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Energy-Aware Data Centre Management

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Presentation Outline

- Definition of the research problem in the data centre domain
- Research objectives: network energy awareness and efficiency
- Research solution: the e-CAB
- Energy context-aware evaluation: a case study
- Conclusion and future work

Problem Domain

- Data centre resource selection may be **managed as a function of energy efficiency** in addition to **latency** (which is influenced by client proximity to and physical resources and operational performance in the data centre) characteristics traditionally associated with this operation, in terms of how efficient operation is at the data centre and on the path between client and data centre.
- In addition to carbon cost, **electricity cost** may also be considered in the decision-making process, taking into account both environmental and operational sustainability concerns, a fact attracting increasing attention due to the rising price of electricity.
- Characteristics used to manage data centre communications according to efficiency objectives therefore include:
  1. Latency on the end-to-end path
  2. Number of nodes on the end-to-end path
  3. Data centre ability to support application and QoS requirements
  4. Cost of electricity along end-to-end path and at the data centre
  5. Carbon emissions from the data centre
  6. Carbon emissions from the end-to-end path

Research Objectives

Energy awareness

Ability to quantify carbon cost C_1 emitted from the network, which is a function of traffic volume *T*, queuing delay *Q*, bandwidth availability *B*, bit error rate *ER* and packet loss ratio *R* on the path:

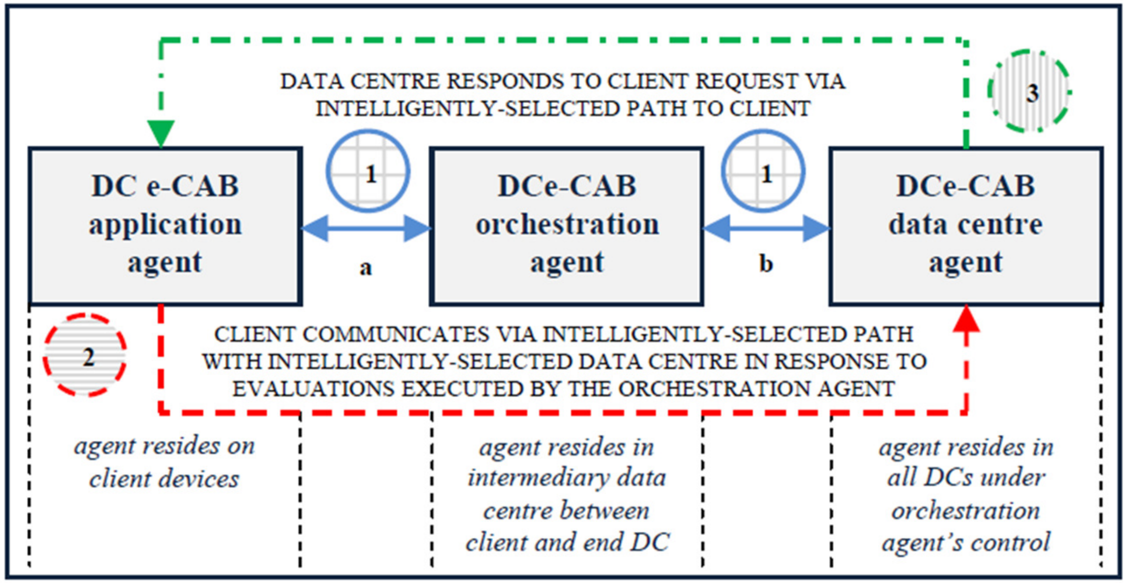
$$C_1 = f\,(T, Q, B, ER, R)$$

Energy efficiency

Ability to enforce dynamic network management (during which energy awareness drives energy efficiency), with an aim to achieve a carbon cost C_2, where $C_2 < C_1$.

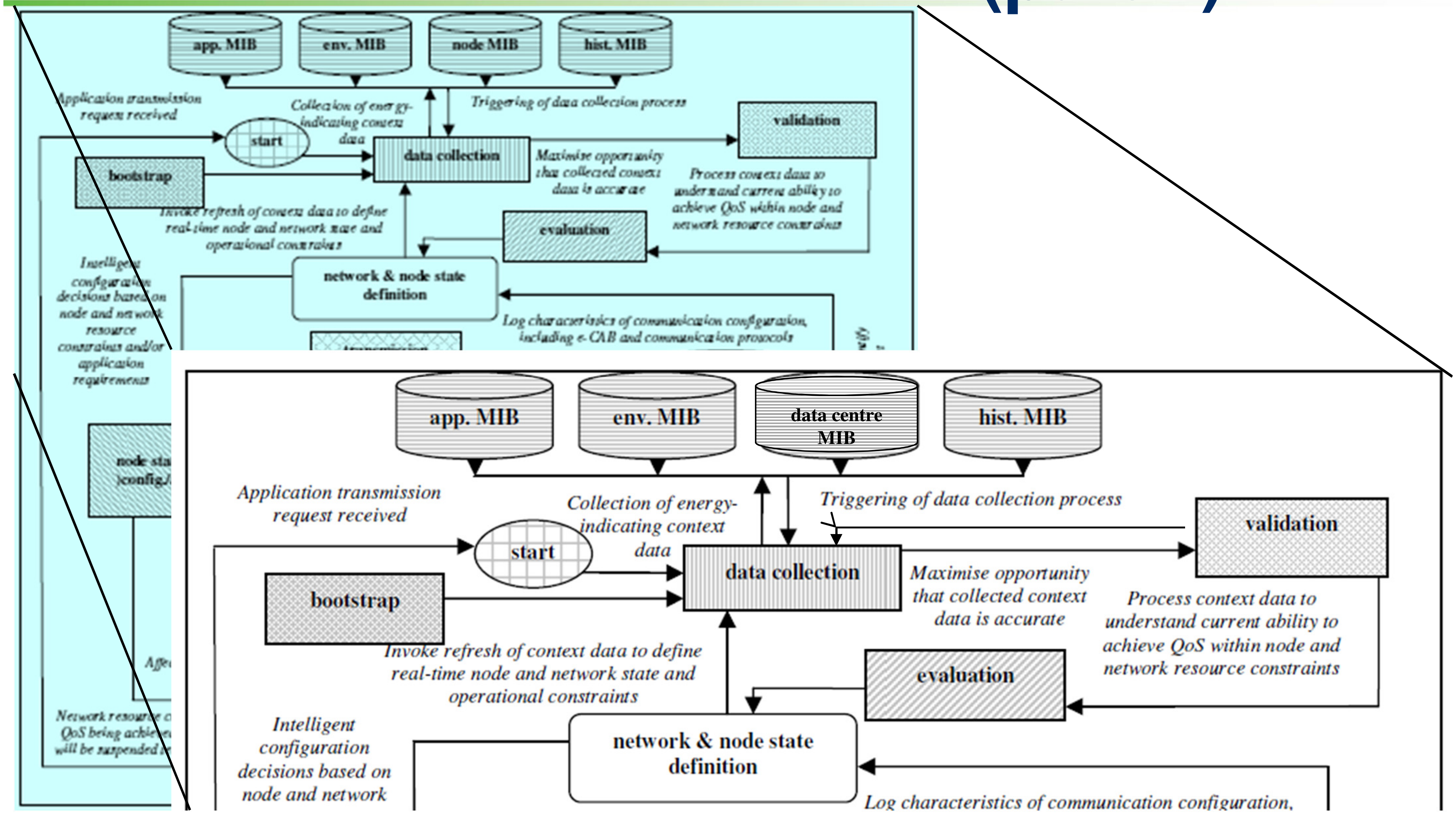
The overall objective is therefore to identify ways in which awareness and efficiency may be achieved by influencing throughput, queuing delay and the reaction of protocols to loss.

Research Solution: e-CAB in the Data Centre Domain

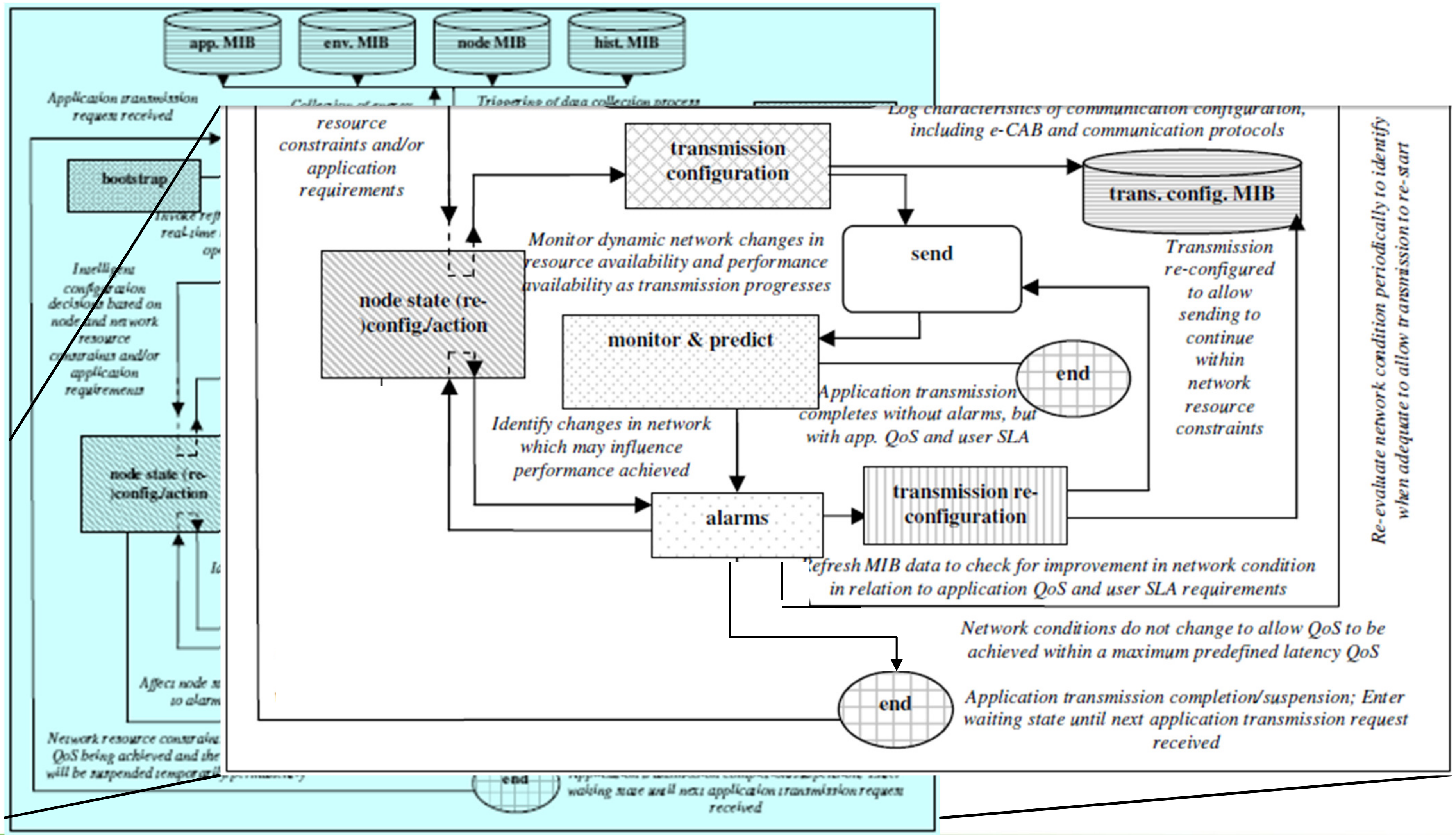


- Manages communications on the end-to-end link between clients and data centre to minimise the carbon costs associated with data centre communications.
- The architecture consists of an orchestration agent and one or more data centre and application agents.

e-CAB Algorithm (part 1)



e-CAB Algorithm (part 2)



Algorithm Design Objectives

Path *p* to the selected DC server from the client device will ideally be one which minimises the number of nodes *n*, carbon emissions *EM*, queuing delay *Q* and electricity cost *el* from operating nodes along the path and at the data centre:

$$\underset{p \in P^{*}(i,j;G)}{minimise} \; EM$$

Note: *EM* is also replaced with *n*, *Q* and *el*

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Constrained Optimisation

- Attempting to achieve these objectives simultaneously however, presents a constrained optimisation challenge.
- Constrained optimisation describes a situation where attempts are made to minimise (or maximise) a cost function.
- The goal is therefore to find a solution which maximises the weight of satisfied constraints.
- The best situation which can be aimed for is to minimise the cost of a reduced number of elements, and maintain the others at, at worst, a threshold.

Research Objective

- The overall objective in selecting a data centre and path to the data centre is therefore to:

$$\underset{p \in P^{*(d;G)}}{minimise}\ EM$$

$$\underset{p \in P^{*(i,j;G)}}{minimise}\ EM$$

- allowing carbon costs *EM* associated with flows arriving on path *p* at a data centre after traversing sub-links (*i,j*) and nodes *d* in the wider external network *G* to be minimised, where $P^{*(d;G)}$ and $P^{*(i,j;G)}$ is the set of all nodes and sub-paths traversed on path *P* within network *G* between the client device and data centre.

Simultaneous Research Objectives

Given the constrained optimisation challenge, minimisation of the carbon cost should *ideally* be achieved while:

- maintaining average queuing delays,
- average electricity cost, and
- restricting the number of nodes traversed when servicing the client request.

Path and Data Centre Selection: Approach 1

Path selection as a function of average carbon emission *EM*, queuing delay *Q* and electricity cost *el* incurred at nodes *d* traversed en route between client device and data centre, where $P^{*(d;G)}$ is the set of all nodes *d* traversed in network *G* on path *P* between device and data centre, weighted by number of nodes *d*:

$$d\left(\overline{\quad EM_{p\in P^{*(d;G)}} \quad Q_{p\in P^{*(d;G)}} \quad el_{p\in P^{*(d;G)}} \quad}\right)$$

Path and Data Centre Selection: Approach 2

Path selection as a function of average carbon emission *EM*, queuing delay *Q* and electricity cost *el* incurred at nodes *d* traversed en route between client device and data centre where $P^{*(d;G)}$ is the set of all nodes *d* traversed in network *G* on path *P* between device and data centre, weighted by the number of nodes *n* and average carbon emissions on path *P* within network *G*:

$$d\left(\overline{\underset{p\in P^{*(d;G)}}{EM} \quad \underset{p\in P^{*(d;G)}}{Q} \quad \underset{p\in P^{*(d;G)}}{el}} \right) \overline{\underset{p\in P^{*(d;G)}}{EM}}$$

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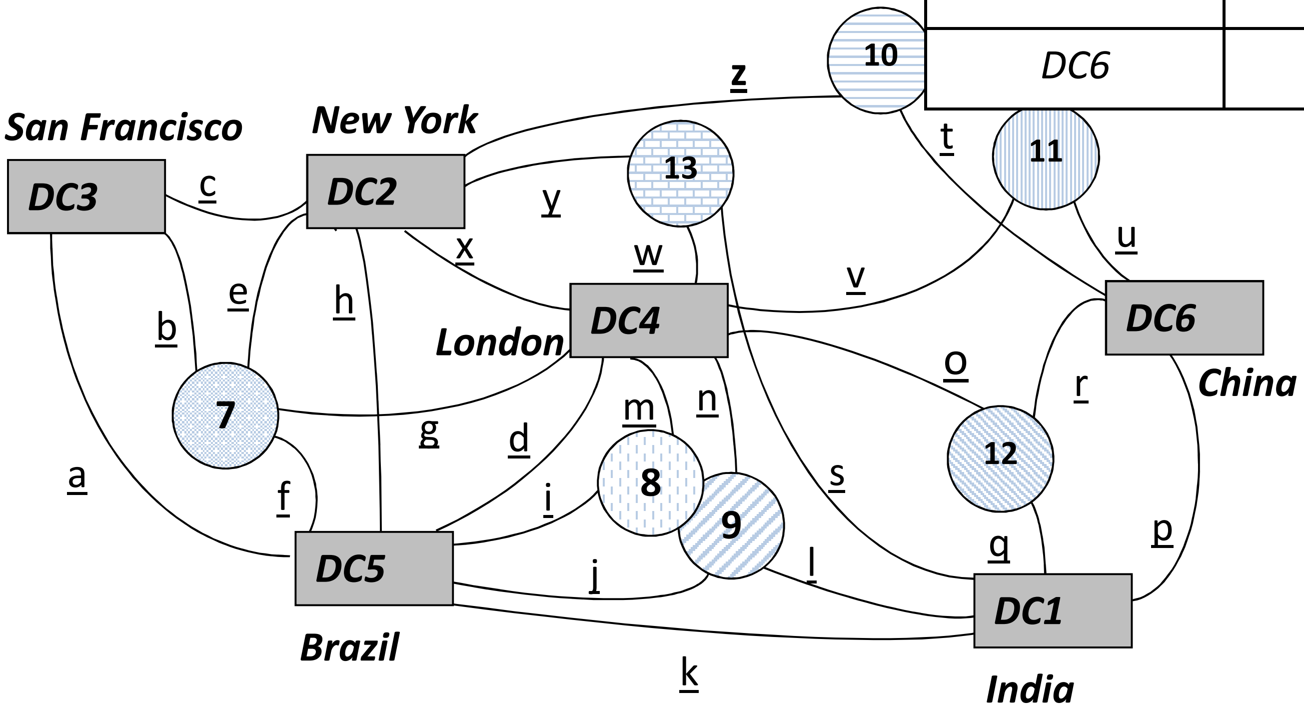
Case Study Scenario

Data Centre ID	Data Centre Carbon Emission Conversion Factors ($kgCO_2/kWh$)
DC1	0.5
DC2	0.8
DC3	0.75
DC4	1
DC5	0.8
DC6	0.65

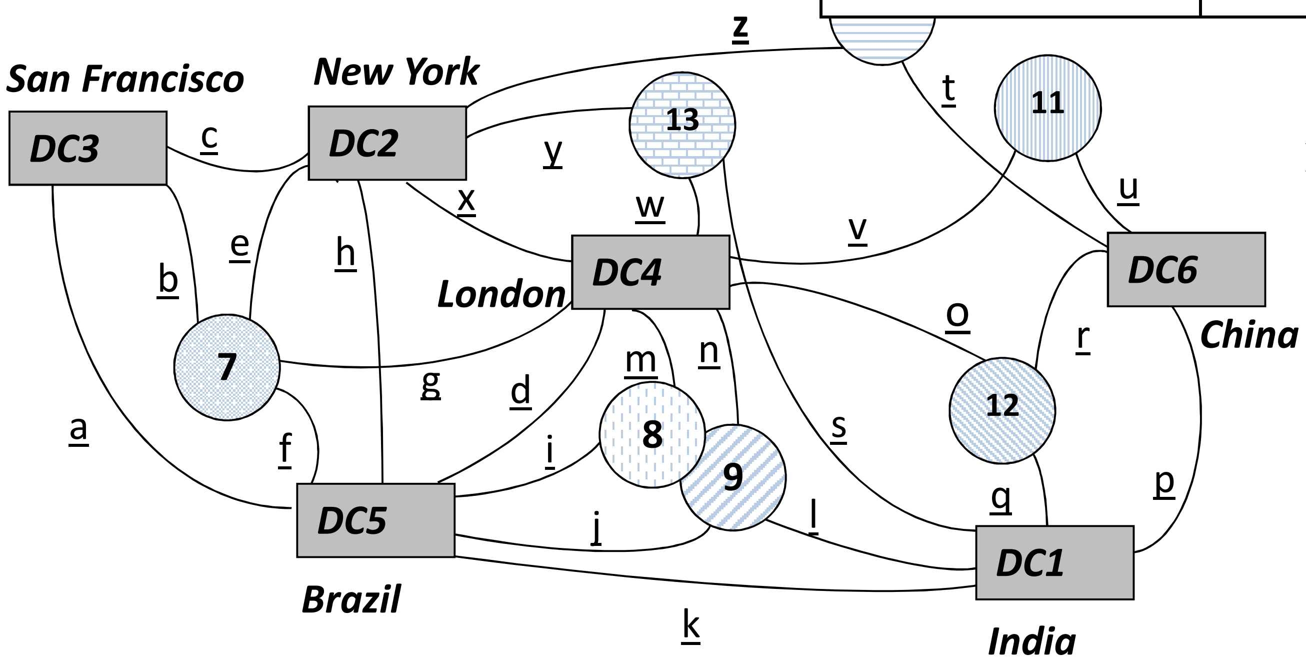


[**Reference**] Department of Environment, Food and Rural Affairs (DEFRA), "BNXSO1: Carbon Dioxide Emission Factors for UK Energy Use," Mar. 2009, pp. 1-8.

Case Study Scenario

Data Centre ID	Electricity Cost (pence per unit)
DC1	13.3
DC2	15
DC3	11
DC4	12.2
DC5	10
DC6	14

[**Reference**] Biomass Energy Centre, "Fuel costs per kwh," Dec. 2010.



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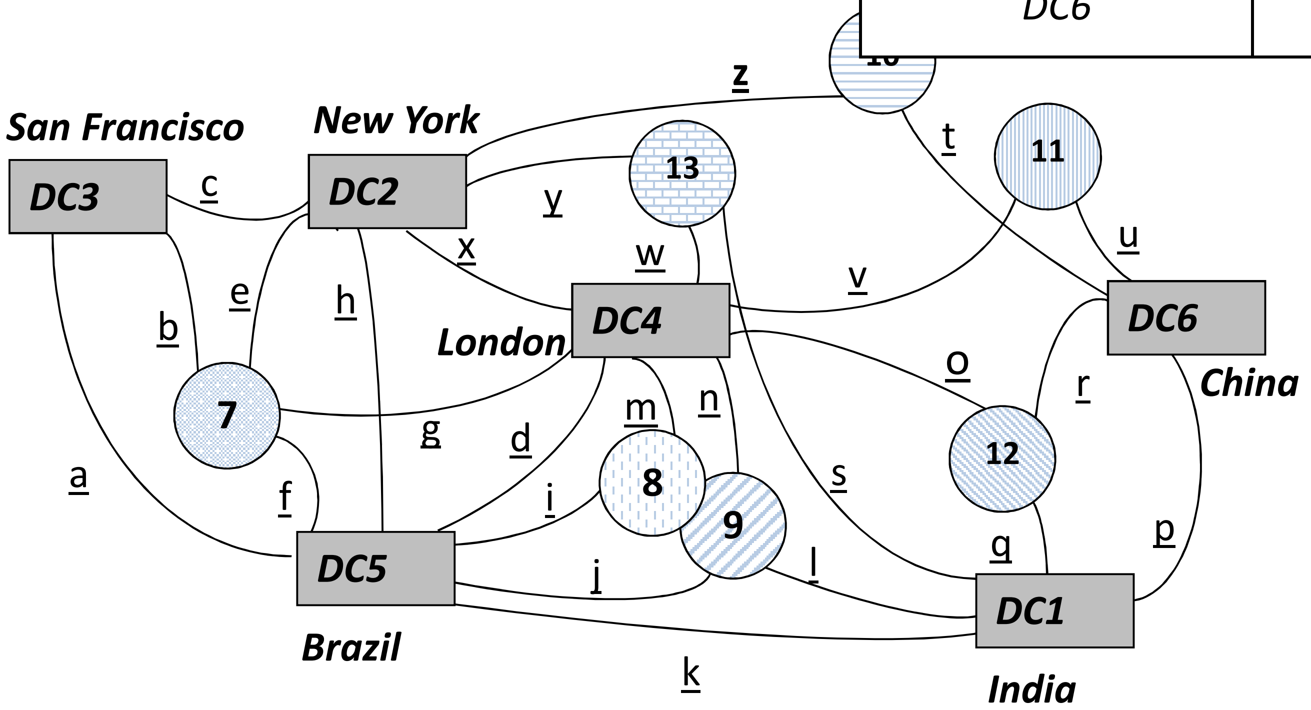
Case Study Scenario

Data Centre ID	Queuing Delay (seconds)
DC1	0.5
DC2	1
DC3	0.2
DC4	0.05
DC5	1
DC6	0.02



Characteristics of One-Hop Paths Selected from Client Devices

Client	DC	*el*	*Q*	*EM*	Approach which selects path:
9	1	13.3	0.5	0.5	Approach 2
9	5	10	1	0.8	Approach 1
9	4	12.2	0.05	1	x

Approach 2 prioritises carbon cost in its data centre selection, while Approach 1 achieves a greater balance between context attributes

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Characteristics of Paths Selected from Client Devices

Client	DC	*el*	*Q*	*EM*	Approach which selects path:
10	6	14	0.02	0.65	Approach 2
10	2	15	1	0.65	x

Approach 2 prioritises carbon cost in its data centre selection

Client	DC	el	Q	EM	Approach which selects path:
10	2	15	1	0.8	Approach 1
	3	11	0.2	0.75	
	5	10	1	0.8	

Approach 1 selects (over two-hop path) data centre with lowest electricity cost and average carbon cost

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Conclusion

- The constrained optimisation challenge results in a drive to develop an approach where the goal is to **maximise the weight of satisfied constraints** such that a value with a lowest combined weight is selected by a context-aware algorithm with a carbon cost, which is proportional to queuing delay, number of nodes and the emission factor at the data centre, is minimised.
- Selection approaches presented demonstrate a balance achieved between performance-influencing attributes and compromise on cost incurred to optimise the energy efficiency of communications between data centres and devices.
- Selection Approach 1 **balances relationships** between all attributes included in the equation, while **cost in the data centre is prioritised** when using Approach 2.
- Limitations which may exist in relation to this approach is that it assumes that all context is available; **future work** involves development of selection approaches for which a greater range of context is included in evaluation.

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