Carbon-aware Networking

An Environmental Impact use case for Time Variant Routing (TVR)

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The Backdrop

- Urgency to address UN IPCC recommendation re 1.5C degree threshold
- ICT contribution to GHG emissions sizeable and growing
  - Network impact rivals Data Center footprint
  - Must adopt renewables to get to NetZero?
- Will need 4x the amount of electricity currently generated to support the electrification of transportation, etc
  - Long arc of infrastructure roll-out …
What is carbon-awareness?

- Include energy carbon-intensity as a non-traditional QoS "cost" metric
  - It is not enough to be energy efficient – i.e., to consume less energy
  - Must also decarbonize the energy consumed
  - Account for other environmental impacts

- Inspired by DC adoption of Carbon-aware Computing
  - Time- and space-shift workloads
  - Maximize usage of renewable and clean energy
  - Consume excess renewable energy that would otherwise go wasted, to help stabilize the grid
What is carbon-aware networking?

Multiple facets

- **Carbon-aware routing**
  - Select routes with the greatest carbon efficiency

- **Carbon-aware transport**
  - Apply time- and space- shifting to network data transmission – *DTN-like*

- **Carbon-aware traffic engineering**
  - Guarantee carbon efficiency thresholds along paths through the network, possibly reserving resources along the way – *DetNet-inspired*

- **Carbon-aware telemetry**
  - Instrument the network to be self-aware and to apply carbon-awareness to telemetry data stewardship
Carbon-aware networking

Overview

• **An example of use case 2: Operating efficiency**
  - when carbon-intensity is comprehended as part of the cost function of a link

• **Shades of use case 1: Resource preservation**
  - when the device/infrastructure opts for battery operation, e.g., when the battery is rated as having a mix of electricity whose carbon-intensity is less (which is better) than the carbon-intensity of the electricity coming out of the wall socket

• **Shades of Use case 3: Mobile devices**
  - when mobile distributed energy resources can be dispatched to places where needed

• **Cause for the loss (re-appearance) of an adjacent link:**
  - External environmental factors like the lack (abundance) of sun or wind or other clean energy sources
  - Threshold exceeded (met) for carbon-intensity

• **Possible TVR Benefits**
  - Expected loss of links are not seen as error conditions, but as optimizations
  - Expected resumption of a link does not always need to be rediscovered
Use Case 2: Operating efficiency - revisited
Assumptions and Expected TVR Benefits for Carbon-aware networking

Assumptions

• **Cost Measureability.**
  - Infrastructure costs can be related to node functions.

• **Cost Predictability.**
  - Cost changes can be communicated in advance. More than just “the current cost at the moment”.

• **Cost Persistence.**
  - Cost changes are infrequent enough that behavior can be adjusted in response to their changing.

• **Cost Magnitude.**
  - The magnitude of cost savings justify the efforts required to optimize cost.
    - *Models of black-out aversion in CA in summer’22, if all EV batteries leveraged*

Possible TVR Benefits

• **Link Filtering.**
  - Individual links can be filters based on cost to minimize the use of high-cost links unless needed by type of traffic (e.g. high priority).
    - *In the extreme, links are only up in the presence of clean energy*

• **Burst Planning.**
  - Where there is a cost savings associated with fewer longer transmissions (versus many smaller transmissions), nodes might accumulate a sufficient data volume exists to justify a transmission.

• **Environmental Measurement.**
  - If link quality is insufficient due to environmental conditions (such as clouds on an optical link or long distance RF transmission in a storm) the cost required to communicate over the link may be too much, even if access to infrastructure is otherwise in a less expensive time of day.
    - *Regulatory pressure, like carbon taxes?*
Considerations

- Granularity, frequency, coverage of carbon-intensity measurement
- Interplay of stored electricity in battery and (live) electricity generation
- Justification function
Additional resources

Thank You
BACKUP
Green SW Foundation: Software Carbon Intensity

The SCI score is a rate of carbon emissions, not a total. The equation is a simple and elegant solution to the extremely complex problem behind it:

\[
SCI = \left( (E \cdot I) + M \right) \text{ per } R
\]

- Carbon emitted per kWh of energy, gCO2/kWh
- Carbon emitted through the hardware that the software is running on
- Energy consumed by software in kWh
- Functional Unit; this is how software scales, for example per user or per device

The “per R” is what makes the SCI into a tool that works for every software domain, every use case, and every person.

Source: https://grnsft.org/sci
Carbon-responsive packet routing

Enabled by:
- Exposure of carbon-intensity data from eGrid
- Uptake of carbon-intensity in QoS-enabled routing protocols (and apps)