Architecting and Operating Energy-Efficient Networks

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Global research consortium representing industry, government and academic organizations

- Launched in May 2010
- Focus on sustainability and growth
- Holistic and ambitious: Goal of 1000x
- 57 member organizations
- 300+ leading scientists
- Recognized by the World Economic Forum as an industry-led best practice toward sustainability

- Moving from fundamental research into the pre-competitive area through standardization
- Leading Green ICT: cooperation with other NGOs such as GeSI, ITU-T, GreenGrid, Carbon Trust, ITRS
- Creating a new innovation model for sustainability

DELIVER ARCHITECTURE, SPECIFICATIONS AND SOLUTIONS AND DEMONSTRATE KEY TECHNOLOGIES TO INCREASE NETWORK ENERGY EFFICIENCY BY A FACTOR 1000 COMPARED TO 2010

Courtesy Greentouch
A NEW WIRELESS WORLD / INTERNET

Courtesy Thierry Klein
MASSIVE DATA TRAFFIC GROWTH

30x growth over 5 years!

Today

- 5 000 000 towers
- 17.5 GigaWatts
- ~ 9 Hoover Dams
- ~ 15 nuclear power plants

Future

- 78 Mtons of CO₂
- ~ 15M car emissions a year
- ~ 150,000 Paris to New York round-trip flights

MORE DATA MEANS MORE POWER

5 000 000 000 people without broadband

Courtesy Thierry Klein
ESnet5: Science at 100Gbps
Traffic Analysis – Growth Trends

ESnet Accepted Traffic: Jan 1990 - Apr 2012 (Log Scale)

Extrapolation: Expecting 100 Petabytes/month of data in 2015
From the IEEE 802 Plenary in San Diego in July.

Findings of the IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc
GROWING NETWORK ENERGY GAP

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

INTERNET = 5th HIGHEST COUNTRY
If the internet was a country: energy consumption is higher than Russia and a little less than Japan

ENERGY +27% INCREASE
Energy consumption in communications service provider (CSP) networks is forecast to increase by 27% from 2012 to 2016

Courtesy Thierry Klein
Content from Data Center to Client:
~ 3 hops in long haul
~ 10-15 hops in metro

Energy E consumed on:
~ Nodes, $E_n$
~ Transponders, $E_{tx}$
~ Amplifiers, $E_a$

Energy efficiency is all about getting content to users with minimum energy over network

Courtesy Yan Pan and Dan Kilper
Big Picture

Hardware Testbed

Simulation

Large-scale Dynamic Energy-efficient Network Mesh

Theoretical Analysis

$e = mc^2$
Sub-Networks

Wireless Access & Core
- eNB (LTE)
- SGW
- PGW
- NodeB

Residential Fixed Access
- ONU
- SPLT
- OLT

Metro/Edge Network
- Ethernet Switch
- ROADM
- Metro Router
- OTN

Enterprise Fixed Access
- Access Switch
- Agg’n Switch
- Core Sw
- Firewall/ WAN

Long-Haul Network
- Core Router
- OTN
- ROADM

Courtesy - Tutorial: Energy Efficient Networks
## Models for each Sub-Network

<table>
<thead>
<tr>
<th>Network</th>
<th>Efficiency Model (energy/bit)</th>
<th>Notes &amp; Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Access</td>
<td>[ \frac{P_{TU}}{A \cdot N_{TU}} + \frac{P_{cpe}}{A} ]</td>
<td>CPE does not include CATV, A is the access rate</td>
</tr>
<tr>
<td>Edge Aggr.</td>
<td>[ \eta_{pr} \eta_c \frac{P_{Eth}}{C_{Eth}} ]</td>
<td></td>
</tr>
<tr>
<td>Metro</td>
<td>( (H_M + 2)\eta_{pr} \eta_c \left( \frac{P_R}{C_R} + \frac{P_{OTN}}{C_{OTN}} \right) + H_M \eta_{pr} \eta_c \left( \frac{P_{TR0}}{C_{TR0}} + \frac{1}{2} \frac{P_{TR1}}{C_{TR1}} \right) )</td>
<td>One metro hop is taken to be an inter-carrier exchange point with no transmission between routing equip.</td>
</tr>
<tr>
<td>Long Haul</td>
<td>( (H_{LH} + 1)\eta_{pr} \eta_c \left( \frac{P_R}{C_R} + \frac{P_{OTN}}{C_{OTN}} \right) + H_{LH} \eta_{pr} \eta_c \left( \frac{P_{TR0}}{C_{TR0}} + \frac{P_{TR1}}{C_{TR1}} \right) )</td>
<td></td>
</tr>
<tr>
<td>Enterprise</td>
<td>[ \eta_{pr} \eta_c \left( \frac{P_{AS}}{C_{AS}} + \frac{P_{AgS}}{C_{AgS}} + \frac{P_{CS}}{C_{CS}} + \frac{P_{FW}}{C_{FW}} \right) ]</td>
<td></td>
</tr>
<tr>
<td>Mobile</td>
<td>[ \frac{P_{BTS} N_{BTS}}{N_{U} T_{M}} + \eta_{pr} \eta_c \left( \frac{P_{PGW}}{C_{PGW}} + \frac{P_{SGW}}{C_{SGW}} \right) ]</td>
<td>LTE model with converged voice and data, ( T_W ) is a reference wireless access rate per user</td>
</tr>
</tbody>
</table>

Courtesy - Tutorial: Energy Efficient Networks
Optimizing Network architectures for Energy consumption

Computation model requires

• Large Scale
• End to End
• Multi-Layer
• Dynamic Traffic/Flows
• Dynamically configured networks
• Energy model specifications
Cross Layer, from nano-scale to macro-scale

• Glue physical-layer simulation with packet-level simulation
  – Scaling in time and size
    • Large network sizes
    • Long times (year+)
  – Adjust simulation granularity and accuracy
    • For long times
  – Fine time simulation for dynamic physical layer
    • Optical transients
    • Buffer occupancy in packet queues
  – Built in power models

• Optimization modules for the above
  – Optimize for power, layer, cost, etc.
An Example

Enhanced Network Simulator (NS2/NS3) (ECOFEN)

Packets, IP, TCP, buffers

Wavelengths, RWA, GMPLS, Impairments

ATOM: A Transparent Optical Mesh
ECOFEN: Energy Consumption Model For End-to-end Networks

Contributors
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Summary

• Networks are not designed with energy in mind
  – Modeling and simulation are needed together with real testbeds to calibrate

• Simulation capabilities include
  – Ability to provide different levels of abstraction
  – Capability to target wide range of time scales and behaviors of interest
  – Careful construction and validation of models derived from a deep understanding of the underlying technologies

• Cross-Layer, End-to-End
  – Application, packet and physical layer

• True simulations
  – To capture cross-layer interactions that cannot be captured by abstractions

Simulation of Energy efficiency and performance needed in order to scale and manage networks in the future
ESnet’s ANI power monitoring portal

Live at: https://my.es.net/ani/power (in beta over a testbed)

• Goal:
  • Establish a baseline power profile for end-to-end networking
  • Champion efficiency and optimization, both at device-level and network-wide
  • Expose live power dataset to researchers

• Metrics Proposed: Joules/bit
  – Power measured:
    • ALL network equipment (terminal servers, DNS servers, optical gear, L2/L3 etc) sans humans
  
  – Bits measured:
    • Useful bits i.e. bits delivered to customer
    • Does not count bits for operating the network

9/11/12