Motivation

- In the near future the ICT sector is expected to contribute approx. **3%** of global carbon emissions, overtaking the aviation industry.
- How to reduce the carbon footprint of the ICT sector using smart algorithms and new energy efficient technologies?
- In this demo we are looking at networking infrastructure.

Research question

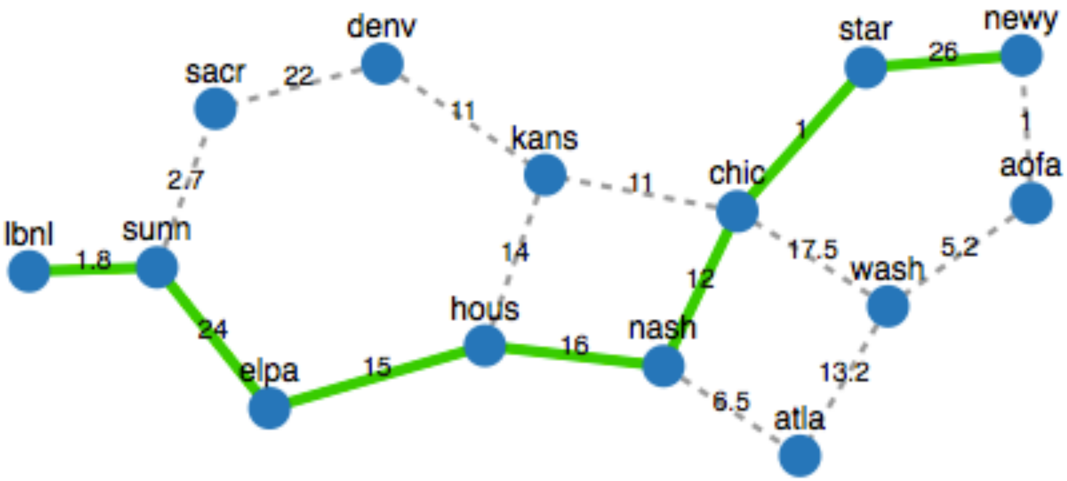
- How to accomplish "green" routing with the goal of reducing overall carbon emissions?
  - How to use power data collected from the infrastructure?
  - How do networking infrastructures with different characteristics compare?
  - How do the fastest, greenest, and cheapest paths compare?
  - Are significant reductions in carbon footprint possible?

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

Scenario

- Subset of ESnet topology.
- Uses real data collected by ESnet real-time monitoring services.
- What is the carbon footprint of transporting N GBytes from A to B?



Model

- C (grams CO2) = 8 * N * T * (sum Pi * Xi for i in Path)
  - N = GBytes you want to transport
  - T (hours) = 1 / Throughput / 3600
    - Throughput of Path in Gbits/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
    - u_i: utilization %
  - Xi (grams CO2 / kWh) = Energy production mix
    - Depends on physical location (region)
    - Example: 40% coal, 30% nuclear, 20% hydro, 10% solar

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

Emissions and cost per region

Region	Production mix (grams CO_2 / kWh)	kWh rate (dollar cents / kWh)
Netherlands	519	31.71
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

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

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/

Preliminary conclusions

- Clear differences between fastest, greenest, and cheapest paths.
- Energy saving technologies make green pathing viable.
- Lossless networks produce far less emissions than lossy networks.

More information

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