Exploring the Benefits of Carbon-Aware Routing

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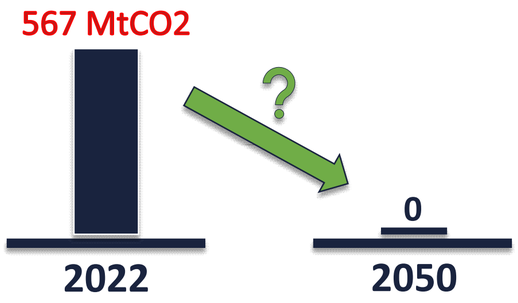
Problem: The carbon footprint of the Internet is significant.

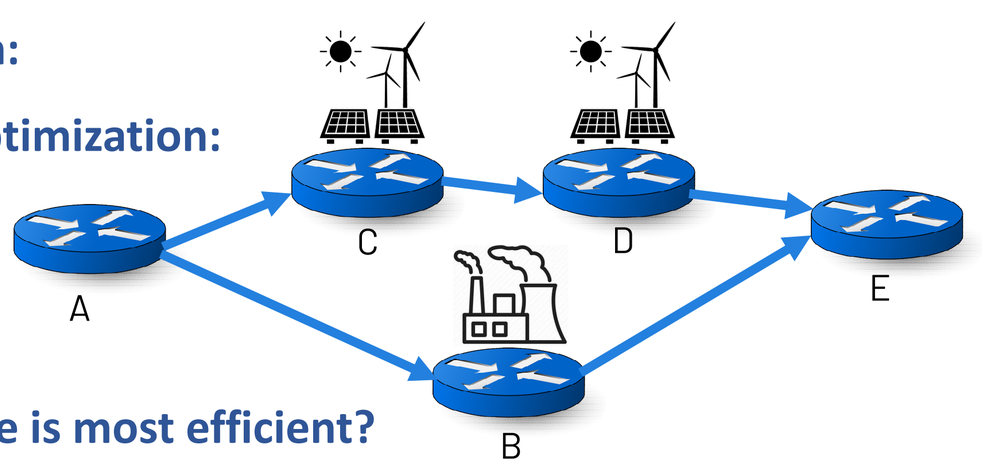


- Lack of standard green solutions
- Lack of sustainability metrics
- Lack of accurate and granular carbon measurements
- Lack of policy

Motivation:

Routing Optimization:

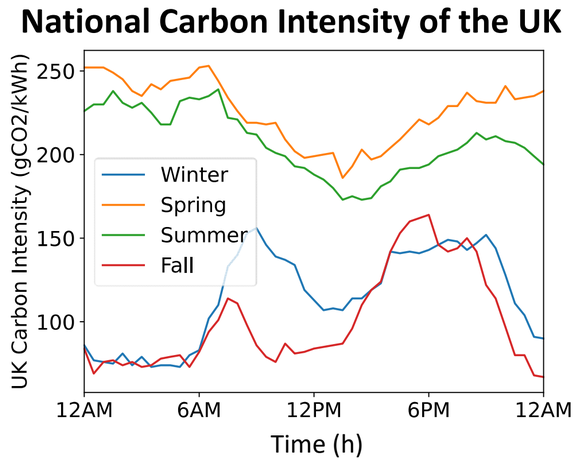
A – B – E
vs
A – C – D – E



Which route is most efficient?

- Different locations → different carbon intensity
- Carbon intensity in gCO2/kWh
- Carbon intensity varies:
  - per region
  - per season
  - per day
- Carbon intensity is predictable

National Carbon Intensity of the UK



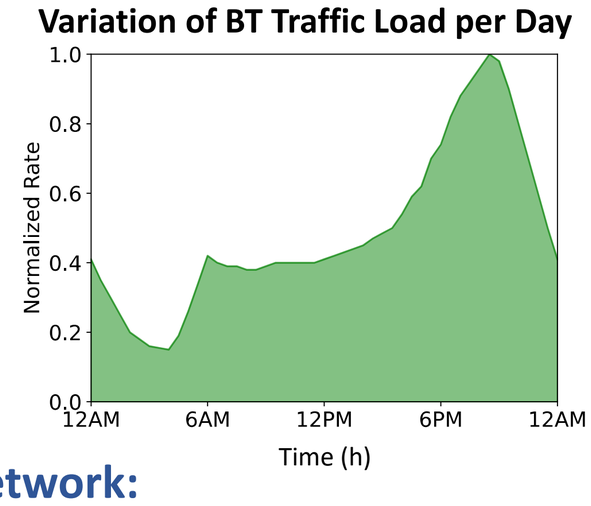
→ Goal: Explore and quantify the potential energy and carbon savings of carbon-aware routing

Understanding UK's Internet:

Traffic Patterns:

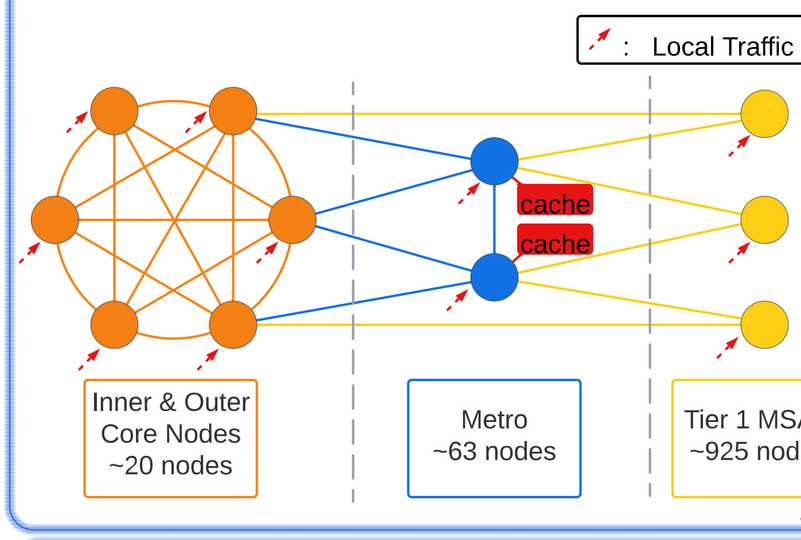
Day-Traffic	Evening-Traffic
Business customers	Residential customers
Symmetric traffic	Downstream video
Throughput constant	Peak at 7:00-8:00 PM

Variation of BT Traffic Load per Day

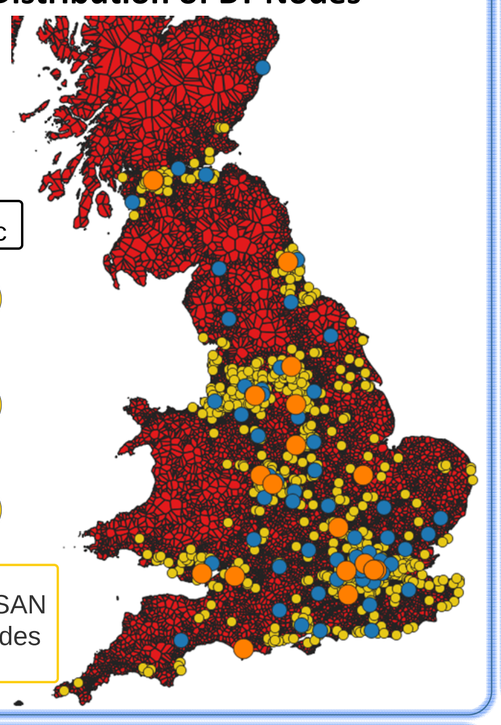


Hierarchal Structure of BT's Network:

- BT connects all of the UK
- All sites serve local community and connect to other sites
- Content is streamed from caches



Distribution of BT Nodes



Energy-Related Metrics:

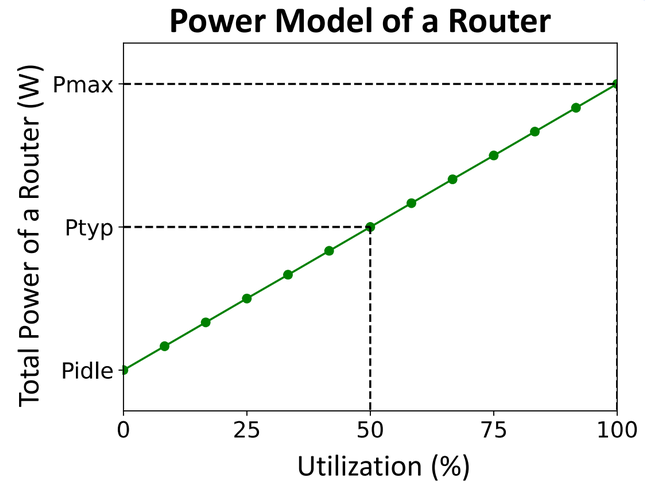
- Typical power
- Energy Rating (not a standard yet!)
- Incremental Dynamic Power per Unit of Traffic

Carbon-Related Metrics:

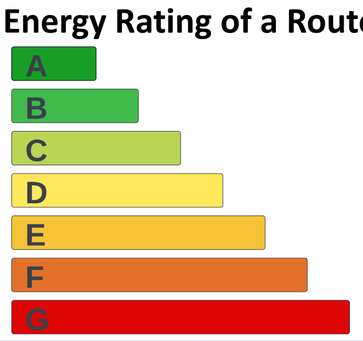
- Carbon Intensity
- Past Carbon Emissions

+ Combination of Metrics
(ex: Energy Rating + Carbon Intensity)

Power Model of a Router



Energy Rating of a Router

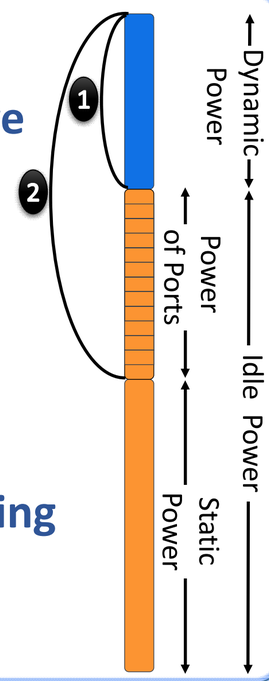


Approach:

1) Change link costs based on the metrics above
2) CATE: Carbon-Aware Traffic Engineering

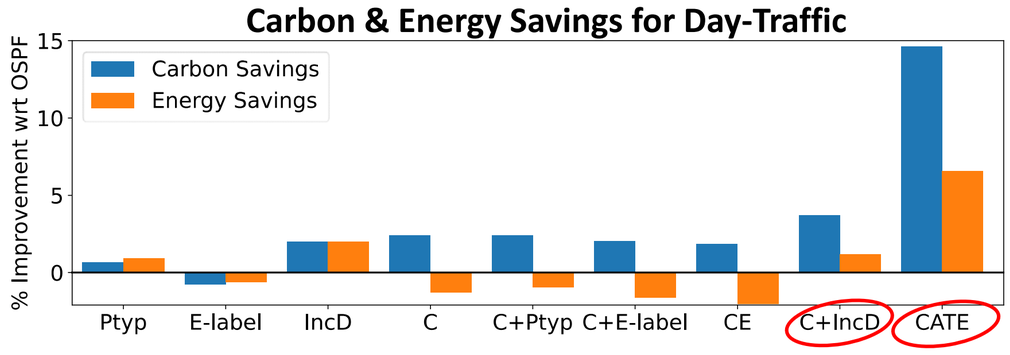
- Pick links with least utilization and highest carbon emissions, and shut them down
- Guarantee network connectivity

→ Solve for all UK network while accounting for user experience constraints



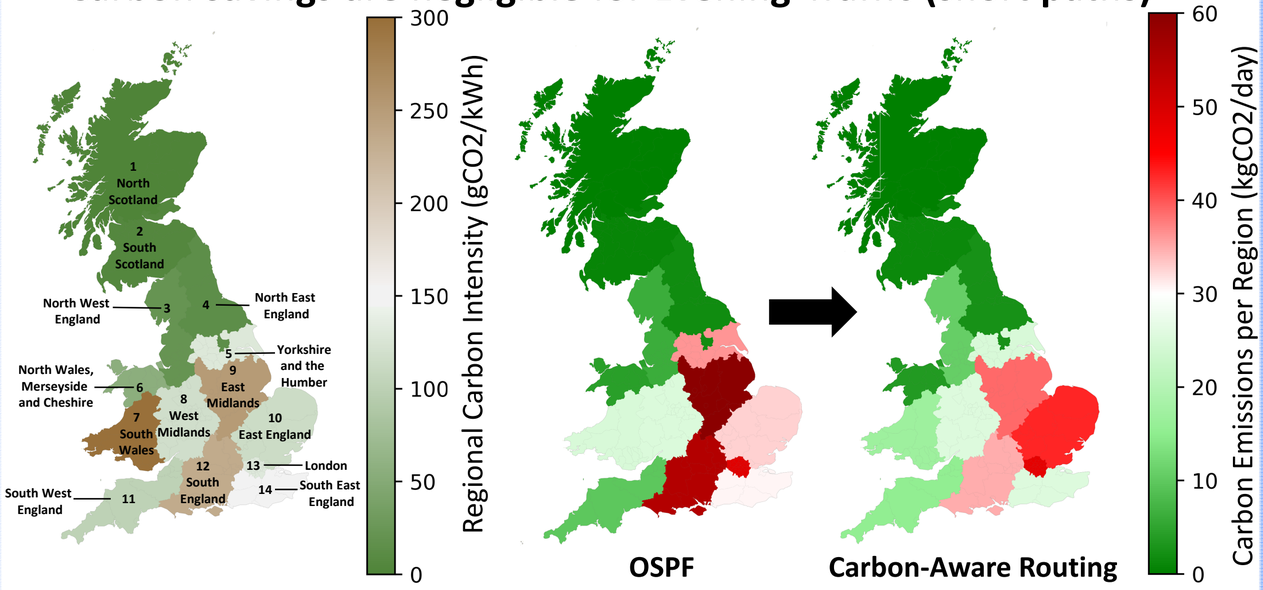
Key Results:

Carbon & Energy Savings for Day-Traffic



Legend:
Ptyp: Typical Power
E-label: Energy Label
IncD: Dynamic Power per Unit Traffic
C: Carbon Intensity
CE: Carbon Emissions

- Metrics: carbon intensity + dynamic power → most carbon savings
- CATE: highest savings at the expense of path stretching of 5%
- Carbon savings are negligible for Evening-Traffic (short paths)



- Internet traffic is routed away from carbon-intensive regions
- Overall carbon emissions are reduced

Recommendations:

- Define a standard set of energy and carbon metrics
- Distinguish between use cases for carbon emissions minimization
- Regulate energy rating for ICT equipment
- Reduce the static power of routers with greener design techniques
- Enforce detailed and accurate reporting of carbon by ISPs

Impact:

- ISPs: immediate steps to reduce emissions without incurring additional costs or changes to their infrastructure
- Users: ability to compare and choose the most environmentally friendly ISP
- Policy makers: informed policy recommendations