Low-Carbon Routing Algorithms For Cloud Computing Services in IP-over-WDM Networks

TREND Plenary Meeting, Volos-Greece 01-05/10/2012

TD3.3: Energy-efficient service provisioning and content distribution

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SEVENTH FRAMEWORK PROGRAMME

Summary

- Introduction
- Power consumption models
- Low-carbon routing algorithms
- Case study
- Conclusions

Summary

- Introduction
  - Scope
  - Renewable energy sources
- Power consumption models
- Low-carbon routing algorithms
- Case study
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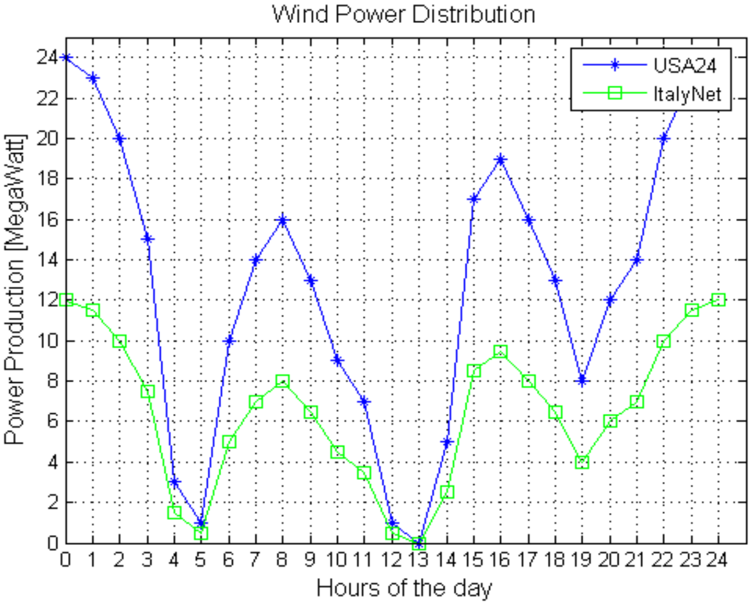
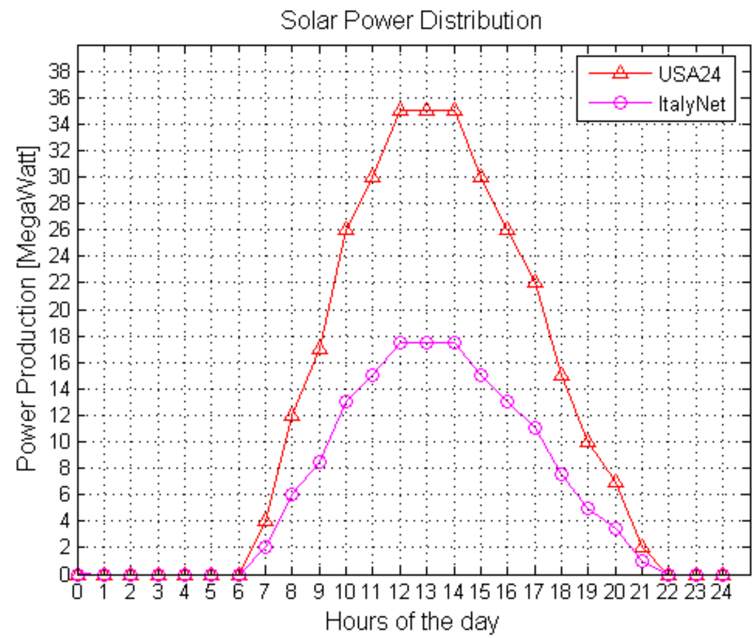
Scope

- ICT responsible for 8% of global energy consumption (2% of total CO_2 emissions)
- Great benefits in reduction of greenhouse gas emissions using renewable energy sources (RES) e.g., sun and wind
  - RES usually in remote locations, hard to connect to electrical grid → DCs delocalization
- Scope: dynamic low-CO_2 emissions routing
  - Difference between CO_2 reduction and energy efficiency
  - Trade-off: transport power vs processing power (in DCs)

Renewable energy sources



- Wind powered data centers
- Power profile during 24 hours of the day
- Shifted according to the time zone
- Variations due to the waxing and waning of the wind → hard to predict



- Solar powered data centers
- Power profile during 24 hours of the day
- Shifted according to the time zone
- Variations mainly due to diurnal cycle of the sun →power from 6 to 22

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  - Data center power supply
  - Processing power
- Low-carbon routing algorithms
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Renewable energy production

- Power needed in each DC to support the whole traffic request:
  - 300 MW for USA24 topology
  - 150 MW for ItalyNet topology
- Solar Energy generated from CSP (Concentrated Solar Power) system with parabolic troughs
  - Reference: Nevada Solar One
  - Our case: area of 6 km^2 for USA24 and 3 km^2 for ItalyNet
- Wind Energy generated from Wind farm, group of wind turbines joined together
  - Reference: Wild Horse Wind Farm, Washington
  - Our case: 166 turbines (1.8 MW each) covering an area of 47 km^2 for USA24 and 83 turbines in 23 km^2 for ItalyNet

Processing power

- Analysis on energy consumption of Cloud Computing*, describing 3 possible types of service:
  - Storage as a Service (***$S_t$aaS***)
  - Software as a Service (***SaaS***)
  - Processing as a Service (***PaaS***)

- We estimate the energy for a single connection during the processing phase

*Baliga *et al.*, "Green cloud computing: Balancing energy in processing, storage and transport".

Data center consumption and design

- Model for the energy consumption per unity of Gbit (Wh/Gbit) of a single user connection:

$$E_{proc} = 1.5 * T_{proc} * P_{server}$$

Cooling factor + OH

Processing time

Server consumption

Data center consumption and design

- Model for the energy consumption per unity of Gbit (Wh/Gbit) of a single user connection:

$$E_{proc}=1.5 * T_{proc} * P_{server}$$

- We assume a 8.54 Gbyte (DVD) video file conversion from MPEG-2 to MPEG-4 which requires on the computation server (HP DL380 G5) 1.25 hours → 0.0183 hours/Gbit
- Consider a 10 Gb/s lightpath which lasts *t* seconds (10**t* Gb of data):

$$1.5 * 10*t\ (Gbit) * 0.0183\ (h/Gbit) * 355\ (W) = 97.4*t\ Wh \sim 100*t\ Wh$$

- For *SaaS* and $S_t aaS$ the power consumption is 27**t* and 1.41**t* Wh

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- Low-carbon routing algorithms
  - Anycast routing
  - Energy-aware routing algorithms
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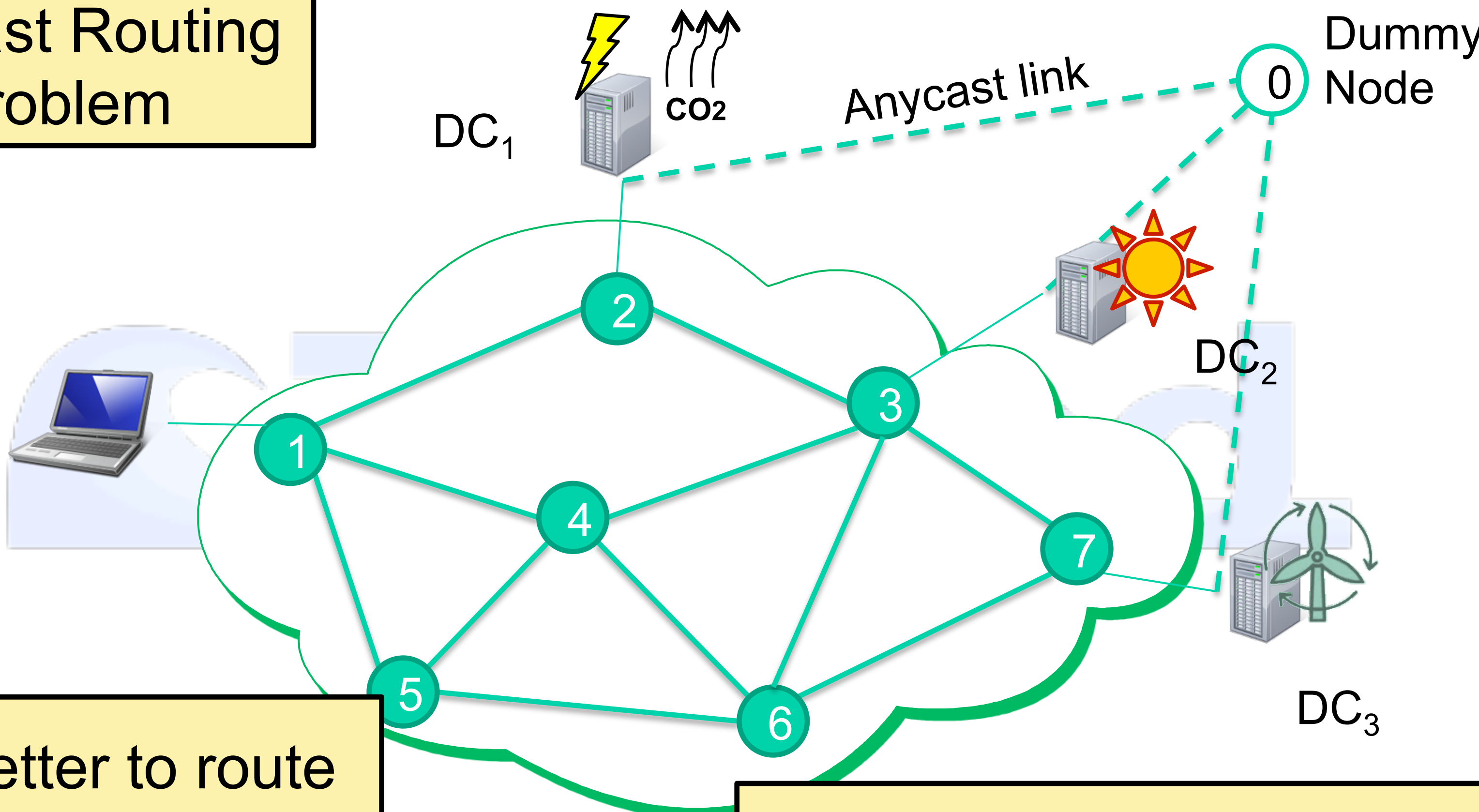
Routing problem

Anycast Routing Problem



Is it better to route towards a remote DC with renewable energy ?

Trade-off between transport and processing power

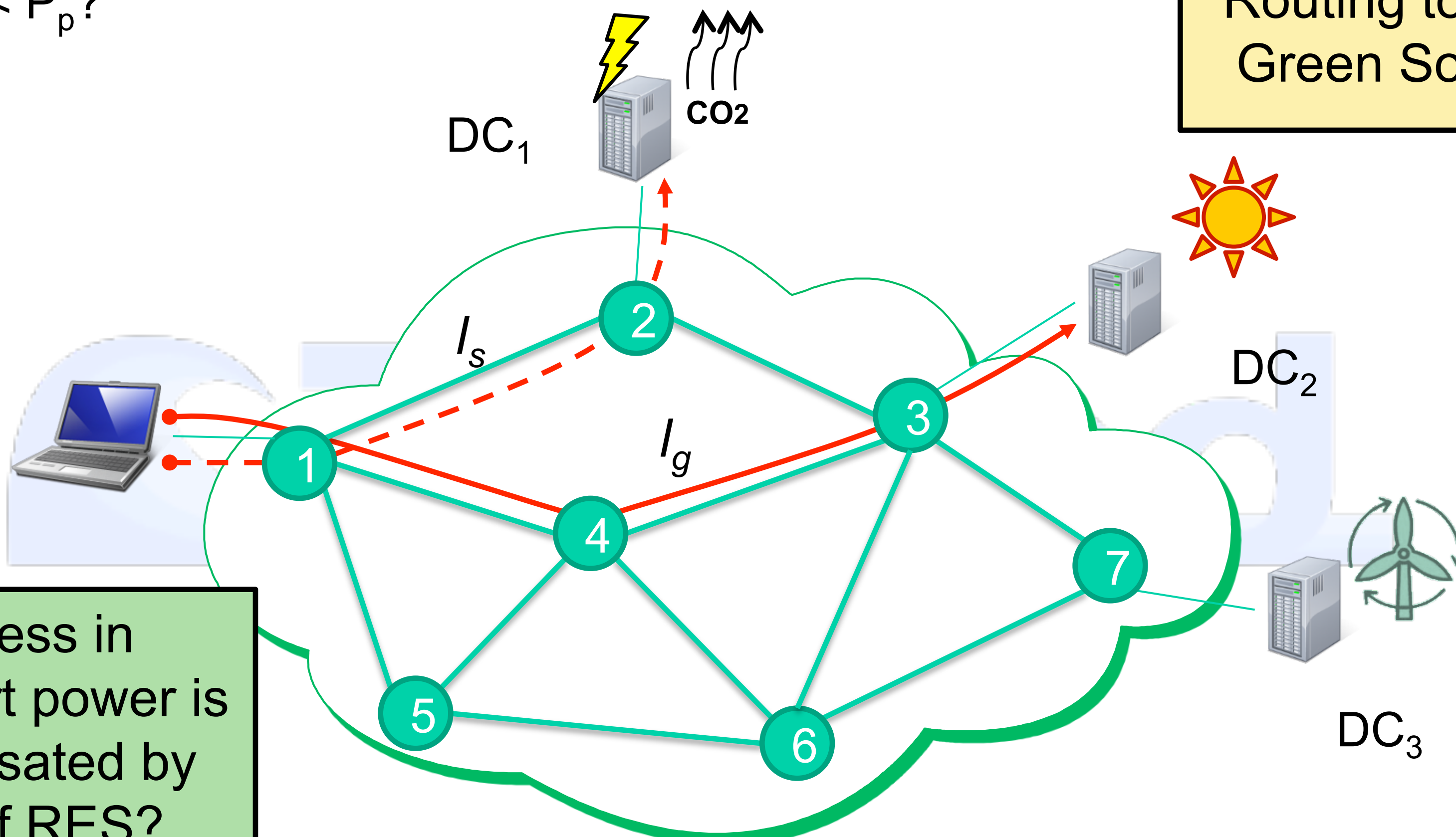
Algorithms

- Routing algorithms: aim to *minimize the total non-renewable (brown) energy* of the network (emissions → 1 kwh=228 gCO_2)
- *Sun&Wind Energy-Aware Routing* (SWEAR): chooses for each connection between two paths
  - 1 - Maximum usage of renewable energy
  - 2 - Lowest transport energy
- *Green Energy-Aware Routing* (GEAR): finds for each connection the path with
  - Lowest non-renewable (brown) energy
- Consider trasport power (brown)
  - Trade-off between transport power and (green) processing power

SWEAR - A simple example

P_{lg}-P_{ls} < P_p?

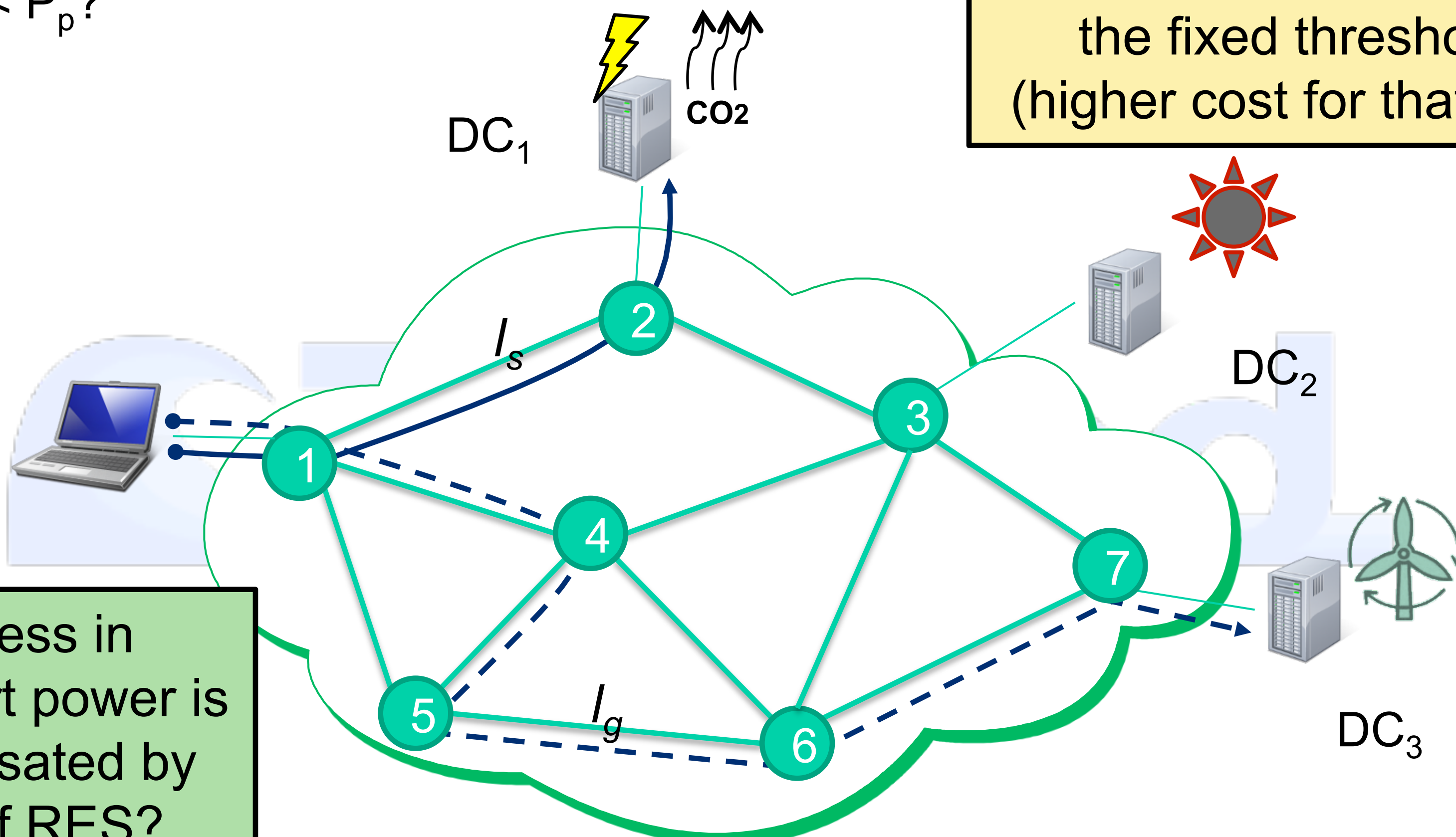
Routing towards Green Sources



The excess in transport power is compensated by usage of RES? YES→choose l_g

SWEAR - A simple example

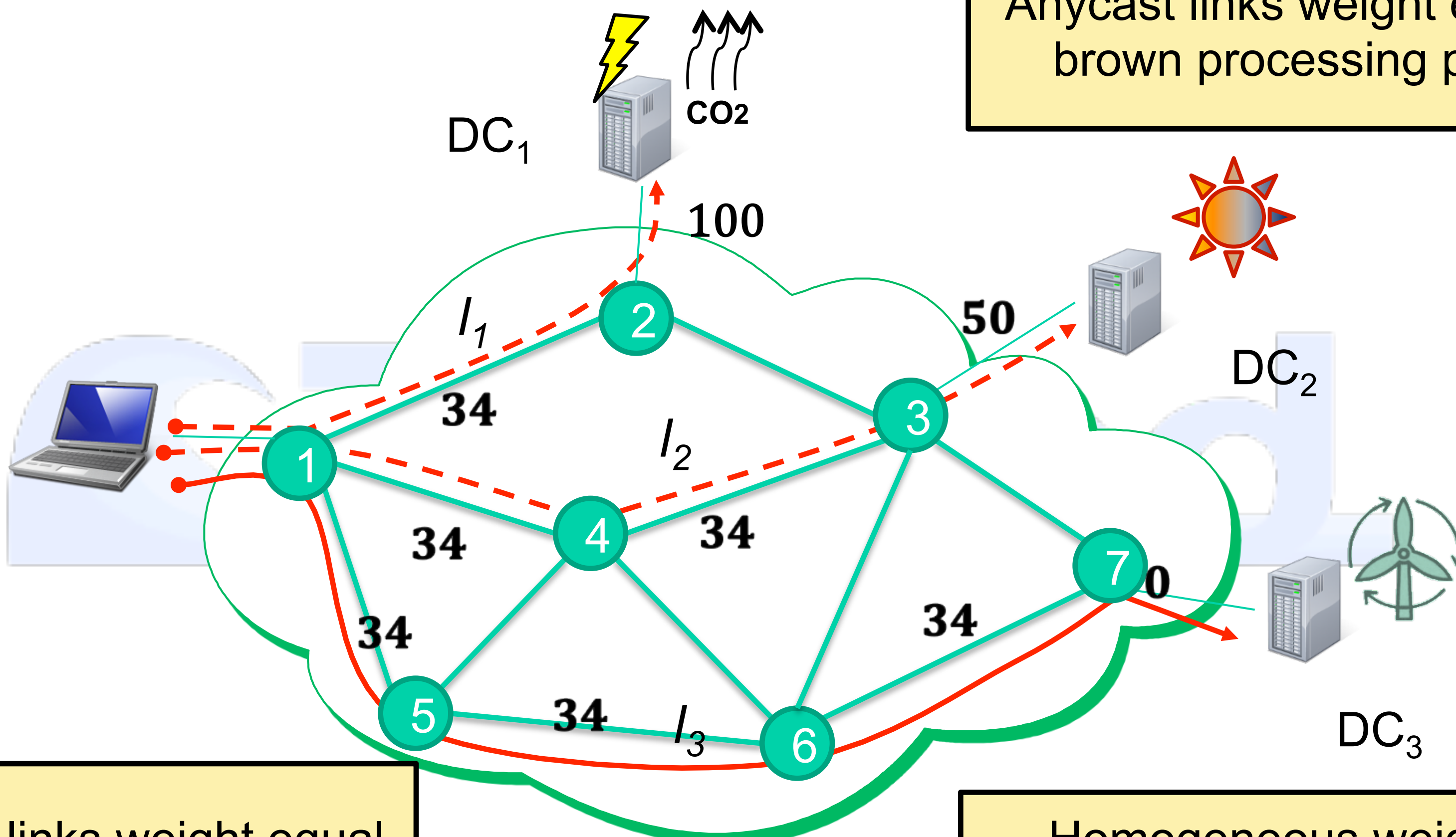
P_{lg}-P_{ls} < P_p?



Load Balancing when the traffic on a link overcome the fixed threshold (higher cost for that link)

The excess in transport power is compensated by usage of RES? NO→choose l_s

GEAR - A simple example



Anycast links weight equal to brown processing power

Transport links weight equal to transport power

Homogeneous weights assignment (brown power) for all network links

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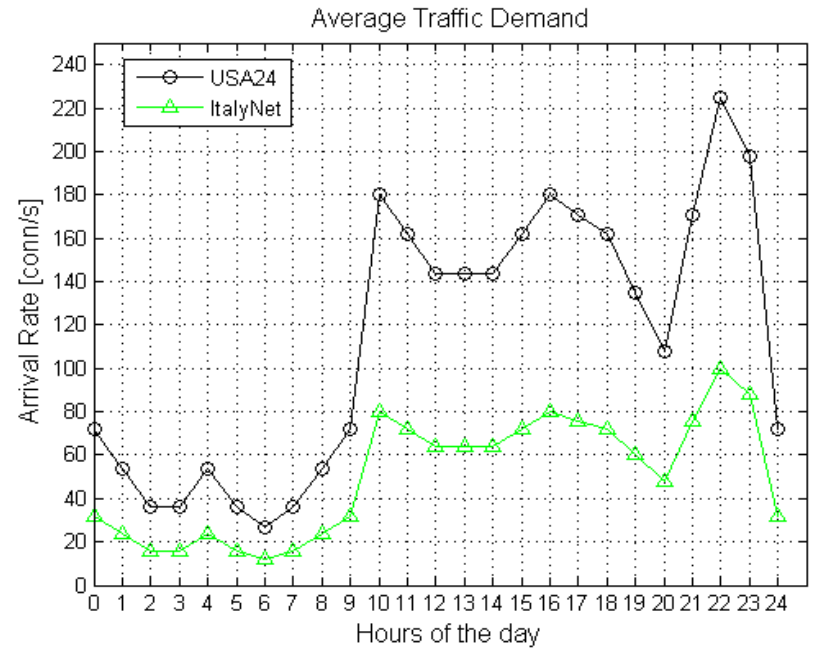
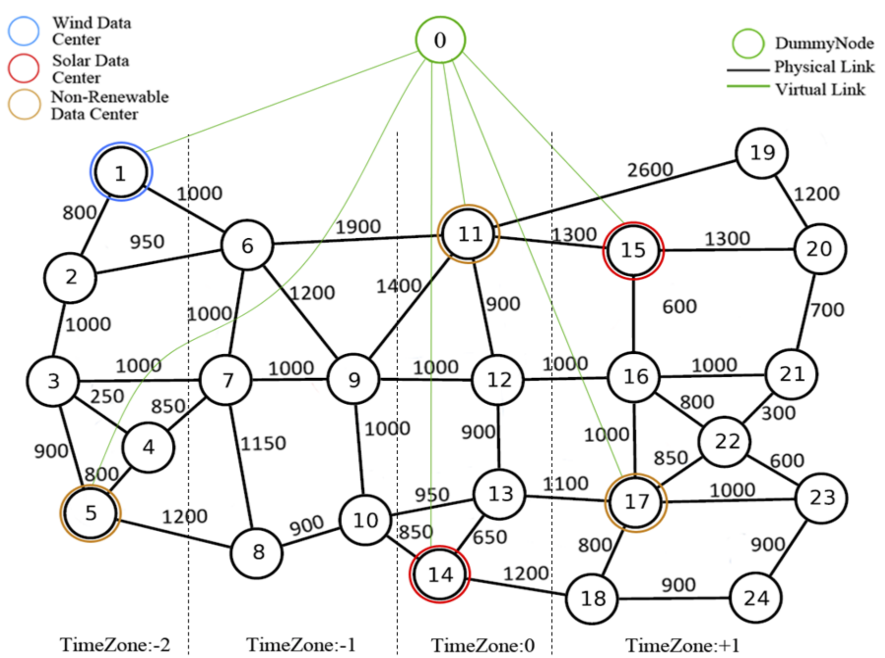
Case Study

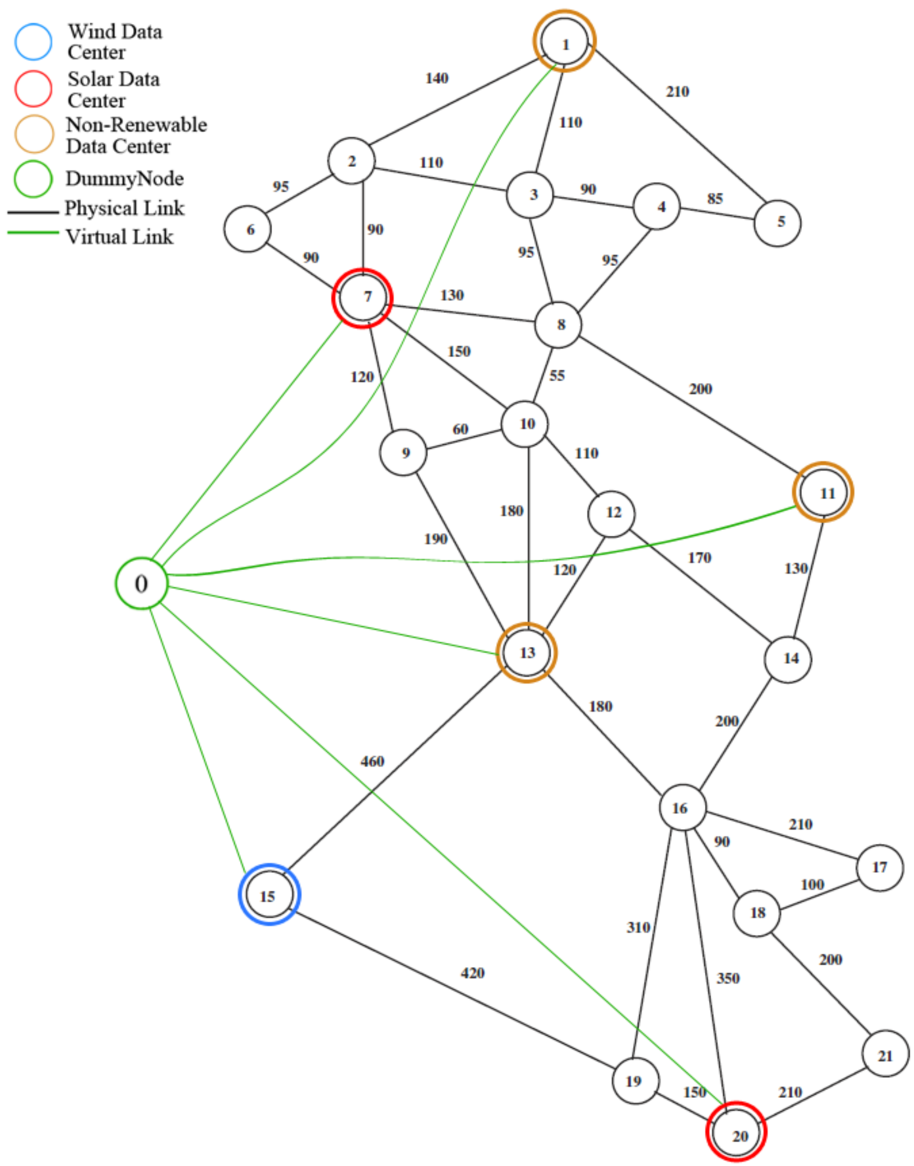
- Poisson interarrival traffic
- Holding time with negative exponential distribution
  - Average duration 1 s
- Each connection requires an entire 10 Gbit/s lighpath
- Traffic uniformly distributed

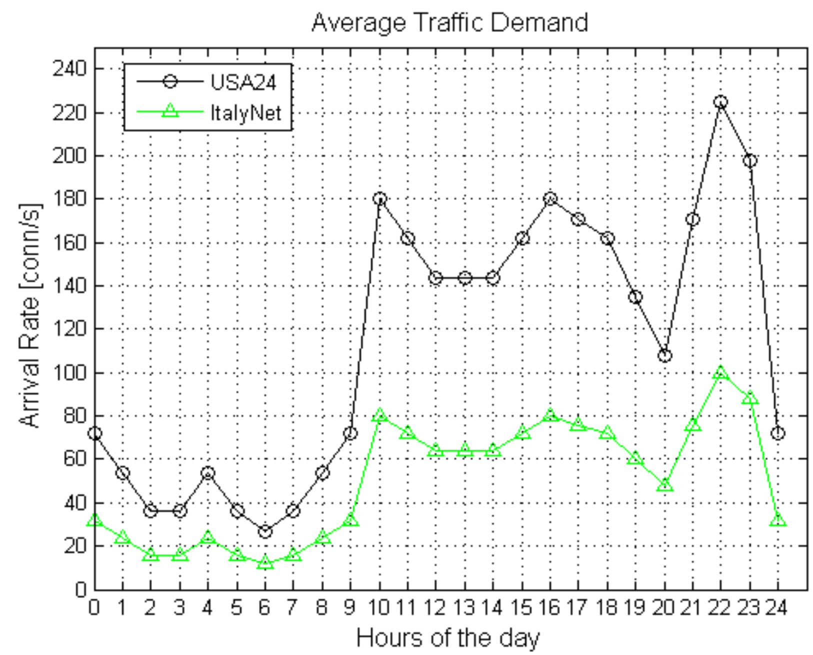




- 24 nodes, 43 links
- 16 wavelenghts/link
- 6 Data centers:
  - 1 with Wind energy (1)
  - 2 with Solar energy (14,15)
  - 3 with Non-Renewable energy (5,11,17)

Case Study



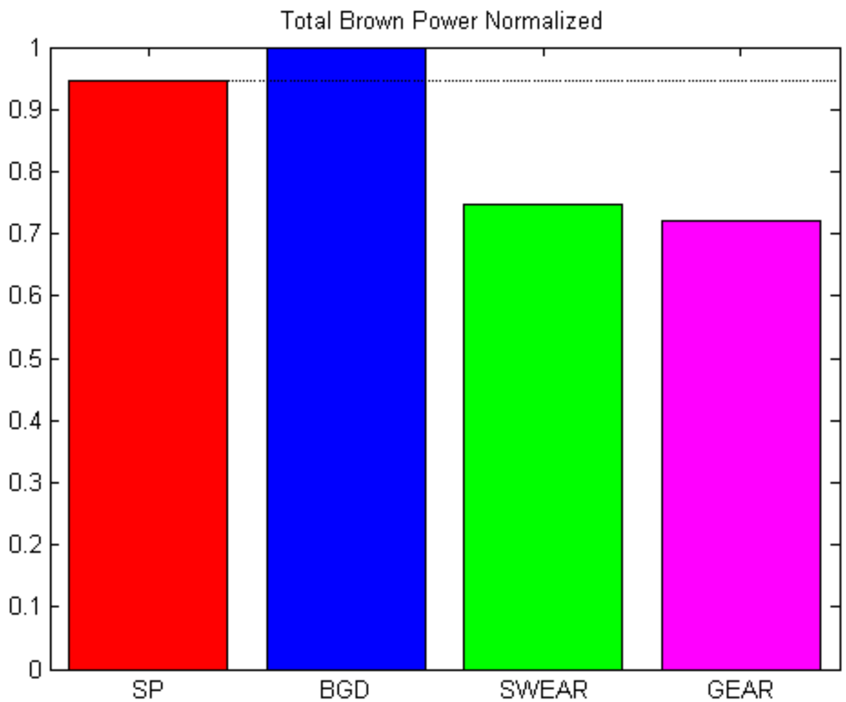


- 21 nodes, 36 links
- 16 wavelenghts/link
- 6 Data centers:
  - 1 with Wind energy (15)
  - 2 with Solar energy (7,20)
  - 3 with Non-Renewable energy (1,11,13)

Case Study

- GEAR and SWEAR compared with two reference algorithms:
  - *Shortest Path* (SP)
  - *Best Green Data Center* (BGD): always routing towards the DC with more renewable energy

Results (*Total Brown Power*)



Reduction in total emissions vs. SP:

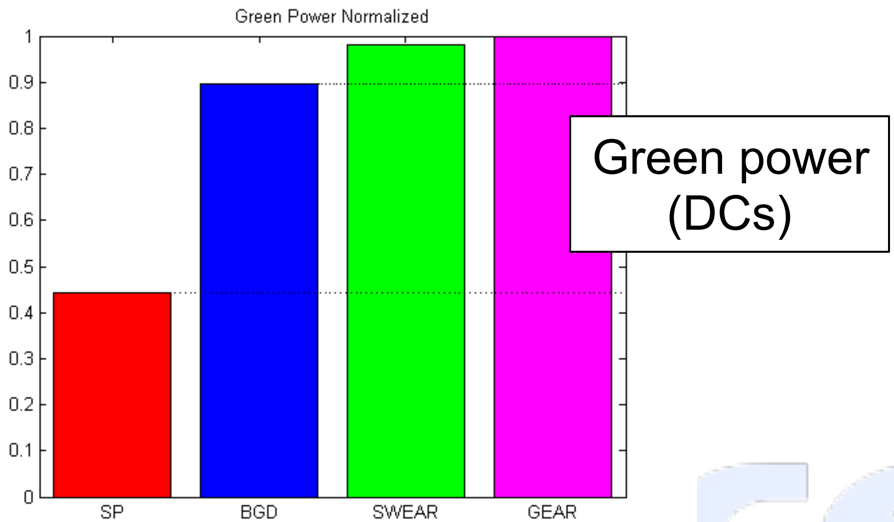
- 21% with SWEAR
- 24% with GEAR

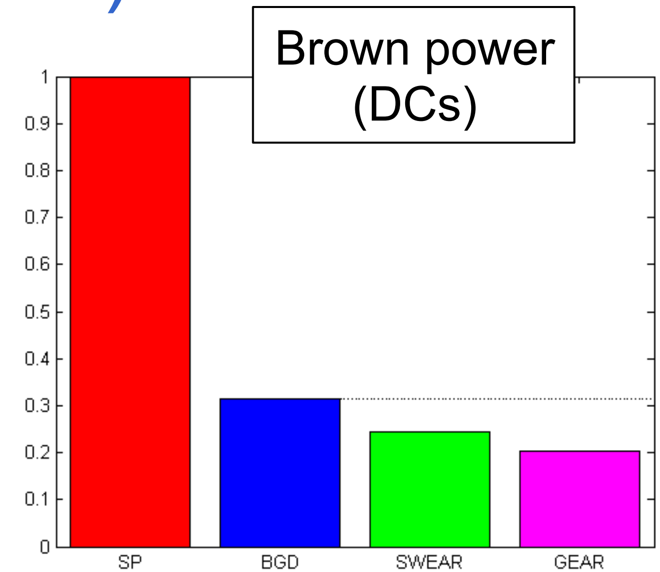
Reduction in total emissions vs. BGD:

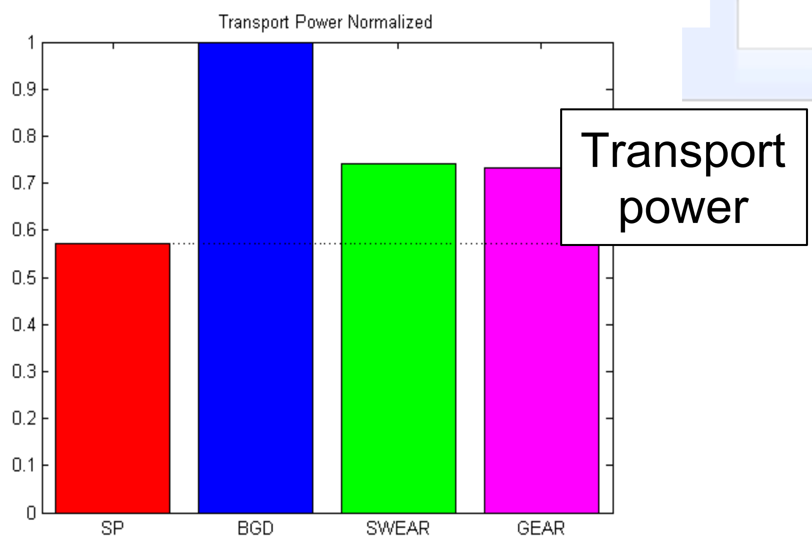
- 25% with SWEAR
- 27% with GEAR

Results for *ItalyNet*

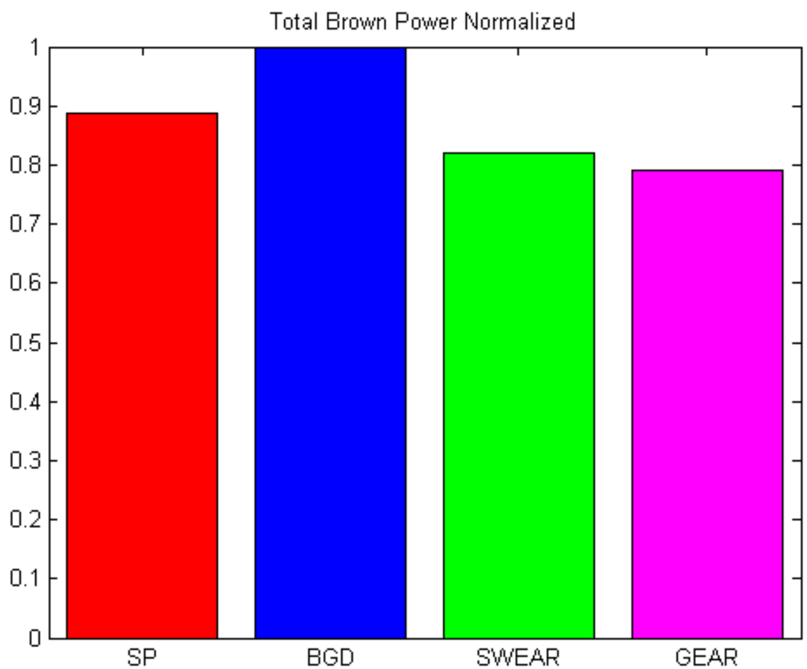
Results (*Other contributions*)



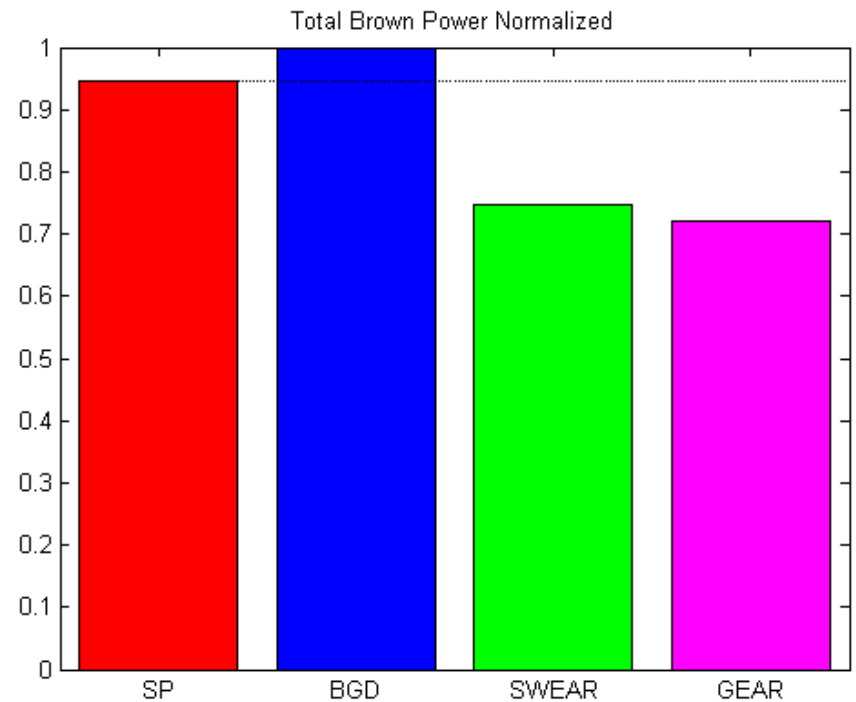




Results (*Total Brown Power*)



Results for USA24

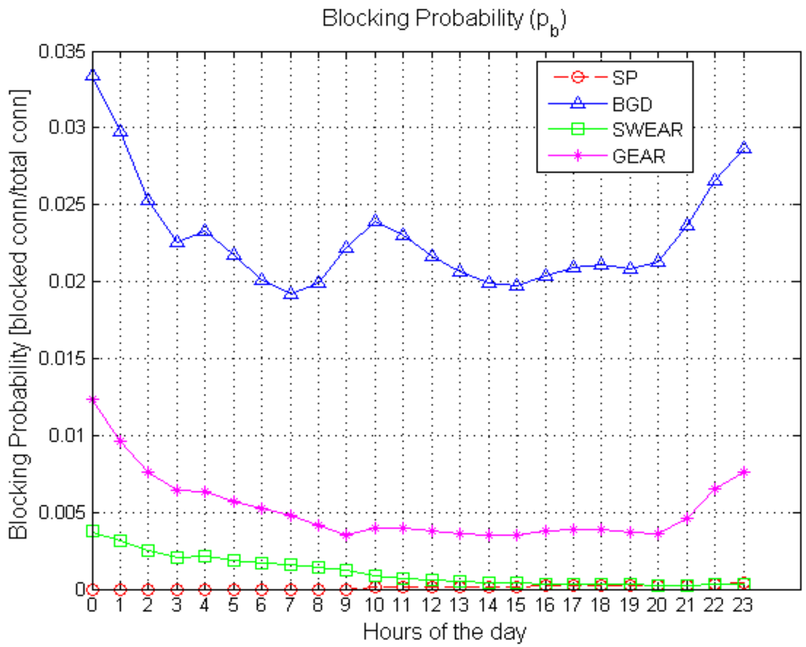


Results for *ItalyNet*

Results (*Blocking probability*)

- SP shows best performances, routing without constraints on emissions
- SWEAR performances are comparable to SP, thanks to the Load Balancing phase
- GEAR has worse performances than SWEAR
- BGD forces the routing towards the DC with more green energy

→ create bottlenecks that arise P_b



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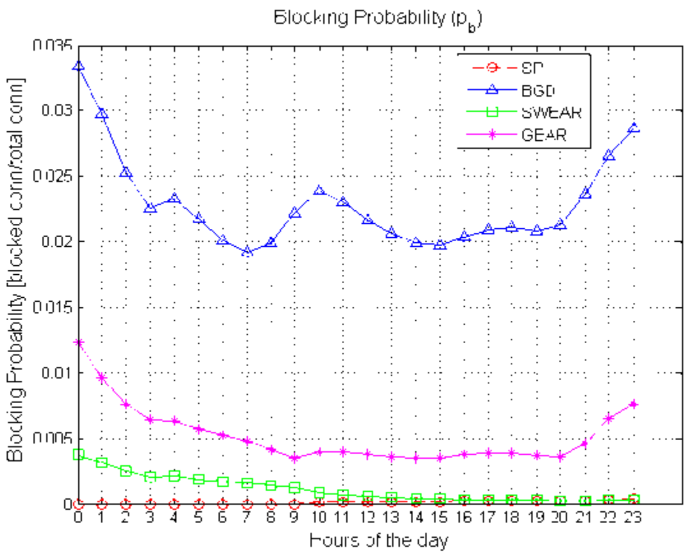
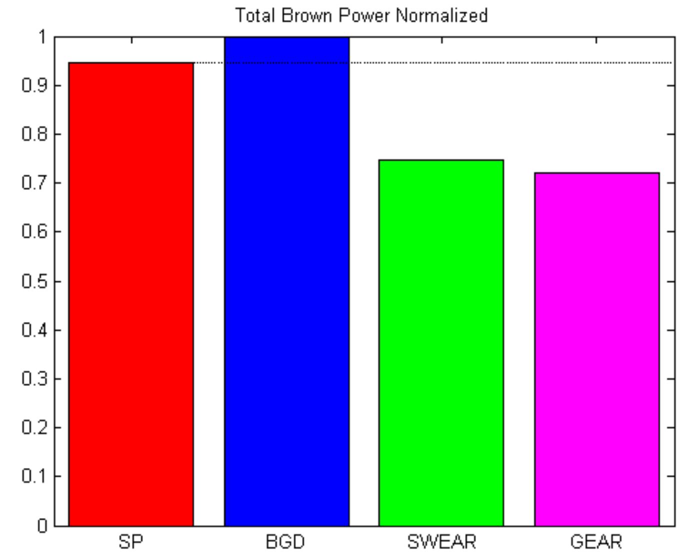
Conclusions

- On national network we achieve a total emissions reduction up to 24% vs SP and 27% vs BGD
- On continental network we achieve a total emissions reduction up to 11% vs SP and 20% vs BGD (lower reduction due to transport power effect)
- P_b performance remains acceptable
- If it's not done properly, "Follow the wind&sun" routing can be useless





Thank you!