Architecting and Operating Energy-Efficient Networks

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GREENTOUCH™ (www.greentouch.org)

GreenTouch™

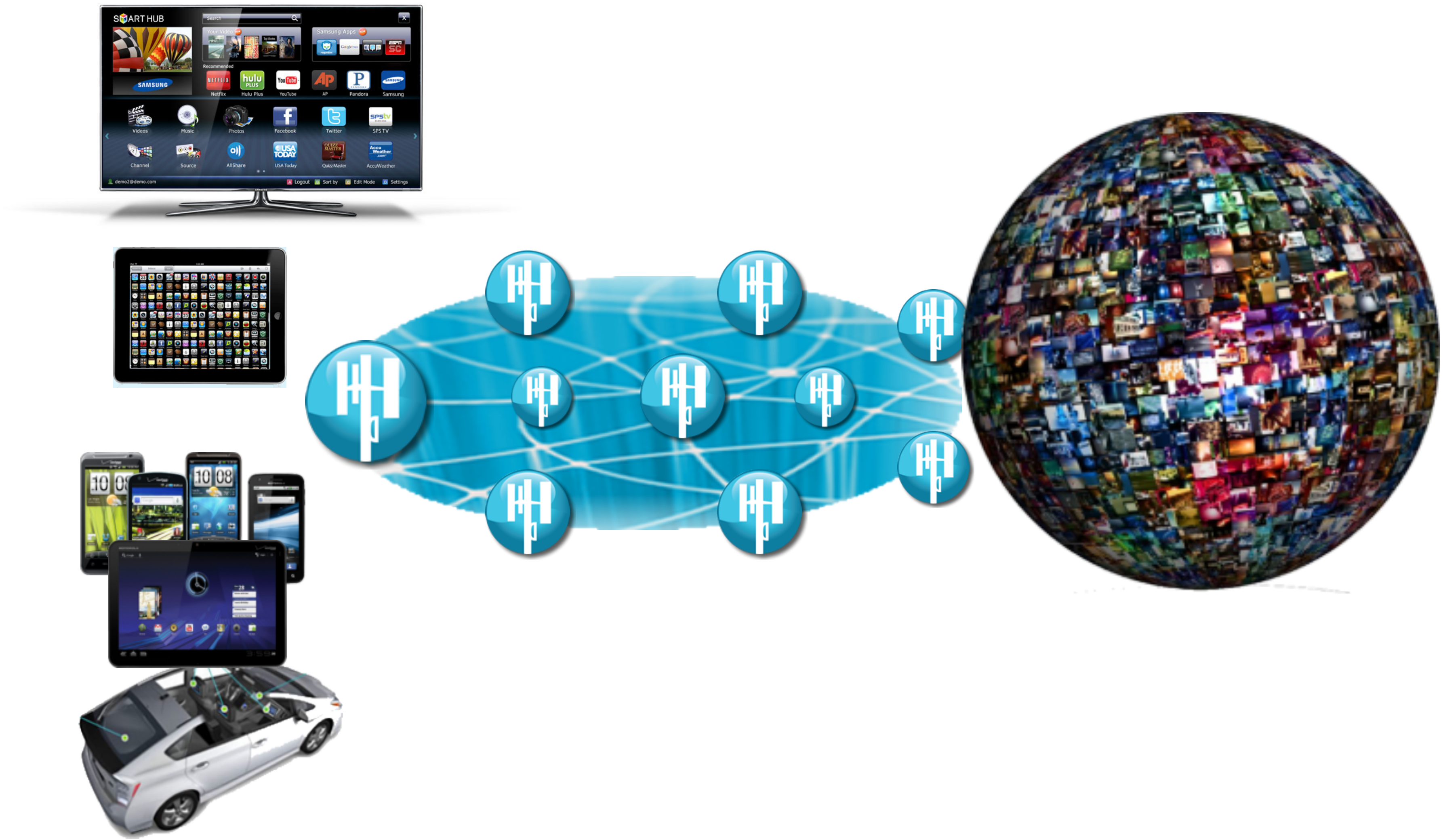
It takes an ecosystem

- 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

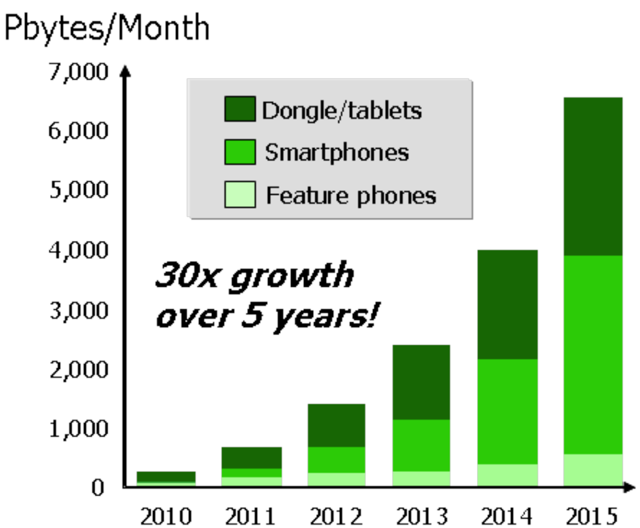
Courtesy Greentouch

A NEW WIRELESS WORLD / INTERNET



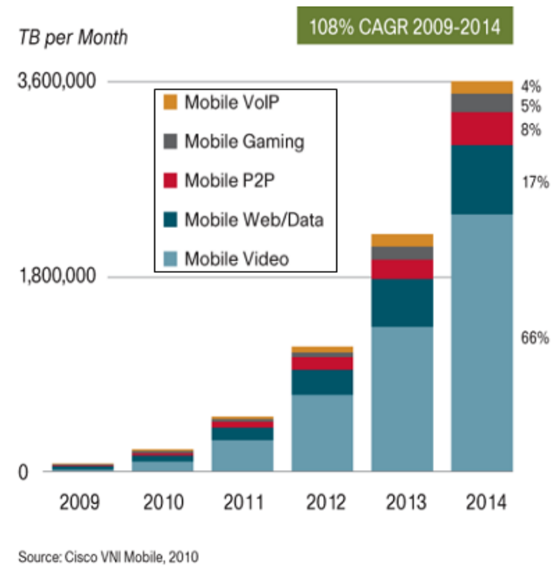
Courtesy Thierry Klein

MASSIVE DATA TRAFFIC GROWTH



Today

MORE DATA MEANS MORE POWER



Future

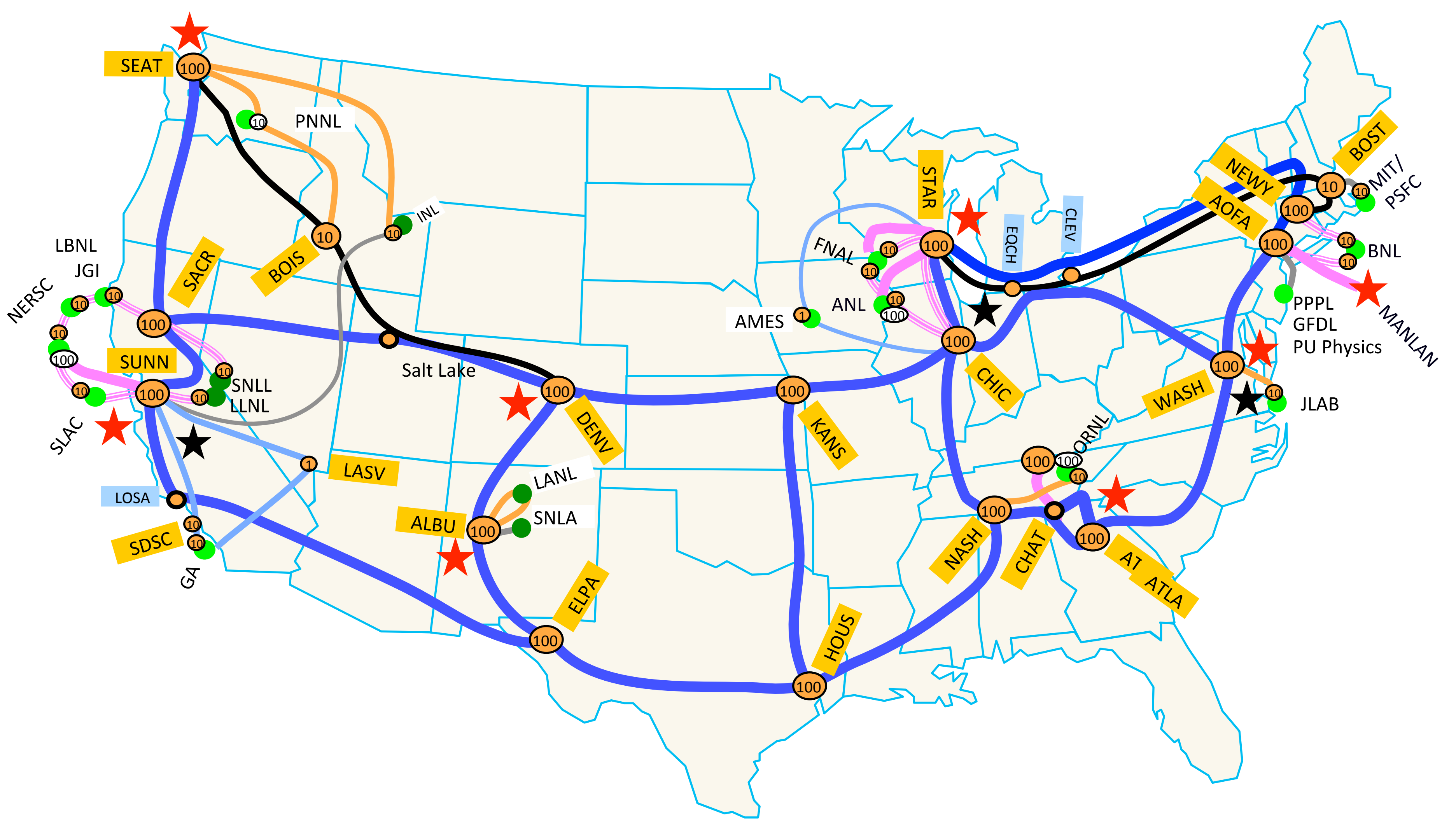
=

- 17.5 GigaWatts
- ~ 9 Hoover Dams
- ~ 15 nuclear power plants

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

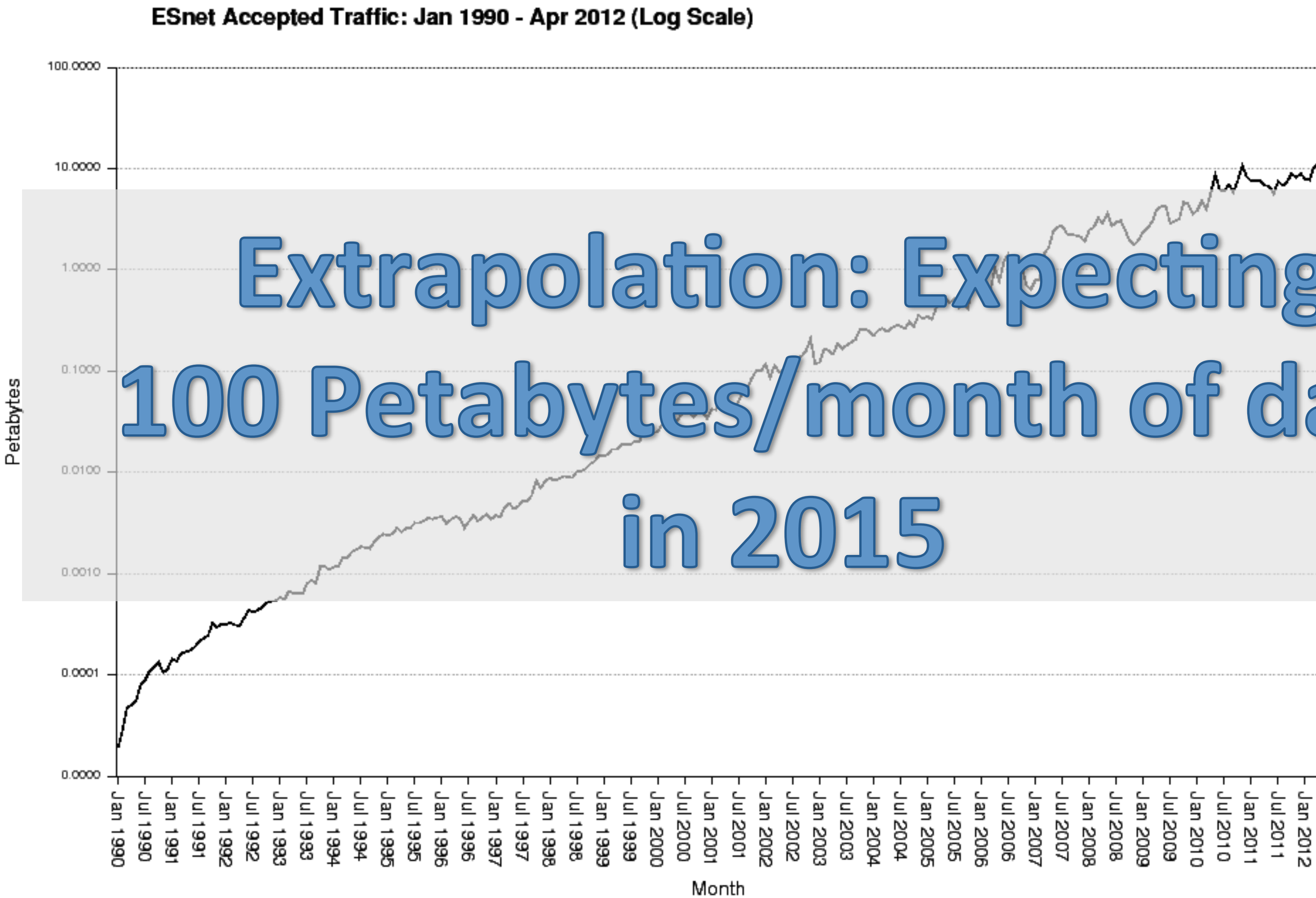
Courtesy Thierry Klein

ESnet5: Science at 100Gbps



Geography is only representational

Traffic Analysis – Growth Trends



Extrapolation: Expecting 100 Petabytes/month of data in 2015

NYSE > Science > all else

From the IEEE 802 Plenary in San Diego in July.

Findings of the IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc

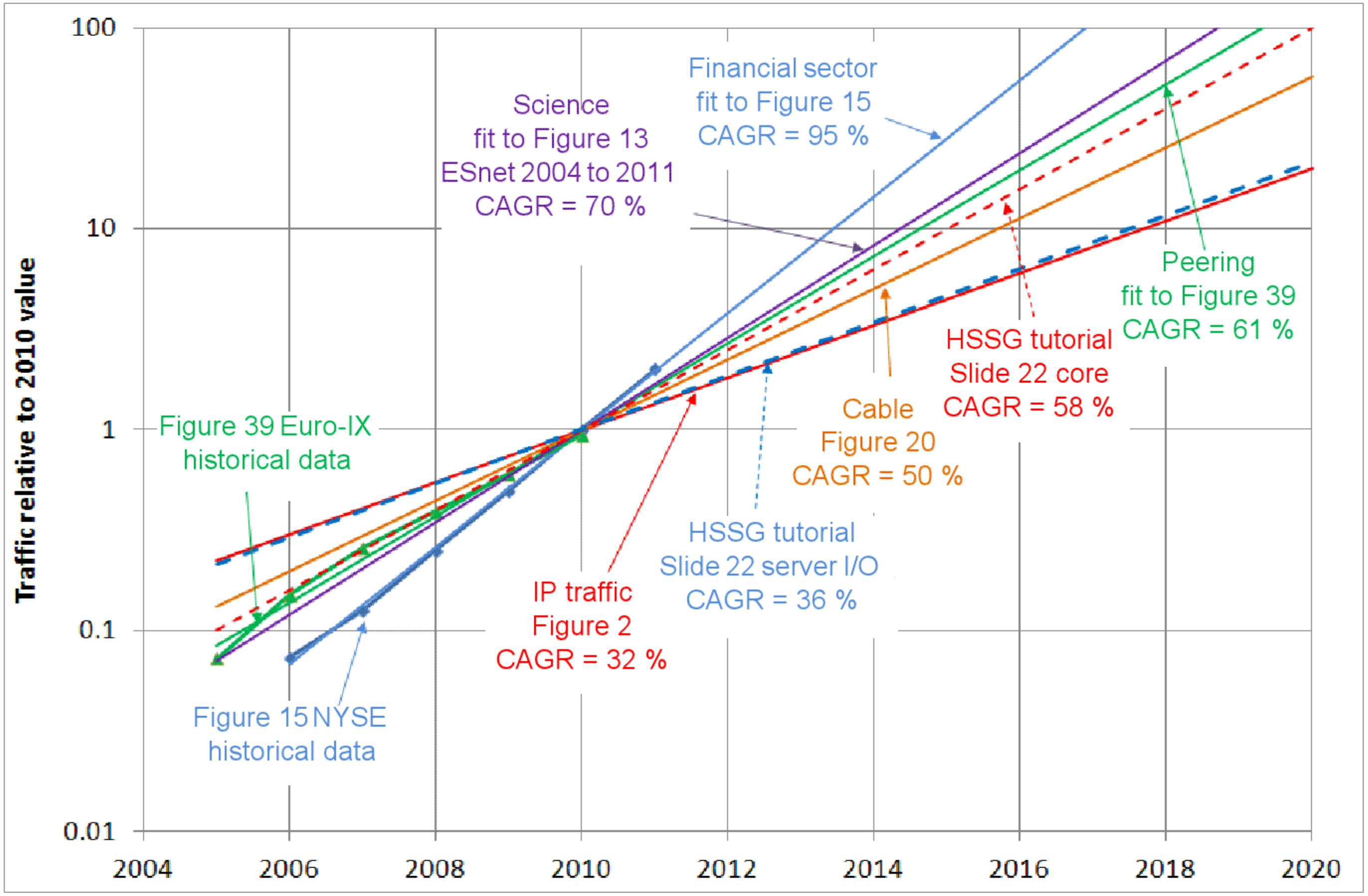


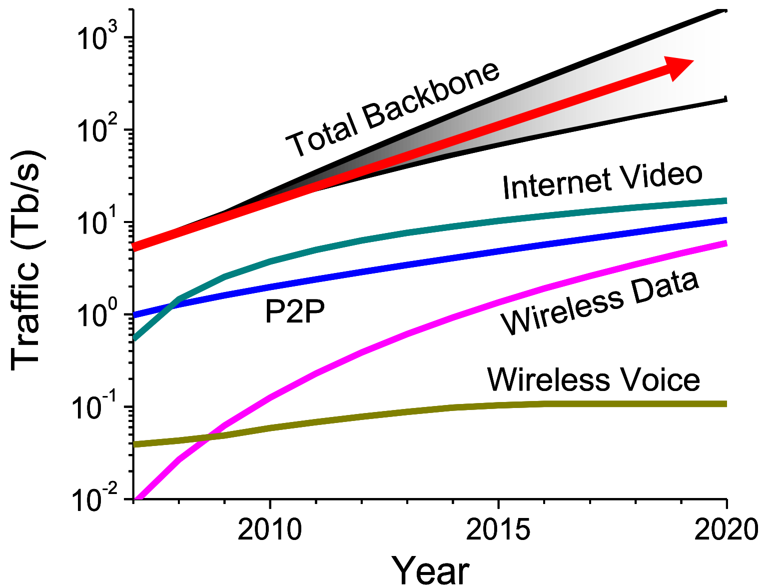
Figure 40—Relative traffic increase normalized to 2010

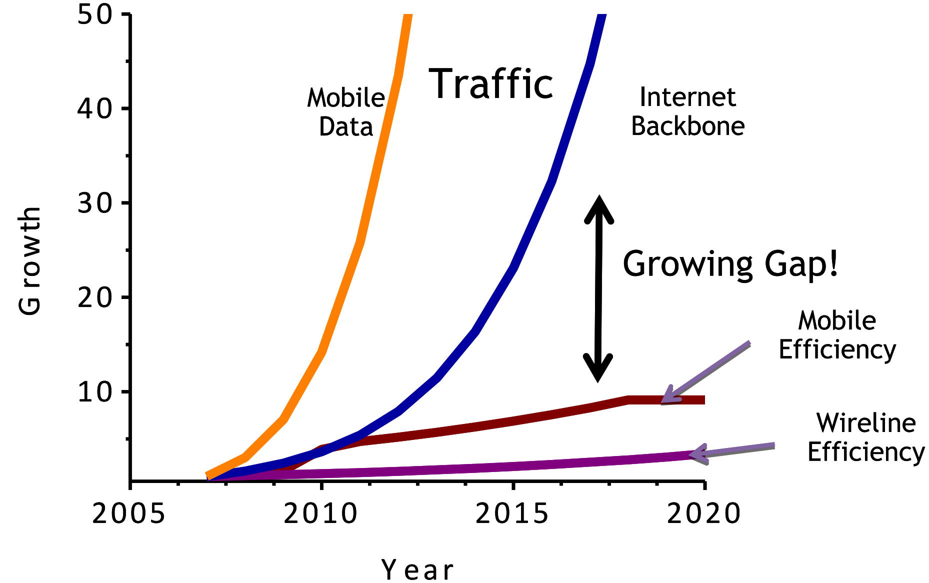
Source: Pete Anslow, Senior Standards Advisor, Ciena

http://www.ieee802.org/802_tutorials/2012-07/BWATutorial_D1_12_0716.pdf

GROWING NETWORK ENERGY GAP

North America





<u>Data from</u>: RHK, McKinsey-JPMorgan, AT&T, MINTS, Arbor, ALU, and <u>Bell Labs Analysis</u>: 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%

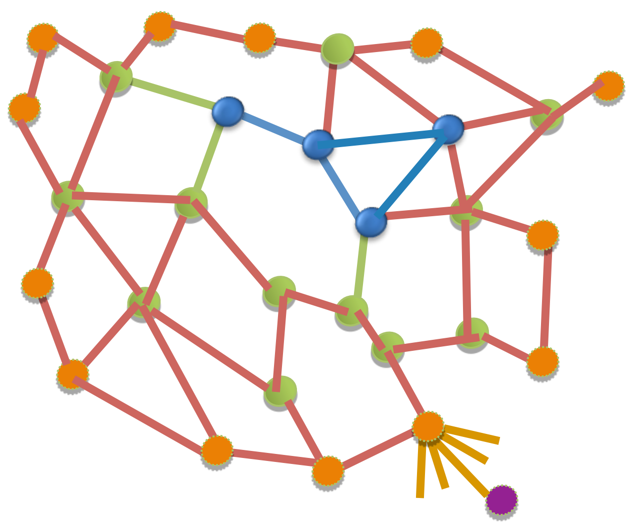
INCREASE

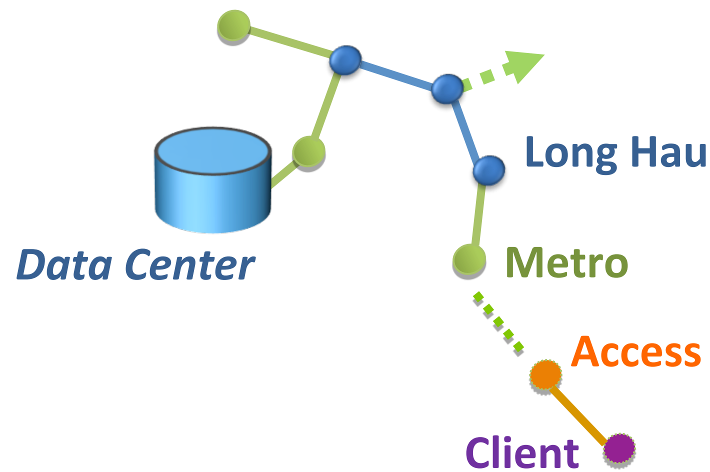
Energy consumption in communications service provider (CSP) networks is forecast to increase by 27% from 2012 to 2016

Courtesy Thierry Klein

Networks & Content & Energy …

GreenTouch™





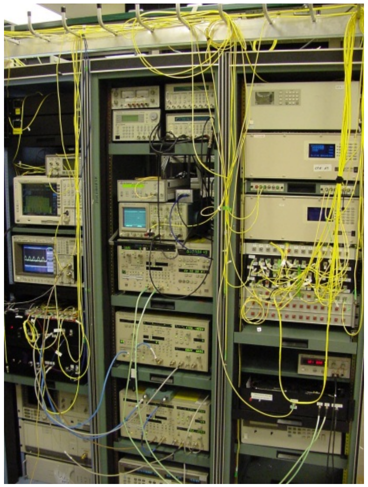
Content from Data Center to Client:
~ 3 hops in long haul
~ 10-15 hops in metro

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

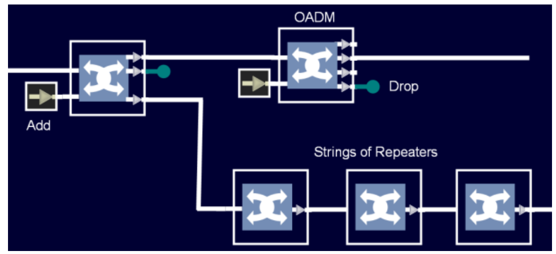
Energy efficiency is all about getting content to users with minimum energy over network

Courtesy Yan Pan and Dan Kilper

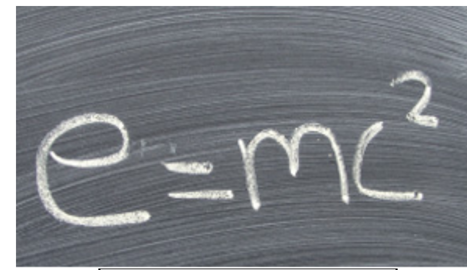
Big Picture



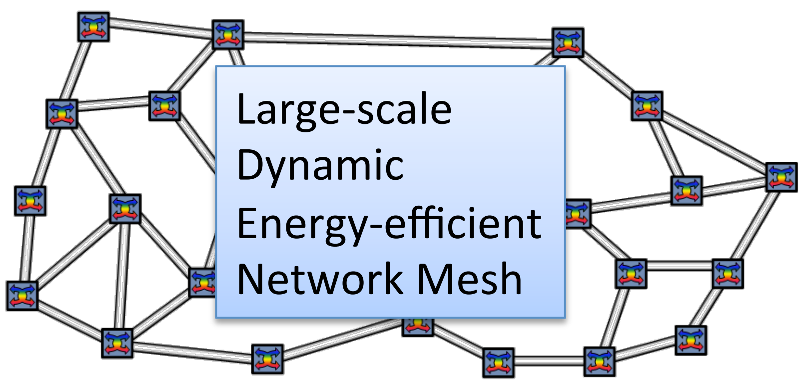
Hardware Testbed



Simulation

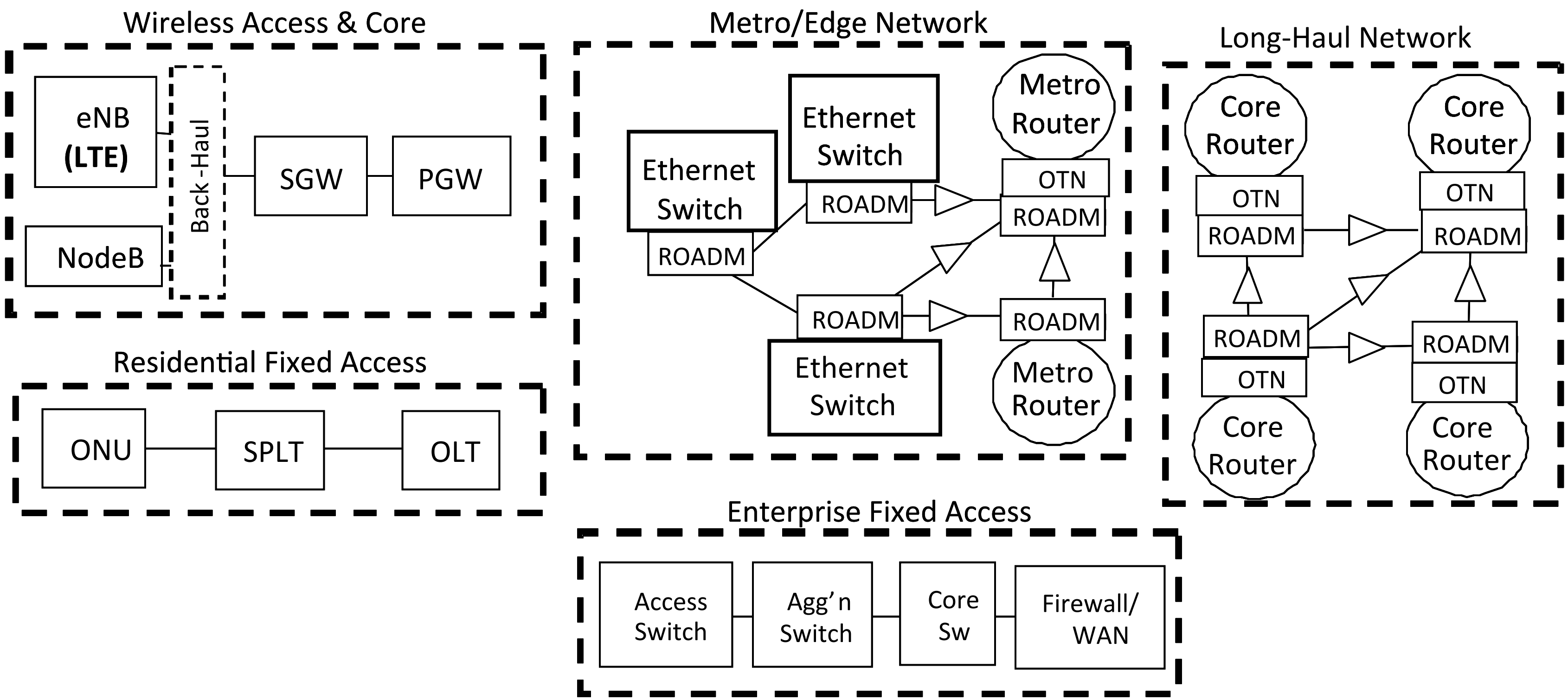


Theoretical Analysis



Large-scale
Dynamic
Energy-efficient
Network Mesh

Sub-Networks



Courtesy - Tutorial: Energy Efficient Networks

Models for each Sub-Network

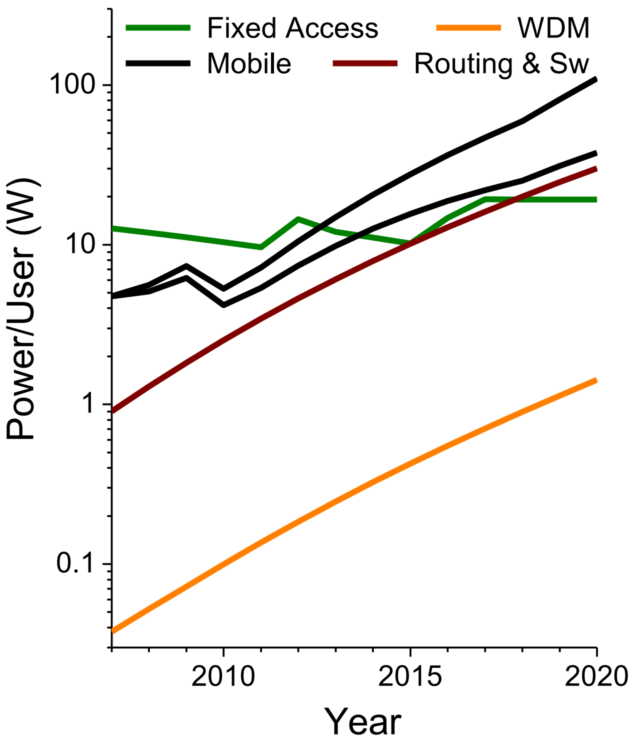
Network	Efficiency Model (energy/bit)	Notes & Exceptions
Fixed Access	$\frac{P_{TU}}{A \cdot N_{TU}} + \frac{P_{cpe}}{A}$	CPE does not include CATV, A is the access rate
Edge Aggr.	$\eta_{pr}\eta_c \frac{P_{Eth}}{C_{Eth}}$	
Metro	$(H_M + 2)\eta_{pr}\eta_c\left(\frac{P_R}{C_R} + \frac{P_{OTN}}{C_{OTN}}\right)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

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

Contributors
INRIA
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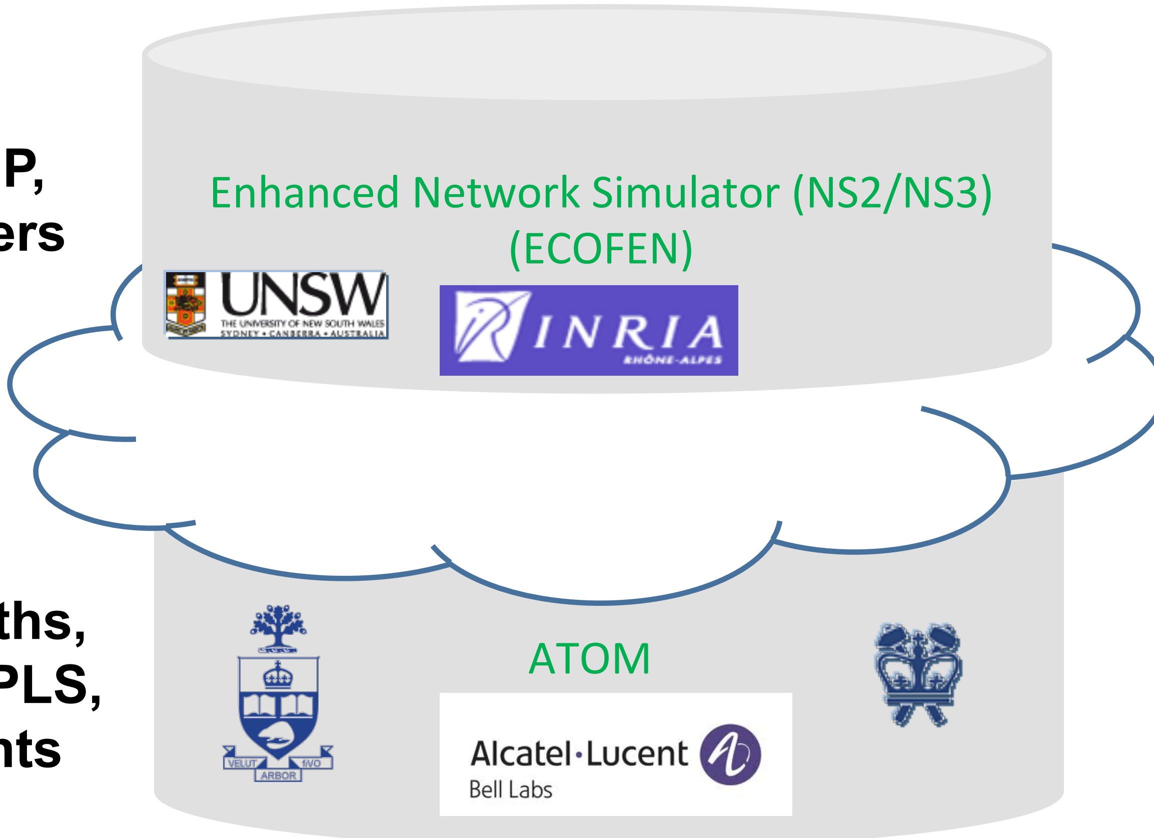
Columbia Univ.
Univ. of Toronto

Packets, IP, TCP, buffers



Wavelengths, RWA, GMPLS, Impairments

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

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**
  - <u>Power measured</u>:
    - **ALL network equipment** (terminal servers, DNS servers, optical gear, L2/L3 etc) sans humans
  - <u>Bits measured</u>:
    - Useful bits i.e. bits delivered to customer
    - Does not count bits for operating the network