - Sustainability
  - Optimization

4. Towards an Optimized Power Management (3)

- **Power saving is profitable for several reasons**
  - ➥ to increase speed (next 10 years: bandwidth increase by factor 100!)
  - ➥ to save direct power costs
- **New Design Objectives**
  - ➥ optimize $\frac{\text{computation performance}}{\text{watt}}$
- **Many Degrees of Freedom**
  - ➥ new technologies
  - ➥ power aware operation
  - ➥ economic use of data
  - ➥ protocol design
- **Revised System Architectures**

$\Rightarrow$ **Optimized Power Management as Competitive Asset**

Weiterführende Quellen zur allgemeinen Thematik der Energieversorgung

- **Smart 2020: Enabling the Low Carbon Economy in the Information Age**
  The Climate Group, Global eSustainability Initiative (GeSI), 2008
  info@theclimategroup.org
- **Der Beitrag moderner Technologien zu Klimaschutz und Energieversorgung - Stellungnahme zur Bedeutung der Energietechnik für eine nachhaltige Energieversorgung**
  acatech Themennetzwerk Energie, Bau, Infrastruktur und Umwelt
- **Die Zukunft der Energieversorgung in Deutschland**
  Herausforderungen-Perspektiven-Lösungswege
  B. Hillmeier (Hrsg.), acatech-Symposium, 21.11.2006
  über: www.irb.fraunhofer.de
- **Dezentrale Energieversorgung 2020**
  VDE-Studie, 2007
  www.vde.com/etg