Motivation

- In the near future the ICT sector is expected to contribute approx. **3%** of global carbon emissions, possibly overtaking the aviation industry.
- How to reduce the carbon footprint of the ICT sector using smart algorithms and new energy efficient technologies?
- Focus on networking infrastructure for now.

Research question

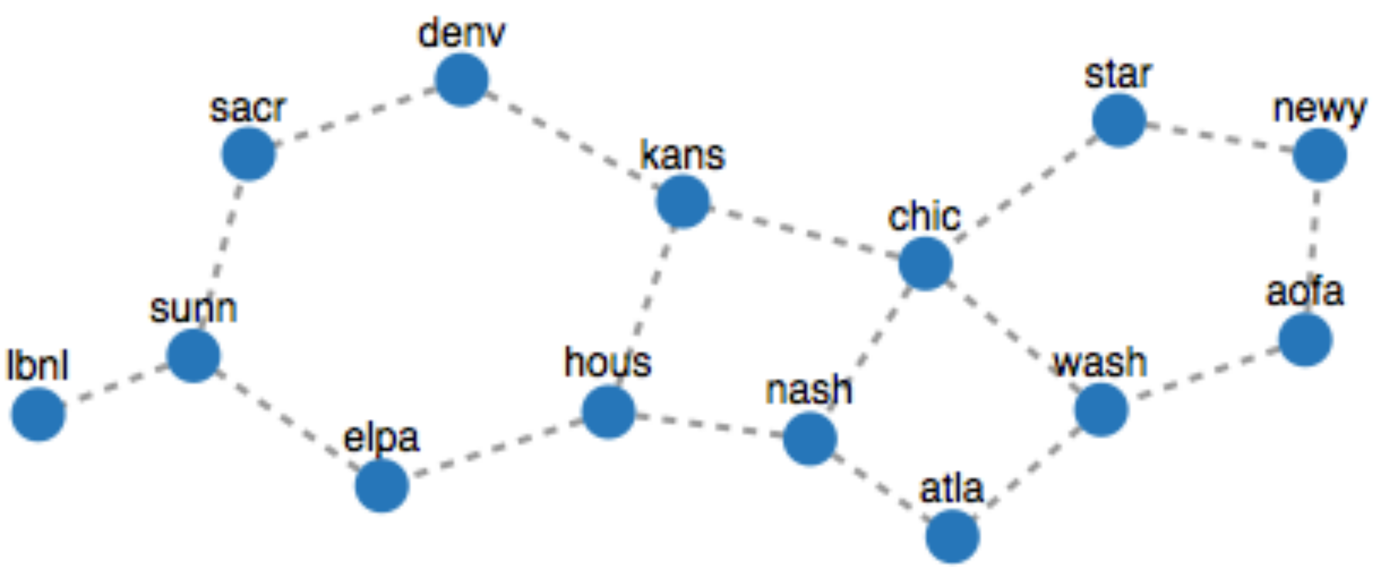
- How to accomplish “green” path provisioning with the goal of reducing overall carbon emissions?
  - Are significant reductions in the carbon footprint of NRENs possible?
  - How do the greenest and cheapest paths compare?
- Circuit switching (not IP packet switching).
- Definitions:
  - Green path: Path with least CO2 impact.
  - Cheap path: Path with least energy cost.

NREN networks

- Current situation:
  - Most networking devices consume constant amount of power regardless of traffic.
  - Only way to save energy is by shutting down (parts of) the network.
- Preferred situation:
  - Networking devices can adjust power consumption depending on traffic load.
    - Energy Efficient Ethernet - IEEE 802.3az
  - Reduce the carbon footprint of NRENs by applying energy efficient technologies and "green" pathing algorithms.
    - How much can be gained from this?

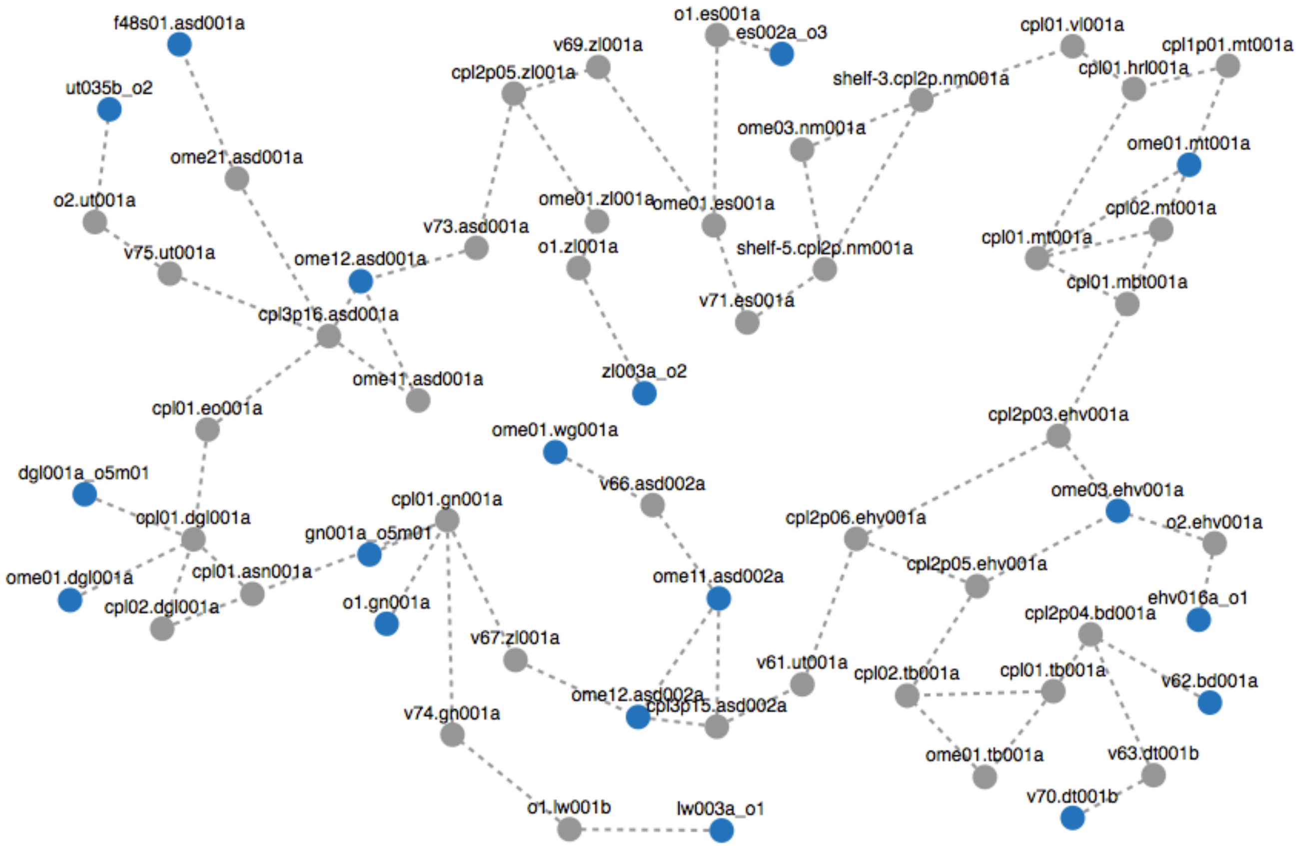
Use Case I: ESnet

- Subset of ESnet topology (L3 only).
- Using real power data collected from ESnet monitoring services.
- How to reduce the total carbon footprint of the network?



Use Case II: SURFnet

- Subset of SURFnet topology (L1 and L2).
- Using real power measurements collected from Joulex.



Green path selection demo

- ESnet
  - http://145.100.132.159:7777
- SURFnet
  - http://145.100.132.159:8888

Algorithm

- Want to transport N Gbytes of data from A to B at a given throughput.
- Calculate all paths (without loops) between A and B.
  - For each path, calculate CO_2 cost.
  - Choose the path with the smallest CO_2 cost.

Model

- Total grams CO_2 of a path =
  - Sum of (kWh * grams CO_2/kWh) per node in path.
    - kWh = kW * transmission time
    - Scaled by device utilization and dynamic power.
- Variables
  - Transmission time: inverse of throughput * Gbits
  - kW: Device measurement
  - gr. CO_2/kWh: Depends on energy production sources (region)

Emissions and cost per region

Region	Production mix (grams CO_2 / kWh)	kWh rate (dollar cents / kWh)
NY State	250	15.66
Massachusetts	459	15.53
California	254	13.58
Maryland	571	13.11
Texas	524	10.18
Illinois	488	9.13
Georgia	611	8.76
Tennessee	537	8.66
Colorado	700	8.36
Kansas	698	8.07
Netherlands	520	31.55

1. Institute of Energy Research - http://www.instituteforenergyresearch.org/states

Demo vs simulation

- Demo: Calculates "greenest" path disregarding other traffic.
- Simulation: Estimates total CO_2 footprint of a network over time given a distribution of traffic.
  - Paper submission to International Green Computing Conference awaiting acceptance.

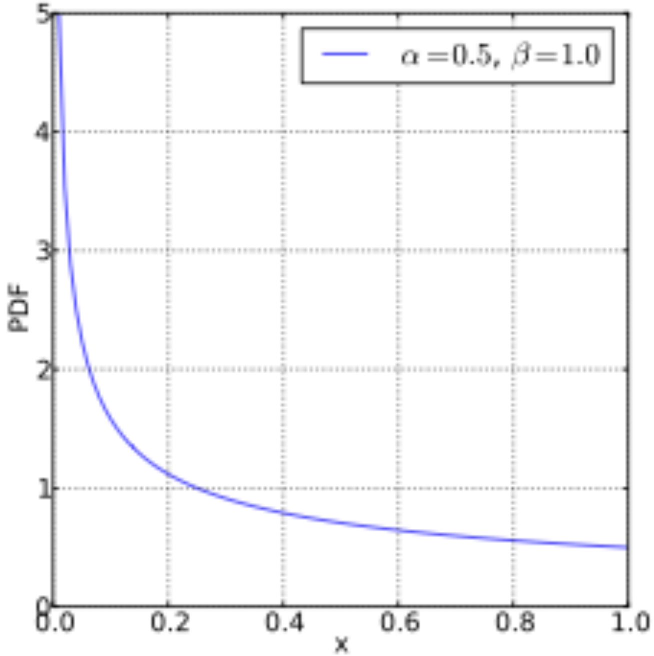
Experiments

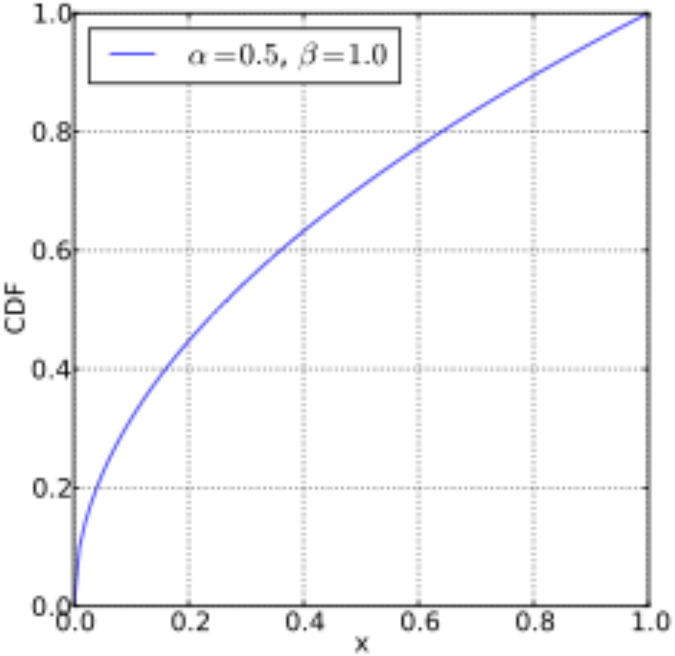
- Event simulation of traffic flows in ESnet network.
- Ends when 1 TByte of data has been pushed through the network.
- Calculates total CO_2 footprint over time.
- Parameters:
  - 1/mu: mean inter-arrival time (exponential distribution): 0.1, 1.0, 10 secs.
  - d: energy proportionality of routers: 0, 25, 50, 75, 100%.
  - Path selection metric: shortest, greenest, cheapest.
  - Flow type: short-lived, long-lived, uniform.

Flows

Flow	Throughput (Gbit/s)	Data (GBytes)
Long-lived	0.1	[1, 10]
Short-lived	1.0	[1, 10]
Uniform	[0.1, 1.0]	[1, 10]

$$x \sim B(\alpha, \beta)$$
$$Data = 1 + 9x \text{ GBytes}$$
$$Throughput = 0.1 + 0.9x \text{ Gbit/s}$$





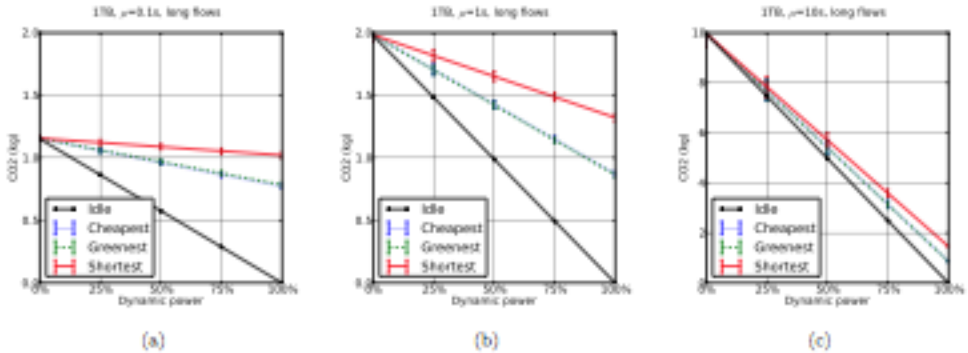


Figure 3: Carbon footprint of 1TByte of traffic: Long flows.

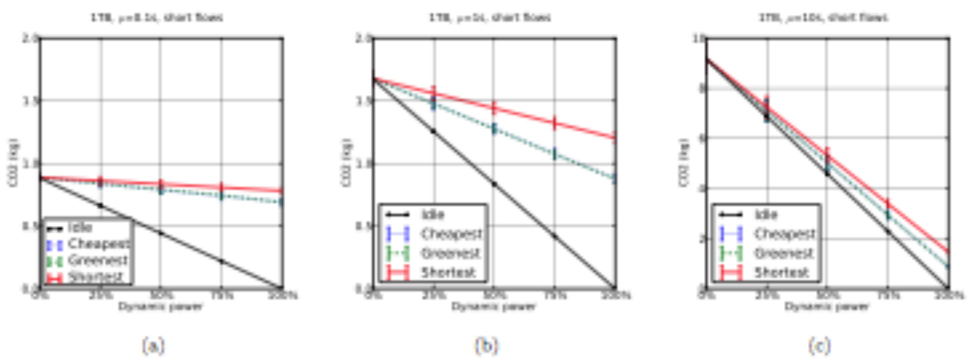


Figure 4: Carbon footprint of 1TByte of traffic: Short flows.

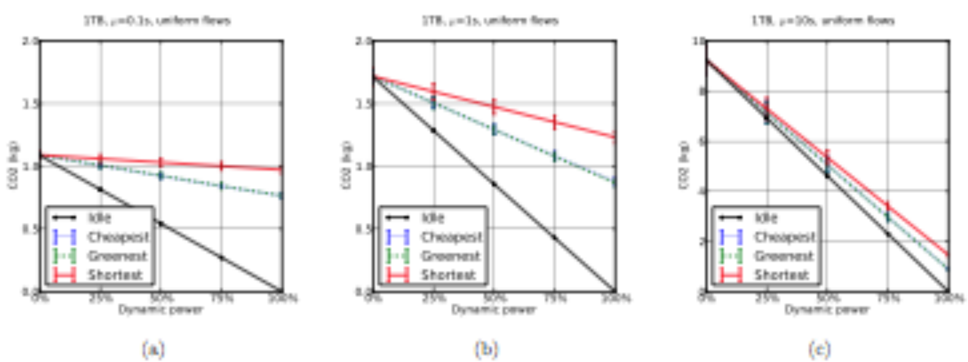
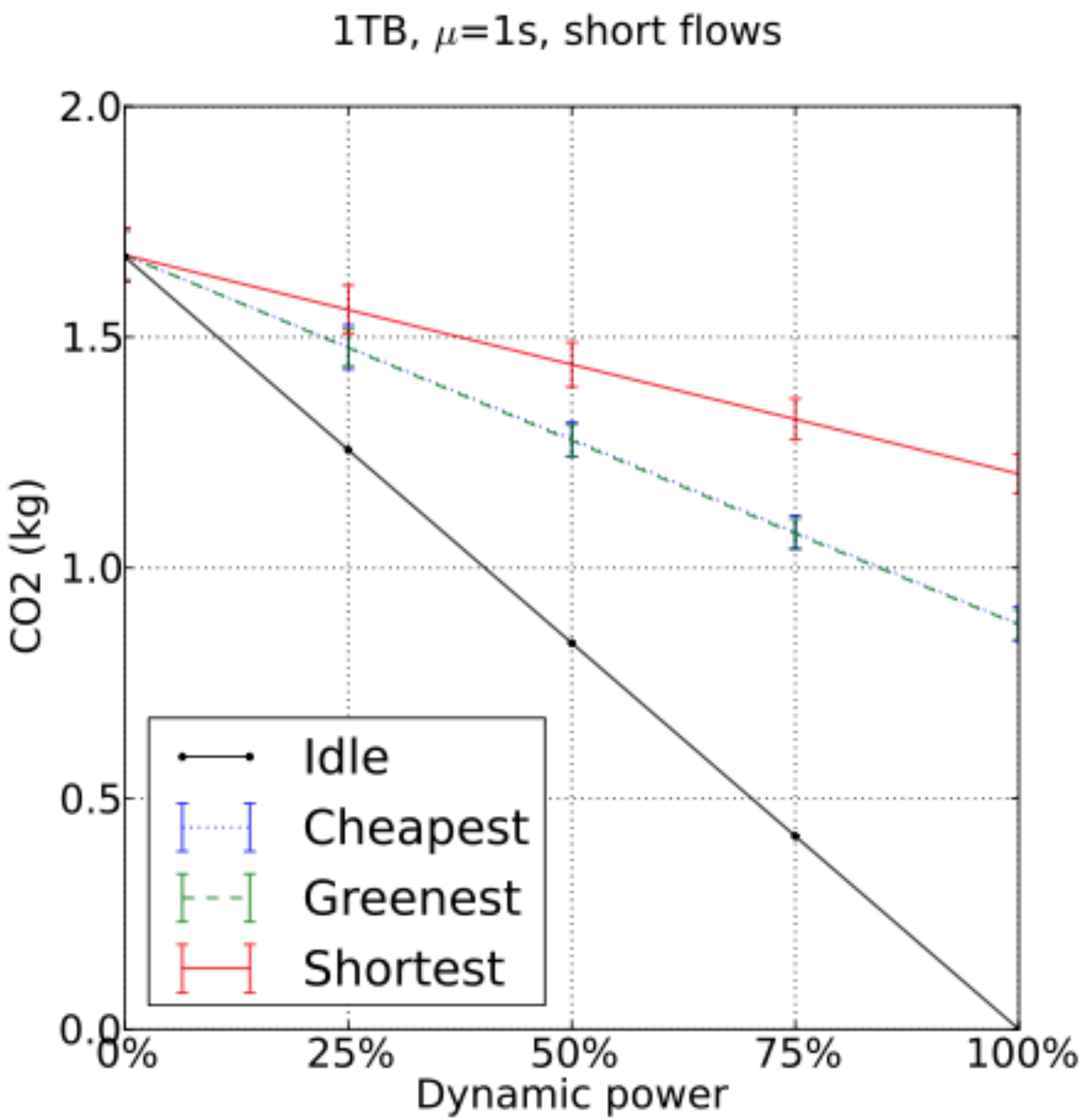


Figure 5: Carbon footprint of 1TByte of traffic: Uniform flows.


1TB, μ=1s, short flows
CO2 (kg)
2.0
1.5
1.0
0.5
0.0
0%
25%
50%
75%
100%
Dynamic power
Idle
Cheapest
Greenest
Shortest

Discussion

- In all cases energy proportional routers reduce the CO_2 footprint.
  - "Green" paths reduce the footprint even further.
    - 5 to 23% less CO_2 @ 25% proportionality.
    - 22 to 91% less CO_2 @ 100% proportionality.
  - There is almost very little difference between green and cheap paths.
- Improvements depend on topology and geographical location, so cannot simply extrapolate results to general case.

Conclusions

- It is possible to reduce the CO2 footprint of NRENs provided:
  - Have energy proportional devices.
  - Can control setup of network paths directly.
    - OSCARS, OpenFlow, etc.
  - Access to (up-to-date) information about CO2 emissions resulting from energy sources in the region.

Future work

- Investigate and compare NRENs in the manner described.
  - Similarities? Differences?
- Investigate optimality of networks.
  - Given a network, what is the maximum benefit that can be attained by provisioning green paths?
  - Optimal topology for minimal CO2 footprint?
- Combine with power/performance model for (HPC) clouds.
- Implementation…

Interested?

- We are looking for NRENs who are interested in sharing information about their network to help us with our research.
  - Current NRENs: ESnet and SURFnet.
- Information we need:
  - Topology
  - Power measurements
  - Geographical (if possible)
  - Traffic patterns, distributions

Questions?

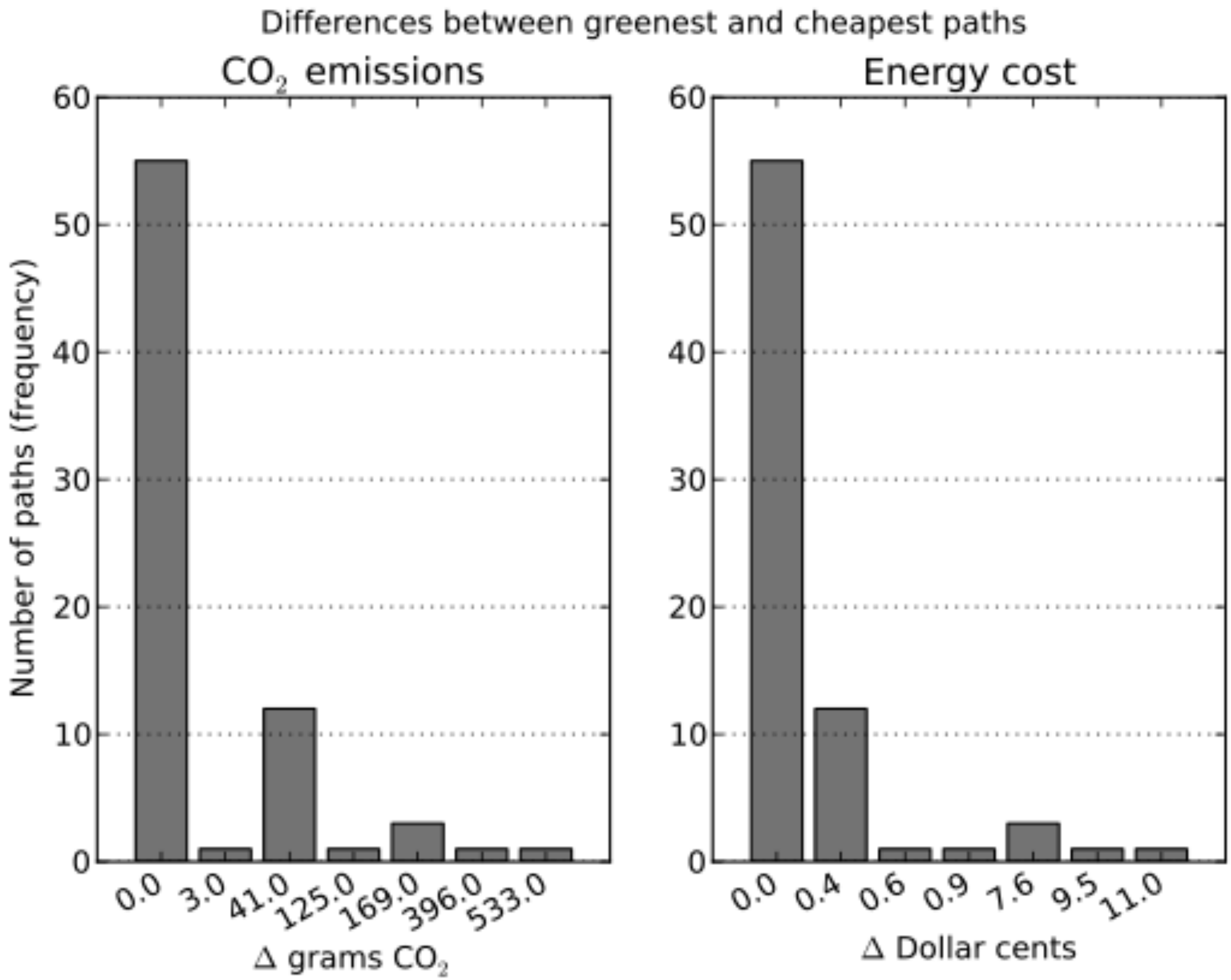
- ???

Model

- C (grams CO_2) = 8 * N * T * (sum Pi * Xi for i in Path)
  - N = GBytes you want to transport
  - T (hours) = 1 / Throughput / 3600
    - Throughput in Gbits/s
  - u_i = (Bcur_i + Throughput) / Bmax_i
    - u_i: router utilization (%)
    - Bcur_i: Current reserved bandwidth
    - Bmax_i: Maximum bandwidth capacity (ie 10G/s)
  - Pi (kW) = Ps_i + Pd_i * (1 - d) + Pd_i * d_i * u_i
    - Ps_i: static (unchanging) power (dwdms)
    - Pd_i: power that can vary with utilization (router)
    - d_i: % of power that changes with utilization
  - Xi (grams CO_2 / kWh) = Energy production mix
    - Depends on physical location (region)
    - Example: 40% coal, 30% nuclear, 20% hydro, 10% solar
  - Constraint: u_i <= 1.0 for all i

Model

- Total CO2 footprint of network:
  - C_network = sum P_n * X_n for n in network
    - n: node in the network


Differences between greenest and cheapest paths
CO2 emissions
Energy cost
Number of paths (frequency)
60
50
40
30
20
10
0
0.0
3.0
41.0
125.0
169.0
396.0
533.0
Δ grams CO2
0.0
0.4
0.6
0.9
7.6
9.5
11.0
Δ Dollar cents

Carbon emissions comparisons

Airplane, return trip, economy class:
- Berlin – New York: 3.87 tons of CO_2
- Hamburg – Munich: 0.32 tons of CO_2
- Frankfurt am Main – Alicante: 0.85 tons of CO_2

Train, return trip:
- Hamburg – Munich: 0.07 tons of CO_2
- Leipzig – Cologne: 0.05 tons of CO_2
- Stuttgart – Paris: 0.01 tons of CO_2

Car, per 1000 km (625 miles):
- Toyota Prius Hybrid: 0.092 tons of CO_2
- Volkswagen Golf 1.6 TDI BlueMotion: 0.099 tons of CO_2
- Mercedes-Benz C220 CDI BlueEfficiency: 1.17 tons of CO_2

Electrical, per year:
- Lighting of a residential building: 0.135 tons of CO_2
- Use of a mobile phone: 0.112 tons of CO_2
- Television set: 0.025 tons of CO_2

Diet, per year:
- Meat-heavy: 6.7 tons of CO_2
- Vegetarian: 1.22 tons of CO_2
- Vegan: 0.19 tons of CO_2

1. http://thecompensators.org/en/compensate/examples-of-emissions/

Challenges

- How to collect, store, and access power measurements of networking equipment?
  - Multi-Domain
- Ongoing work on developing software architecture to accomplish this.
  - GreenSONAR
  - Simple Lookup Service (sLS)
  - Etc

Energy production

Energy source	CO_2 emissions (grams CO_2 / kWh)
Coal	950
Anthracite	870
Oil	640
Gas works gas	400
Natural gas	380
Nuclear	66
Geothermal	40
Biomass	30
Solar	22
Hydroelectric	15
Wind	10

1. IEA, "CO2 emissions from fuel combustion–highlights," Paris, July 2011
2. Benjamin K. Sovacool, "Valuing the greenhouse gas emissions from nuclear power: A critical survey," Energy Policy, vol. 36, no. 8, pp. 2950–2963, 2008.
3. Wikipedia, Emission Intensity

Progress

- Q4 2013: Worked at ESnet.
  - Developed model for "green" path selection.
  - Demo at SuperComputing 2013.
- Q1 2014: Submitted paper to ACM e-Energy.
  - Network simulation to investigate benefits of "green" pathing.
  - Notification on March 31.
- Q2 2014: Presentation at TNC 2014.