Core Switching and Routing Working Group
Overview, Research Targets and Challenges

Thierry E. Klein
Chair, Core Switching and Routing Working Group
GreenTouch Open Forum
November 17th, 2011
Overview

- Core Switching and Routing Working Group
  - Technology Limitations
  - Energy Efficiency Challenges
  - Focus Statement
  - Membership
- Energy Efficiency Improvement Opportunity
- Research Targets
- Key Research Projects and Activities
Past and Anticipated Internet Growth

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

Internet Traffic Growth Rate

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>ANNUAL GROWTH RATE (%)</td>
<td>250</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>50</td>
<td>24-53%/year</td>
</tr>
</tbody>
</table>

RHK - NA  McKinsey - NA  MINTS - Global  Arbor - Global

SKK, 2010 (Sources: RHK, 2004; McKinsey, JPMorgan, AT&T, 2001; MINTS, 2009; Arbor, 2009).
Traffic Growth and Technology Slow-Down

- Traffic doubling every 2 years
  - 40% per year
  - 30x in 10 years
  - 1000x in 20 years
- Slow-down in technology
  - Network energy efficiency increasing 10-15% per year
- Leading to an energy gap
Some Specific Router Limitations

*INTERCONNECTS*

- Optics
- Framers
- L2 Buffering

*18 Chip-to-chip Interconnects*

- L1+L2

- Output Queuing
- Input Queuing

- Receive Fwd Engine
- Fabric Interface

- Buffer Mem

- Switch Fabric
- Switch Fabric

**ENERGY DOES NOT FOLLOW LOAD**

**PACKET SIZE**

IPv4 Cumulative


http://www.caida.org/research/traffic-analysis/pkt_size_distribution/graphs.xml
Focus Statement for Core Switching and Routing

Focused on components, technologies, systems, algorithms and protocols at the data link layer (L2), the network layer (L3) and the transport layer (L4) as well as interactions with lower and higher layers and research efficiencies that can be obtained from cross-layer optimizations and joint designs

- **Network equipment hardware (routers and switches)**
  - Architecture and components
  - Functions, features and dimensioning
  - Low energy technologies (including electronics, photonics, etc)
  - Power measurements

- **Network topologies and architectures**
  - Tradeoff between optical and electronic data transport
  - Optimal joint IP-optical network design
  - Packet versus circuit-switched architectures
  - Energy efficient and simplified routing

- **Integration of application and transport layers**
  - Cross-layer optimization for efficient content distribution

- **Traffic engineering**
  - Bandwidth allocation & traffic grooming
  - Elimination of over-provisioning
  - Efficient protection and restoration
  - Multicasting, elimination of junk and redundant traffic ....

- **Network management, operation and control**
  - Quality of service support
  - Network-wide reconfiguration and control of network elements (offline or online). Holistic, end to end approach
  - Protocols and algorithms for managing and controlling network elements
  - Control and data plane
  - Energy and traffic monitoring
Working Group Membership

- Athens Information Technology (AIT)
- Bell Labs (Chair: Thierry Klein)
- Broadcom
- Chunghwa Telecom
- Columbia University
- Dublin City University
- Electronics and Telecommunication Research Institute (ETRI)
- Energy Sciences Network / Lawrence Berkeley Labs
- Politecnico di Milano
- Freescale Semiconductor
- Fujitsu
- Huawei Technologies
- IBBT
- IIT Delhi
- INRIA
- KAIST
- Karlsruhe Institute of Technology
- Nippon Telegraph and Telephone Corporation
- Politecnico di Torino
- Samsung Advanced Institute of Technology (SAIT)
- Seoul National University
- University of Manchester
- University of Melbourne
- University College London
- University of Cambridge
- University of Leeds (Co-Chair: Jaafar Elmirghani)
- University of New South Wales
- University of Toronto

28 members organizations with 67 individual members
Energy Efficiency Improvement Opportunity

- Provide assessment of potential opportunities for power efficiency improvements in packet networks
  - Include the electronically switched portion of a service provider network, including IP, Ethernet and OTN
  - Excluding fixed and wireless access networks
  - Excluding optical transport
  - Excluding opportunities for traffic reduction, e.g. via caching

- Goal is to assess the opportunity for energy efficiency improvement with a realistic path towards realization within the GreenTouch timeframe

- Determine “independent” dimensions so that power efficiency numbers can be multiplied to arrive at overall efficiency opportunity
Background and Assumptions

- **Timeframe:**
  - Consistent with GreenTouch timeframe
  - Algorithms, architectures and technologies that can be demonstrated by 2015
  - With evolutionary improvements through 2020
  - Applied to 2020 traffic
  - Comparison with 2010 traffic and 2010 technologies

- **Assumptions:**
  - Consider the traditional IP packet data network framework
  - Alternative paths and technologies are possible, but more speculative and are not expected to fit in the timeframe:
    - Optical burst switching
    - Content centric networking
    - Adiabatic switching, quantum dot cellular automata, ....
Overall Efficiency Opportunity

- Defined 5 independent categories:
  - Chip level components and devices: 15x
  - Network element design: 1.5x
  - Network architecture: 2x
  - Dynamic resource management: 3x
  - Power utilization efficiency: 2x

- Overall power efficiency opportunity: 270x

- Caveats:
  - Numbers are best current estimates of efficiency improvement opportunity
    - Large degree of uncertainty especially around network element architecture and network architecture
  - Optimistic estimates since not clear if and how all the targets can be achieved
  - Pessimistic estimates since constrained to current IP packet network architectures and further-out technologies not considered
## Research Targets by Functional Topic (1)

<table>
<thead>
<tr>
<th>Research Target</th>
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<tr>
<td><strong>Chip Level Components and Devices</strong></td>
<td></td>
</tr>
<tr>
<td>Low power electronics and photonics</td>
<td>3x - 10x</td>
</tr>
<tr>
<td>Opto-electronic integrated circuits</td>
<td>3x - 10x</td>
</tr>
<tr>
<td><strong>Network Element Design</strong></td>
<td></td>
</tr>
<tr>
<td>Scalable and energy efficient router architectures for peta-bit routers</td>
<td>1.5x</td>
</tr>
<tr>
<td>Simplified and energy efficient protocols to eliminate unnecessary and redundant packet processing. Energy efficient software</td>
<td></td>
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<tr>
<td>Integrated transceiver and wavelength circuit switching fabric operating in a core network to eliminate routing infrastructure and reduce layer-2 switch energy/bit for targeted services</td>
<td>10x</td>
</tr>
<tr>
<td><strong>Network Architecture</strong></td>
<td></td>
</tr>
<tr>
<td>Network architectures, topologies and joint IP-optical design</td>
<td>3x - 10x</td>
</tr>
<tr>
<td>Energy efficient content routing (content router design, protocols and content placement and replacement algorithms)</td>
<td>10x</td>
</tr>
<tr>
<td>Energy optimized combined source and channel coding designed for end to end service dependent efficiency</td>
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<td>Research Target</td>
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<tr>
<td><strong>Dynamic Resource Management</strong></td>
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<tr>
<td>Rate adaptation and sleep cycles (processors, buffers, switch fabrics, linecards, router)</td>
<td>2x - 4x</td>
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<tr>
<td>Energy efficient routing</td>
<td>2x</td>
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<tr>
<td>Energy aware scheduling algorithms designed for delay tolerant services that enable end to end bufferless transmission respecting service QoS requirements</td>
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<tr>
<td>Power aware protection and restoration</td>
<td>2x</td>
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<td>Passive cooling and advanced thermal management</td>
<td>1.5x</td>
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- Requires equipment and network models with energy equations to determine overall energy efficiency improvement opportunity
- Gain understanding into which research targets are additive and multiplicative
- Gain understanding into most impactful research areas
SCORPION
Silicon Photonic Interconnects and Single-Chip Linecard

Contributing Members
Bell Labs
OPERA: OPtimal End to end Resource Allocation

Contributing Members

[Logos of various universities and organizations]
STAR: SwiTching And tRansmission

IP layer  WDM layer

Contributing Members

UNIVERSITY OF CAMBRIDGE

UNIVERSITY OF LEEDS

Bell Labs
ZeBRA: Zero Buffer Router Architecture

Contributing Members
REPTILE: Router Power Measurements

Contributing Members
TIGER: TIme for a Greener Internet

Time is Used to Synchronize/Pipeline Forwarding of Time Frames

Switch A

Switch B

Switch C

Time Frame containing a plurality of packets

Contributing Members
SEASON
Service Energy Aware Sustainable Optical Networks

Contributing Members

Bell Labs
University of Toronto
UNSW
CEET
Columbia Univ.
INRIA

Multi-fiber, silicon-photonic fast switching & control devices
Service-aware flow switching
Energy-aware wavelength routing & protocols
Energy & locality aware placement and execution of app center services
## Research Targets and Mapping to Projects (1)

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<td><strong>Network Architecture</strong></td>
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<tr>
<td>Network architectures, topologies and joint IP-optical design</td>
<td>OPERA, TIGER, ZeBRA, STAR, SEASON</td>
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<tr>
<td>Energy efficient content routing (content router design, protocols and content</td>
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<tr>
<td>placement and replacement algorithms)</td>
<td>CROCODILE (to be approved)</td>
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<tr>
<td>Energy optimized combined source and channel coding designed for end to end</td>
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<tr>
<td>service dependent efficiency</td>
<td>SEASON</td>
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## Research Targets and Mapping to Projects (2)

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