Research in GreenTouch™

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Power Consumption of the Global Internet

- Global electricity supply: $10^{13}$ W
- Power Consumption of Internet (Excluding data centres): $10^{12}$ W
- GreenTouch goal: $10^{10}$ W
- 40% p.a. Data growth
- 10% p.a. Growth in user numbers
- 3% p.a. growth
- 0% p.a. efficiency gains
- 15% p.a. efficiency gains

Sources: Hinton et al., Tucker, IEEE
Inside the Network

- **Core Network**
  - Core Router
  - Fiber
  - Hot spots

- **Metro/Edge Network**
  - Edge Routers
  - Broadband Network Gateways
  - Ethernet Switch

- **Access Network**
  - DSLAM
  - DSL
  - Fiber
  - FTTP
  - PON
  - OLT
  - Fiber
  - FTTN

- **Data Center**
  - Server
  - Storage

- **Content Distribution Network**
  - Server
  - Storage

- **Content Distribution Network**
  - Storage

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GreenTouch

ceet centre for energy-efficient telecommunications

Bell Labs and University of Melbourne
Energy per Bit in Key Equipment

Source: O. Tamm et al. 2010

[Bar chart showing energy per bit for different equipment types over years 2005 to 2019.]

- Router
- Packet switch
- SDH Cross-connect
- OTN Cross-connect

Year:
- 2005
- 2007
- 2009
- 2011
- 2013
- 2015
- 2017
- 2019

Energy per Bit (nJ):
- 0
- 2
- 4
- 6
- 8
- 10
- 12
- 14
- 16
- 18
- 20
Router Energy Consumption Trends

Router Energy Efficiency

Linear fit gives ~25% improvement pa

Actual improvement may be declining

Source: Nielsen, ECOC 2011
Internet Traffic Growth Trends

Source: Kilper et al., JSTQE 2011
Data Centers and Content Servers

- **Load-Balancing Switches**
- **Aggregation Switches**
- **Racktop Switches**
- **Racks of Servers**
- **Border Routers**

- 15% of traffic to users
- 5% of traffic to other data centers
- 80% of traffic stays in data center
Gap Between Theory and Practice

Source: Tucker, JSTQE 2011
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.

- Global research consortium representing industry, government and academic organizations
- Launched in May 2010
- 52 member organizations
- 300 individual participants from 19 countries
- 25+ projects across wireless, wireline, routing, networking and optical transmission
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
Power Consumption of Wireless Access

Total Energy = 2 TWh/yr
0.1W per user for 3 billion Subscriptions

Total Energy = 60 TWh/yr
1kW per Base Station for 4 million Base Stations

Total Energy = <1 TWh/yr
1kW per controller for 10,000 Controllers

Total Energy = 14 TWh/yr
10kW per user for other elements

The greatest opportunity to reduce energy consumption is to improve base stations.

Based on: ETSI RRS05_024, NSN
Green Wireless Opportunities (1)

**Deployment:**
- Relays Nodes
- Multi RAT
- Heterogeneous Networks

**Network Management:**
- BS cooperation, Adaptive NW configuration

**Multi-Antenna Techniques:**
- Reconfigurable antennas, Beam forming, Spatial multiplexing
Green Wireless Opportunities (2)

Radio Resource Management:

Energy efficient scheduling, Sleep modes, Bandwidth Adaptation

- Saved energy
- Telecom traffic

Power consumption model per cell

- Constant power
- Variable power
- DTX power
- PA utilization

Graph of Power Consumption per Cell [W] vs Time [h]

- SOTA
- BW Adaptation
- Capacity Adaptation
- Micro DTX

Resource blocks:
- Resource block with data
- Resource block with pilots only
- Empty resource block

Load scenarios:
- High load: Most resources used
- Low load: Capacity adaptation
- BW adaptation: Pilots suppressed
Some Specific Router Limitations

INTERCONNECTS

18 Chip-to-chip Interconnects

PACKET SIZE

IPv4 Cumulative

http://www.caida.org/research/traffic-analysis/pkt_size_distribution/graphs.xml

ENERGY DOES NOT FOLLOW LOAD

Router T1600 (640Gb/s)

D. Kharitonov, “2009 IEEE GLOBECOM Workshops”
Efficient Switching and Routing

SCORPION:  SILICON PHOTONIC INTERCONNECT AND SINGLE CHIP LINE CARD

Contributing Members
Bell Labs
Contributing Members

Bell Labs

PoliMi
Bell Labs

UNSW

Bell Labs

Univ. of Toronto

Energy-aware wavelength routing & protocols

Univ. of Toronto

Columbia Univ.

CEET

INRIA

Service-aware flow switching

Multi-fiber, silicon-photonic fast switching & control devices

Robust & distributed multi-layer control

End-to-end FEC

Energy & locality aware placement and execution of app center services
OPERA:
OPTIMAL END TO END RESOURCE ALLOCATION

Contributing Members
REPTILE: ROUTER POWER MEASUREMENTS

Contributing Member

GreenTouch

CEET (Centre for Energy-Efficient Telecommunications)
Wireline Access Networks

- Virtual HGW
- Un-cooled tunable lasers
- PON Sleepmode
- Min. energy access architectures
- Hybrid PON
- Low power OFDM in optical access

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Novel PON protocols; Low power CPE

INTEC design

Fiber in the Home

Also:
- TNO
- ZTE, KAIST
Wireline Access Networks

Bit-Interleaved PON

Conventional PON

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Status of GreenTouch

- Over 15 research programs and 25 research projects
  - Wireless and mobile communications
  - Wireline access
  - Core networks and optical transmission
  - Services, applications and trends

- New approaches being taken:
  - Devices and low power electronics / photonics
  - Architectures, algorithms and protocols
  - “Power-follows-load” intelligent management
  - Service and energy optimized networks

- Two major public demonstrations in wireless and fiber-to-the-home technologies

- Establishing and defining common reference architecture and roadmap with strategic research directions

- New members are welcome!