How Well Do Traffic Engineering Objective Functions Meet TE Requirements ?

Research Unit in Networking (RUN)

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Outline

- Introduction
- TE requirements & Notations
- TE Metrics
- TE objective functions
- Simulation Results
- Conclusion

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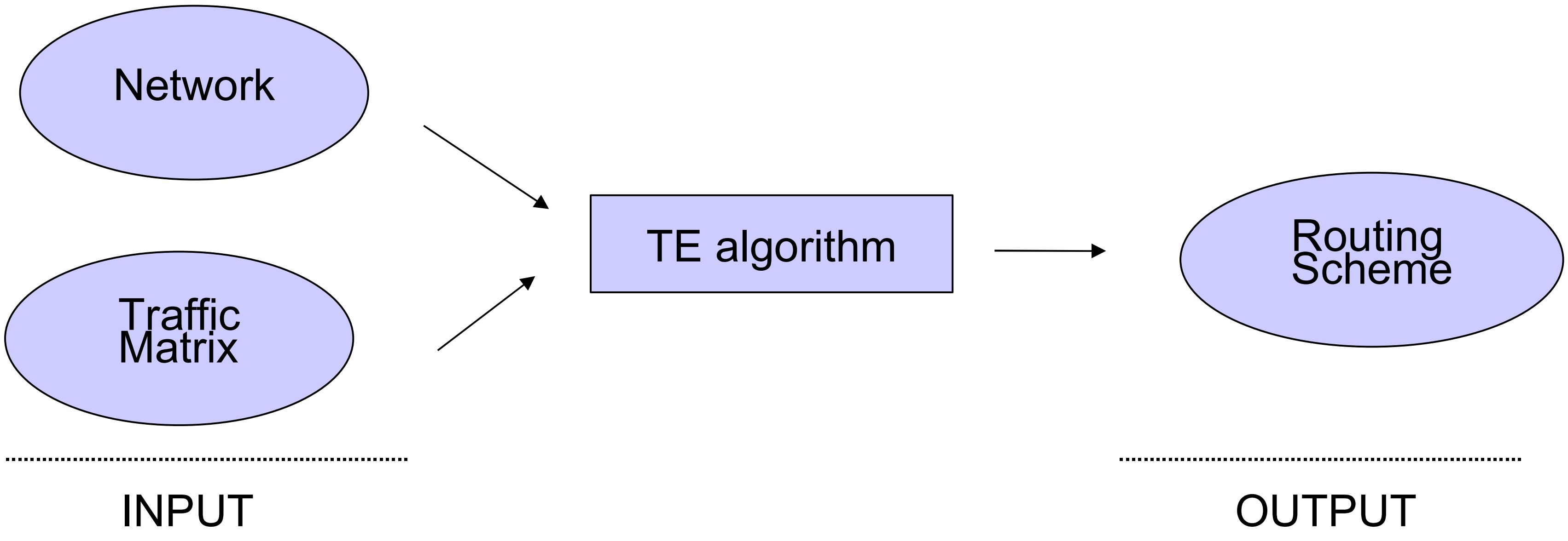
- Goal of the study: Compare and evaluate how TE objective functions fulfil TE requirements
- We consider the "routing problem" :



Introduction (2)

- TE algorithm is supposed to find a "good" routing scheme (i.e. a set of paths)
- What is a "good" routing scheme?

  It is generally a routing scheme that associates a high score to a chosen *objective function*
- We can find many objective functions which are very different in the literature. How is it possible to choose the best ?
- We also want to separate the benefits due to heuristic from the benefit due to the objective function of well known TE algorithms presented as a whole solution in many papers

Introduction (3)

- But how well do objective functions reflect TE requirements?
- We try to answer this question with simulations. We find the optimum for each Objective Function with LP formulation of the routing problem. We arrive to this kind of simulation results :

Objective Function	u_{max}	θ_{tot}	$\ldots$
$MIRA$	100%	6504 Mbps	$\ldots$
$Delay$	42%	6309 Mbps	$\ldots$
$\vdots$	$\vdots$	$\vdots$	$\ddots$

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TE Requirements

- TE objectives (view of IETF):
  - performance optimization of operational networks
  - minimize packet loss, delay, delay variation
  - maximize throughput
  - enforce Service Level Agreements
  - minimize maximum resource utilisation
- How do well-known TE algorithms address these TE objectives?

- Notations :
  - Network modelled by a graph $G=(N,A)$
  - Each link a has a capacity $c(a)$
  - Traffic Matrix D
  - Each link a has a load $l(a)$
  - Utilisation of link a is $u(a) = l(a) / c(a)$
  - Available bandwidth of link a is $ABW(a) = c(a) - l(a)$

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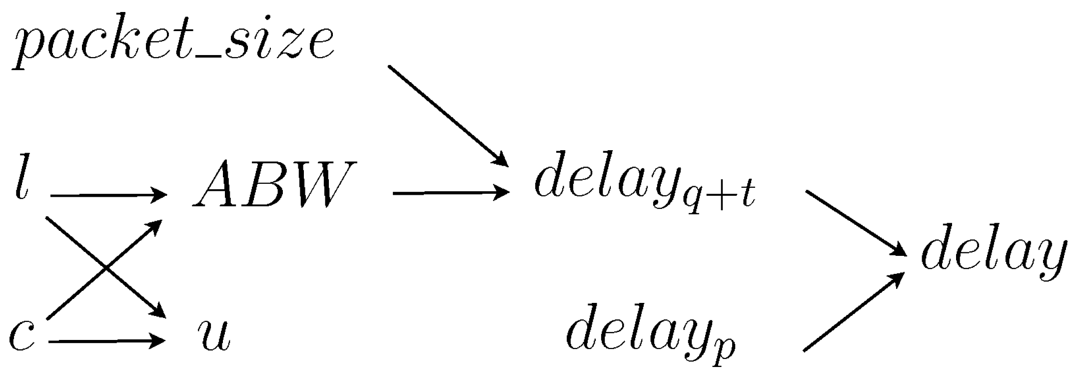
TE Metrics

- Mean queuing + transmission delay :

$$Delay_{q+t} = \frac{mean\_packet\_size}{ABW}$$

- Link parameters:



TE metrics (2)

- Residual Max Flow between nodes *s* and *t*: θ_{st}

- TE Metric Summary:

	Metric characterising good current state	Metric characterising likely good future
$\text{Link}_{(a)}$	$Delay_a$	$u_a,\ ABW_a$
$\text{Path}_{(s,t)}$	$\sum_{a \in \mathcal{P}(s,t)} Delay_a$	$\theta_{st},\ max_{a \in \mathcal{P}(s,t)} u_a$
Network	$\frac{\sum_{a \in A} Delay_a}{\lvert A \rvert},\ \frac{\sum_{a \in A} l_a.Delay_a}{AllTr}$	$min_{(s,t)} \theta_{st},\ max_{a \in A} u_a$ $\sum_{(s,t)} \theta_{st}$

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TE objective functions

- InvCap: $$\sum_{a \in A} u_a$$ *This function is minimized by CISCO recommended IP routing – which computes shortest paths based on link cost = 1/c(a)*
- U_{max}: $$u_{max}$$ *This function minimizes the maximal link utilisation.*
- MinHop: $$\sum_{a \in A} l_a$$ *This function is minimised by minimum hop routing (if the used paths are the path with minimum number of links)*

TE objective functions

Transmission + Queuing delay of link *a* $\approx \frac{1}{c(a) - l(a)}$

- MeanDelay: $$\sum_{a \in A} \frac{1}{c(a) - l(a)}$$

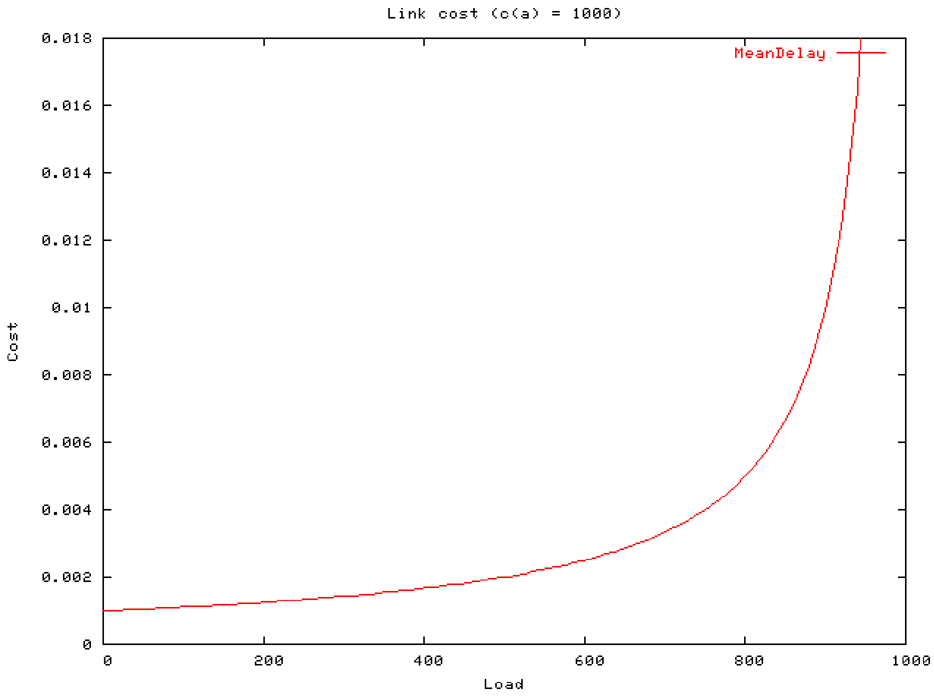
Minimizes the mean link delay

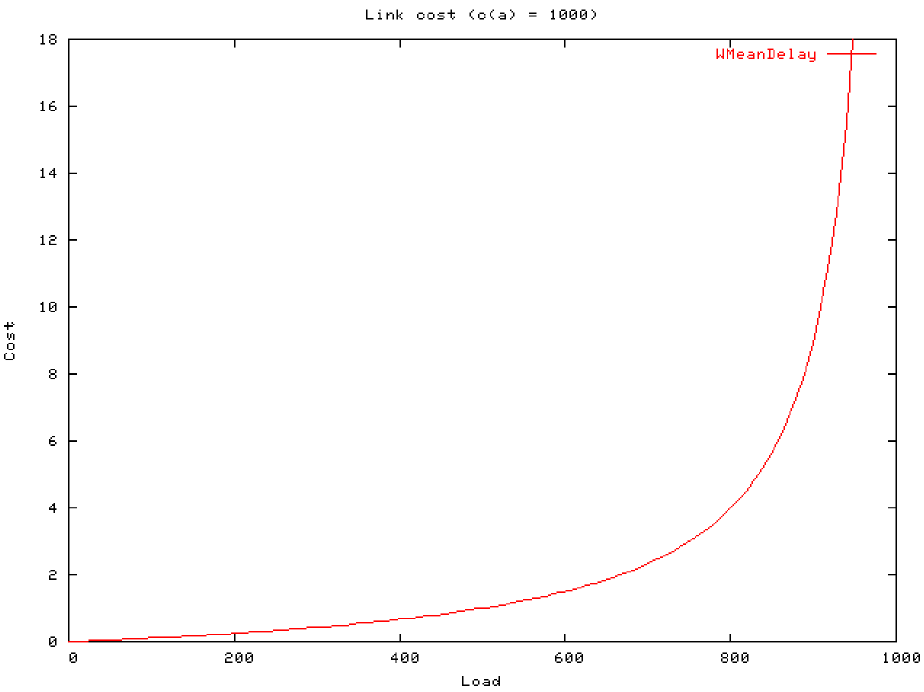
- WMeanDelay: $$\sum_{a \in A} \frac{l(a)}{c(a) - l(a)} = \sum_{a \in A} \frac{1}{\frac{1}{u(a)} - 1}$$

Minimizes the weighted mean link delay = weighted mean path delay

TE objective functions

- Delay link cost:



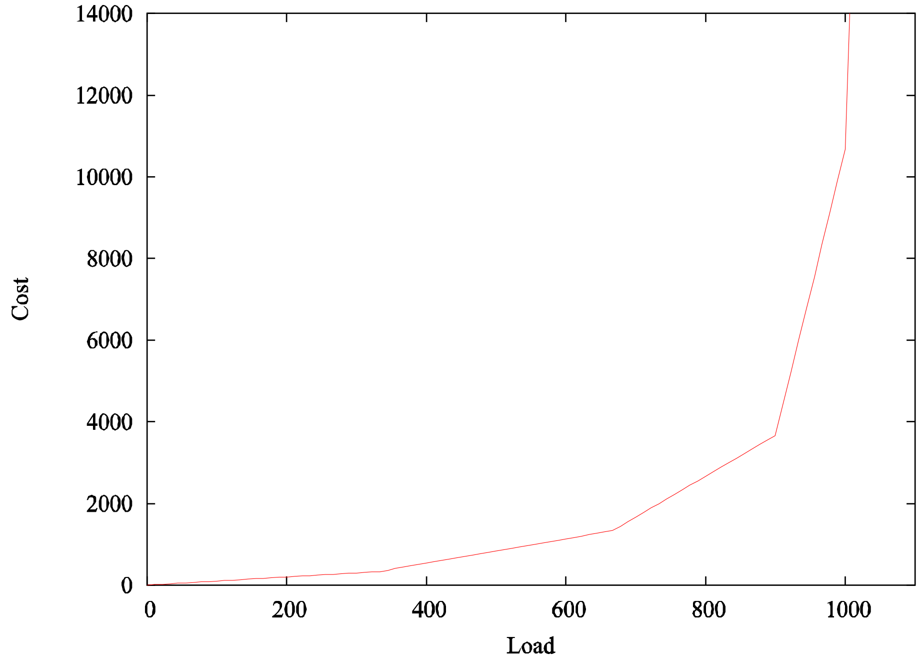


TE objective functions

- Fortz: *min* $\phi = \sum_{a \in A} \phi_a$

ϕ_a :

(for a link of capacity 1000)



Associates a high cost to high loaded links so that paths should avoid these links

TE objective functions

- MIRA: concept of minimum interference routing
- If θ_{st} is the max flow from *s* to *t* on the residual topology, $MIRA = max \sum_{(s,t)} \alpha_{st}\theta_{st}$
- α_{st} are administrative weights

Try to minimize the decrease in the total residual max flow due to the routing of some trafic on a path

TE objective functions

- Degrande: $C_B.B - C_U.U$
  - Balance: $B = 1 - u_{max}$
  - Network utilisation: $U = \sum_{a \in A} u(a)$

Try to minimize both the maximal link utilisation and the mean link utilisation

TE objective functions

- *Blanchy* :

$$\sum_{a \in A} (u(a) - u_{mean})^2 + \alpha \sum_{a \in A} (u(a))^2$$

Load balancing term

Traffic minimisation term

The load balancing term try to flatten the link utilisations while the traffic minimization term try to limit the size of paths which would otherwise make to long detours.

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Simulations

- Simulation to compare all presented objective functions:
  - LP formulation of the routing problem
  - Linearize non-linear objective functions
  - Solve the problem to optimality
  - Compare all the results
- All the objectives functions are compared with the same algorithm → easy to compare
- Results on three different networks (→ one random network with random Traffic Matrix and two real networks with real Traffic Matrices)

Simulation Results

- Results on a network of 25 nodes (random Waxman topology):

Objective function	u_{max} % TM	u_{max} % 2TM	u_{per10} % TM	u_{per10} % 2TM	u_{mean} % TM	u_{mean} % 2TM	ABW_{min} Mbps TM	ABW_{min} Mbps 2TM	l_{mean} Mbps TM	l_{mean} Mbps 2TM	θ_{tot} Mbps TM	θ_{tot} Mbps 2TM
Fortz	(1.14)	(1.14)	(1.28)	(1.33)	(1.26)	(1.21)	(0.67)	*(0.55)*	**(1.03)**	**(1.05)**	**(0.97)**	**(0.95)**
MIRA	*100*	*100*	(1.40)	(1.48)	(1.17)	(1.16)	*0.0*	*0.0*	(1.15)	(1.10)	**6504**	**5012**
Blanchy	(1.22)	(1.23)	**26.0**	**50.0**	(1.13)	(1.12)	(0.88)	**531**	(1.12)	(1.11)	**(0.96)**	**(0.94)**
Delay	(1.20)	**(1.08)**	(1.17)	(1.20)	**(1.04)**	(1.11)	**882.0**	**(0.95)**	(1.16)	(1.11)	**(0.97)**	**(0.95)**
InvCap	*(2.07)*	*100*	(1.55)	(1.61)	**15.7**	**31.5**	**882.0**	*0.0*	(1.21)	(1.20)	**(0.98)**	**(0.96)**
u_{max}	**34.9**	**69.7**	(1.15)	(1.20)	**(1.07)**	(1.12)	(0.74)	*(0.57)*	(1.17)	(1.11)	**(0.97)**	**(0.95)**
Degrande	**34.9**	**69.7**	(1.35)	(1.39)	**(1.05)**	**(1.05)**	(0.74)	*(0.57)*	(1.19)	(1.18)	**(0.97)**	**(0.95)**
MinHop	*100*	*100*	(1.29)	(1.43)	(1.27)	(1.25)	*0.0*	*0.0*	**781**	**1578**	**(0.97)**	**(0.95)**

The table contains absolute optimal values (in green, bold, without parentheses), or relative non-optimal values (between parentheses) with respect to the optimal one. The values that are less than 10% from the optimal value are bold. Finally values that are 2 times worse than the optimum are in italic and red. For each metric we show the values for the actual traffic matrix (TM) and for the doubled traffic matrix (2TM).

Simulation Results (3)

- Metrics at Low Load (LL) and High Load (HL)

Objective Function	u_{max}		u_{per10}		u_{mean}		ABW_{min}		l_{mean}		θ_{tot}	
	LL	HL	LL	HL	LL	HL	LL	HL	LL	HL	LL	HL
Fortz	√	√	√	√	√	√	±	±	√	√	√	√
MIRA	●	●	●	●	√	√	●	●	√	√	√√	√√
Blanchy	√	●	√	√	√	√	√	●	√	√	√	√
Delay	√	√	√	√	√	√	√	√	√	√	√	√
InvCap	●	●	√	±	√√	√√	±	●	√	√	√	√
Degrande	√√	√√	√	√	√	√	√	√	√	√	√	√

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Conclusion

- We have shown how well-known network-wide TE objective functions reflect TE requirements
- Our results show that they are not equivalent
- Although $delay_{q+t}$ is negligible, this Objective Function gives good results for all TE metrics
- Best results for *Delay*, *Degrande* and *Fortz* (in that order)
- Objective basis to choose the best TE function

The End

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