

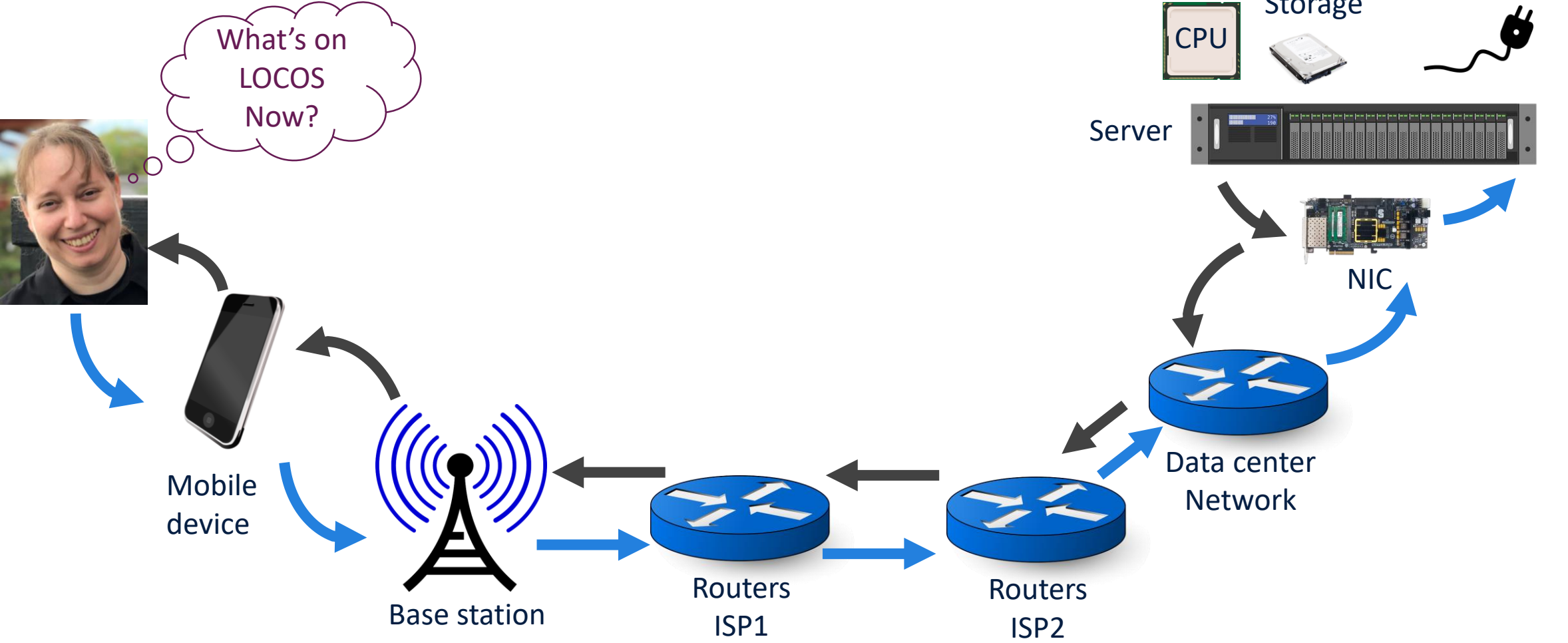


Toward Carbon-Aware Networking

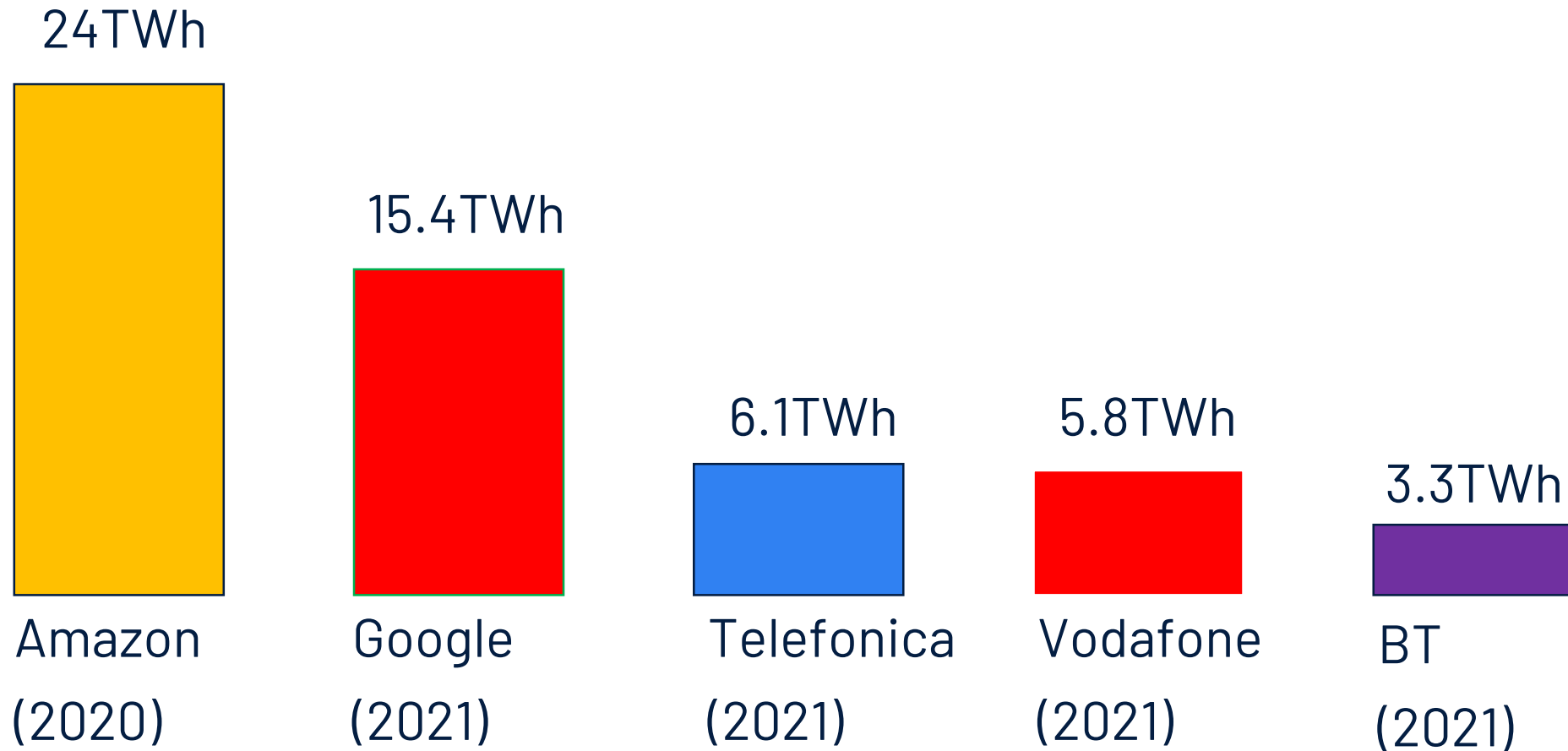
Noa Zilberman, Eve Schooler, Uri Cummings, Rajit Manohar, Dawn Nafus, Robert Soulé and Rick Taylor

March 2023

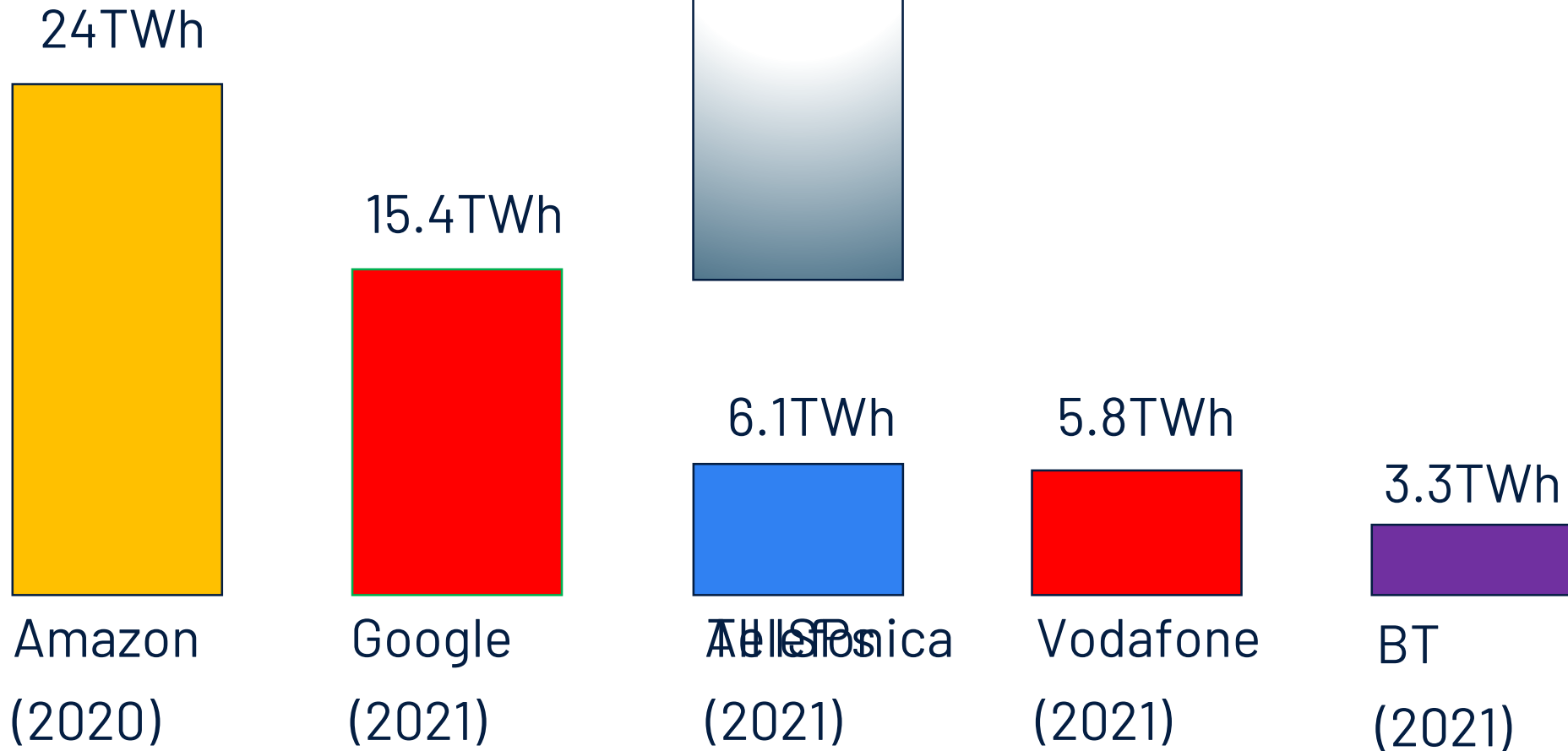
What is the carbon footprint of a networked application?



The network is negligible



The network is ^{Not} negligible

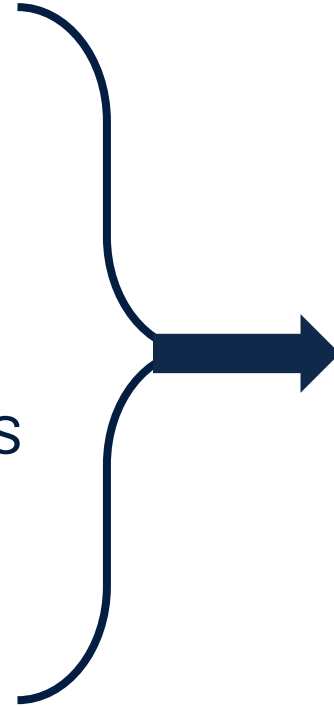


Carbon Reporting Metrics: Policy

- Use standard metrics
- Use standard evaluation environments
- Provide carbon efficiency under different loads
- Provide measured results.
- Avoid double counting
- Trustworthy reporting
- Real time observability

Carbon Reporting Metrics: Technical Challenges

- Across multiple domains
- Multiple types of devices
- Mixed with other services
- Sensitive to load

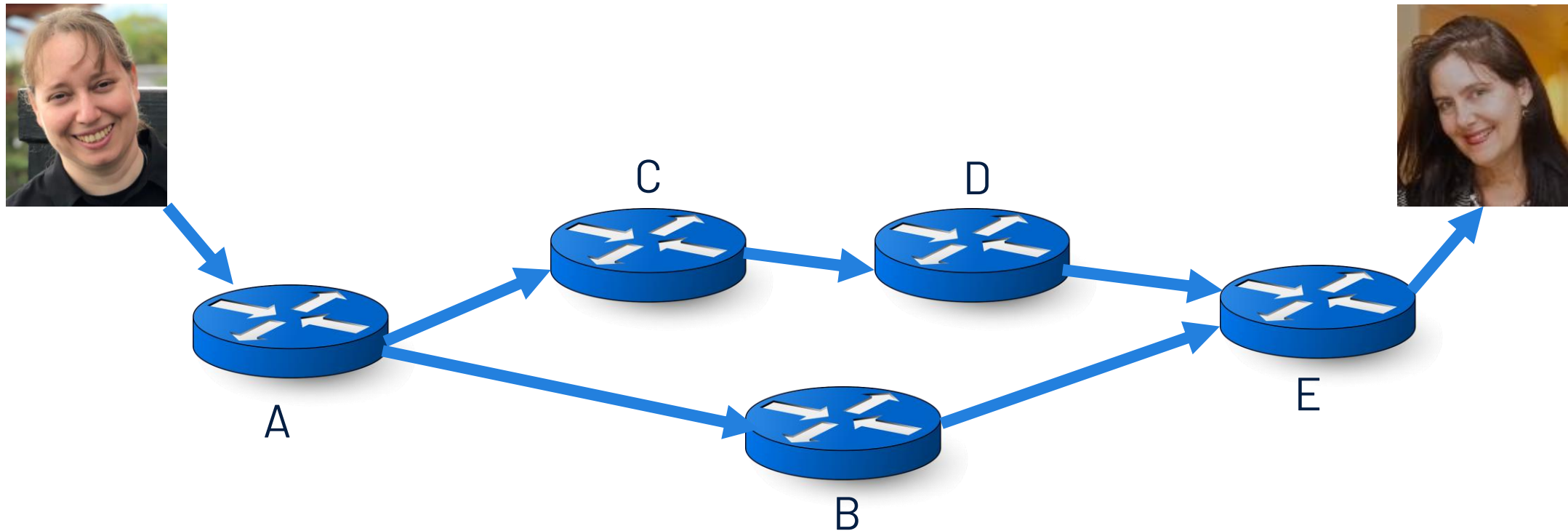


- Real time reporting of:
 - Electricity consumption
 - Carbon intensity
- Tie back to the application
- React in real time

Carbon Aware Networking

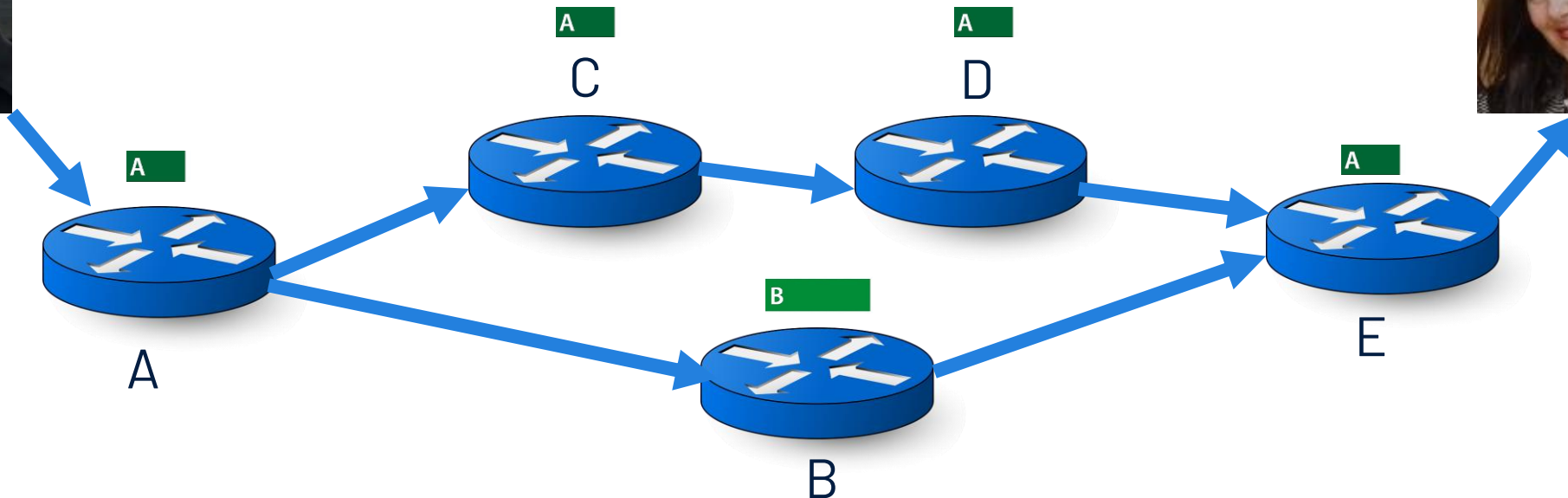
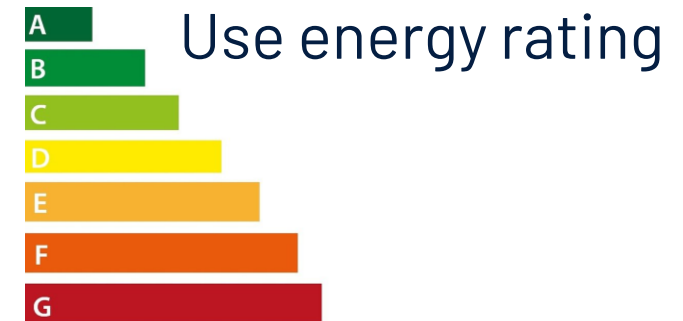
How to find the most carbon efficient route?

Route A-B-E or Route A-C-D-E?



How to find the most carbon efficient route?

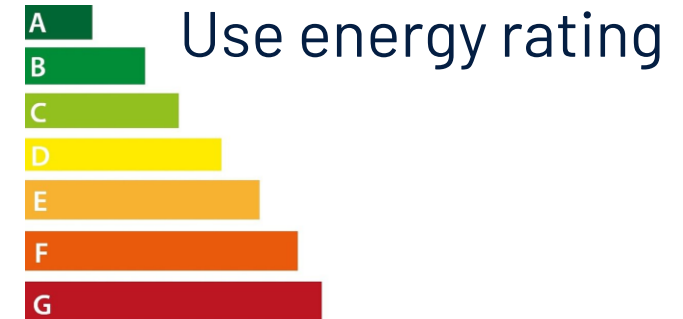
Route A-B-E or Route A-C-D-E?



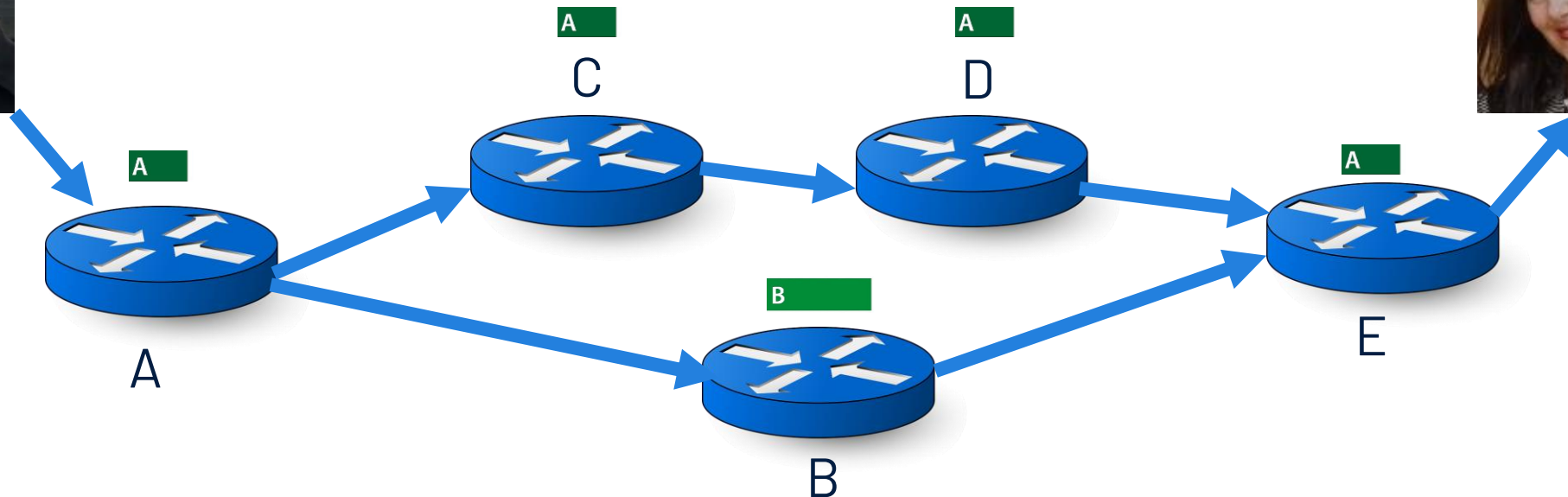
How to find the most carbon efficient route?

Route A-B-E or Route A-C-D-E?

Route A-C-D-E uses only A rated devices



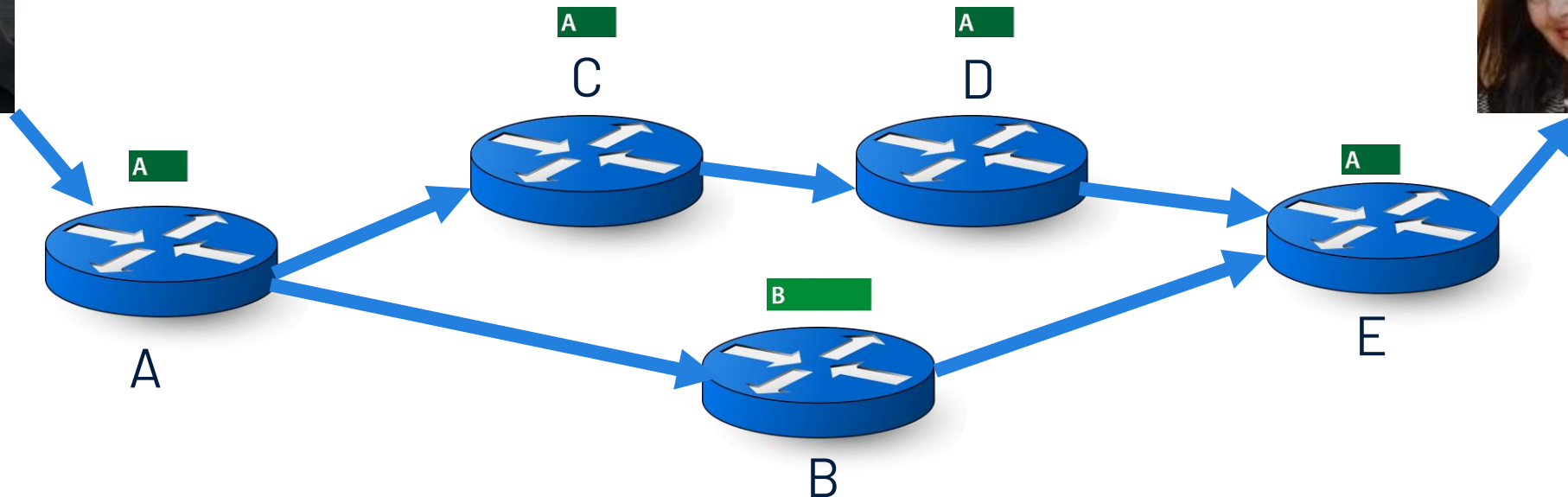
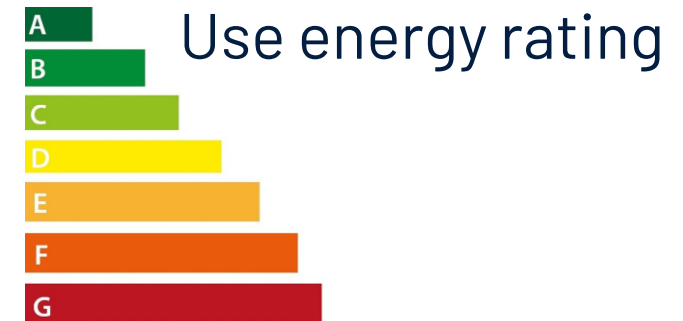
Use In-Network telemetry to collect information



How to find the most carbon efficient route?

Route A-B-E or Route A-C-D-E?

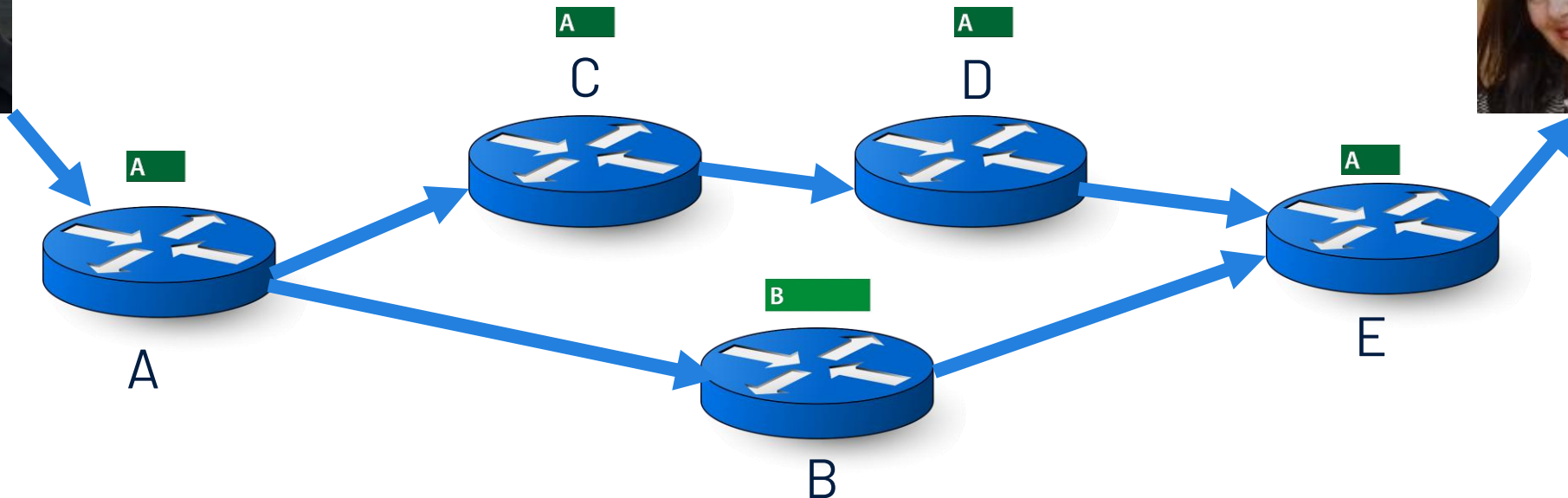
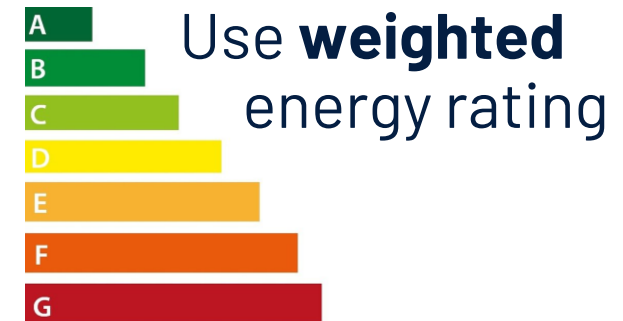
Is 2x A better than 1x B?



How to find the most carbon efficient route?

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Is 2x A better than 1x B?

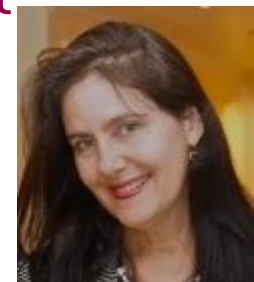
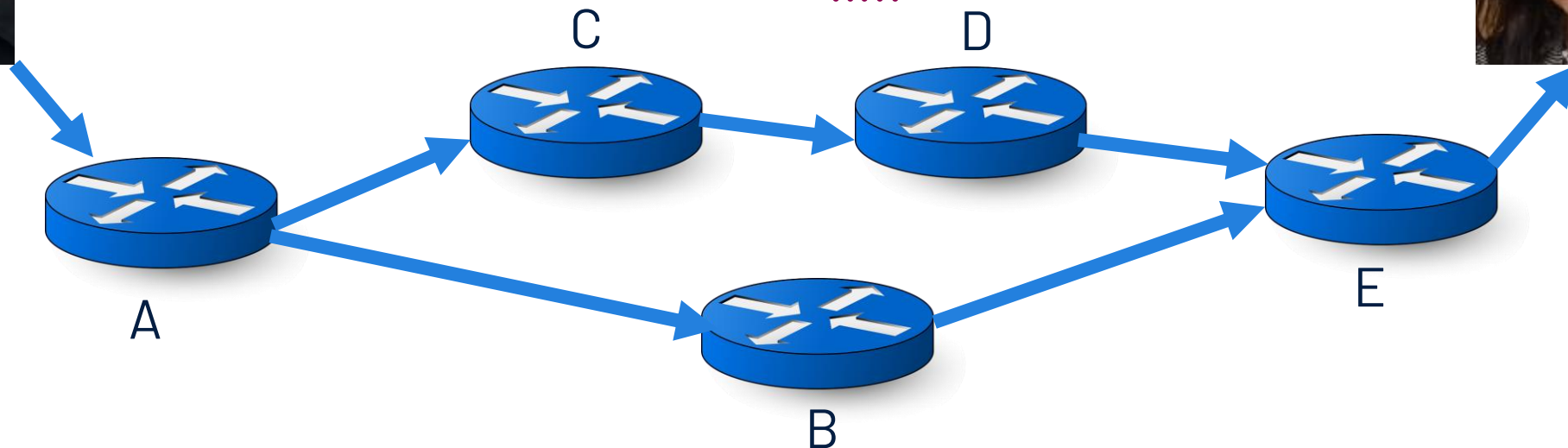


How to find the most carbon efficient route?

Route A-B-E or Route A-C-D-E?

Need to consider:

- Congestion
- Load
- Carbon-efficiency gradient
- Multi-route optimization
-



Carbon Intelligent Networking

Carbon Aware & Intelligent Routing

- **Carbon aware routing**

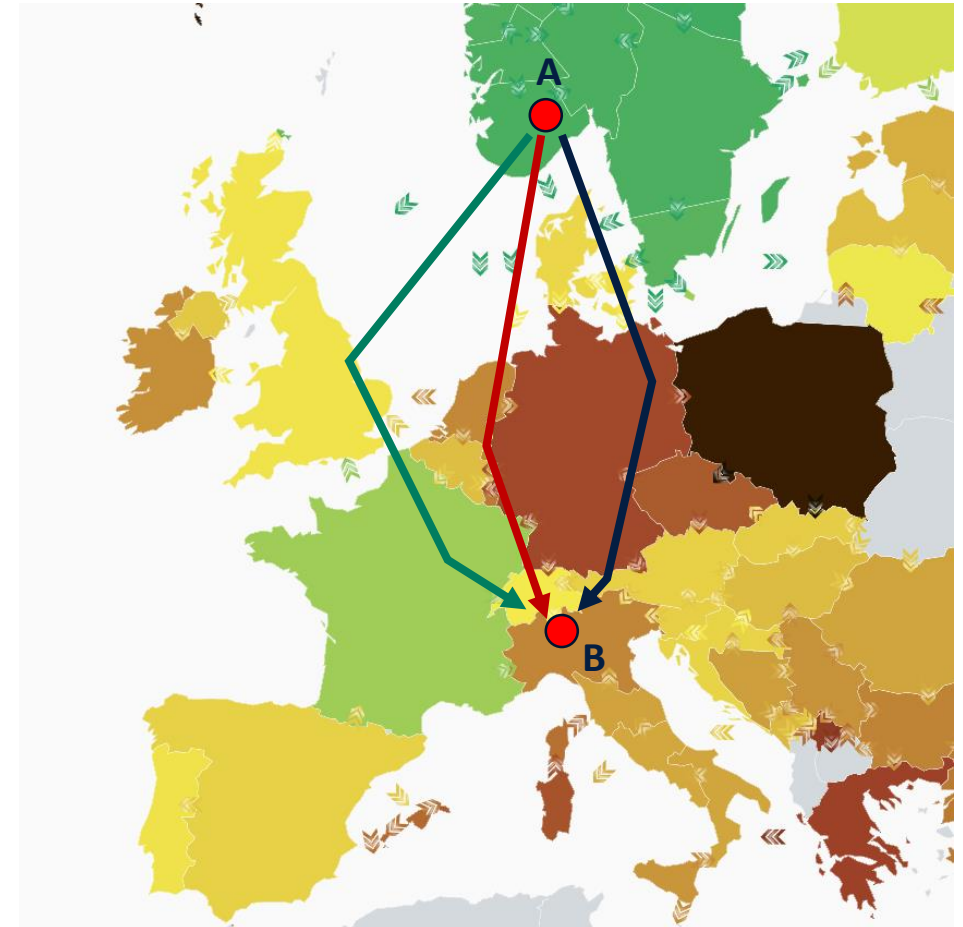
- knowing the carbon emissions and minimizing them while **applying standard routing practices**

- **Carbon intelligent routing**

- knowing the carbon emissions and minimizing them while **taking different approaches to routing and scheduling of data-transfer**

Carbon Aware Routing

- What is the best route from A to B?
- “Best route” – Minimum carbon emissions
- Standard routing protocols
 - Slight modifications



Source: electricitymaps.com

Carbon Intelligent Routing

- Set metrics (e.g., delay) thresholds and carbon-footprint budget
- Use for route optimization
- Examples:
 - Delay tolerant carbon-bounded routing
 - Content distribution optimizing for carbon-efficiency

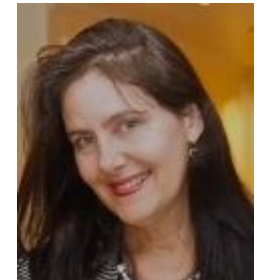
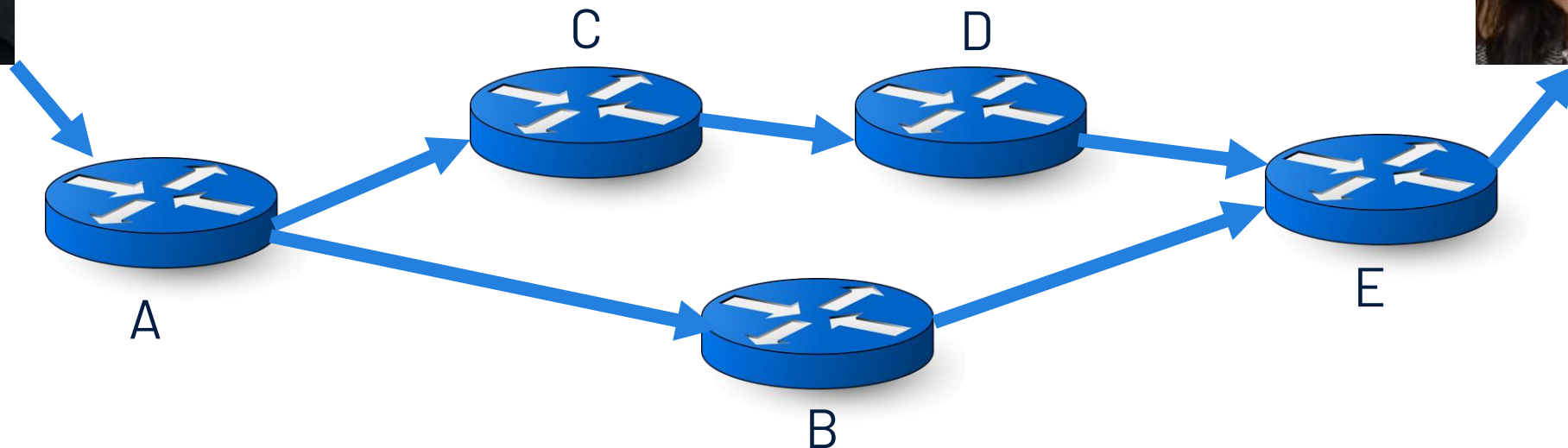
Carbon Intelligent Network Telemetry

- Collect information from network devices along the route, such as:
 - Energy rating (static)
 - Using renewable energy? Yes/No (dynamic)
 - Carbon intensity (dynamic)
 - Platform power consumption (dynamic)

How to find the most carbon efficient route?

Use in-network telemetry to collect real-time carbon intensity

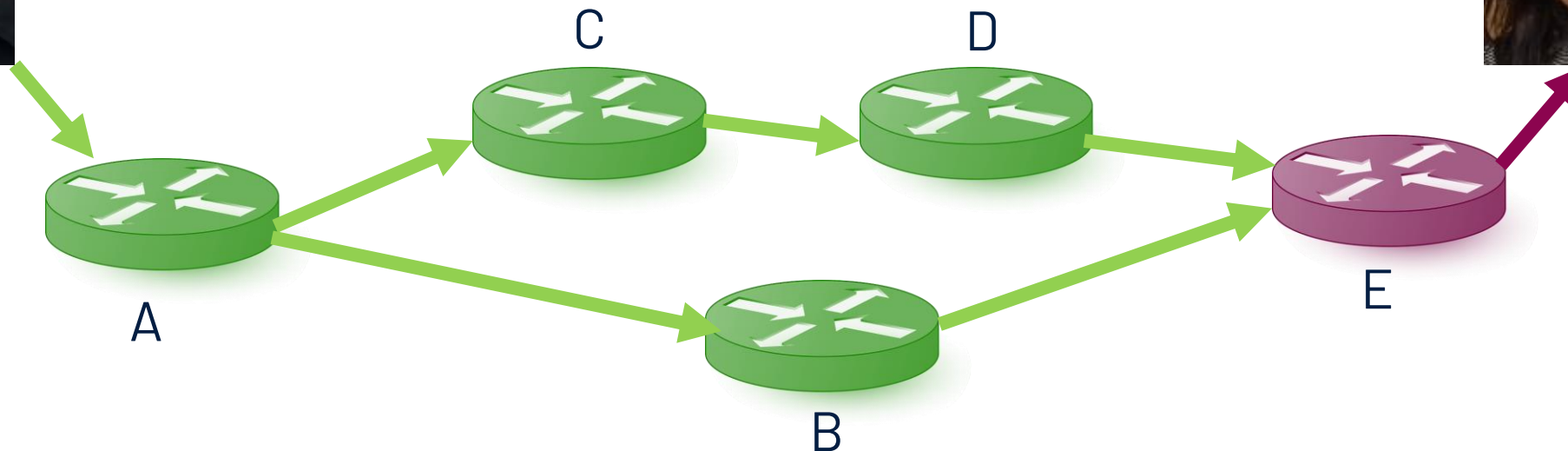
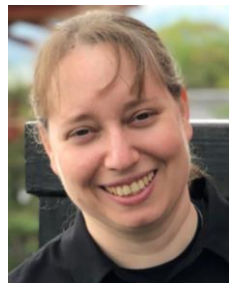
Schedule / buffer message at nodes until carbon-intensity is low



How to find the most carbon efficient route?

Use in-network telemetry to collect real-time carbon intensity

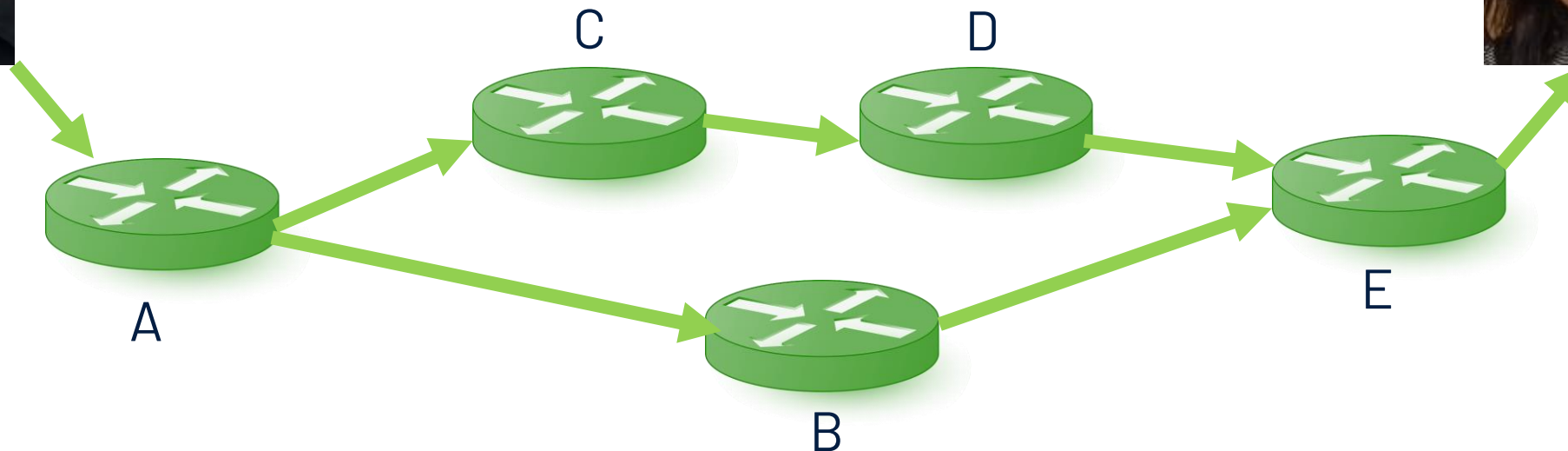
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How to find the most carbon efficient route?

Use in-network telemetry to collect real-time carbon intensity

Schedule / buffer message at nodes until carbon-intensity is low



Summary & A Call to Action

- Networking needs to be carbon-efficient!
- Need more visibility: application, stack, platforms, ...
- Need standard metrics
 - ... and standards!
- Carbon-intelligent routing is the next big challenge

We can make networking GREEN