Next-Generation Energy Efficient Networks:
Overview of the GreenTouch Consortium

Thierry E. Klein, PhD

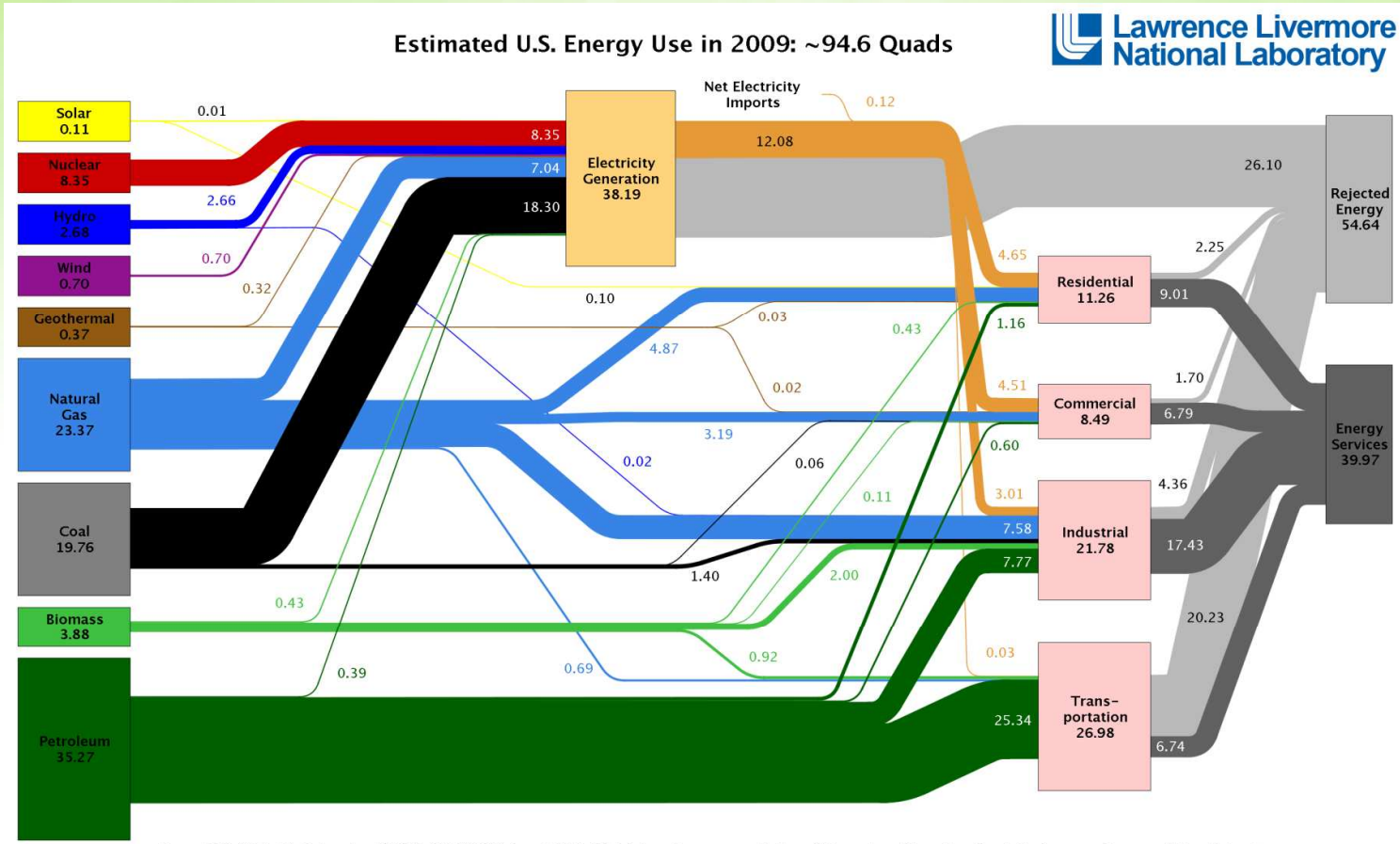
Director, Bell Labs Research / Alcatel-Lucent
Chair, GreenTouch Core Routing and Switching Working Group

Outline

- The Big Picture: Energy in ICT and the Internet
- Traffic Growth and Technology Challenges
- The Energy Gap
- GreenTouch Consortium

US Energy Supply and Consumption

Supply **Consumption**



Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

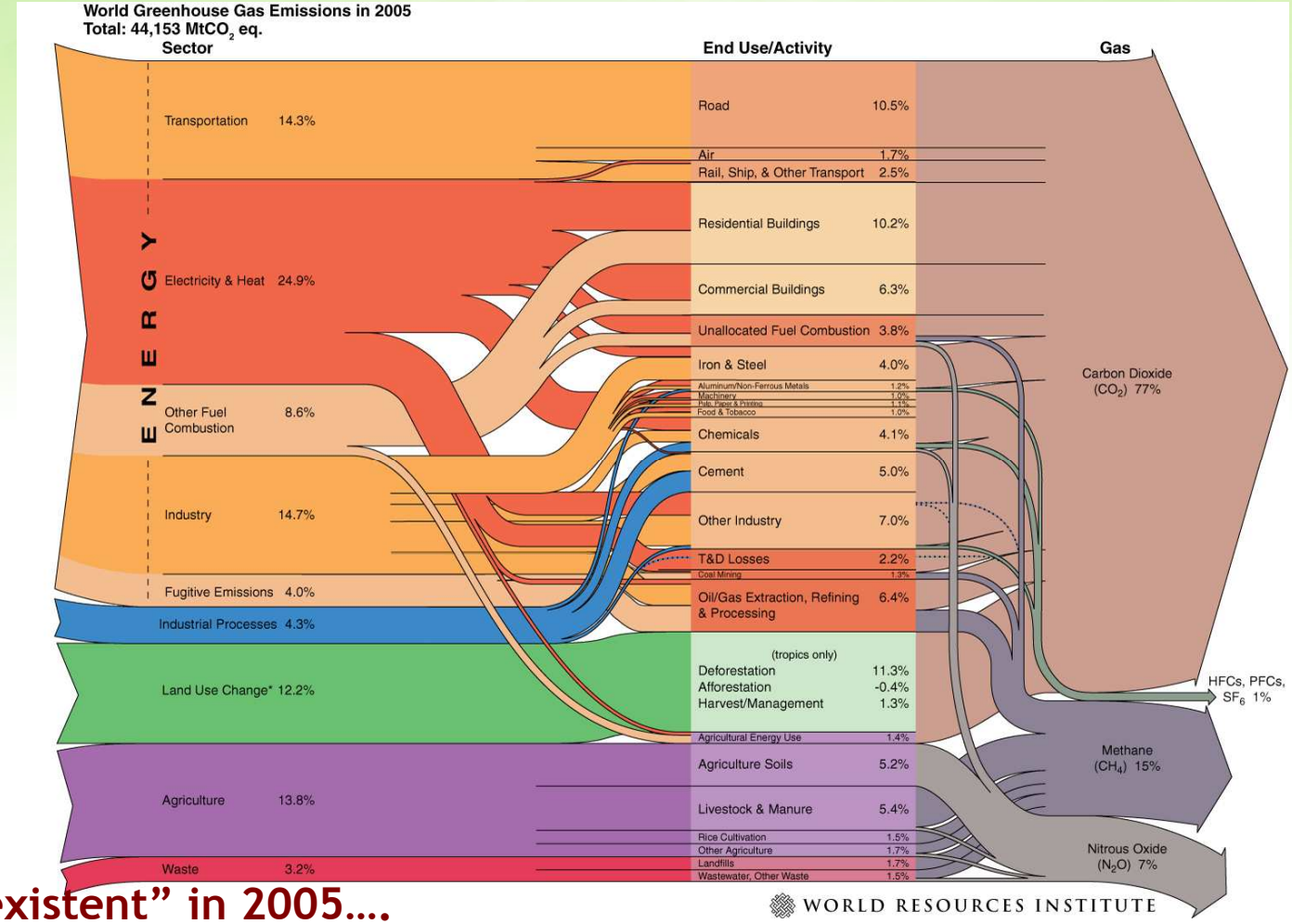
Most Energy is Lost!

Quads (10^{15} BTUs)

Alcatel·Lucent

GreenTouch™

World Greenhouse Gas Emissions (yr 2005)



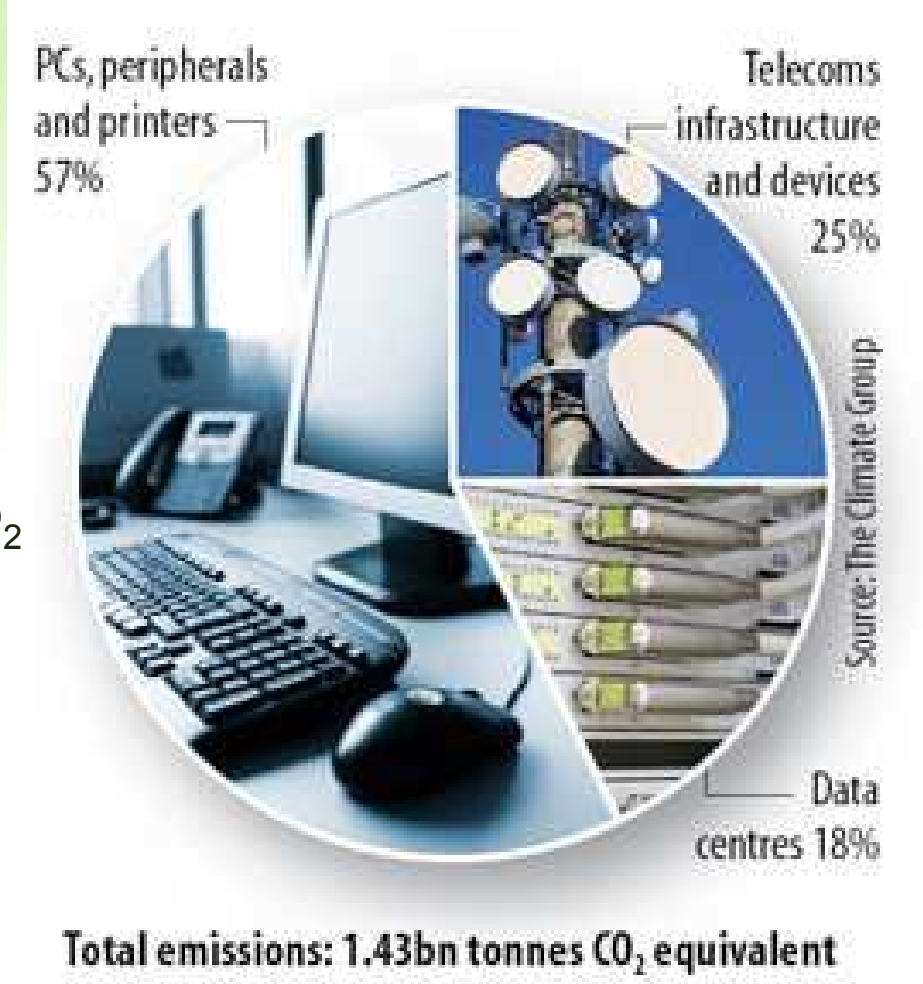
ICT "nonexistent" in 2005….

Alcatel·Lucent

GreenTouch™

2020 ICT Carbon Footprint

820m tons CO_2



360m tons CO_2

2007 Worldwide ICT carbon footprint:
2% = 830 m tons CO_2
Comparable to the global aviation industry

Expected to grow to 4% by 2020

260m tons CO_2

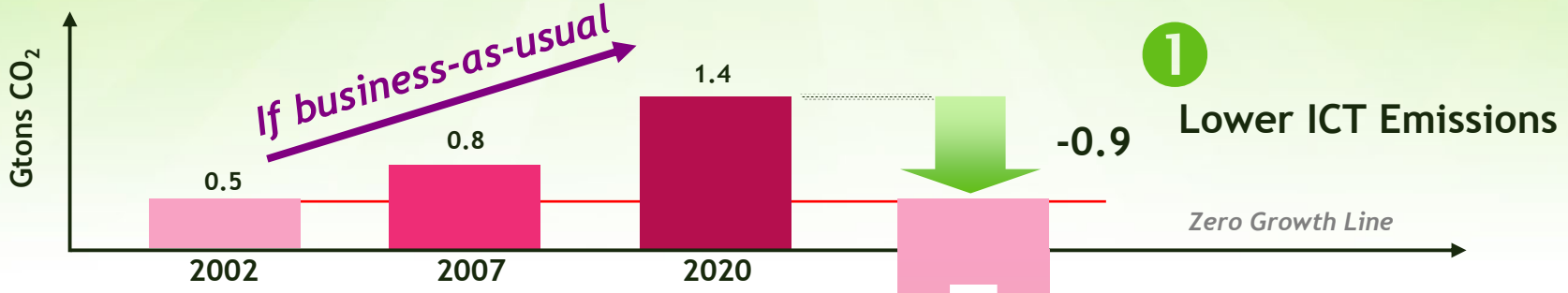
The Climate Group, GeSI report "Smart 2020", 2008

Alcatel·Lucent

GreenTouch™

ICT: A Problem and The Solution

ICT today: 2% of global emissions…
with an opportunity to make tremendous impact on the remaining 98%



1 Lower ICT Emissions

- **'Greening of ICT'**
  - How do I reduce or keep in check the carbon footprint of ICT itself?
- **'Greening with ICT'**
  - How do I use ICT to reduce carbon footprint and achieve sustainable living?
  - Prediction that ICT will save more energy than it will consume

2 Lower emissions from other Industries

-7.8

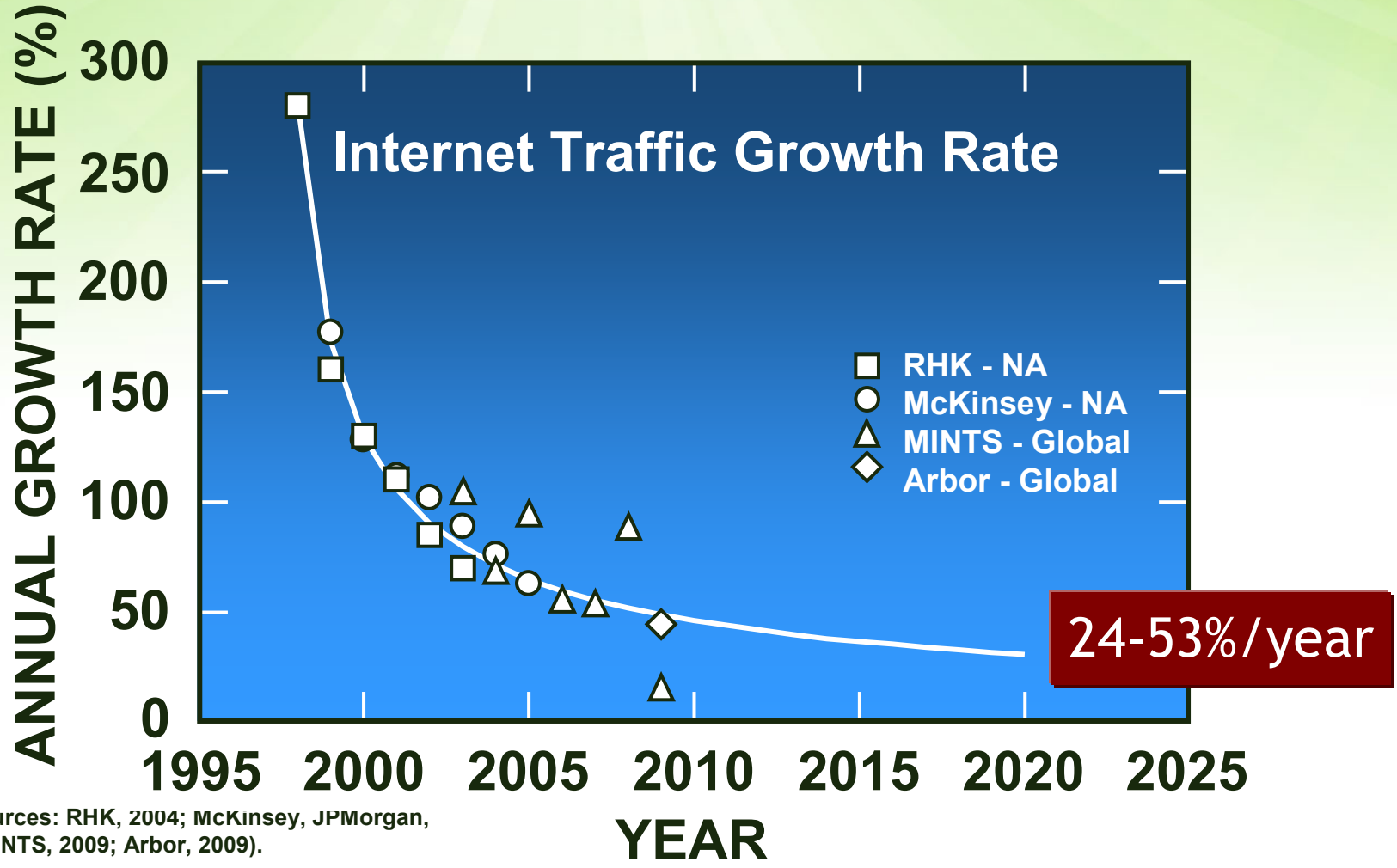
Indirect benefit is 10x ICT target footprint

Source: GeSI – SMART 2020: Enabling the Low Carbon Economy in the Information Age

Alcatel·Lucent

GreenTouch™

Past and Anticipated Internet Growth



SKK, 2010 (Sources: RHK, 2004; McKinsey, JPMorgan, AT&T, 2001; MINTS, 2009; Arbor, 2009).

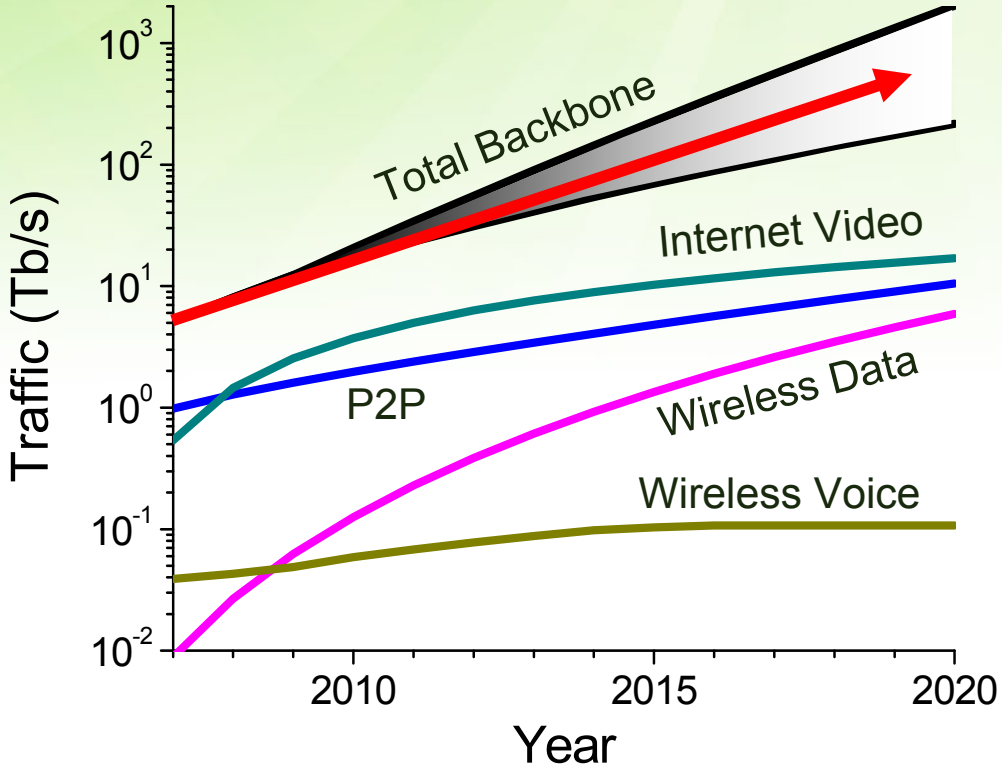
Alcatel·Lucent

Courtesy of Steve Korotky

GreenTouch™

Continued Exponential Traffic Growth

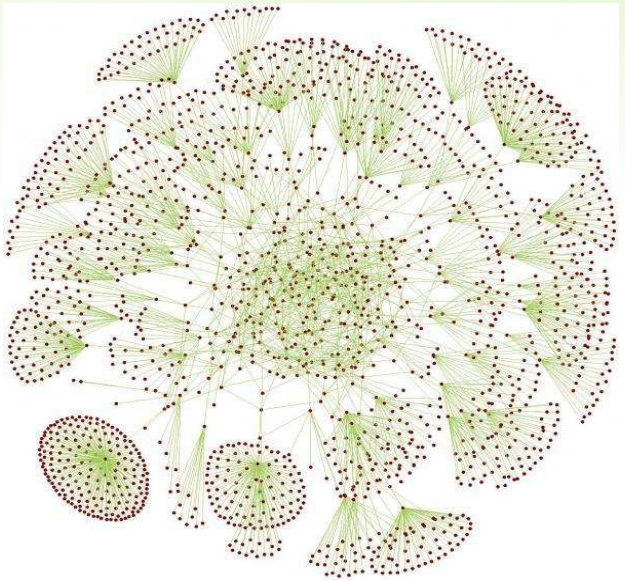
North America



Data from: RHK, McKinsey-JPMorgan, AT&T, MINTS, Arbor, ALU, and Bell Labs Analysis: Linear regression on log(traffic growth rate) versus log(time) with Bayesian learning to compute uncertainty

Traffic doubling every 2 years

- 40% per year
- 30x in 10 years
- 1000x in 20 years

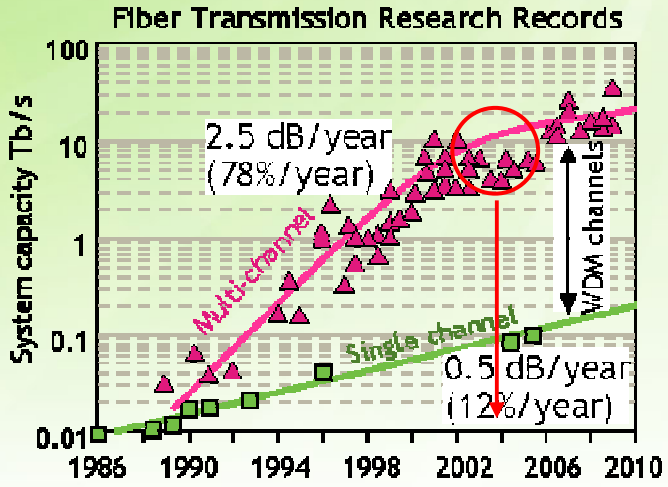


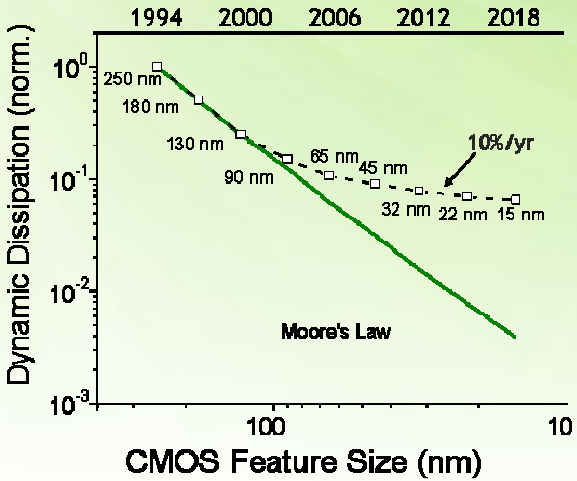
Network energy efficiency increasing 10-15%/year

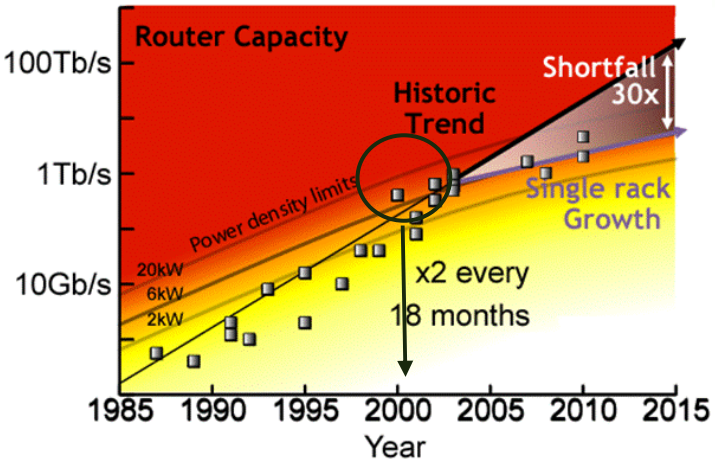
Alcatel·Lucent

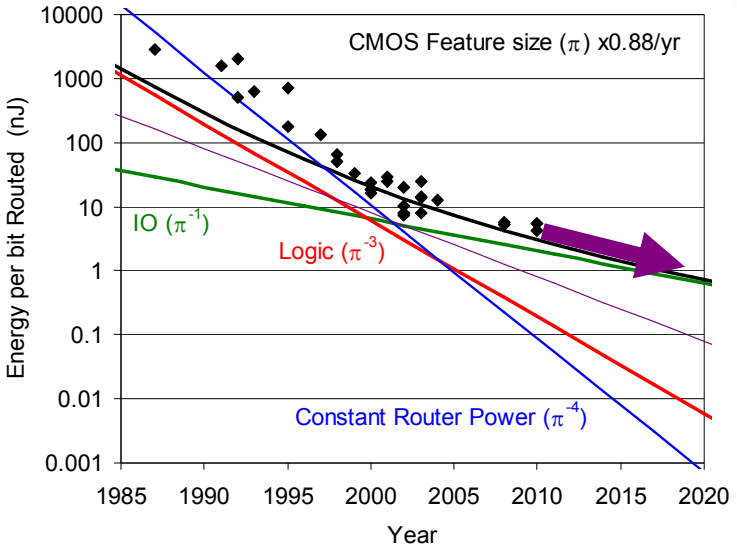
GreenTouch™

Slowdown In Technology







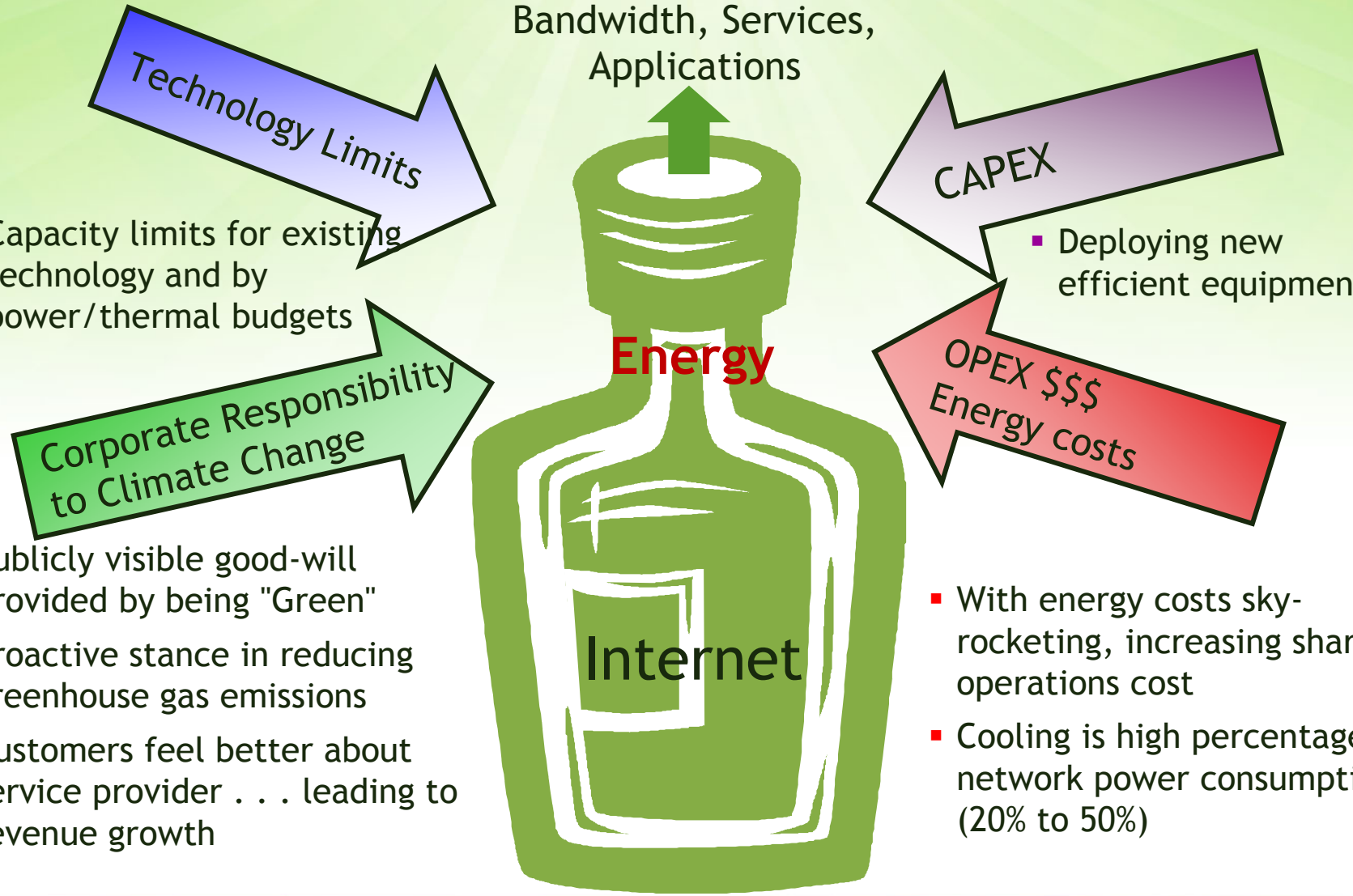


Interconnect power will dominate future router system power dissipation.

Alcatel·Lucent

GreenTouch™

Tightening Energy Bottleneck

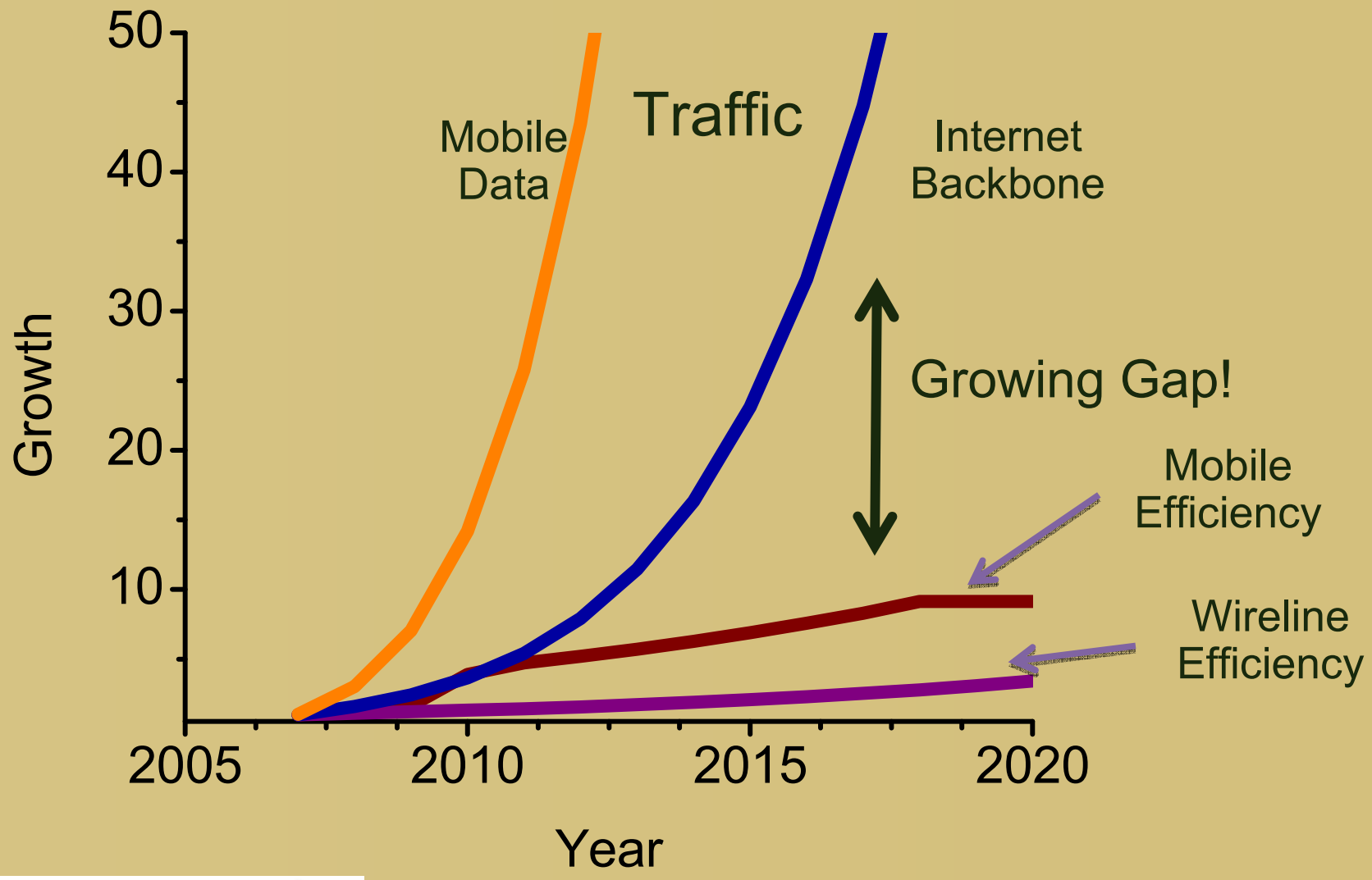


- Capacity limits for existing technology and by power/thermal budgets
- Deploying new efficient equipment
- Publicly visible good-will provided by being "Green"
- Proactive stance in reducing greenhouse gas emissions
- Customers feel better about service provider . . . leading to revenue growth
- With energy costs sky-rocketing, increasing share of operations cost
- Cooling is high percentage of network power consumption (20% to 50%)

Alcatel·Lucent

GreenTouch™

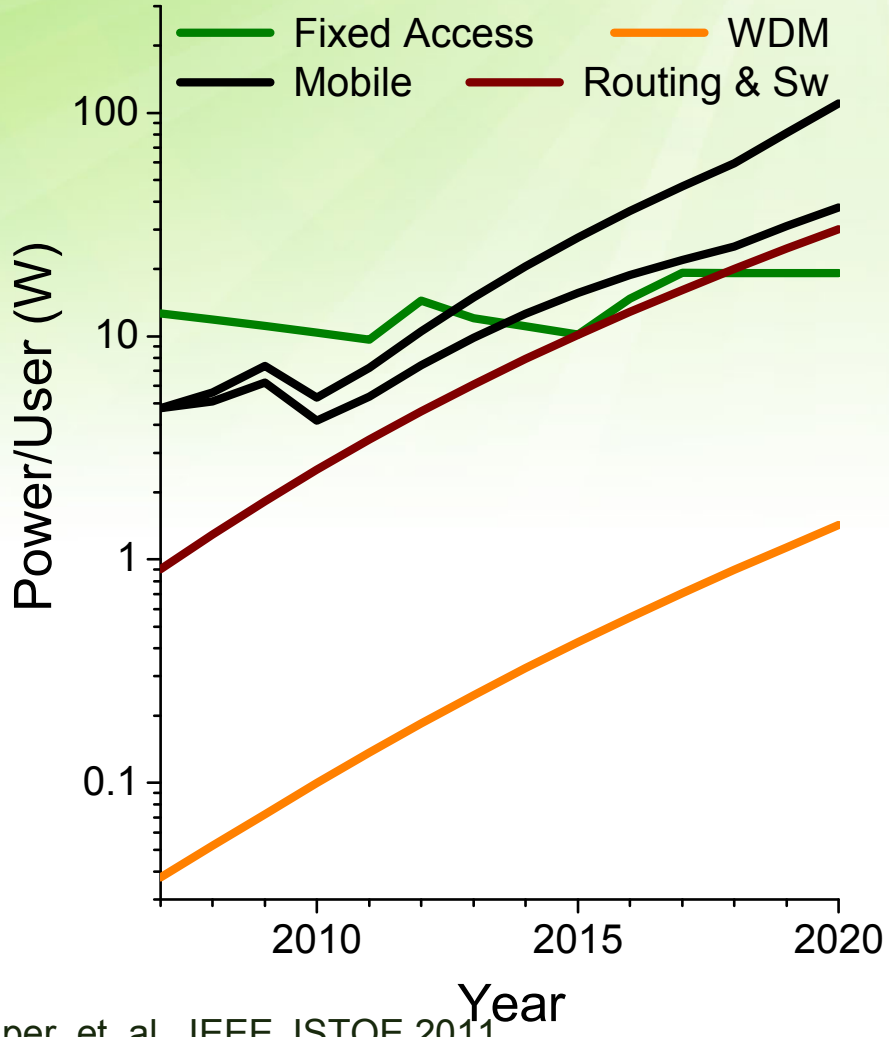
The Network Energy Gap



Alcatel·Lucent

GreenTouch™

Baseline Business-As-Usual Trends



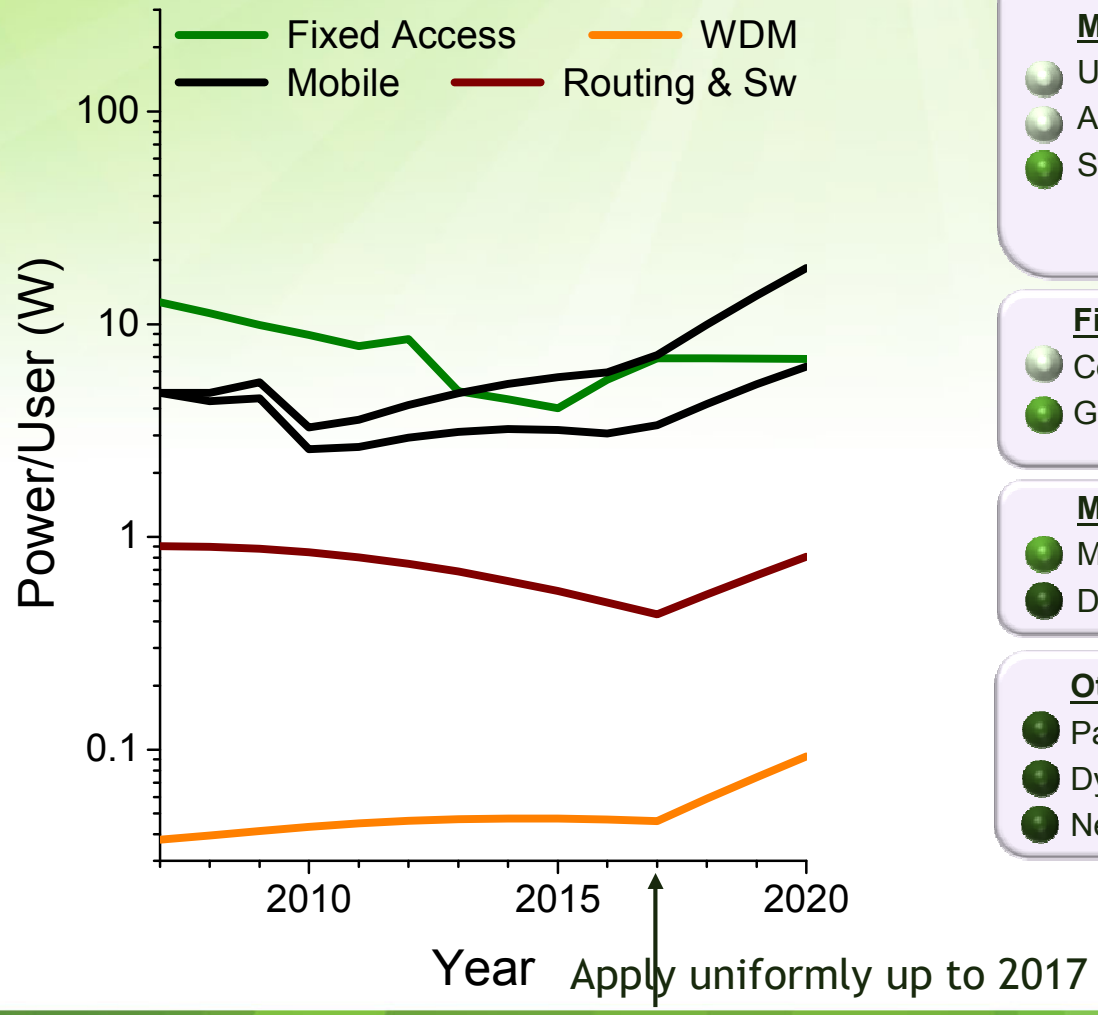
Kilper, et. al., IEEE JSTQE 2011

- State-of-the-art technology evolution
  - Mix of legacy equipment makes picture worse
- Mobile data is rapidly growing problem today
- Historical energy distribution from edge to core changes over next decade
- Includes 10%/year from Moore's Law
- Traffic growth: >30%/year
- Equipment efficiency: 10%-20%/year

Alcatel·Lucent

GreenTouch™

Best Case Efficiency Improvements



Mobile Access:
- Ultra-efficient power amplifiers (70%)
- Active antennas
- Self organizing networks

Fixed Access:
- Cost-reduced FTTH/N
- Green PON (from ~16W/user to ~5W/user)

Metro/Core:
- Mesh protection / fast restoration
- Dynamic Optical Bypass

Other:
- Passive cooling everywhere
- Dynamic energy usage (proportional to load)
- Network Virtualization

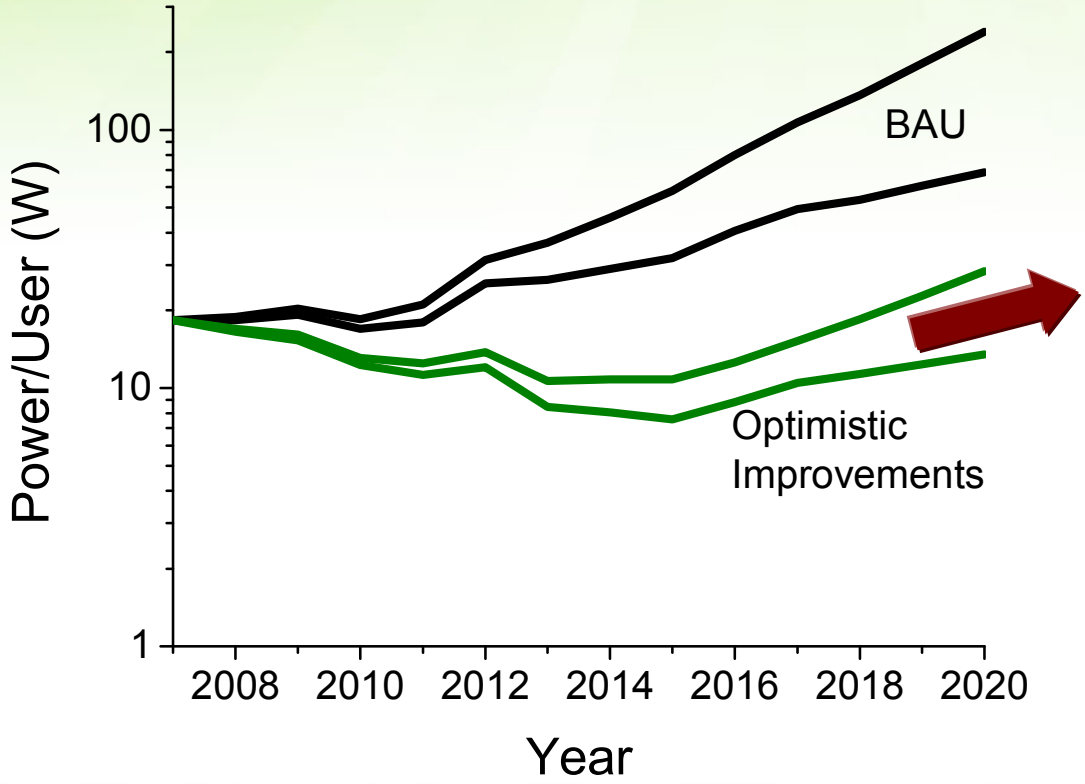
Degree of Difficulty: Lower ↕ Higher

Alcatel·Lucent

GreenTouch™

Ideal Efficiency Improvements on BAU: Flat in 2020

Current technology will only sustain us for another decade: how do we go beyond?



- Improving network efficiency at best keeps power consumption flat over next decade
  - What happens after 2020?
  - Can only use ‘sleep modes’ once

Alcatel·Lucent

GreenTouch™

ICT Industry Responds

- First Step: metrics, awareness, standards, call to action
  - Global e-Sustainability Initiative (GeSI)
  - ITU-T
  - GreenGrid
- Next Step: cooperation, action
  - EARTH: LTE 2x
  - Mobile VCE: Green Radio 100x
  - Institute for Energy Efficiency: Wireless and optical 100x
  - GreenTouch: ICT Networks 1000x

Alcatel·Lucent

GreenTouch™

GreenTouch Consortium

Broad, open and global consortium executing research projects to achieve aggressive goal

Forum for the exchange of information on energy trends, challenges, & research on communication networks

Roadmap organization establishing reference architectures, models and research targets to overcome major challenges facing network scaling and energy

Committed to open innovation and collaboration to accelerate progress

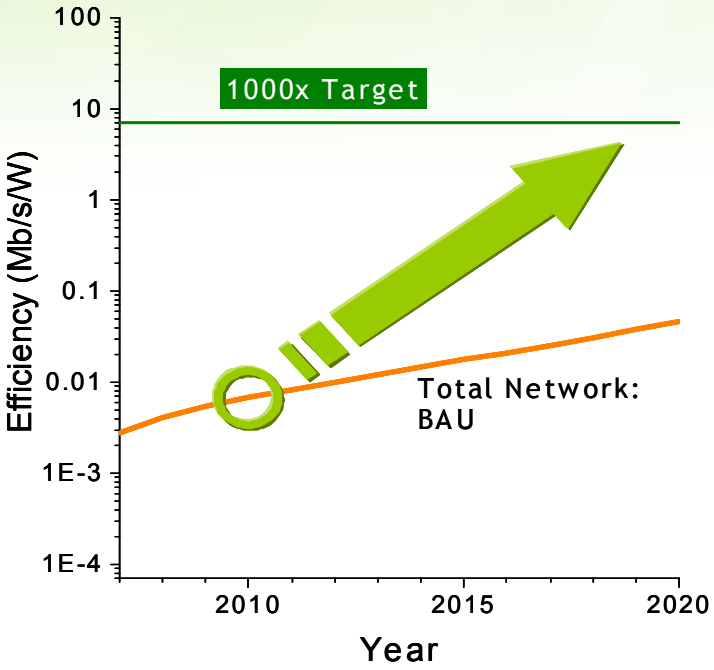
Members are experts from world's top institutions and operators

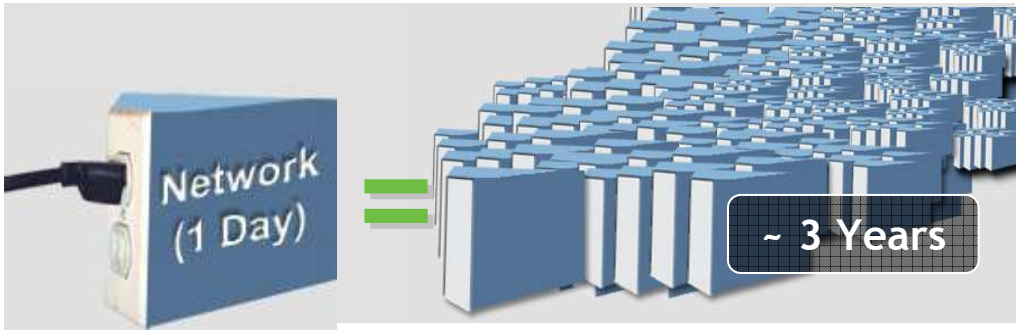
Alcatel·Lucent

GreenTouch™

GreenTouch Mission

By 2015, our goal is to deliver the architecture, specifications and roadmap — and demonstrate key components and technologies —needed to increase network energy efficiency by a factor of 1000 from current levels.





Alcatel·Lucent

GreenTouch™

GreenTouch Members

- AT&T Services
- Athens Information Technology (AIT) Center for Research & Education
- Bell Labs, Alcatel-Lucent
- Broadcom
- Carnegie Mellon University
- CEA-LETI Applied Research Institute for Microelectronics
- China Mobile
- Chunghwa Telecom
- Columbia University
- Draka Communications
- Dublin City University
- Electronics and Telecommunication Research Institute (ETRI)
- Fondazione Politecnico di Milano
- Fraunhofer-Geselleschaft
- France Telecom
- Freescale Semiconductor
- Fujitsu
- Huawei
- IBBT
- IMEC
- INRIA
- KAIST
- Karlsruhe Institute of Technology
- Katholieke Universiteit Leuven (K.U. Leuven)
- King Abdulaziz City for Science and Technology
- KT Corporation
- National ICTA Australia
- Nippon Telegraph and Telephone Corp
- Politecnico di Torino
- Portugal Telecom Inovação, S.A.
- Samsung (SAIT)
- Seoul National University
- Swisscom
- TNO
- Tsinghua University
- TTI
- TU Dresden
- University College London
- University of Cambridge
- University of Delaware
- University of Maryland
- University of Leeds
- University of Melbourne's Institute for a Broadband-Enabled Society (IBES)
- University of New South Wales
- University of Toronto
- Waterford Institute of Technology

Alcatel·Lucent

GreenTouch™

Primary Metric Is Network Energy Efficiency

Green Services

Increase

Growth

Increased Revenue from Services

Bits per Second

$$\text{Network Efficiency} = \frac{\text{Total Traffic Delivered to User}}{\text{Total Power per User}}$$

Watts

Reduce

Reduced Carbon Footprint

Reduced Costs

Makes both Environmental and Economic Sense

Alcatel·Lucent

GreenTouch™

New Approaches: Focus On Energy

- New devices
  - Analog vs digital, best use of optics and electronics
  - Low power electronics and photonics
- New architectures
  - Trade-off transmission/bandwidth and processing, distributed versus centralized
- New protocols
  - Longer packet sizes or no packets at all for certain applications
  - Eliminate unnecessary and redundant processing
- Service optimized networks
  - Move away from one size fits all—use most energy efficiency hardware for the service
  - Coordinate service delivery/applications with network hardware operation
- Restructuring layers, architectures, feature options
  - How much do way pay in energy for convenience? Duplicated functions (FEC)?
  - What technologies do we really need in order to support the essential capabilities?

Minimizing Processing

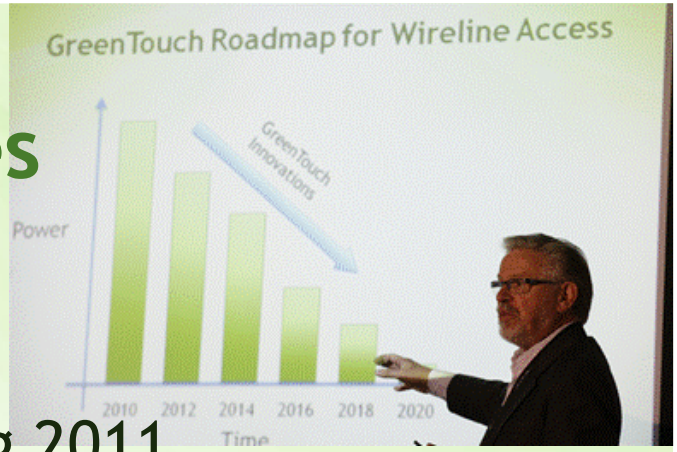
- Repetition
  - Unnecessary router hops
  - Inter-operator exchange
  - Multiple transmissions
- Remove processing from the data path
  - Separate control channel
- Focus on service
  - Content delivery vs. browsing vs messaging
- Push to the edges
  - FEC
  - Security, policy processing
- Simplified addressing
  - Geographic addressing/binary switching

Separate what is needed from what is convenience

A Scalable Internet: Holistic Re-Design

- Processing
  - New addressing—transparent data flow
  - End-to-End—security, FEC
- Back to the Future
  - Optimized hardware for given task: service differentiation
- How many layers do we need?
- How do protocols and algorithms impact hardware design?
- How do we unlock physical potential—small cells, efficient MIMO?
- What is the real energy cost for the features and functions supported in the network?

Initial Activities



- Build research program
- First technology demonstration spring 2011
- Establish common reference architecture
- Define primary research targets
- Establish expected trends on key metrics to 2020
- Provide international forum for cooperation and exchange of ideas on energy research topics

Some Research Projects…

Beyond Cellular – Green Mobile Networks

Virtual Home Gateway

Optimal End-to-End Resource Allocation

Service Energy Aware Optical Networks

Green Transmission Technologies

Minimum Energy Access Architectures

Single-Chip Linecards

Large-Scale Antenna Systems

Highly-Adaptive Layer Mesh Networks

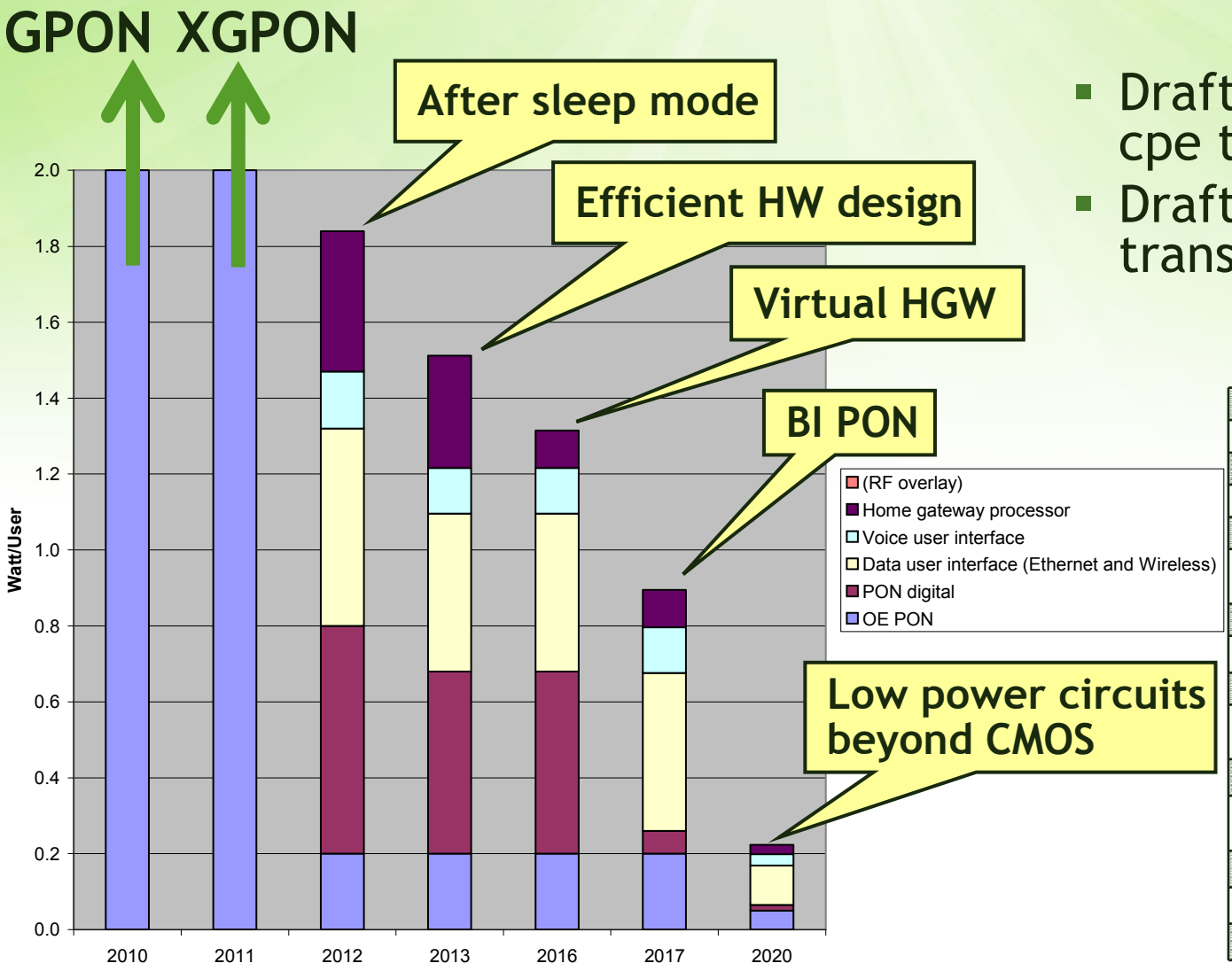
Massive MIMO

25+ Projects Active & In Prep.

Alcatel·Lucent

GreenTouch™

Roadmap Details Underway



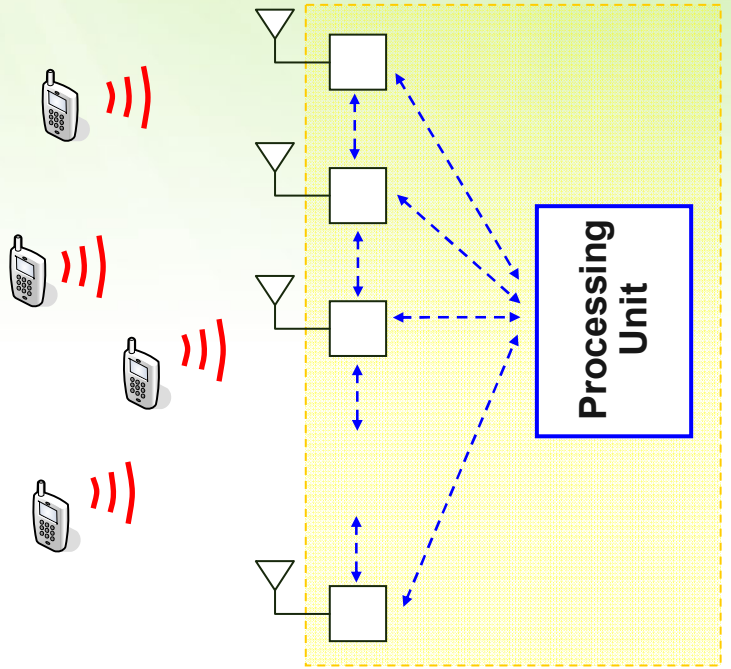
- Draft wireline access cpe trend
- Draft Core Opt Ntwk transponder model

Tx:	P(W)		Notes
Mux	0.40		10pJ/b
Driver	1.00		25pJ/b
Laser	0.06		1.5pJ/b
Mod	0.16		4pJ/b
Subtotal		1.62	
Rx:			
PhotoRx	0.144		3.6pJ/b
DeMux	0.80		20pJ/b
Subtotal		0.95	
		2.56W	20%
+Inefficiencies		10.25W	80%
$P_{function}$		12.81W	
Overheads		12.81W	
Total		25.6W	

Alcatel·Lucent

GreenTouch™

First Technology Demonstration: Large Scale Antenna Array Systems, Using MIMO to Focus RF Energy



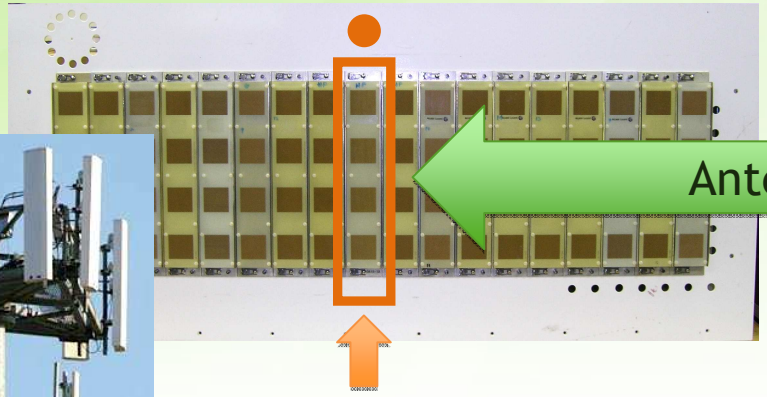
Marzetta, T. L., IEEE Trans Wireless Comm, Nov 2010

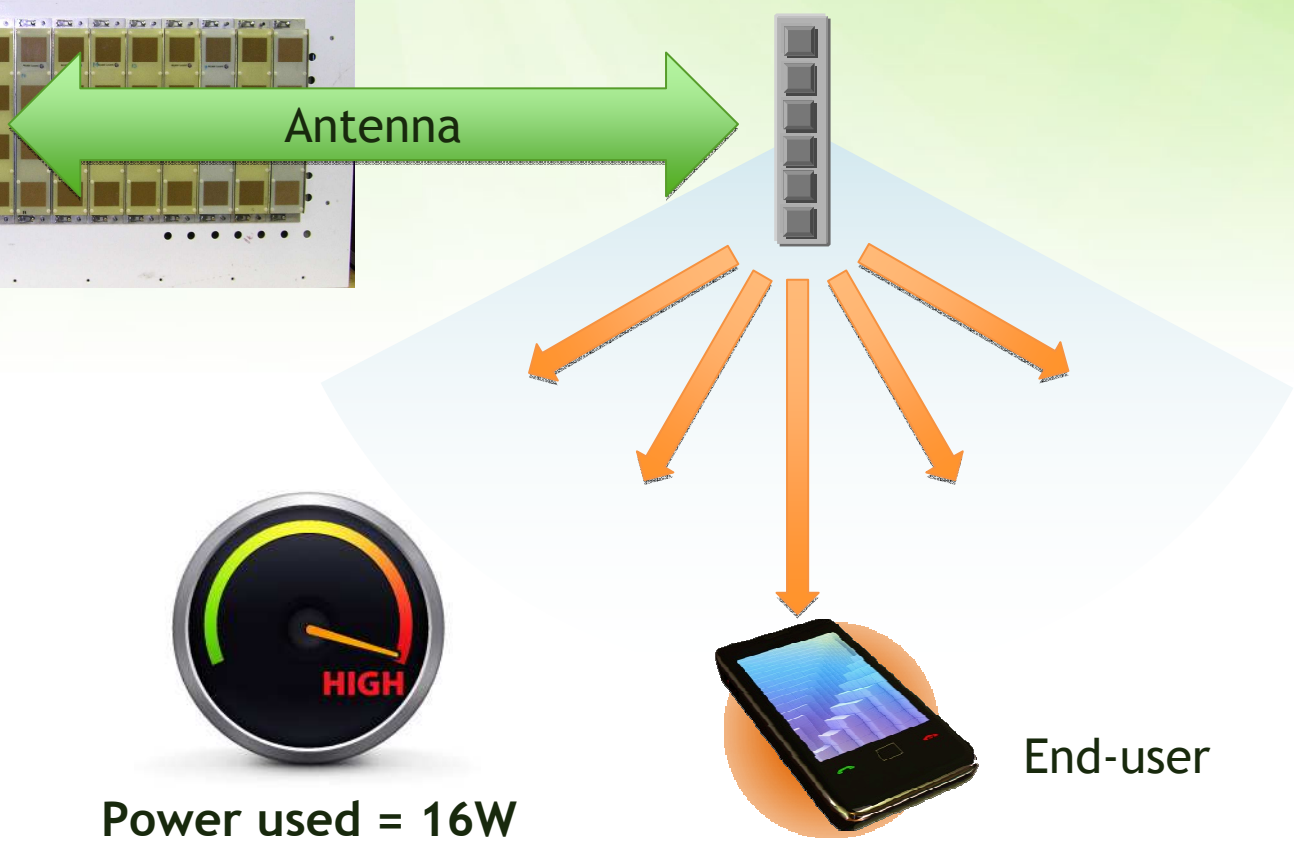
Alcatel·Lucent

GreenTouch™

Current Antenna Technology

16 element antenna array

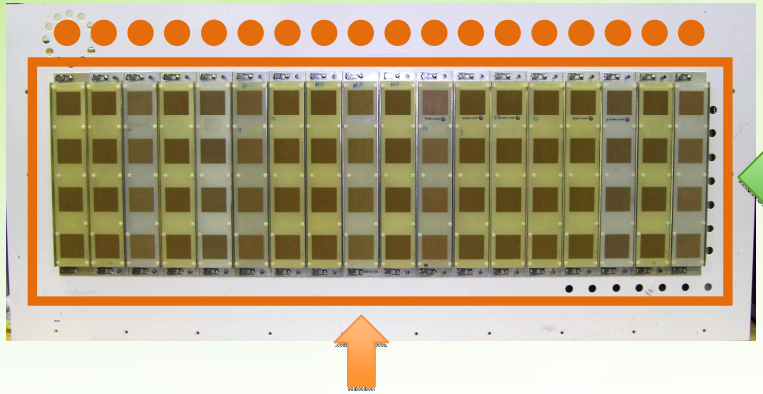




Power used = 16W

End-user

Large Scale Antenna System Demonstration

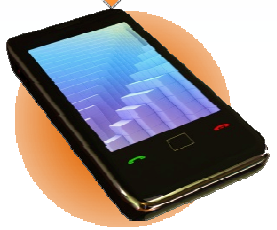


Antenna

16 Antennas → 16x power reduction!

Collaborators:
Bell Labs
Freescale
Huawei
imec
Samsung

Power used = 1W



End-user

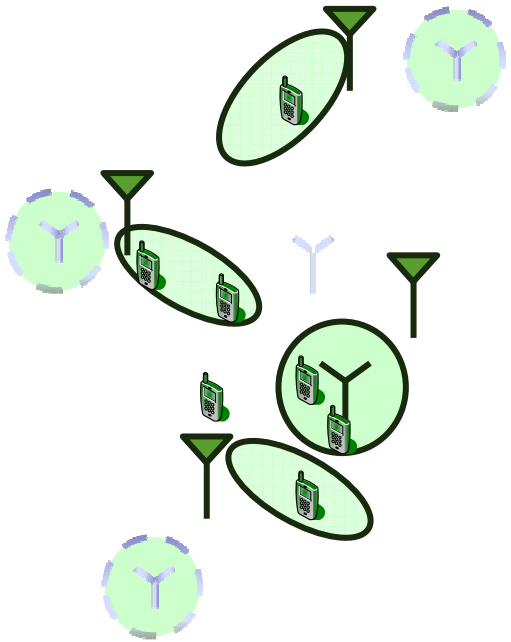
Alcatel·Lucent

GreenTouch™

Beyond Cellular Mobile

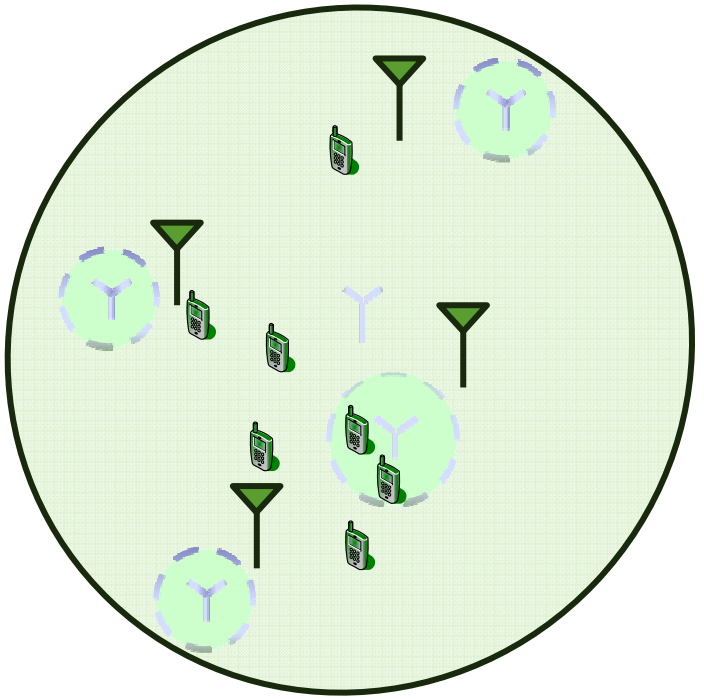
Separating Data Network from Signaling Network

Data Network



Collaborators:
Bell Labs
Huawei
Samsung
INRIA

Signaling Network

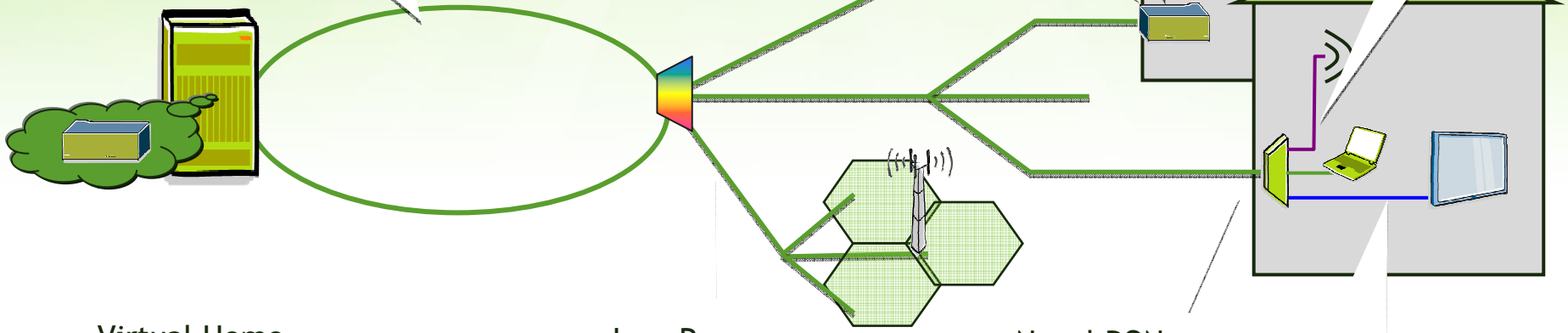


Mobile Communications Working Group

Alcatel·Lucent

GreenTouch™

Wireline Access



Min. Energy Access Architectures

ceet centre for energy-efficient telecommunications — BELL LABS AND UNIVERSITY OF MELBOURNE

ETRI Electronics and Telecommunications Research Institute

Un-cooled Tunable Lasers

UNIVERSITY OF CAMBRIDGE

DCU Dublin City University School of Electronic Engineering

Sleep Modes

HUAWEI

DSP Platforms for Wireless Home Network

imec

Virtual Home Gateway

FRENCH NATIONAL INSTITUTE FOR RESEARCH IN COMPUTER SCIENCE AND CONTROL — INRIA

swisscom

Low Power OFDM in Optical Access

ATHENS INFORMATION TECHNOLOGY 2002 Perceptum ex Optimus

AIT CENTER OF EXCELLENCE FOR RESEARCH AND EDUCATION

Novel PON Protocols; Low Power Customer Premises Equipment

Bell Labs

ceet centre for energy-efficient telecommunications — BELL LABS AND UNIVERSITY OF MELBOURNE

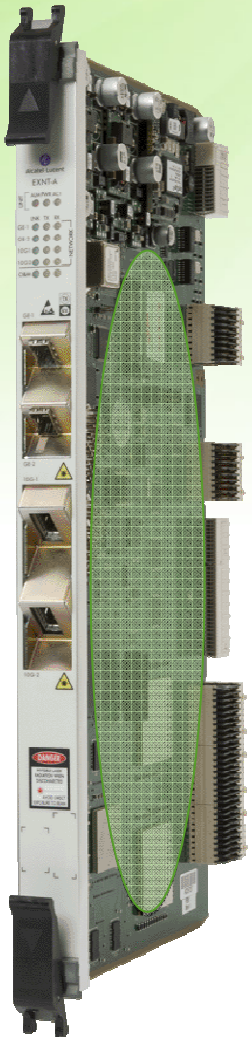
Fiber in the Home

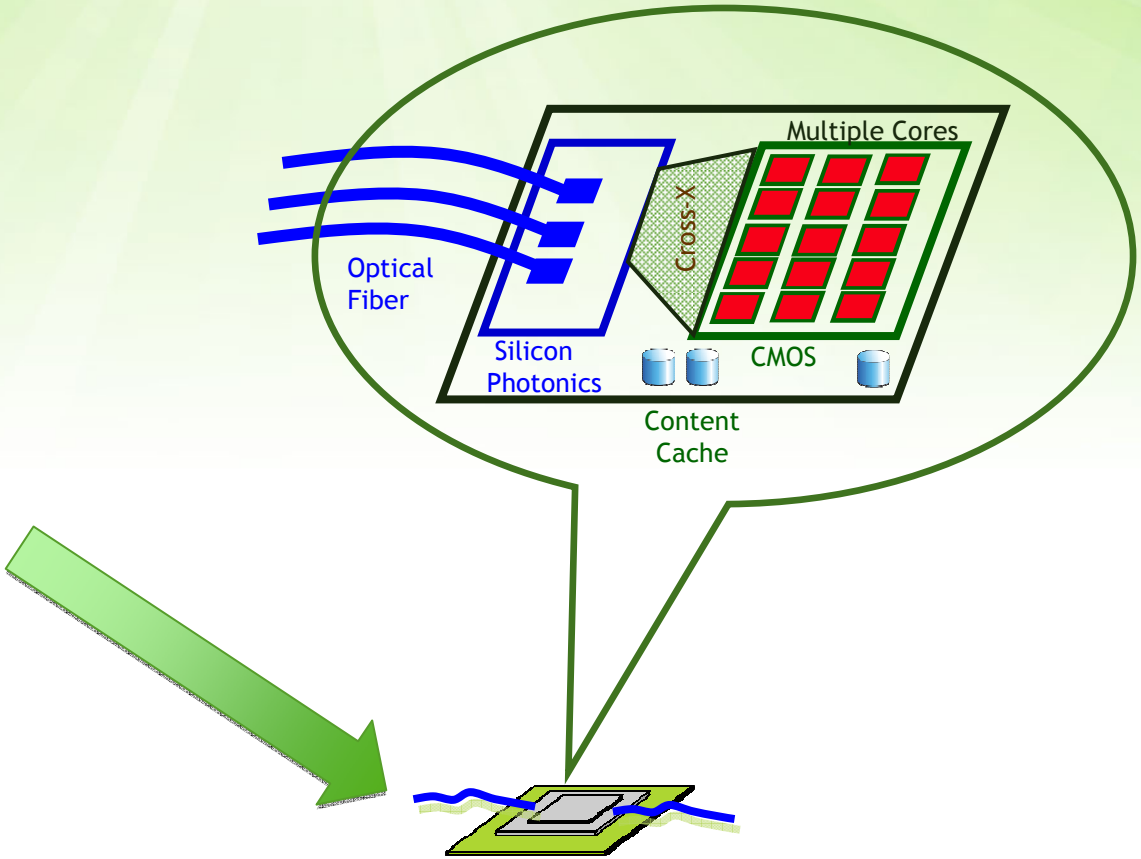
Draka

Alcatel·Lucent

GreenTouch™

Single-Chip Router Linecards





Hybrid Electronic – Photonic Chip

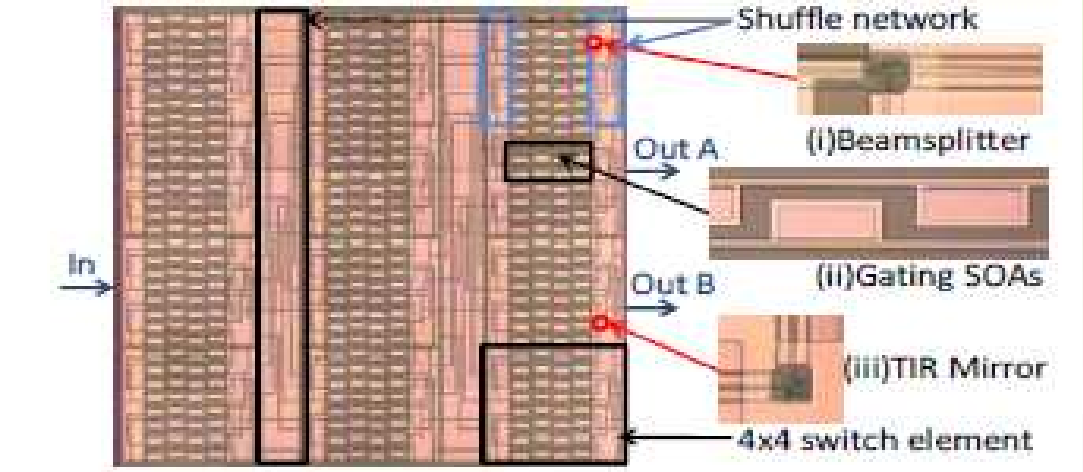
Core Switching & Routing Working Group

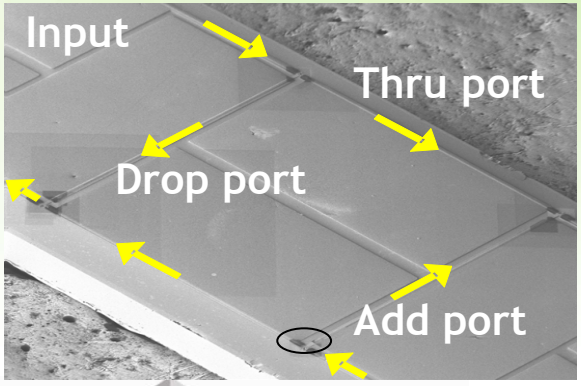
Alcatel·Lucent

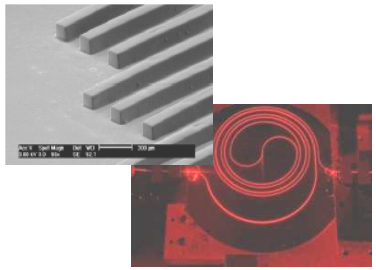
GreenTouch™

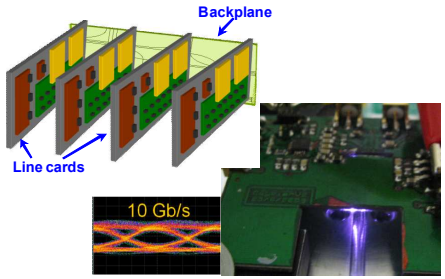
Cooperation Among Diverse Research Groups & Consortia

- Cooperating Project INTERNET: INTelligent Energy awaRe NETworks

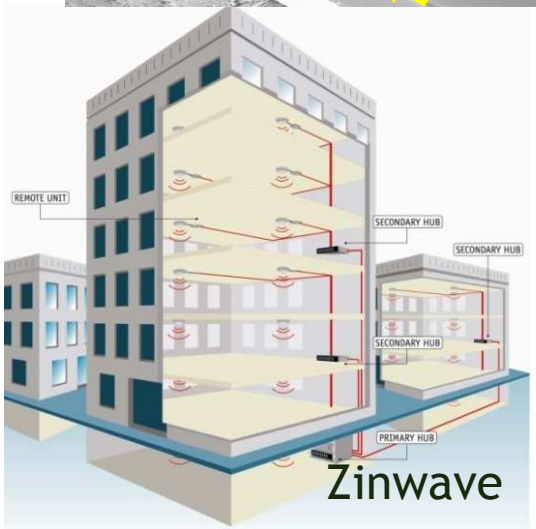








UNIVERSITY OF CAMBRIDGE



UNIVERSITY OF LEEDS

Alcatel·Lucent

GreenTouch™

Conclusions

- Eco-sustainability is crucial for ICT
  - Networks are key part of overall social strategy to reduce carbon footprint
  - Essential tool in realizing sustainable living
  - Benefit must be reconciled against network growth
- Scaling networks is becoming harder
  - Cannot rely on semiconductors alone
  - The industry just doesn't have a current solution
- Understanding energy use in networks is a complex
  - Many trade-offs to be considered
  - Potential for large efficiency improvements from task specific design
  - Integration is essential for minimizing common equipment energy
  - Focus shifting to components, systems, & networks

Thank You

GreenTouch™

www.greentouch.org

Alcatel·Lucent

GreenTouch™