GreenTouch™:
A Five Year Quest to Achieve Sustainable Networking

CMCC Update

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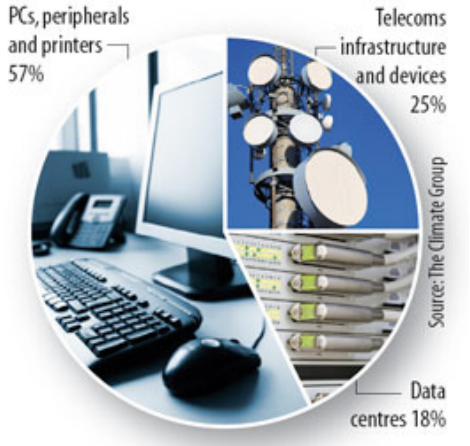
4 November, 2010

Sustainable Network Growth & Low Carbon Economy

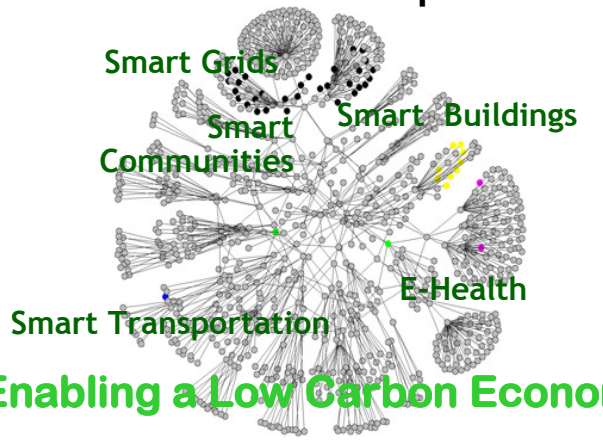
2007: ICT contributes 2% to global GHG



Total emissions: 1.43bn tonnes CO_2 equivalent

- World is going green, need to reduce GHG
- ICT network and data-traffic growth essential to social and economic progress and to low carbon economy
- Innovations have kept network energy consumption in check
- However innovation rate in key technologies is slowing: Moore's law, fiber capacity, router capacity

2020: ICT can offset 5X its own carbon footprint



Enabling a Low Carbon Economy

Huge opportunity to reinvent scalable networks that maximize energy-efficiency while reducing total-cost-of-ownership

GreenTouch™

By 2015, demonstrate architectures and technologies that yield a 1000-fold improvement in network efficiency (using 2020 traffic projections) over 2010 network efficiency

- Global consortium with **experts** from across industry and world's top institutions working together in matrix of **open** innovation
- **Pre-competitive** research that emphasizes clean slate architectures and **out-of-the-box** thinking
- **Broad support** and funding
- **Ambitious goal** in finite period of time

Goal Makes Both Environmental and Economic Sense

Green Services

Increased Revenue from Services

Growth

Increase

Bits per second

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

Watts

Reduce

Reduced Carbon Footprint

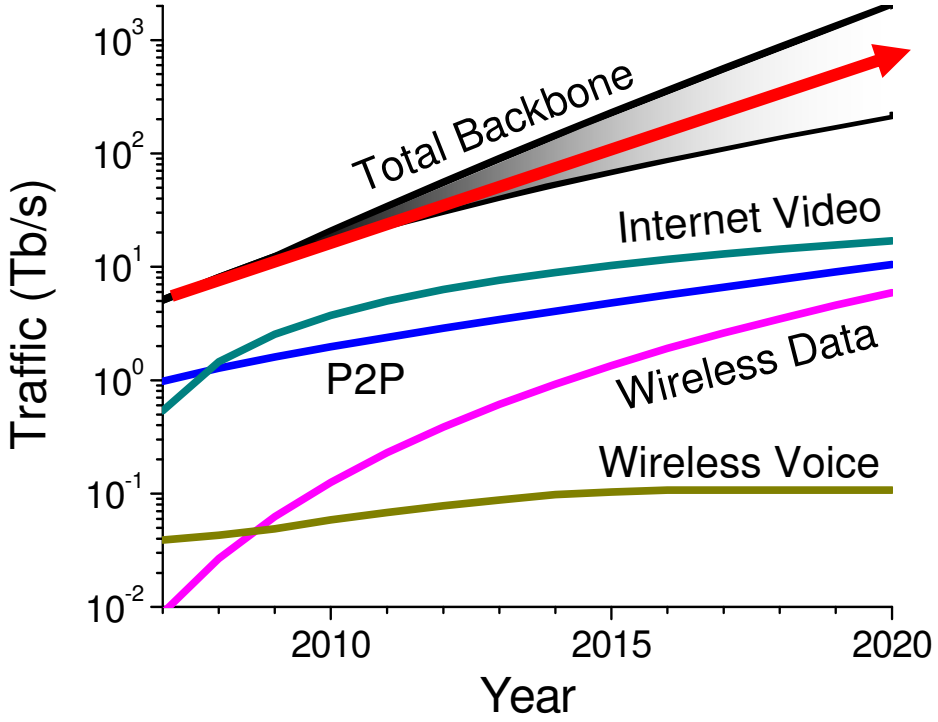
Reduced Costs

GreenTouch™ Members

AIT, AT&T, Bell Labs, CEA LETI, Columbia University, Draka, Dublin City University, Emerson Network Energy, ETRI, Freescale, Huawei, IBBT, IMEC, INRIA, K. A. Lueven, Karlsruhe Institute of Technology, Korea Telecom, Politecnico di Milano, Samsung, Seoul National University, Swisscom, University of Cambridge, University of Leeds, University of Maryland, University of Melbourne, University of New South Wales

Energy Consumption Driven by Exponential Traffic Growth

Bell Labs Traffic Projections for North America



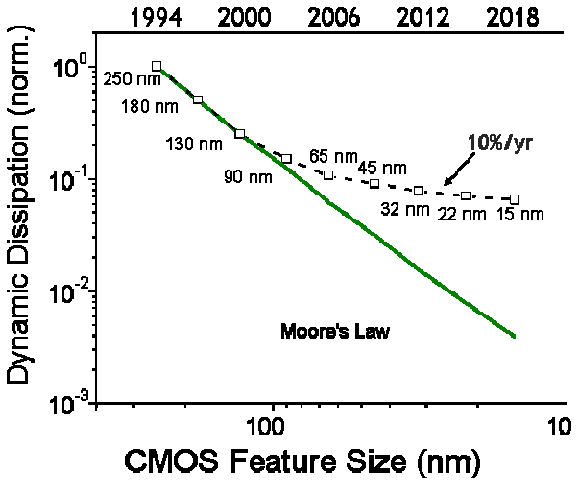
- Traffic Doubling every 2-3 years
- Continuous increases in equipment unit-capacity used to keep network energy in check
- Many technologies are slowing down

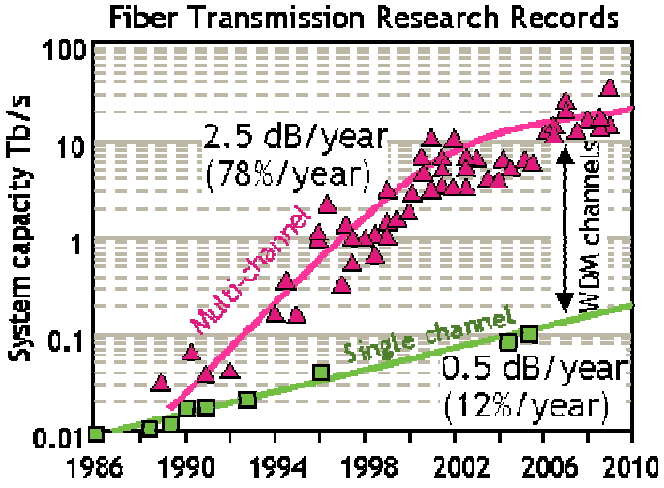
Data from: RHK, McKinsey-JPMorgan, AT&T, MINTS, Arbor, ALU, and
Bell Labs Analysis: Linear regression on log(traffic growth rate) versus log(time) with Bayesian learning to compute uncertainity

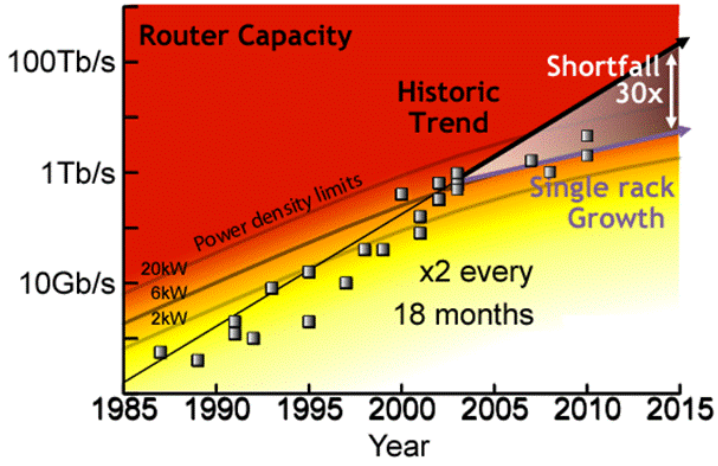
Slowdown in Technology

What do these slowdowns imply for energy efficiency of the entire network?

- Reduction in dynamic dissipation of silicon with feature size, is slowing.
- Capacity of single rack IP routers due to thermal density is saturating
- Capacity of a single fiber transmission system saturating







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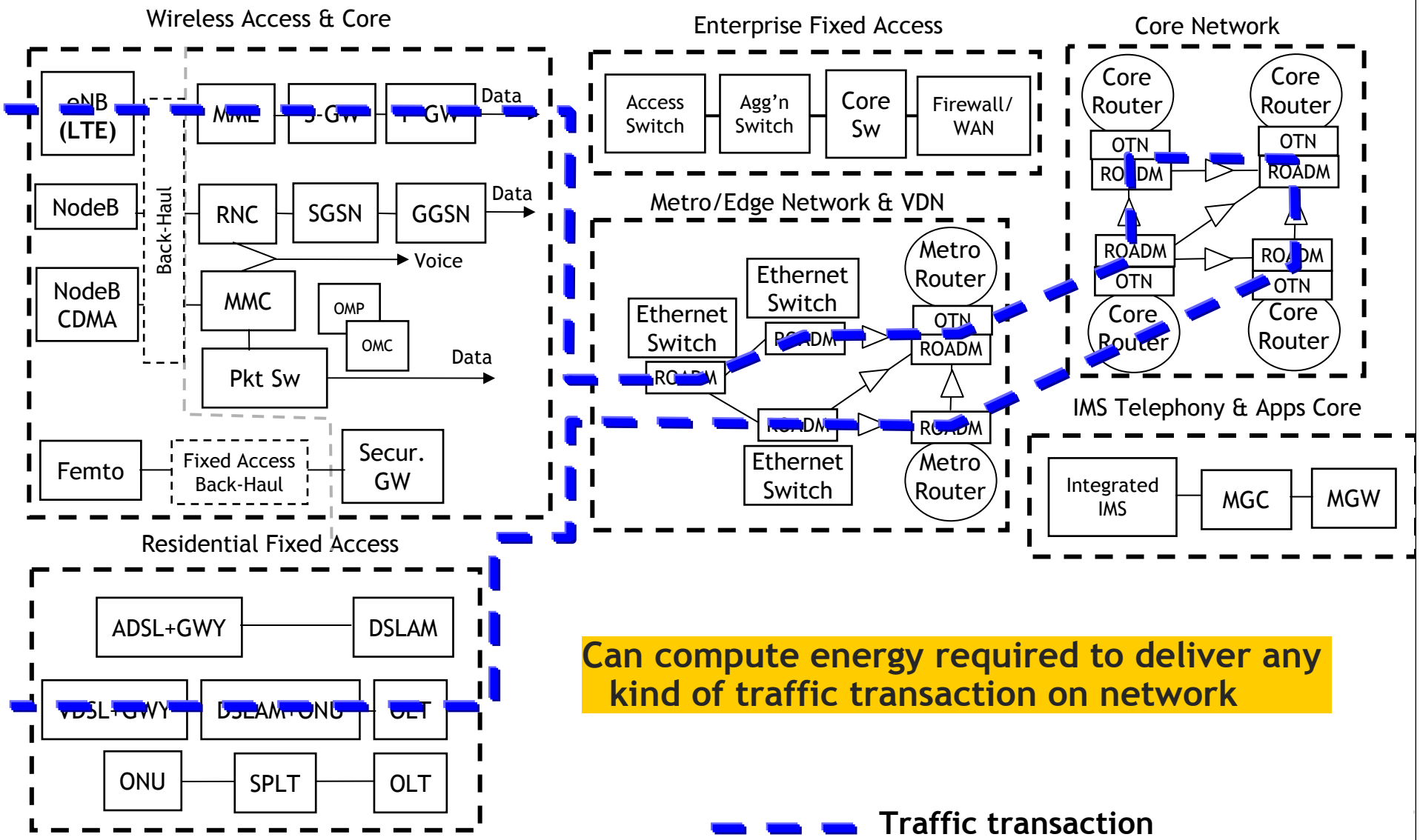
Computing Network Energy Efficiency Trends: Start With Network Model



Can compute energy required to deliver any kind of traffic transaction on network

Traffic transaction

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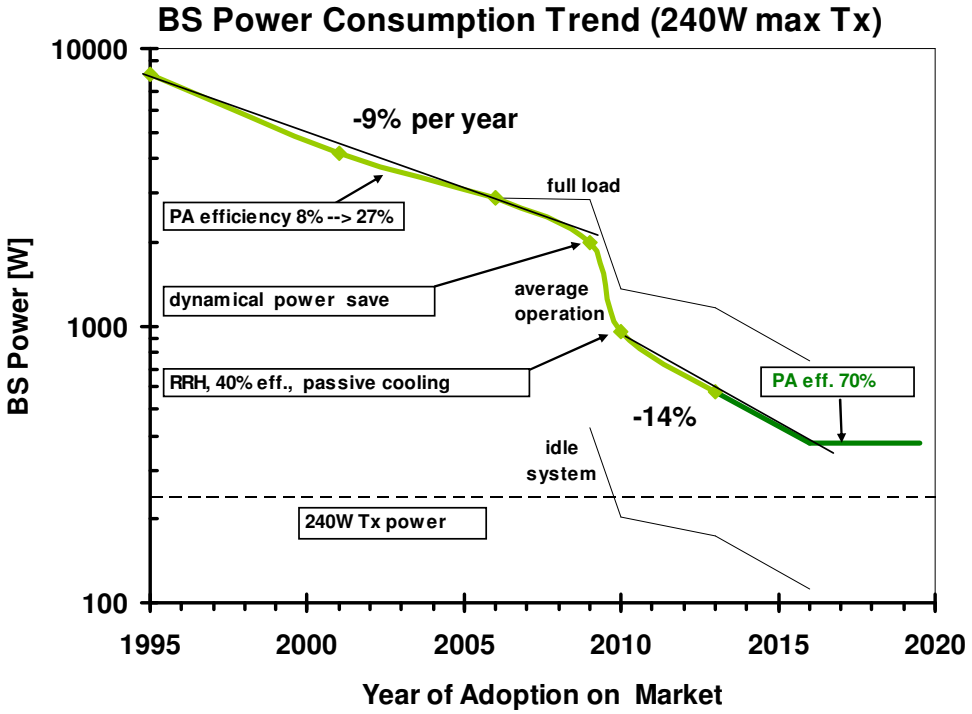
Equations to Compute Energy-Efficiency for Equipment

Transport

η_p = protection, η_c = cooling, η_{op} = over-prov.
η_{tr} = hop fraction w/ trans
η_G = green energy factor
H_C = # hops in core
d = hop transmission distance
P_{tr0} = node power, P_{tr1} = distance dep. power
C_{tr} = transport equip capacity

$$\frac{P_{terr}}{C} = (P_{tr0} + P_{tr1} \cdot d)\eta_G \eta_{op} \eta_c \eta_p \eta_{tr} H_C / C_{tr}$$

Wireless



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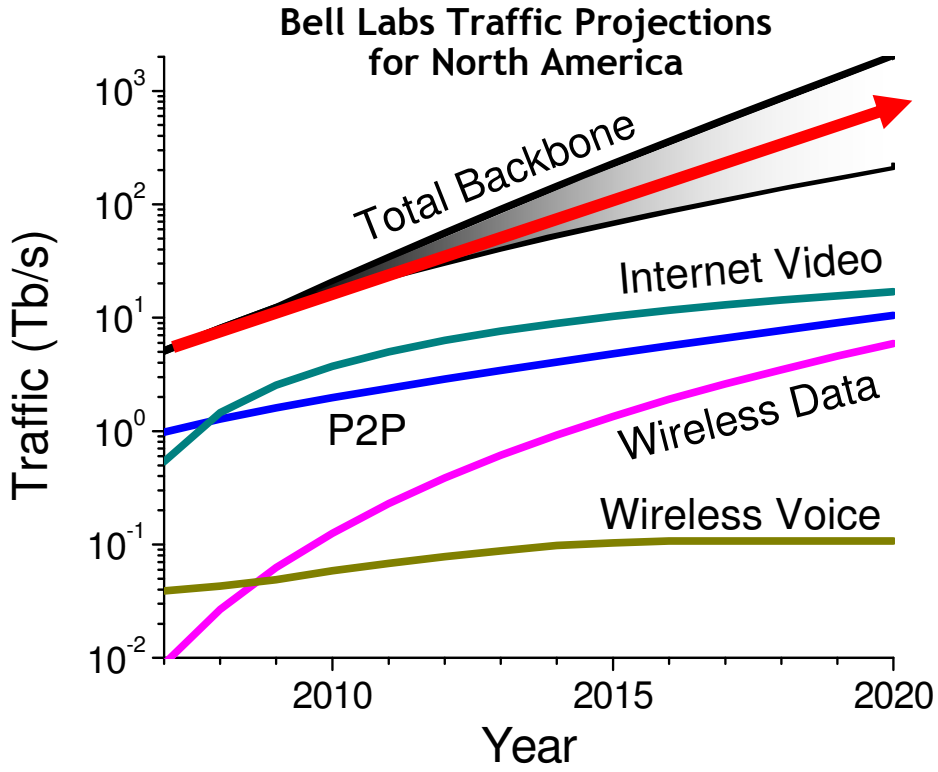
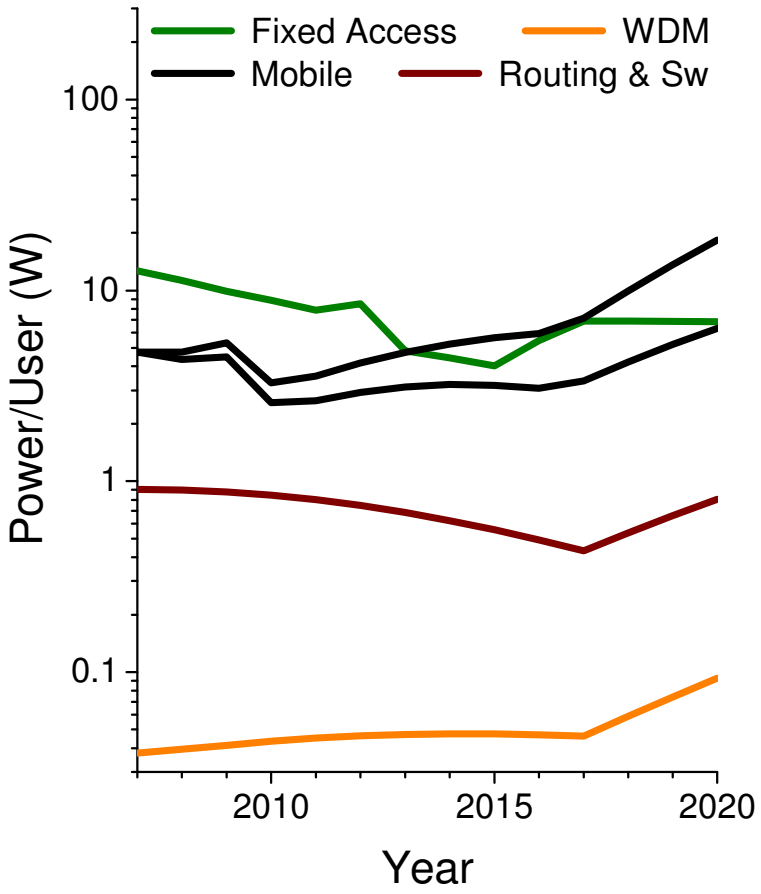
Putting it All Together …

	Traffic Category	Network Path
1	General Internet	Fixed Access+Metro+Long Haul+Metro+Enterprise
2	Peer-to-peer	Fixed Access+Metro+Long Haul+Metro+Fixed Access
3	Video	Fixed Access+Metro+Long Haul+Metro+Enterprise/Carrier
4	Broadcast	Broadcast Fixed Access+Metro+Enterprise/Carrier
5	Wireless Data	Wireless Access+Metro+Long Haul+Metro+Enterprise
6	Wireless Voice	Wireless Access+Metro+Long Haul+Metro

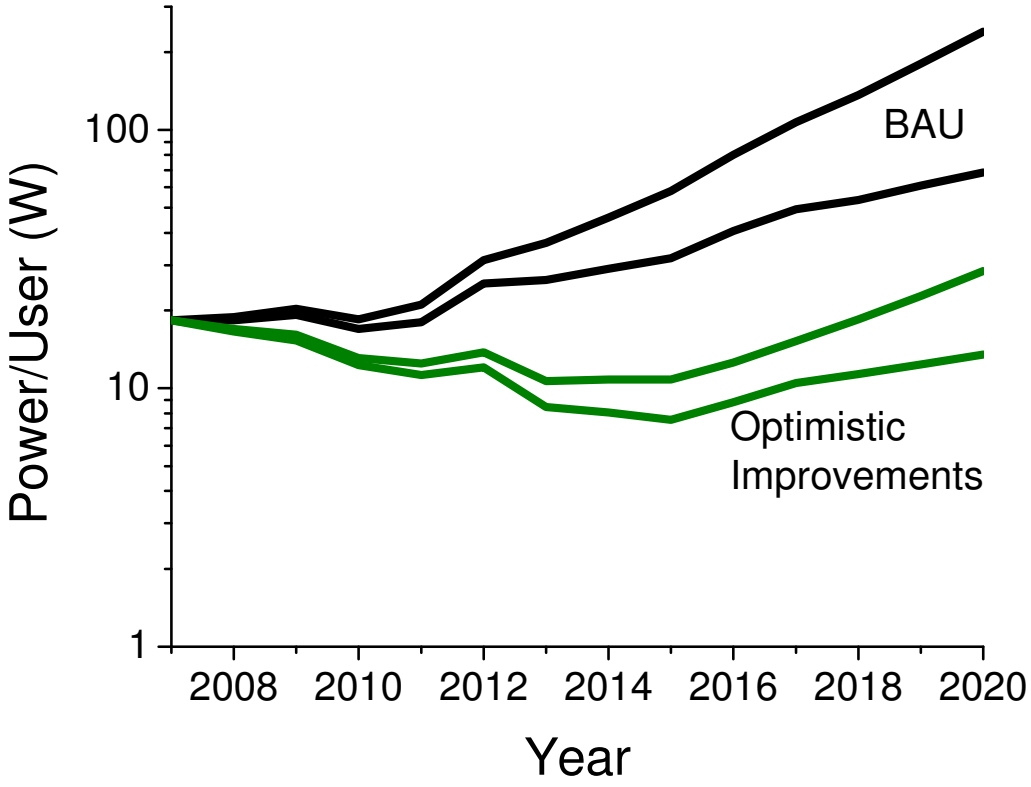


- Adding up energy consumed for all transactions on network gives total network energy consumption
- Total traffic divided by total energy yields network energy-efficiency

Trending Shows That Despite Increasing Efficiency, Energy/User in Network is Rising



- Can we change this trend?
- What is the best we can do?



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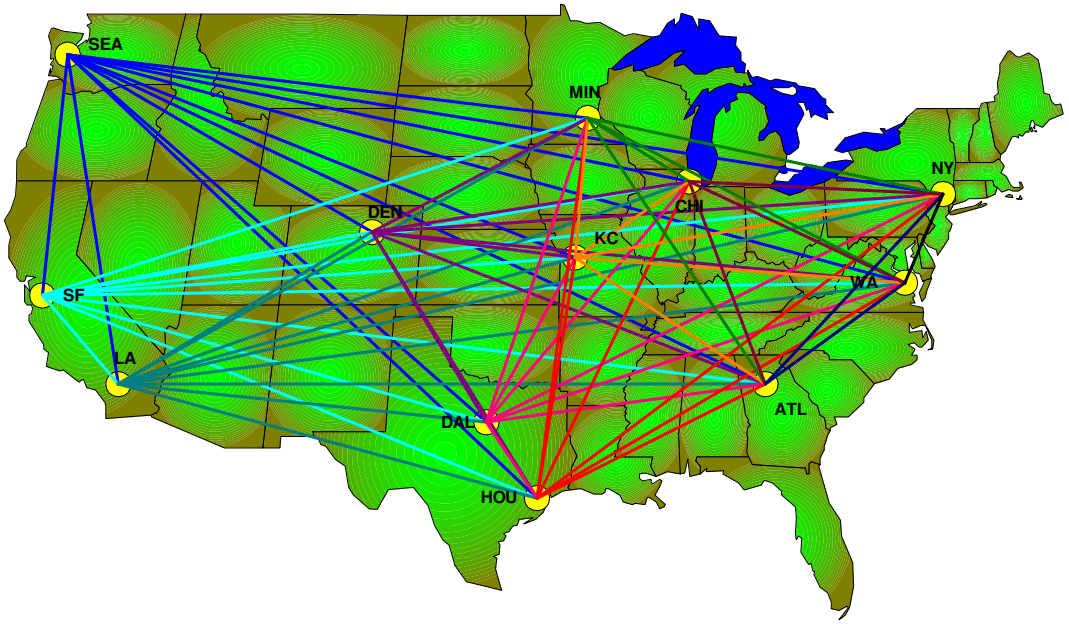
Wireline-Network Energy Consumption Lower Bound

Framed question:

What is minimum energy required to uniquely connect N users over long haul distances?

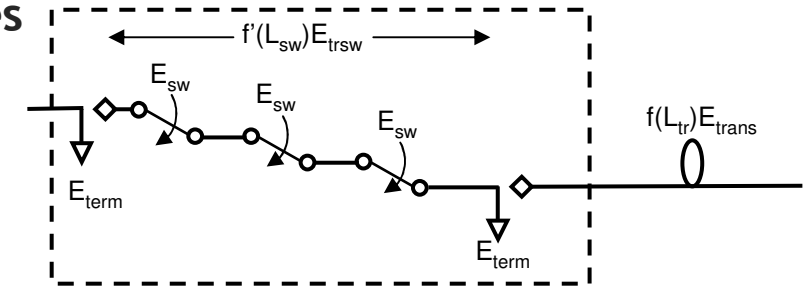


Network Properties

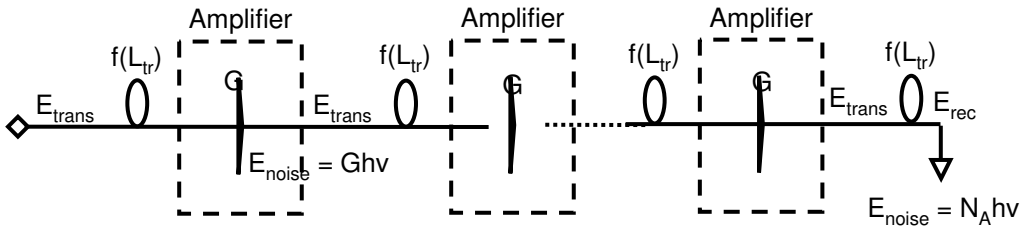
- Connect every pair of users with "Shannon-capacity" fiber
- Use least amount of switching at CMOS estimated-limit
- Energy consumption only depends on size of transaction, not on installed capacity

Estimating Lower Energy Bounds for Wireline Networks

- Minimum energy for single switch: $E_{sw} = CV_{dd}^2$
- For CMOS $E_{sw} = 0.25\,fJ$
- Switch to connect N users activates at least $\log_2 N$ stages



- Assume ideal fiber transport:
  - perfect conversion efficiency
  - 3 dB noise figure amplifiers
  - operating at Shannon limit



$$P(f_b, N, N_A) = [4\log_2 N + 2] f_b \cdot E_{sw} + [1 + N_A] f_b E_{trans}$$

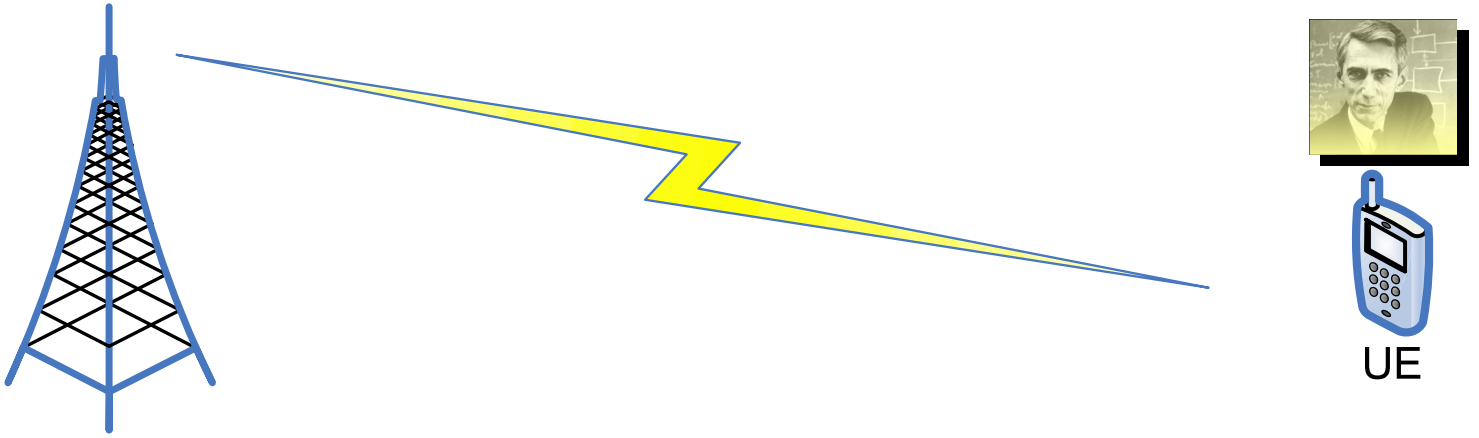
$$P(10^6, 10^8, 100) = 0.03 + 0.12\mu W = 0.15\mu W \rightarrow 0.15x10^{-3}\, nJ/bit$$

Comparing above to P2P transaction today, ~10W, we get the result that networks can be 10^8 more energy-efficient than today

Energy Consumption in Wireless Access
Inherently more inefficient than wireline

10x
(Typical macro BST: 10% of consumed power transmitted as RF Power)

10^{17}x
(Huge difference between transmitted power and minimal required receive power)

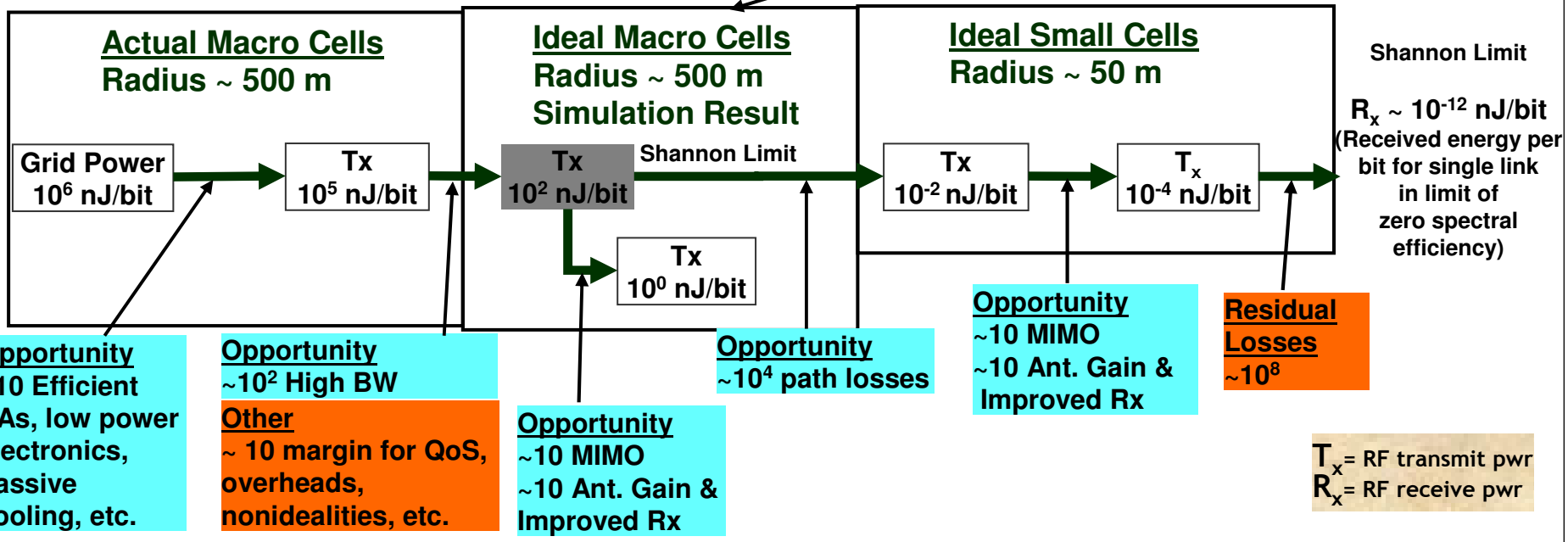


- For energy-efficient wireless communication, focus on reducing need for high transmit power
- Macro BSTs could be 10,000 more efficient that today
- Higher efficiencies possible with small cells

Analysis of Wireless Link Energy Efficiency

Illustration Through Macro Cell of Radius 500m

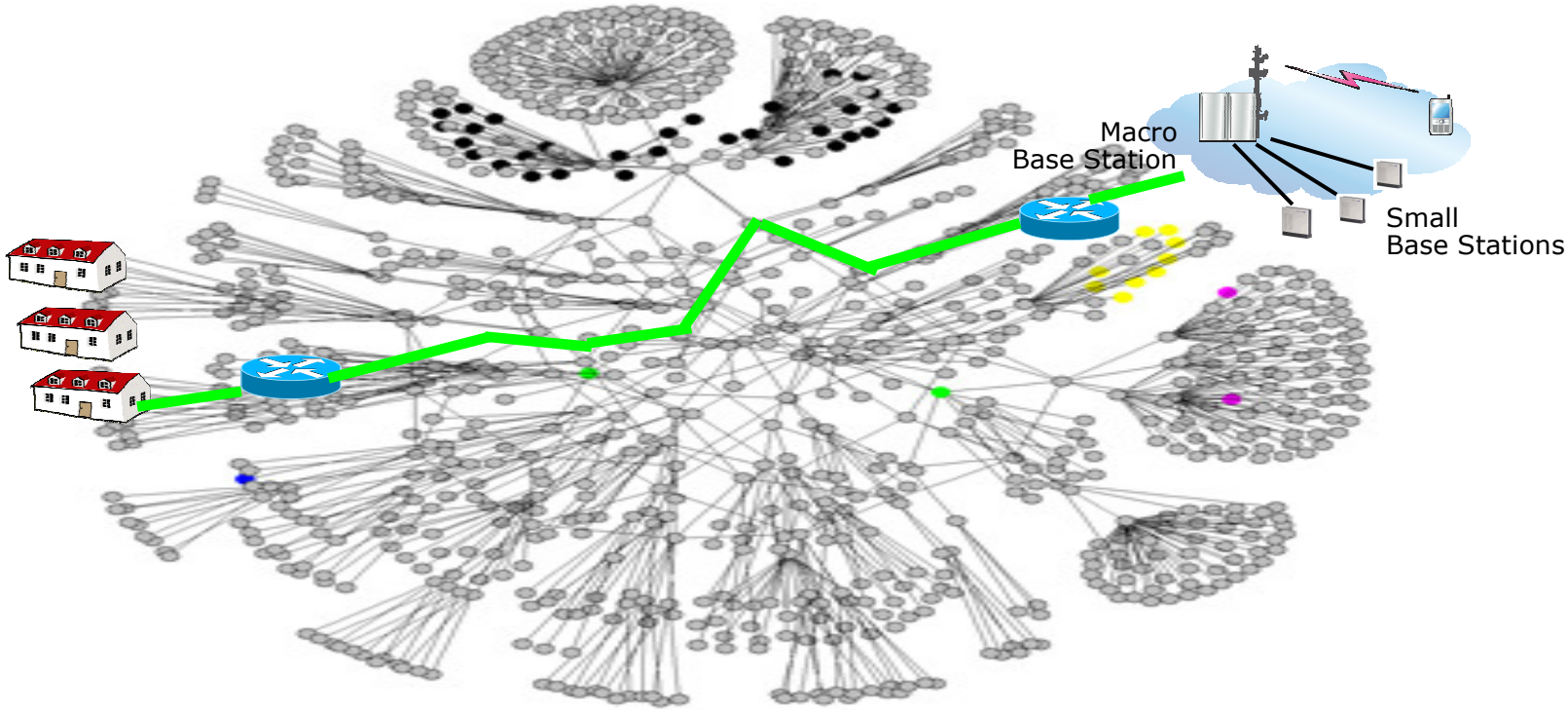
Modeling Assumptions
- Infinite BW
- Antenna gain 14 dBi
- Noise figure 9 dB
- Bldg penetration 20 dB
- Path-loss exponent 3.8
- Shadow fading 8 dB std dev



- Huge difference (17 orders of magnitude) between transmitted power and minimal required received power
- Best ways to capitalize on above opportunity
  - Small Cells
  - Antenna gains (MIMO, etc.)
  - Increased bandwidth

Innovating Ultra Low-Energy Networks is Super-Hard:
Requires Global Consortium, Therefore GreenTouch

- In real networks (mesh in the core, tree at the edges), dynamically allocate/switch a virtual fiber link between the two end-points of a transaction, with minimum routing



- Bring antenna as close to user as economically feasible; design for high antenna gains; opportunistic use of high BW
- Service aware and adaptive network with ultra-low energy information and content delivery
- Low Power, ultra-high energy efficiency, energy-follows load components everywhere

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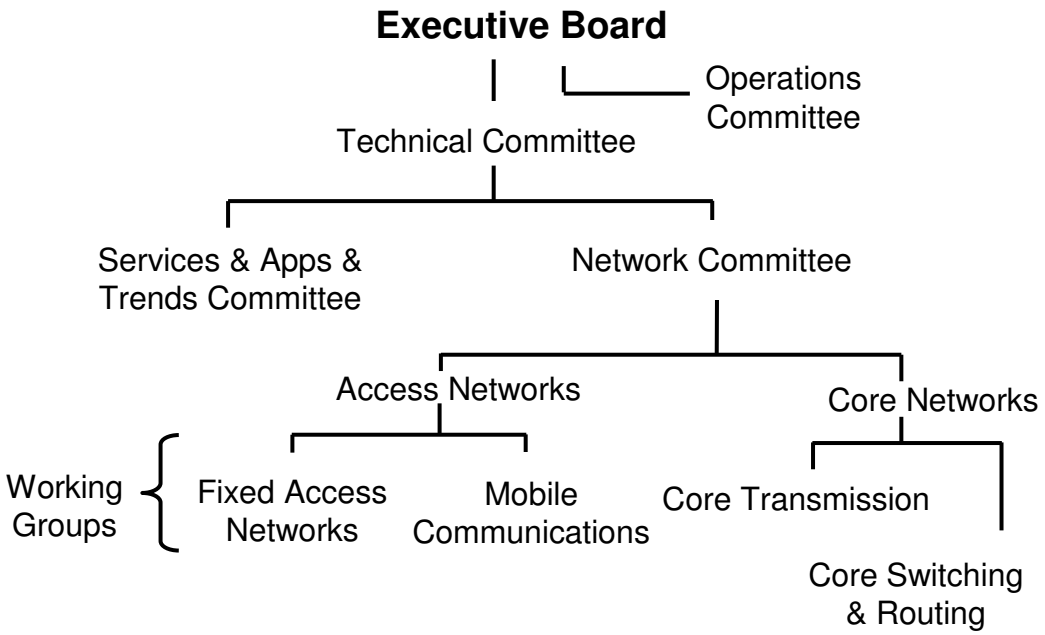
GreenTouch™ : Setting the Pace for Success



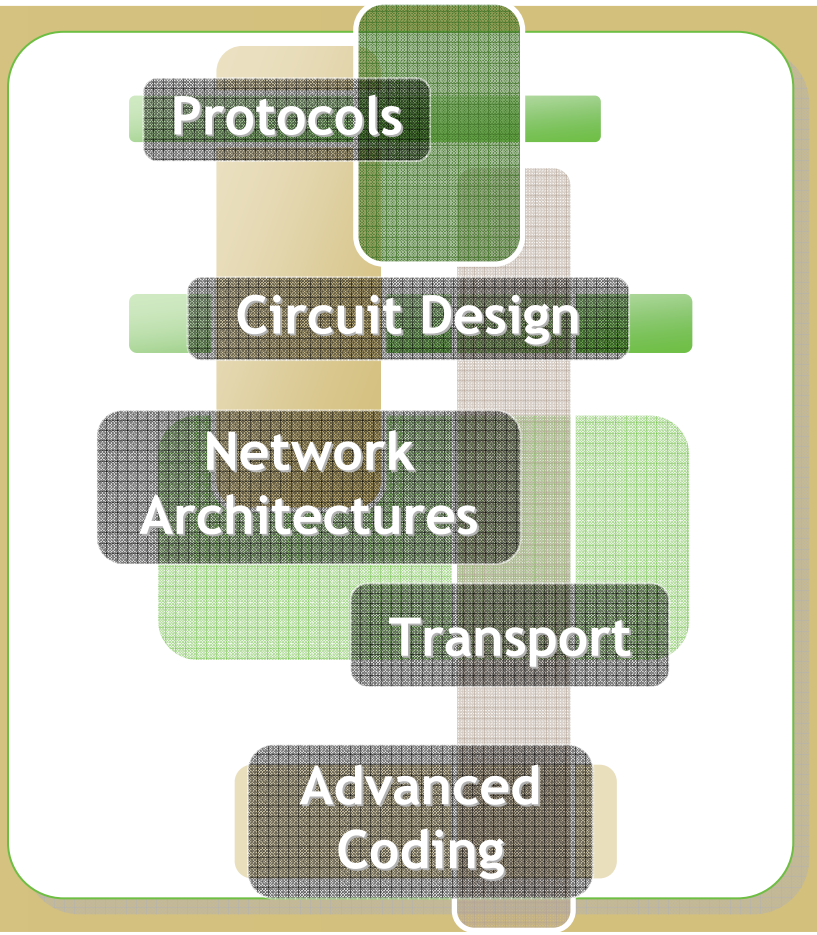
- Announced Jan 11, 2010
- In F2F meetings and calls, rapidly developed consortium structure
- BL analysis, architectures and models accepted by all partners as "the basis for guiding GT technical programs"
- GT opened to all, May 1, 2010
- First F2F of expanded GT, Jun 15-17, 2010
- Technical programs identified including first year demo
- …

GreenTouch™ Approach

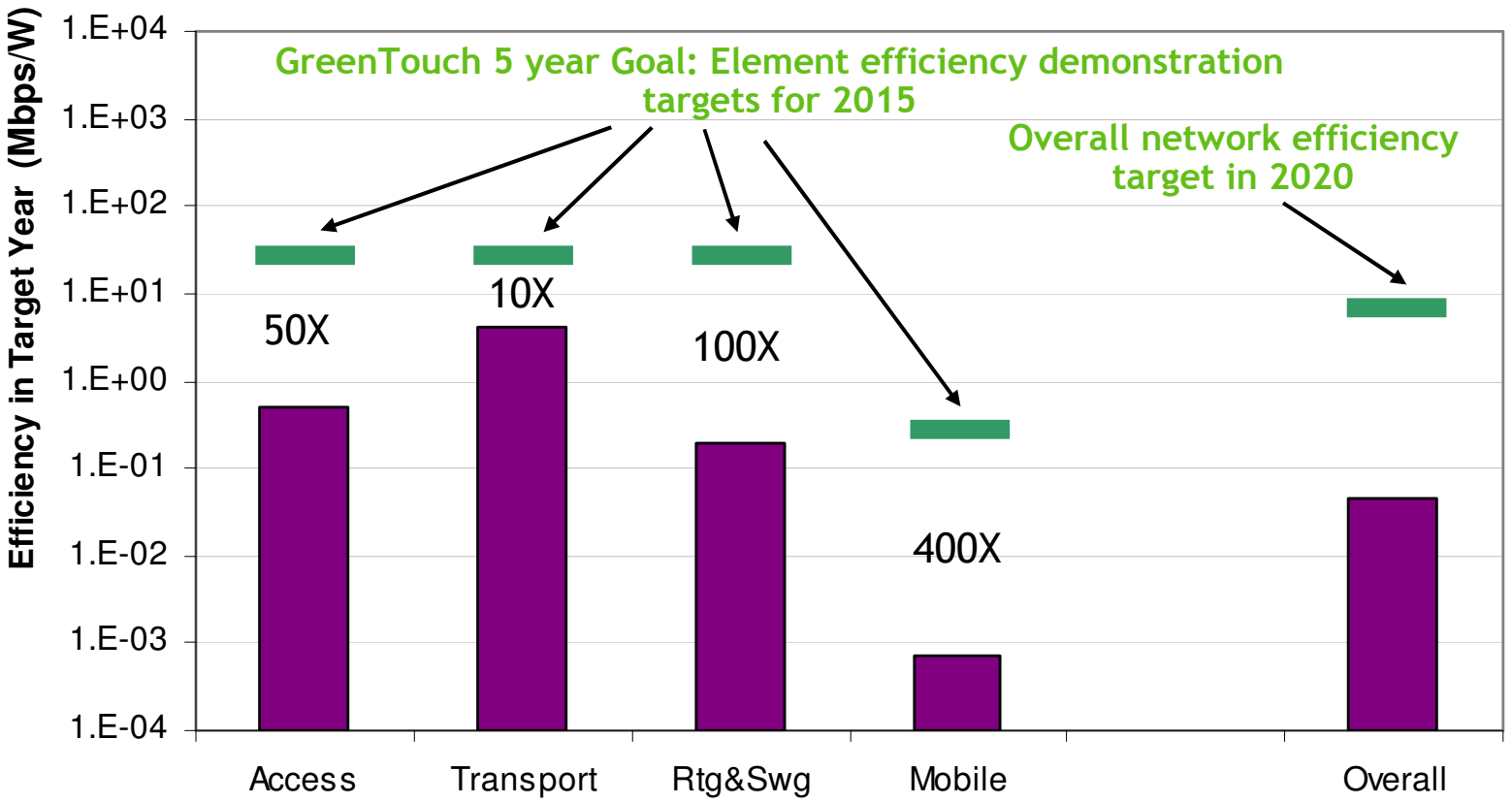
- Bottom Up Research Organization
- Use of models to structure and guide research and collaboration
- Combine resources to innovate & demonstrate new network architectures & technologies
- Funding through member & external contributions
- Measure, model and predict energy consumption in ICT networks
- Gauge impact of innovations on:
  - Alternative metrics (carbon footprint, network power, embedded energy)
  - Adjacent technologies (data centers, handsets)

GreenTouch™ : Ambitious Goal of 1000x

- Stretch goal that forces us to rethink every part and aspect of the network, setting us on an innovation path that focuses on long-term network sustainability
- Unimpeded traffic growth could be 1000x in 20 years
- Goal is well under theoretical limits



Path to 1000x Not Unique: Innovations Beyond Business as Usual



Network efficiency depends upon network architecture and technology, which depends upon services, applications, and traffic

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GreenTouch™: Path to 1000x

- Path to 1000x improvement not unique, but requires aggressive improvements and new architectures
- One scenario:
  - ~3000x improvement in wireless through small cells, MIMO, active antennas, efficient transceivers, etc.
  - ~1200x imporvement in routing & switching with architectures with fewer routers and switches, low power electronics, low power interconnect, reduced processing, power-efficient protocols, minimum size buffers, etc.
  - ~50x improvement in optical transmission with energy efficient components and systems, optical restoration, passive cooling, etc.
  - ~25x improvement in broadband access from dramatic reductions in CPE power (from 11.1 W to 0.4 W) and CO power (from 0.6W/port to 0.1W/port)

- Bell Labs GreenTouch focus on research where:
  - Improvement opportunity is immense
  - Collaboration is essential
  - Research in pre-competitive stage

Approaches to GreenRadio Network Architecture

Green Air Interface (1000x)

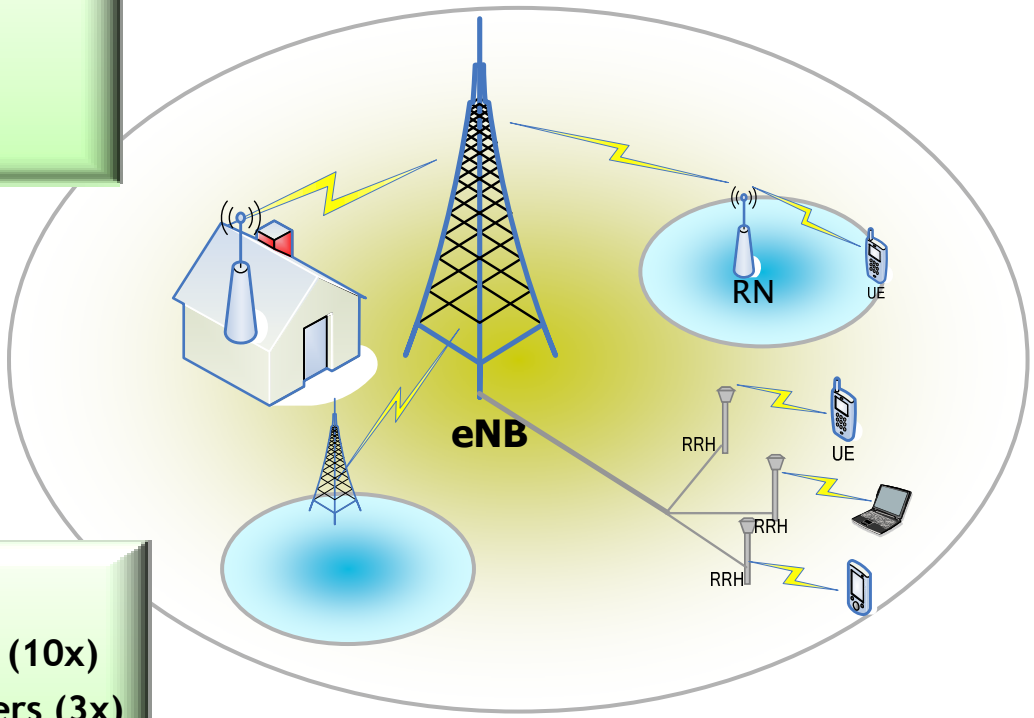
- Small Cells (100x)
- Large Scale MIMO (10-100x)
- Very High Bandwidth (100x)

Network Architecture & Mgmt

- Dynamic Management for EE
- New BS Architecture – Cloud Computing for Signal Processing

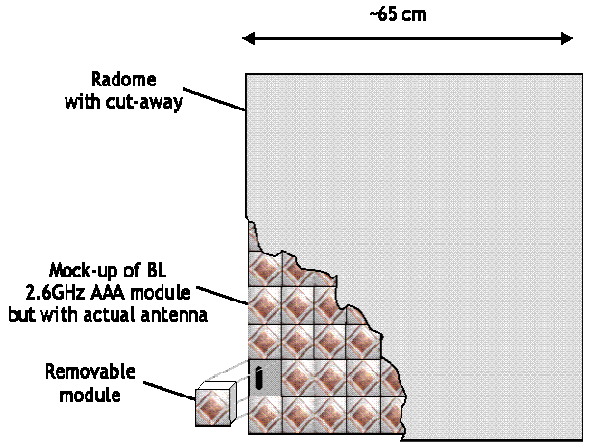
Base Station Hardware (10x)

- Photonic Enablers for RF Systems (10x)
- High Efficiency RF-Power Amplifiers (3x)
- Renewable Energy Powering



Large Scale MIMO: GreenTouch in Action & First Year Demo

- **Concept:** Ultra high energy-efficiency wireless through selective beam-forming, in highly cluttered environments, using base-stations with hundreds of antenna, …
- **Expectation:** ~100x improvement in energy efficiency in highly mobile, multi-user systems
- **Challenges:**
  - Base-station design
  - Acquiring CSI, calibration, …
  - Total power reduction
  - New standards
- **First year demo:**
  - Phase 1: Focus on reverse link (terminal transmit power)
  - Phase 2: Expand to forward link (total base-station power)



Collaborations

- Simulation: Huawei
- Field Issues: France Telecom Orange
- Electronics: Freescale

Summary

- The need for sustainable, yet rapid growth of ICT networks, offers great opportunities for spectacular research in improving network energy-efficiency
- GreenTouch brings together the world's best minds in a collaborative framework to realize the above
- Besides energy-efficiency, GreenTouch also tracks alternative metrics (life-cycle energy, …) and adjacent technologies (data center, …)
- **We need your collaboration for GreenTouch to reach its goals!**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