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Broadband
Mobile
Communication
Networks

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Geringerer Energieverbrauch und mehr Energieeffizienz in Kommunikationsnetzen

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Green IT: Definitions

environmentally sustainable computing or IT (also Green Computing)

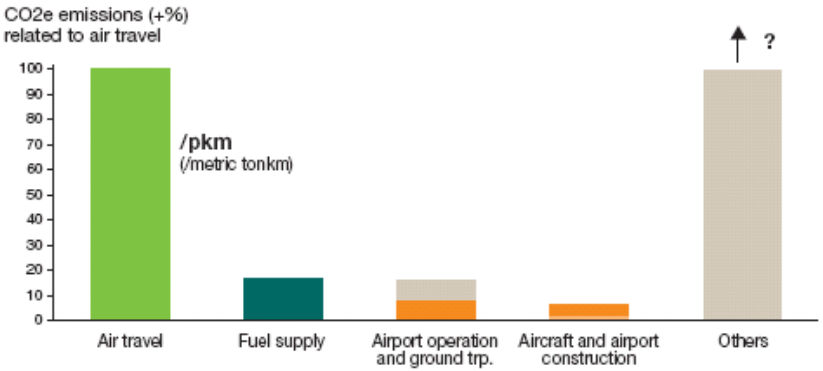
by means of:

- energy savings in the IT
- energy savings by means of IT (smart metering, intelligent power networks): expectd to be 5 times higher than in IT
- secondary effects: avoid business trips
- IT devices itself (production effort, life circle assessment, hazardous materials)

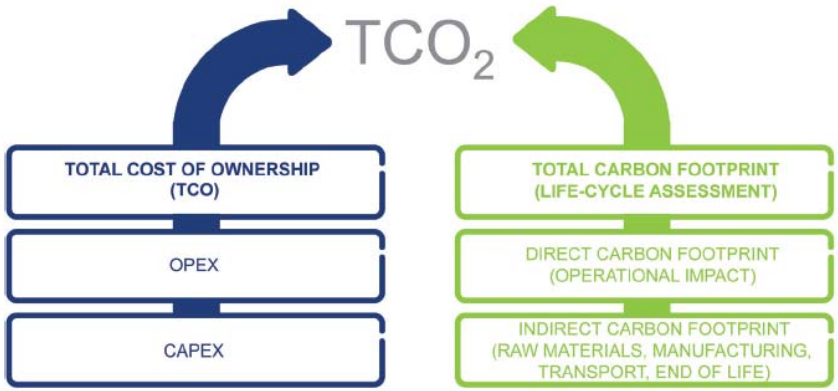
Activities and Initiatives for Green IT (Energy Efficiency)

- European Comission: “Code of Conduct on Energy Consumption of Broadband Equipment”, Limitation to 25 TWh in 2015 (50 TWh expected else)
- Deutsche Bundesregierung: “Aktionsplan Green IT”, 400 Mill. Euro, 40% less emissions in 2013
- IBM: “Big Green”, 1 Billion US $/a reallocated for to increase energy efficiency
- CeBIT: “CeBIT Green IT”, focus since 2007

Topics and Methods



CO2 footprint (Source: Ericsson)



Life circle assessment (Source: Ericsson)

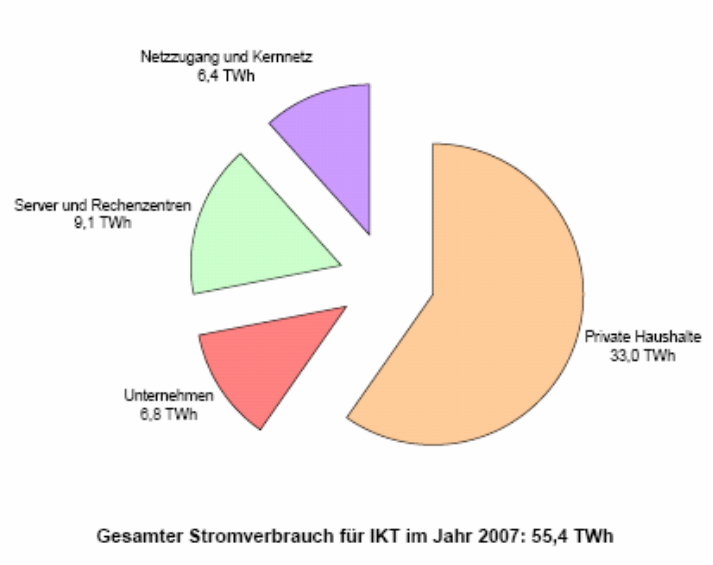
energy efficiency regarding:

- private homes
- commercial use in business
- use in administration
- data centers
- network infrastructure
- mobile networks

methodology and metrics:

- absolute power consumption (kWh/a)
- energy per transmitted bit (J/bit)
- CO2 footprint (kg/a), Ericsson: 29 kg CO2 per UMTS subscriber and year
- life circle assessment (holistic approach)

Germany: Situation 2007



Source: BMWi report

- Power Consumption of IT in 2007: 6324 MW, 55.4 TWh/a (10 power plants)
- 10 % of produced electrical power (550 TWh/a)
- main contributions due to private homes and data centers
- networks (6.4 TWh/a) contribute mainly due to mobile networks
- backhaul and access networks approx. 15% network consumption
- increase in network traffic more than 100% per year
- Increase in power consumption 10/-15% per year

World: 8% (160 GW)

Potential for Green IT: The Main Causes of Power Waste

- primary hardware power consumption (processors, cards, line drivers RF amplifiers,…)
- inefficient design, topology, operation (design for maximum performance, insufficient load balancing,…)
- thermal design (dissipation of heat, cooling systems,…)
- wasted power consumption (insufficient stand-by, always-on,…)
- redundant data storage (useless replications,…)
- redundant network traffic (mail attachments,…)

- different aspects in different technical disciplines
- different solutions: virtualizing, cloud computing, thin clients, intelligent facility management, new materials for semiconductor technology, new network topology, new transmission methods,…

Backhaul and Access Networks

- area-wide copper based VDSL access would lead to 450 MW (3.9 TWh/a) power consumption (Germany)
- optical backhaul currently less than 15% of all network consumption, mainly due to electrical switching

⇨ massive growth in data traffic will lead to much higher consumption in the future

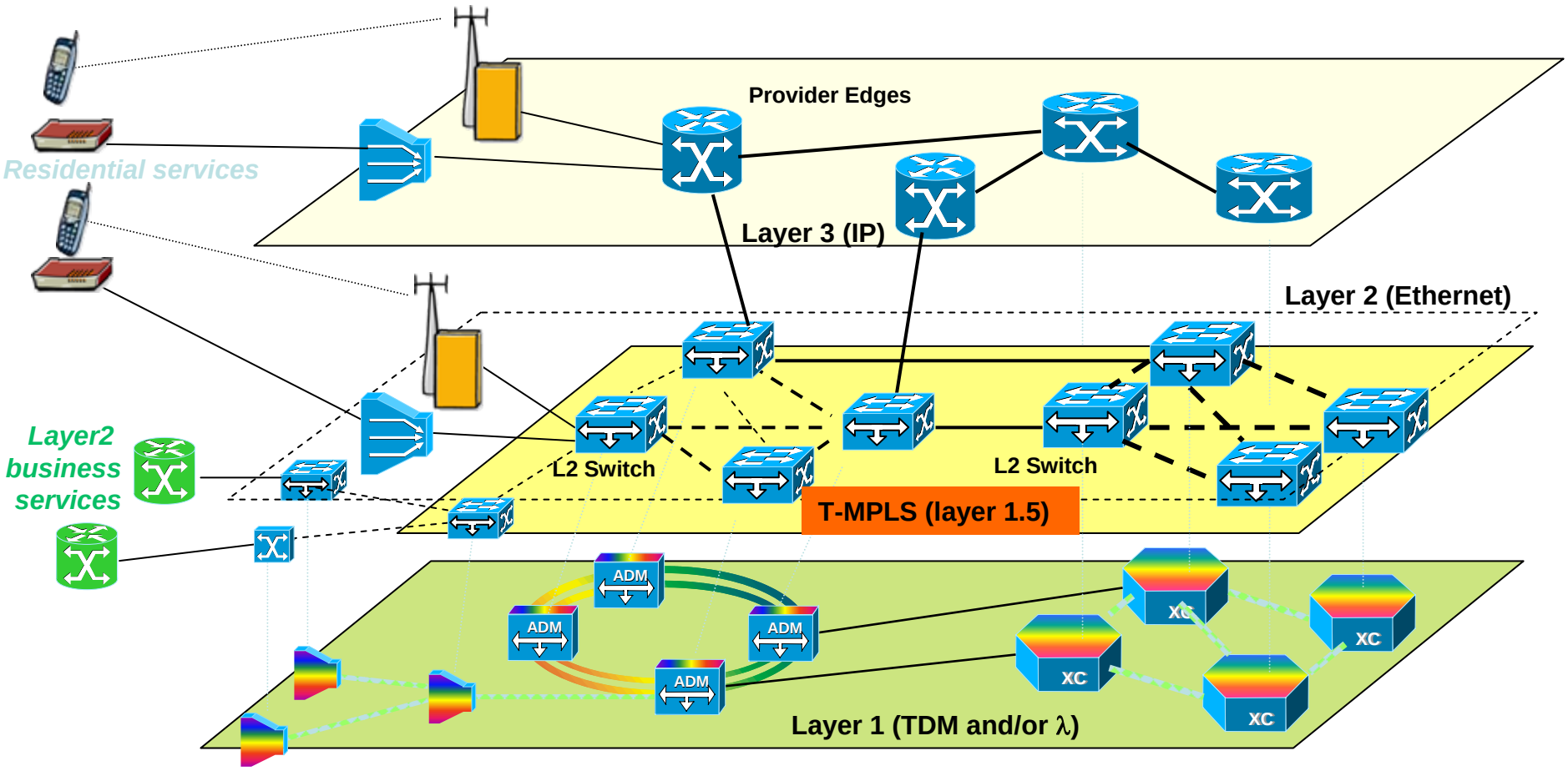
⇨ power as a major contributor to OPEX

Strategies:

- optical access networks
- bypass of electrical switches, switching at the lowest possible layer
- avoid O/E and E/O converters
- reduced number of nodes with long haul connections

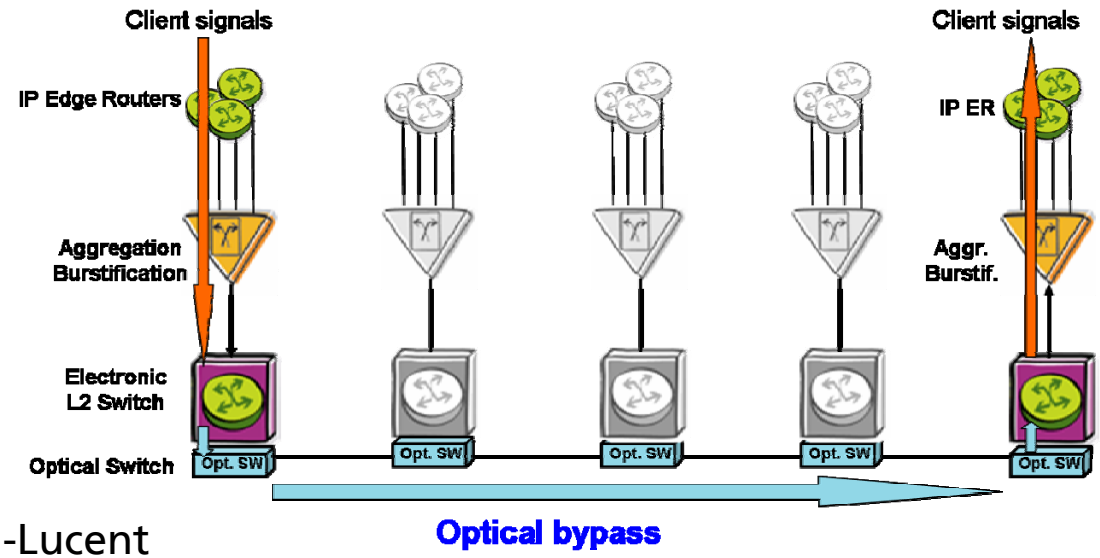
⇨ mostly passive all-optical network

Multi-Layer Network Architecture



Source: Alcatel-Lucent

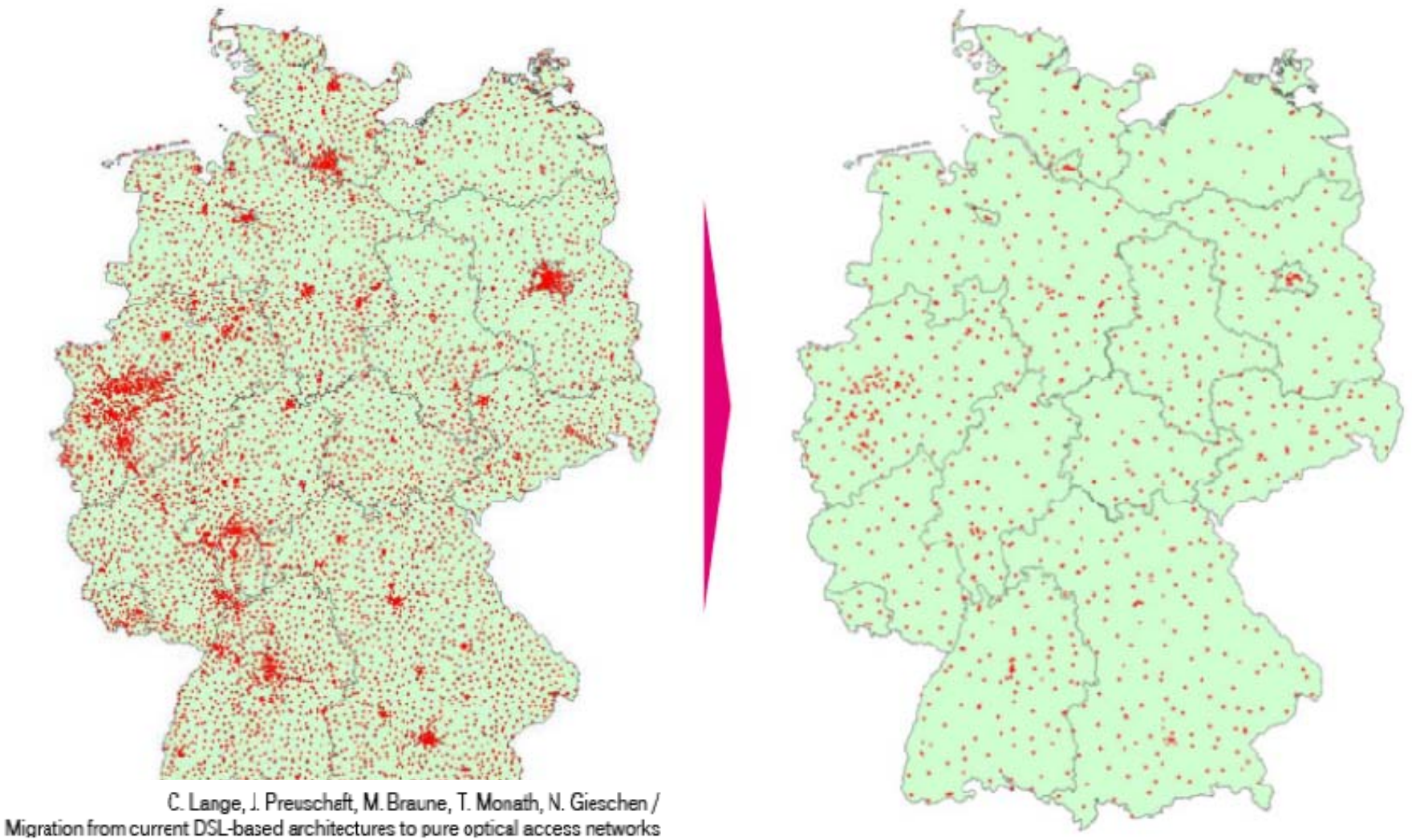
Bypass Switching in the Optical Domain



Source: Alcatel-Lucent

- optical bypass (short/medium term: circuit switching; long term: burst/packet switching)
- transparency domains are limited by signal impairments by nodes and on transmission links
- signal regeneration mandatory for routing of all traffic demands (20% – 40% of traffic not supported!)

Reduction of Network Nodes



C. Lange, J. Preuschaft, M. Braune, T. Monath, N. Gieschen /
Migration from current DSL-based architectures to pure optical access networks

Source: DTAG

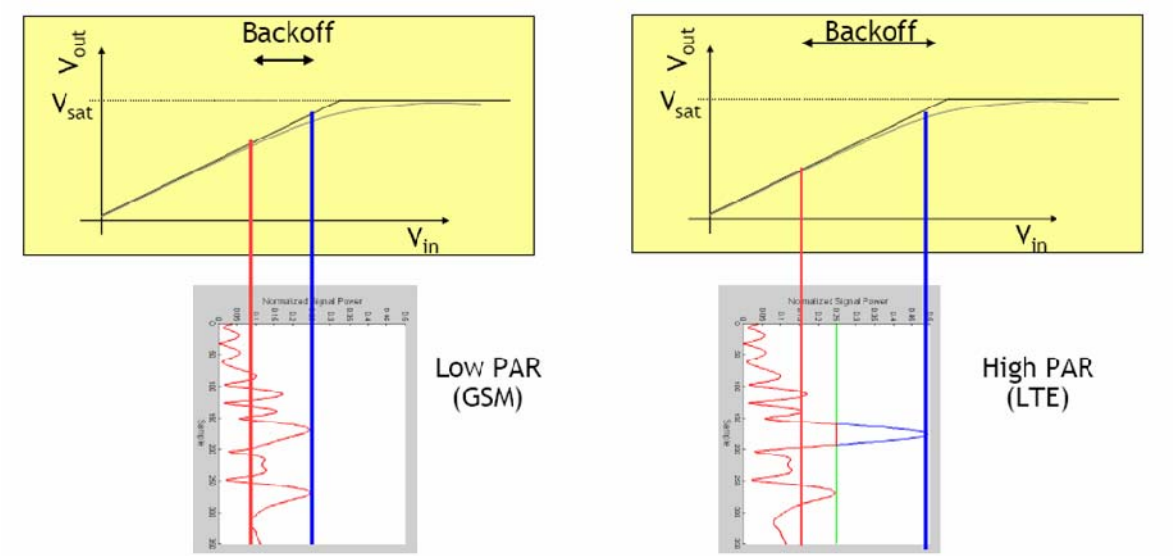
Mobile Networks: Contributions

2G Networks (GSM)			3G Networks (UMTS)		
Part	*Power Consumption*	*Percentage on overall power*	*Part*	*Power*	*Percentage on overall paower*
RF transceiver at base station	1200 W	97%	RF transceiver (Node B)	6000 W	98%
base station controller	500 W	2,2%	radio network controller	2500 W	1,5%
mobile switching center	4000 W	0,8%	mobile switching center	4000 W	0,5%

- RF transceiver at base station has by far highest consumption
- 50% of RF transceiver power is due to power amplifier
- mobile devices nearly negligible, in spite of their great number
- power consumption for 3G is 5 times higher for 2G due to higher linearity requirements (higher peak to averarge power ratio ⇨ higher back-off)

- situation even worse for OFDM-based high speed data transfer (LTE)

Transmit Signals: Peak-to-Average Power Ratio



- GSM (phase modulated GMSK signal): Peak-to-Average Power Ratio (PAPR) < 3dB: power back-off < 3 dB
- UMTS (CDMA signal): PAPR = 7 dB: power back-off = 10 dB
- LTE (OFDM signal): PAPR = 10 dB: power back-off > 10 dB
- efficiency is reduced proportional to power back-off (40% for GSM to 5 % for LTE)
- power consumption of amplifier increases proportional to PAPR

PAPR is equivalent to Peak-to-Average Ratio (PAR) and Crestfactor (CF)

Energy Consumption of Mobile Networks: Germany

Cellular base stations

- 68 243 sites with approx. 150 000 installations
- approx. 4 kW per base station (2G and 3G)
- 600 MW installed power, 5.3 TWh/a (⇨ medium power plant, 1% of overall electrical energy in Germany)
- several hundred million € OPEX (operational costs)
- OPEX + CAPEX, economical need for enhancement

WLAN

- 9 Mill. routers (private and public)
- 10 W – 15 W per router
- approx. 100 MW, 0.9 TWh/a

Mobile devices

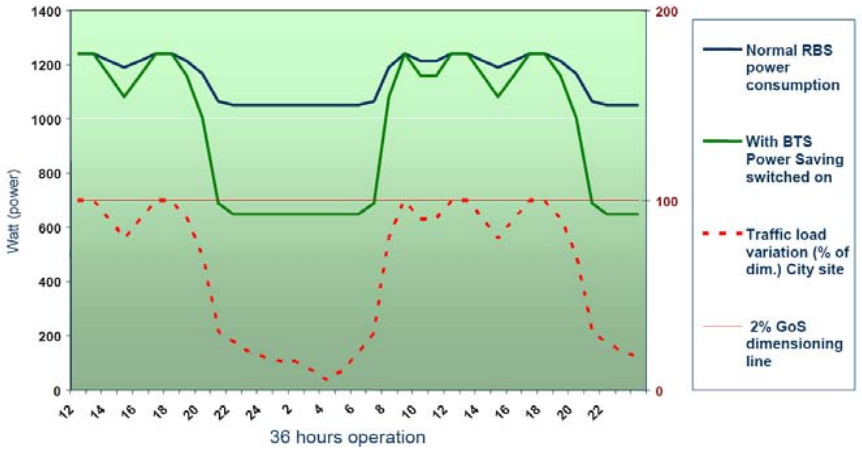
- 85 Mill. Devices
- approx. 1 kWh/a for charging
- 0.085 TWh/a

Strategies for Mobile Networks

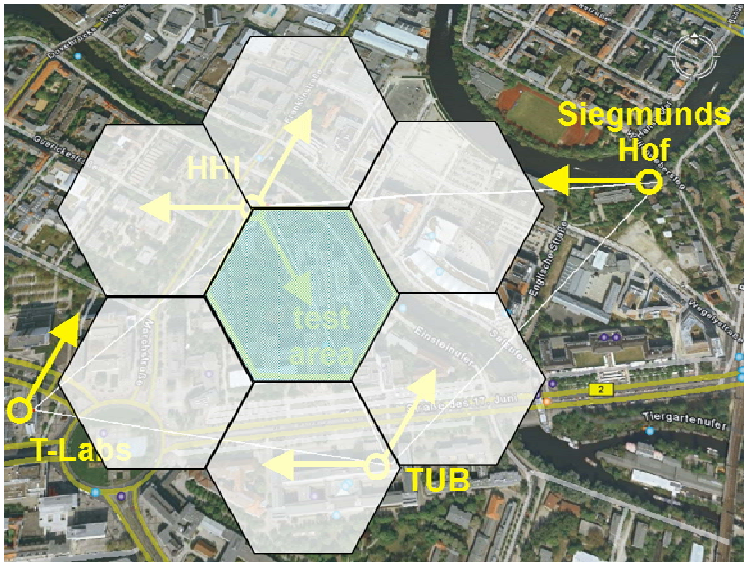
- optimization of network topologie: fewer base stations
- optimization of network operation: load depending power control
- cooperation of adjacent base stations
- heterogeneous networks
- reduce losses in RF path (cables, filters, switches): remote radio head
- more efficient use of radiated energy: MIMO, beamforming
- increase of power amplifier efficiency: digital predistortion to preserve linearity

Efficient Infrastructure Deployment and Operation

Energy management at base station (source: Ericsson)



Cooperating base stations



- energy management operation
- energy optimized network design (fewer sites)
- cooperating base stations
- transmit power control
- heterogeneous networks (multi-hop, relaying, micro-base stations)

Power Amplifier Technologies

Today

Mid Term

Future

good

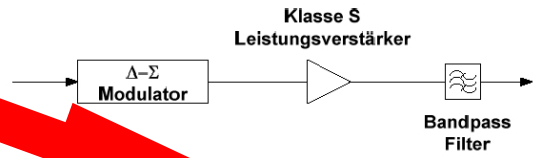
Linearity

good

>50 % ?

Efficiency

Class-S, F, F^{-1}:
Switch Mode



25 - 30 %

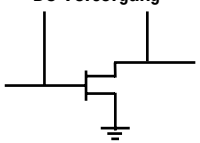
Envelope Tracking:
Source Modulation

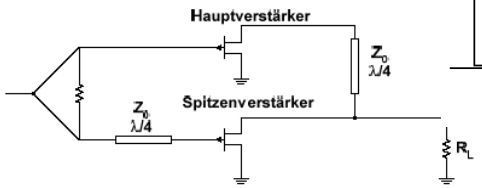
poor

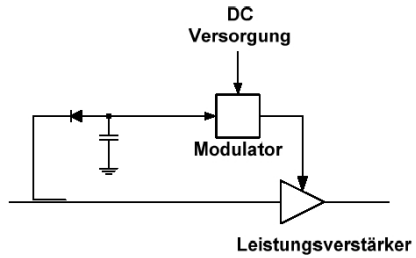
poor

Doherty:
Load Modulation

Class-AB







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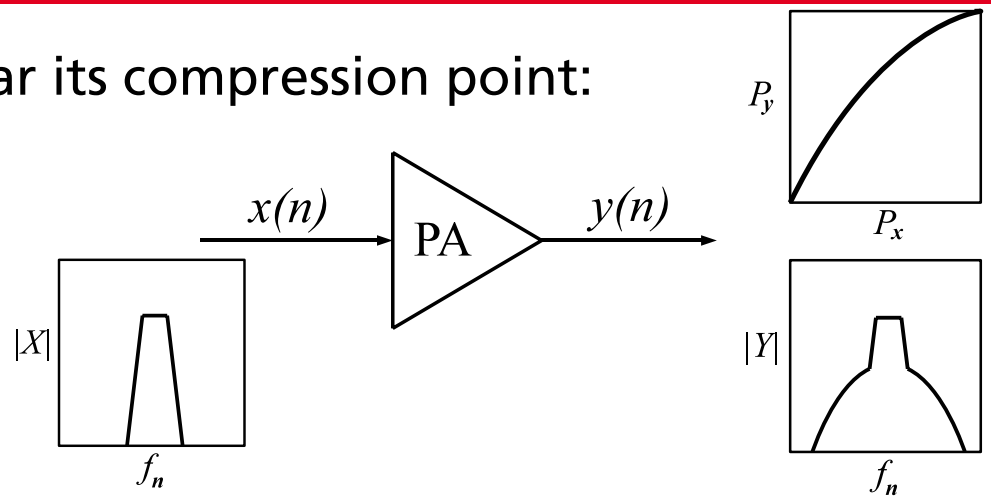
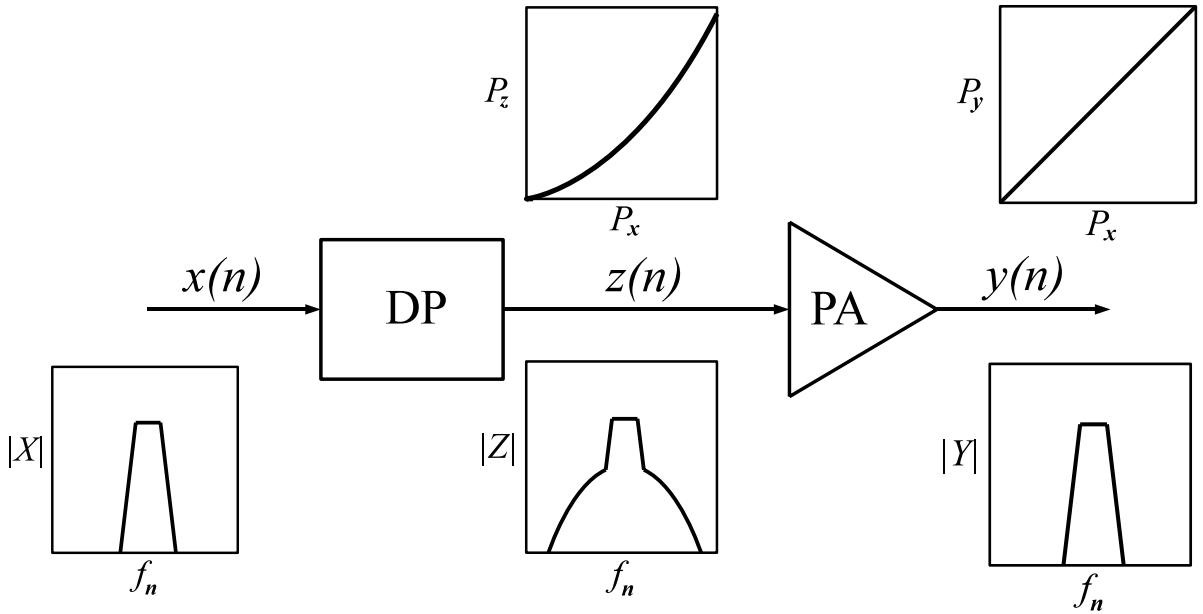
Weak Nonlinearities: Digital Predistortion (DP) Principle

PA working near its compression point:



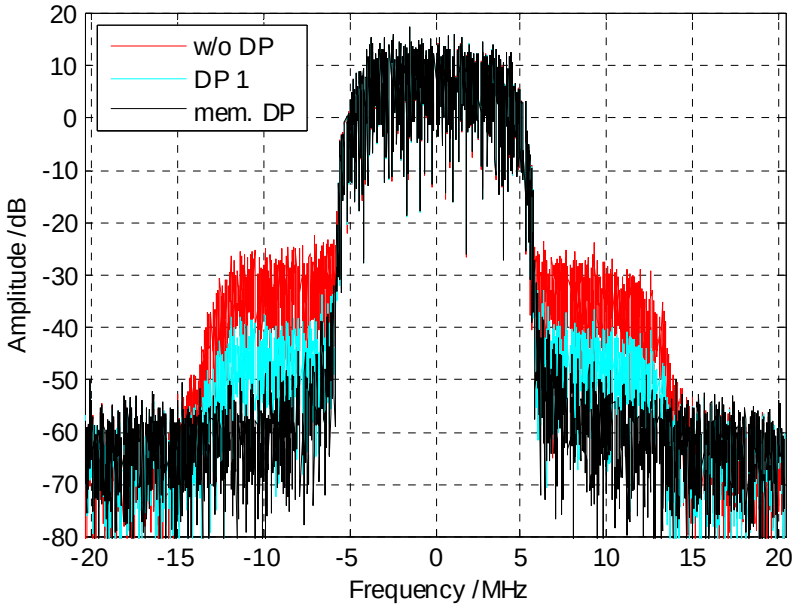
Digital predistortion reduces nonlinear distortions



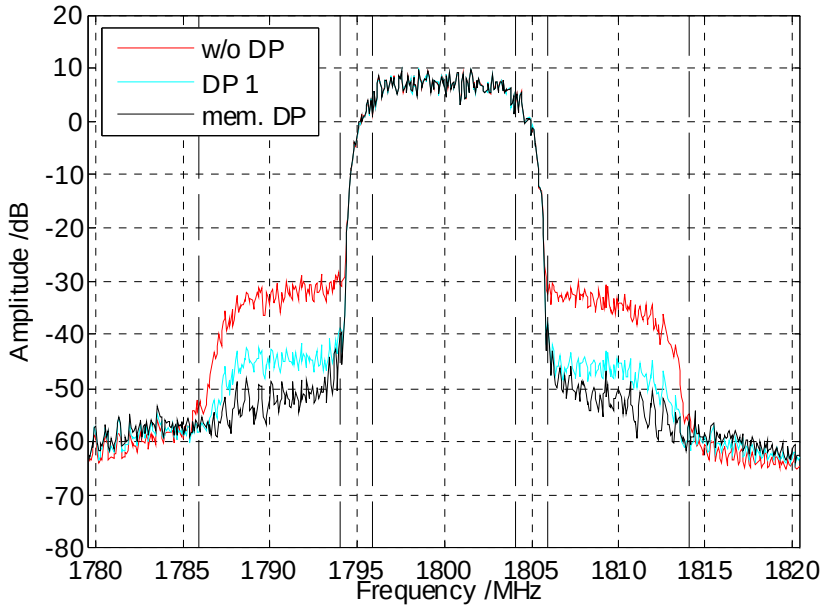
DP Performance

Improvement of ACPR using various DP methods

Matlab Simulation



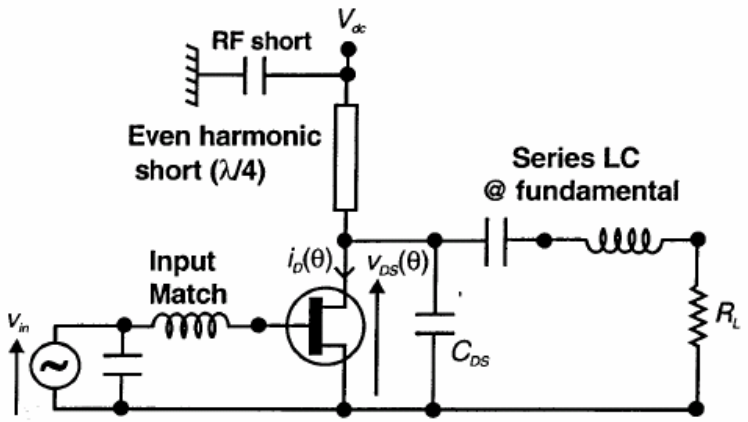
Measurement

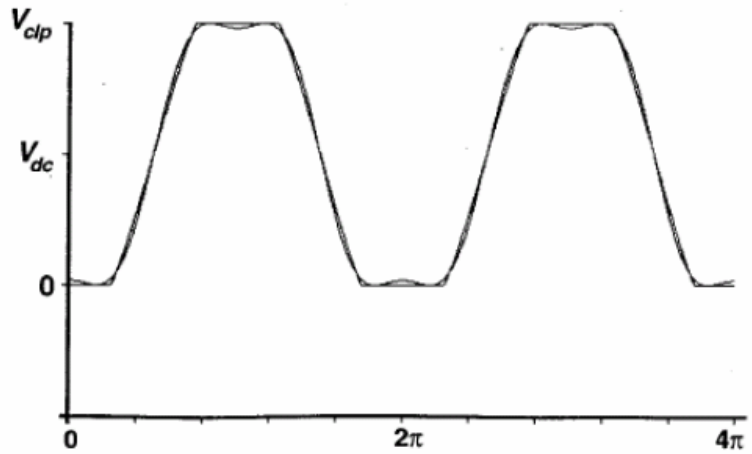


	without DP	memoryless DP	memory DP
P_{OUT} Tx. /dBm	30.9	30.9	30.9
ACPR lower /dB	-40.1	-52.2	-57.7
ACPR upper /dB	-41.6	-53.8	-57.7

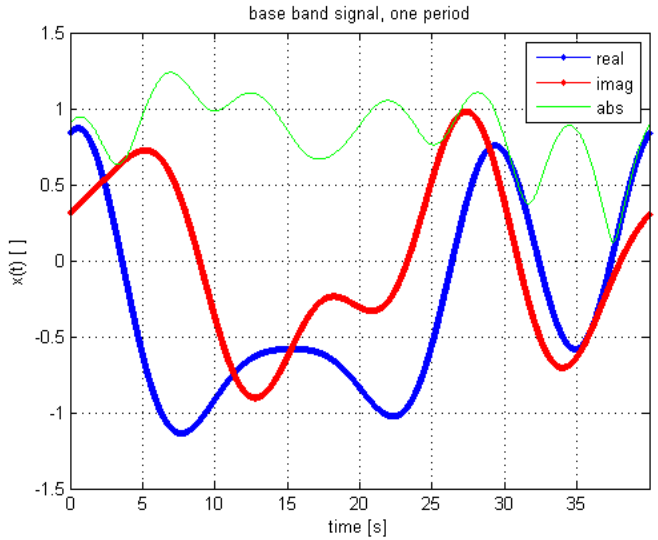
Linearized Switch Mode Amplifier: Principle

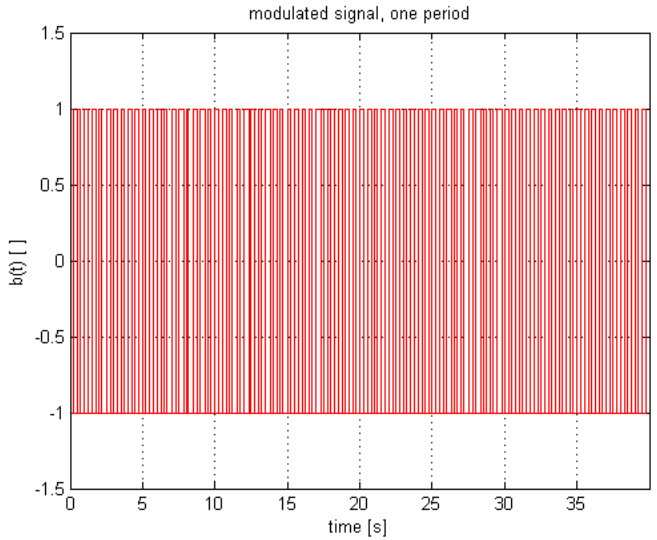
- signal is modulated e.g. Σ-Δ, pulse-width, …
- all information is contained in the zeros (theoretically error-free modulation possible): binary pulses
- binary pulses can be amplified with high efficiency (theoretically with 100% efficiency)
- signal is reconstructed i.e. demodulated by means of a lossless passive device (low pass filter)

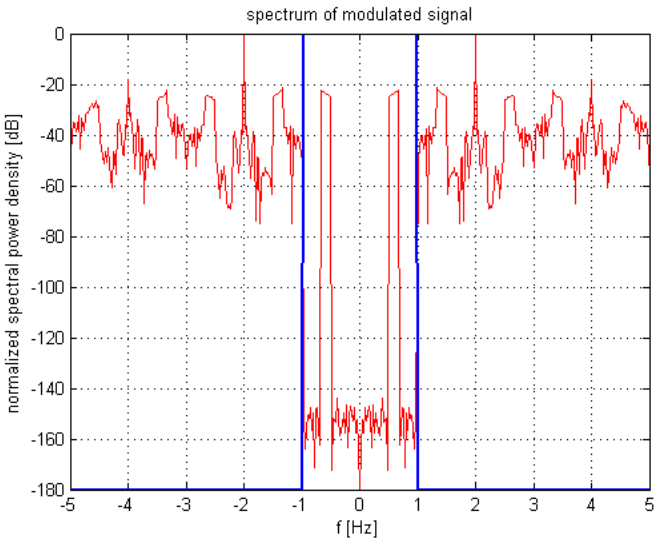


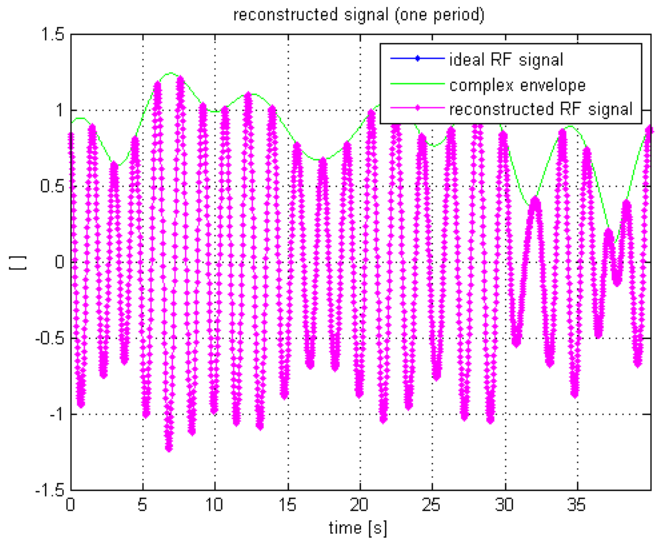


Switch Mode: Example









Switch Mode: Challenges

- most spectral energy is out of band and must be lossless filtered
- losses in switching device
- low pass interacts with device
- implementation of low pass (reconstruction filter)

Acknowledgements and Sources

- Thanks to Erwin Patzak (HHI)

- VDE-Report: “Aspekte der Reduzierung des Energieverbrauchs und der verbesserung der Energieeffizienz in Kommunikationsnetzwerken”
- BMWi Report: “Abschätzung des Energiebedarfs der weiteren Entwicklung der Informationsgesellschaft”
- Alcatel Lucent and Ericsson sources from web and different public workshops