A Genetically Motivated Heuristic for Route Discovery and Selection in Packet-Switched Networks

Peter T. Whiting

pete@sprint.net

University of Kansas

Overview of Presentation

- Brief background
- The proposed heuristic
- State analysis on a Triplet Network
- Adaptation on a Ring Network
- Optimal routing on a Regional Network
- Summary and conclusions

Motivation

- Routing in packet-switched networks
  - Why it is important
  - Why it is difficult
- Heuristics can balance accuracy with feasibility
- This research introduces a heuristic loosely modeled after nature

Overview of the Heuristic

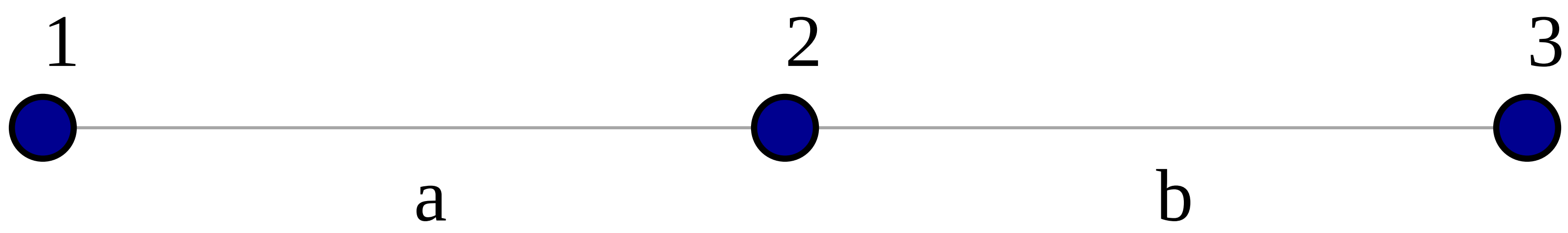
- Parasites
- Populations
- Forwarding

Operators

- Population control
- Selection
- Reproduction
- Mutation
- Sampling
- Congestion control

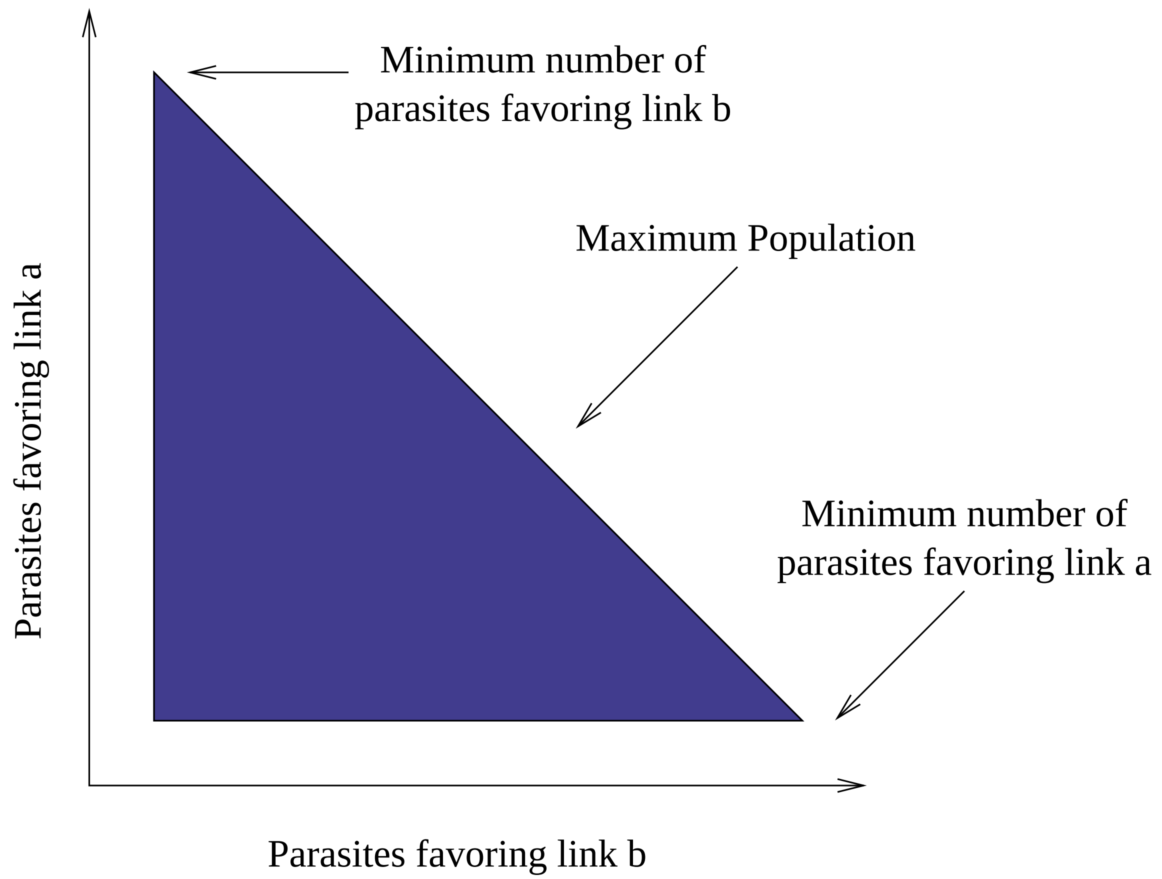
State Analysis of a Triplet Network

Topology

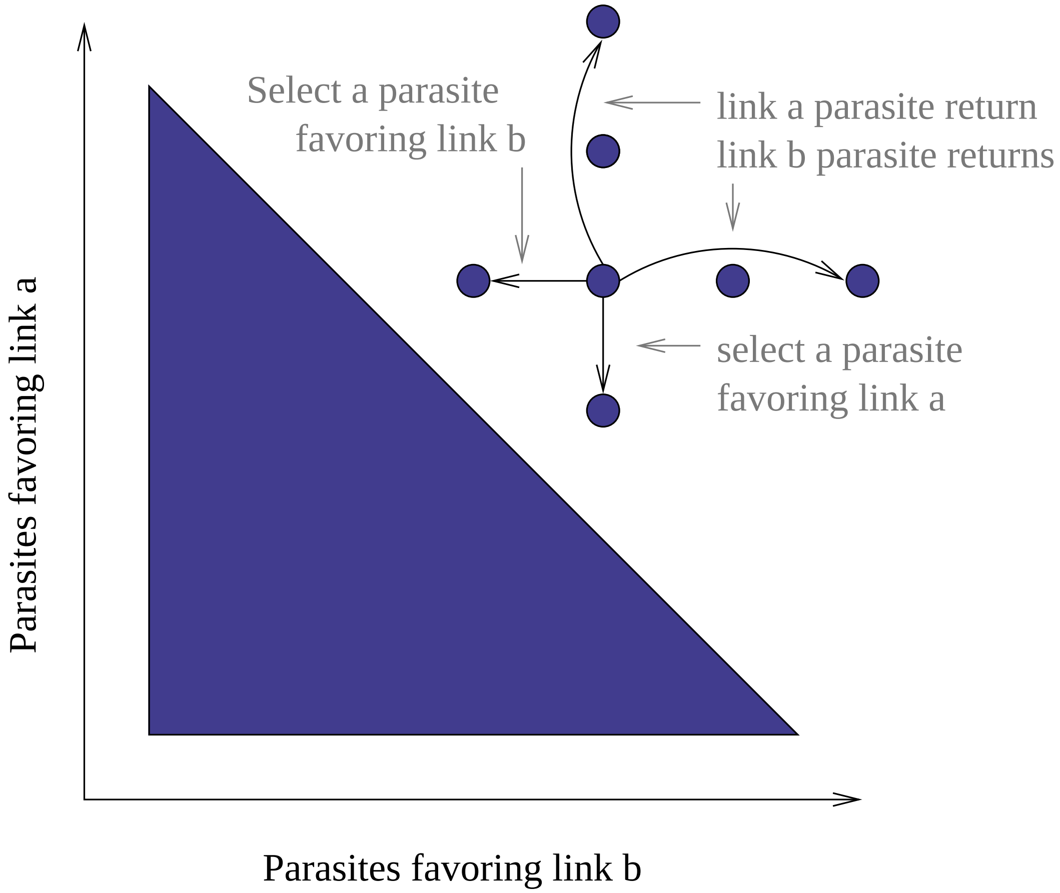


- Single flow
- State on Node 2

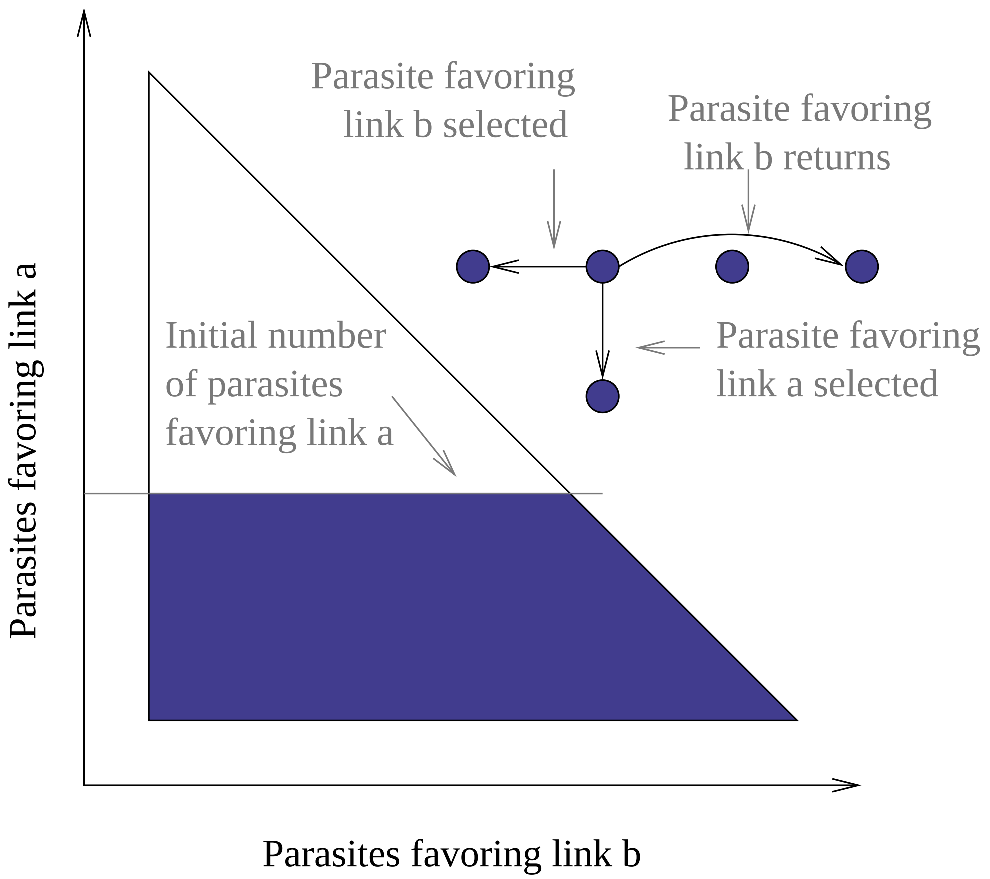
State Space


Minimum number of
parasites favoring link b
Maximum Population
Minimum number of
parasites favoring link a
Parasites favoring link a
Parasites favoring link b

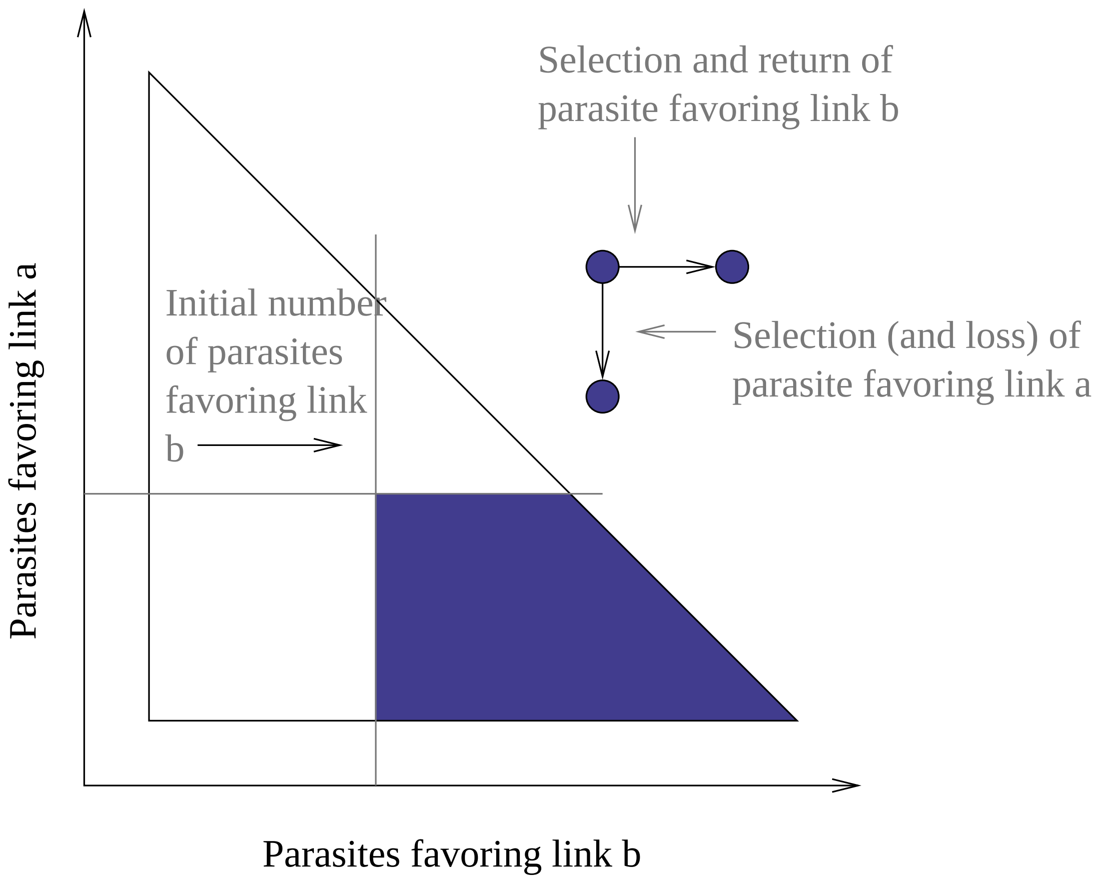
State Space


Select a parasite
favoring link b
link a parasite return
link b parasite returns
select a parasite
favoring link a
Parasites favoring link a
Parasites favoring link b

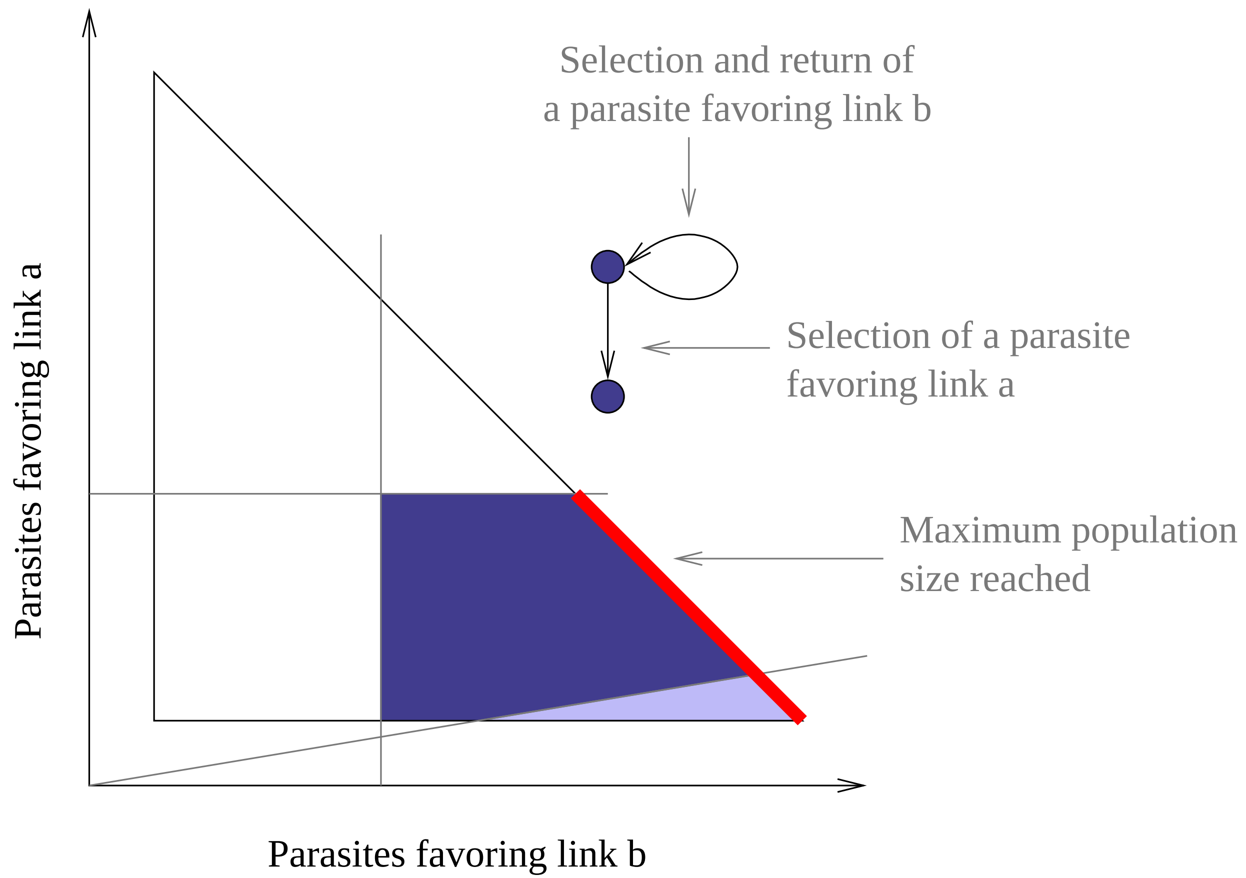
State Space


Parasite favoring
link b selected
Parasite favoring
link b returns
Initial number
of parasites
favoring link a
Parasite favoring
link a selected
Parasites favoring link a
Parasites favoring link b

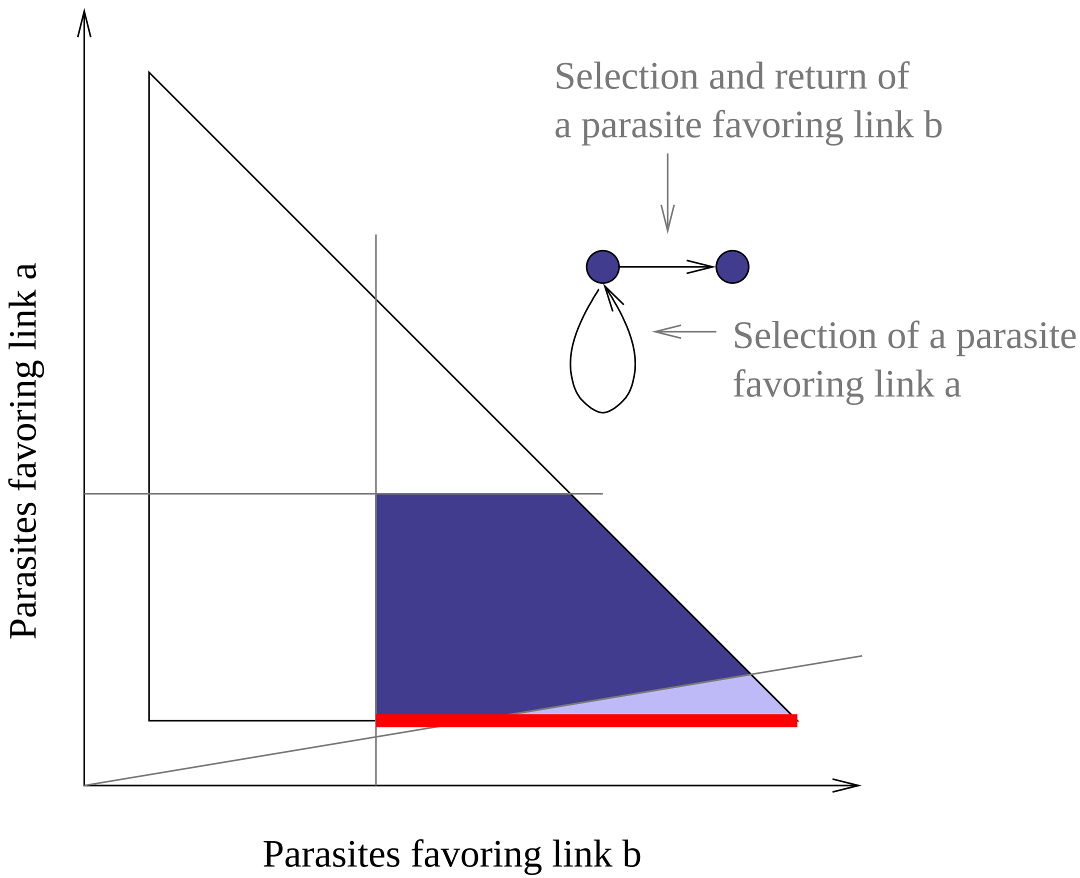
State Space


Selection and return of
parasite favoring link b
Initial number
of parasites
favoring link
b
Selection (and loss) of
parasite favoring link a
Parasites favoring link a
Parasites favoring link b

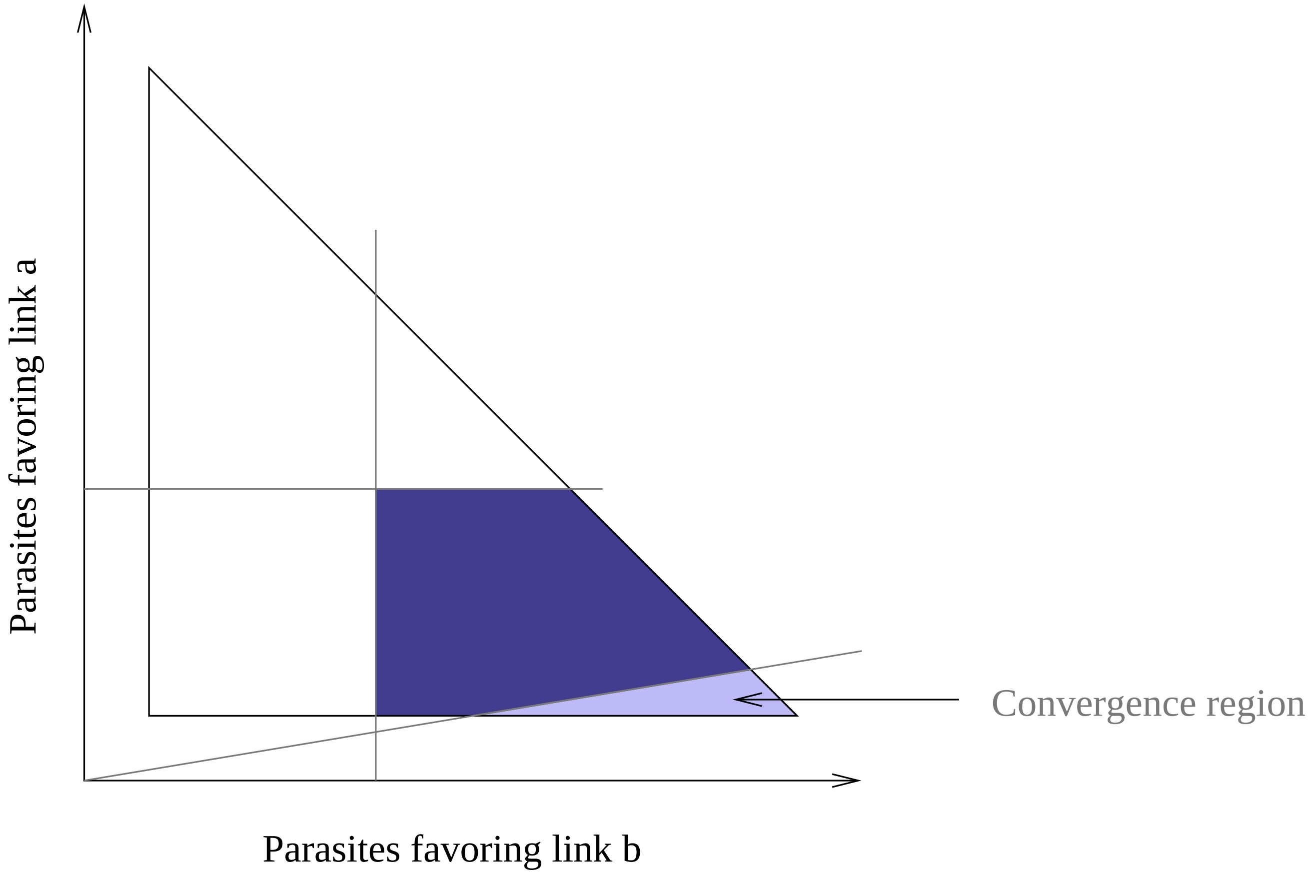
State Space


Selection and return of
a parasite favoring link b
Selection of a parasite
favoring link a
Maximum population
size reached
Parasites favoring link a
Parasites favoring link b

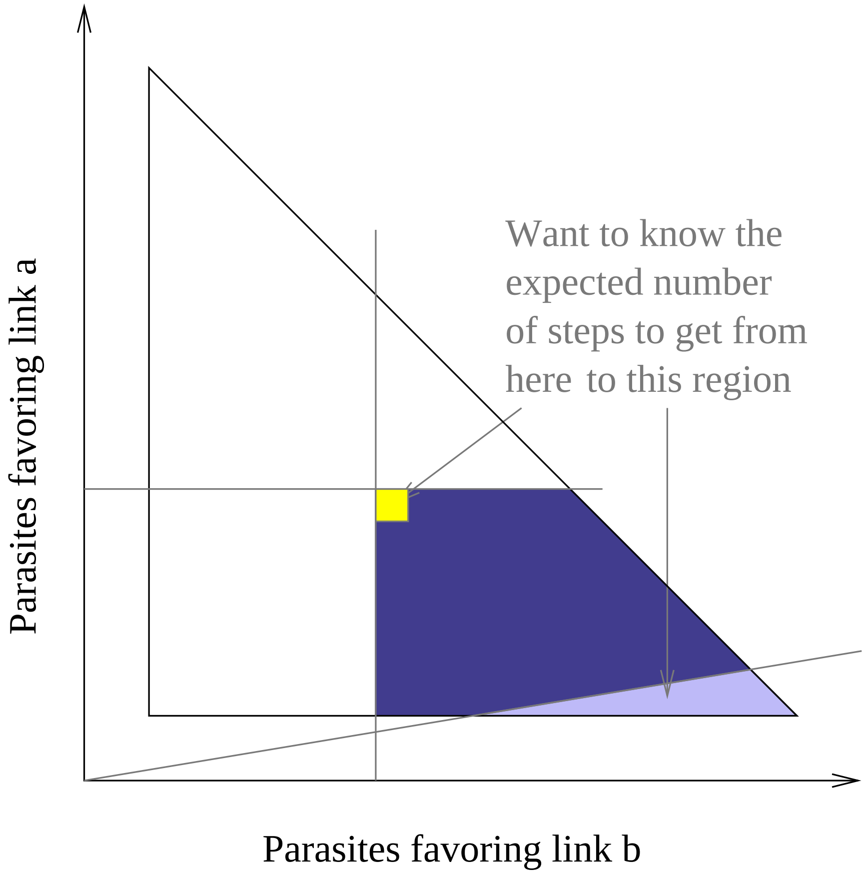
State Space


Selection and return of
a parasite favoring link b
Selection of a parasite
favoring link a
Parasites favoring link a
Parasites favoring link b

State Space


Parasites favoring link a
Convergence region
Parasites favoring link b

State Space


Want to know the
expected number
of steps to get from
here to this region
Parasites favoring link a
Parasites favoring link b

Predicting Convergence

$$e_{x,y} = f(e_{x+1,y}, e_{x,y-1})$$

Predicting Convergence

$$e_{x,y} = f(e_{x+1,y}, e_{x,y-1})$$

p is the probability of selecting a parasite favoring "b"

Predicting Convergence

$$e_{x,y} = f(e_{x+1,y}, e_{x,y-1})$$

p is the probability of selecting a parasite favoring "b"

$$e_{x,y} = p(e_{x+1,y} + 1) + (1 - p)(e_{x,y-1} + 1)$$

Predicting Convergence

$$e_{x,y} = f(e_{x+1,y}, e_{x,y-1})$$

p is the probability of selecting a parasite favoring "b"

$$e_{x,y} = pe_{x+1,y} + (1 - p)(e_{x,y-1}) + 1$$

Predicting Convergence

$$e_{x,y} = f(e_{x+1,y}, e_{x,y-1})$$

p is the probability of selecting a parasite favoring "b"

$$e_{x,y} = pe_{x+1,y} + (1-p)(e_{x,y-1}) + 1$$

Boundary conditions:

$$e_{x,y} = \begin{cases} 0 & \text{if } \frac{x}{x+y} > t \\ pe_{x+1,y} + (1-p)e_{x,y} + 1 & \text{if } y = \eta_{min} \\ pe_{x,y} + (1-p)e_{x,y-1} + 1 & \text{if } x + y = \psi_{max} \end{cases}$$

Predicting Convergence

$$e_{x,y} = f(e_{x+1,y}, e_{x,y-1})$$

p is the probability of selecting a parasite favoring "b"

$$e_{x,y} = pe_{x+1,y} + (1-p)(e_{x,y-1}) + 1$$

Boundary conditions:

$$e_{x,y} = \begin{cases} 0 & \text{if } \frac{x}{x+y} > t \\ \frac{1}{p} + e_{x+1,y} & \text{if } y = \eta_{min} \\ \frac{1}{1-p} + e_{x,y-1} & \text{if } x + y = \psi_{max} \end{cases}$$

Counting Bad Decisions

$$e_{x,y} = p(e_{x+1,y} + 1) + (1 - p)(e_{x,y-1} + 1)$$

Counting Bad Decisions

$$e'_{x,y} = p(e'_{x+1,y} + 0) + (1 - p)(e'_{x,y-1} + 1)$$

Counting Bad Decisions

$$e'_{x,y} = pe'_{x+1,y} + (1-p)(e'_{x,y-1} + 1)$$

Counting Bad Decisions

$$e'_{x,y} = pe'_{x+1,y} + (1-p)(e'_{x,y-1} + 1)$$

Boundary conditions:

$$e'_{x,y} = \begin{cases} 0 & \text{if } \frac{x}{x+y} > t \\ pe'_{x+1,y} + (1-p)(e'_{x,y} + 1) & \text{if } y = \eta_{min} \\ pe'_{x,y} + (1-p)(e'_{x,y-1} + 1) & \text{if } x + y = \psi_{max} \end{cases}$$

Counting Bad Decisions

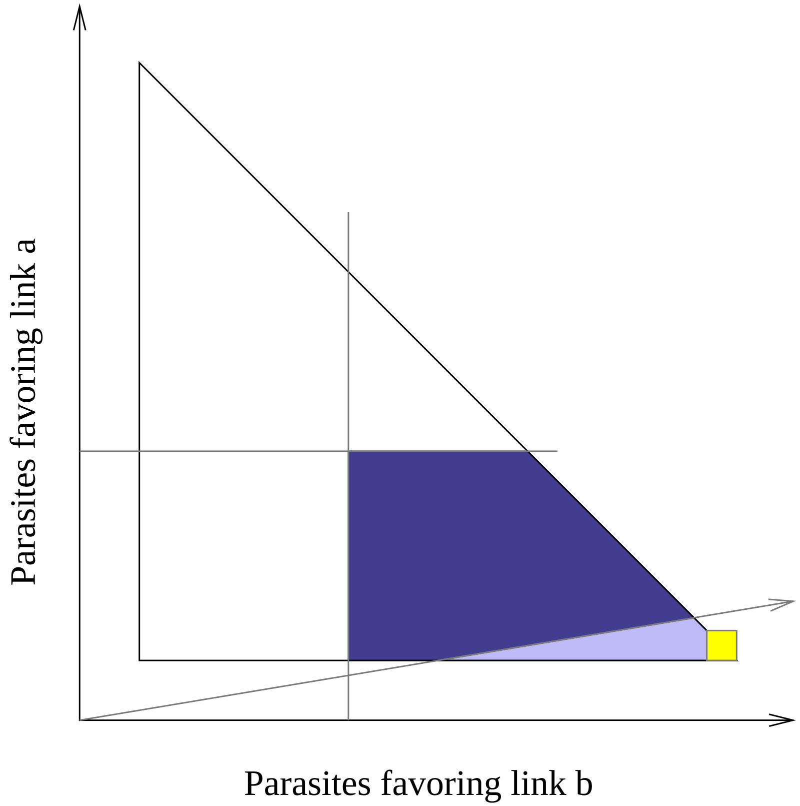
$$e'_{x,y} = pe'_{x+1,y} + (1-p)(e'_{x,y-1} + 1)$$

Boundary conditions:

$$e'_{x,y} = \begin{cases} 0 & \text{if } \frac{x}{x+y} > t \\ \frac{1}{p} + e'_{x+1,y} - 1 & \text{if } y = \eta_{min} \\ e'_{x,y-1} + 1 & \text{if } x + y = \psi_{max} \end{cases}$$

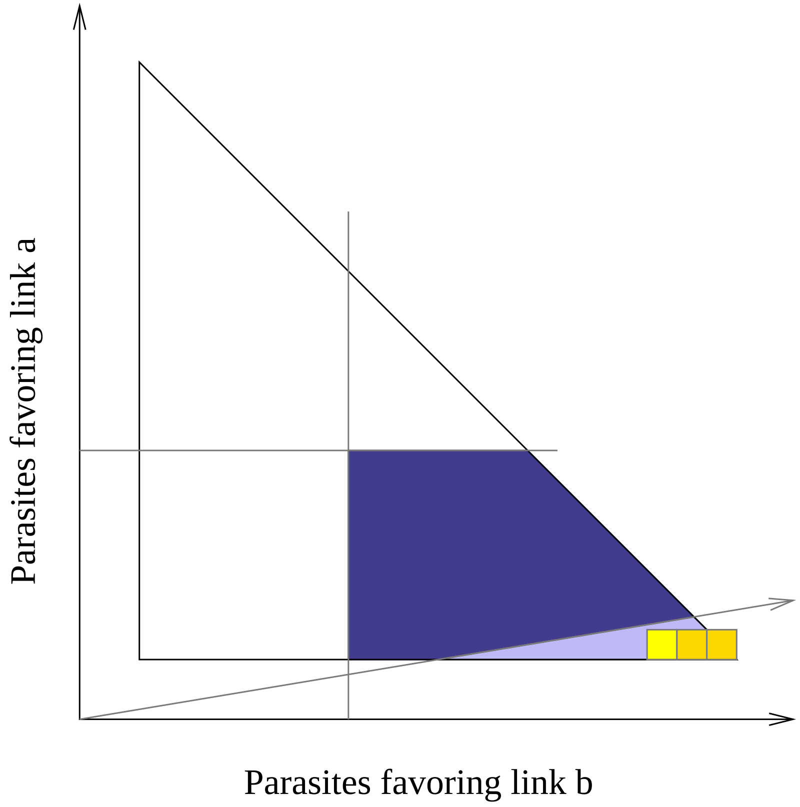
Solving

Calculate from right to left, bottom to top



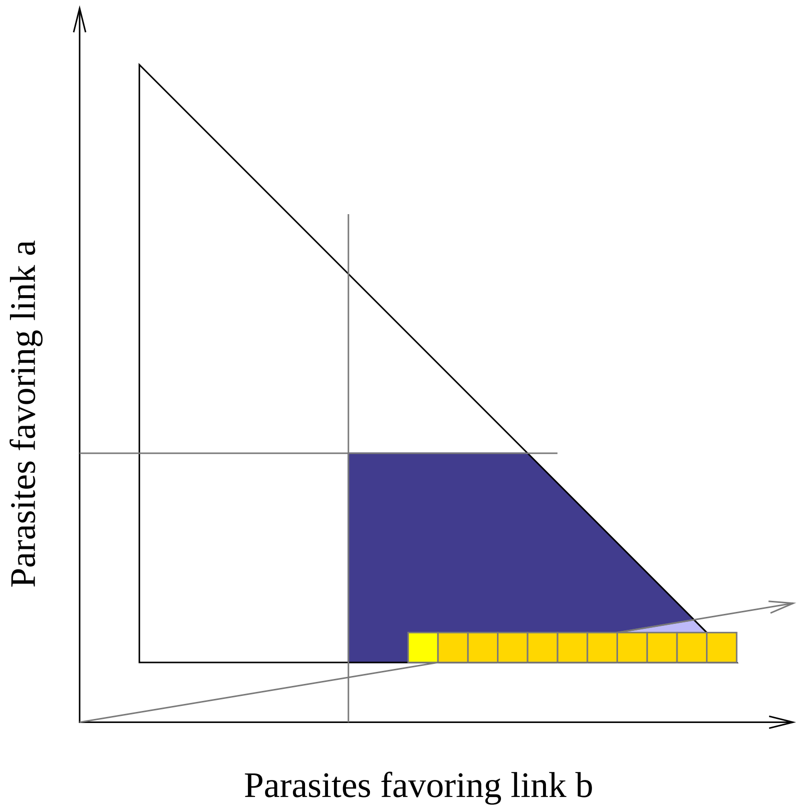
Solving

Calculate from right to left, bottom to top



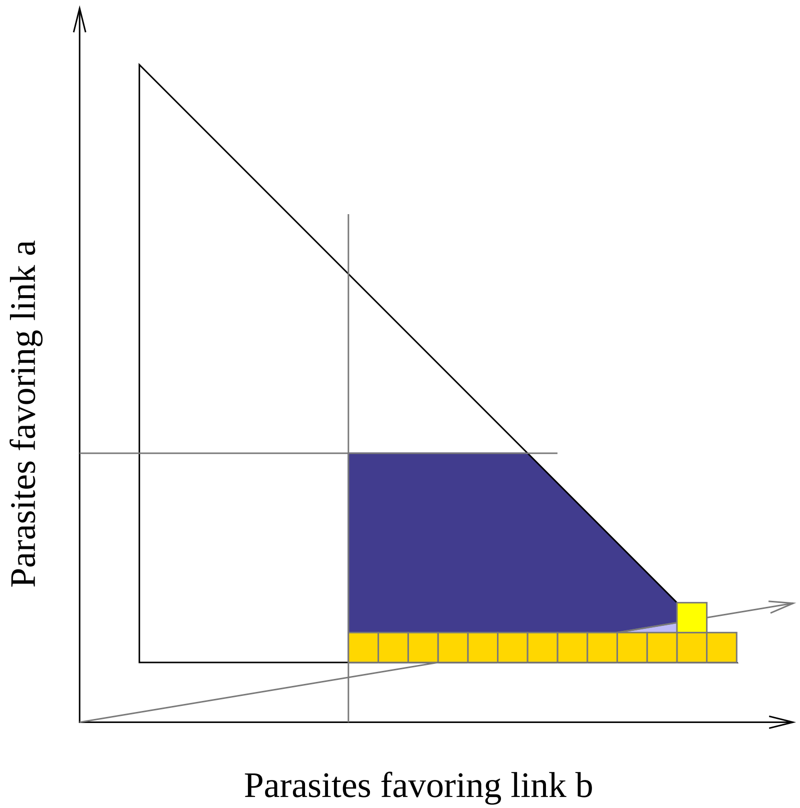
Solving

Calculate from right to left, bottom to top



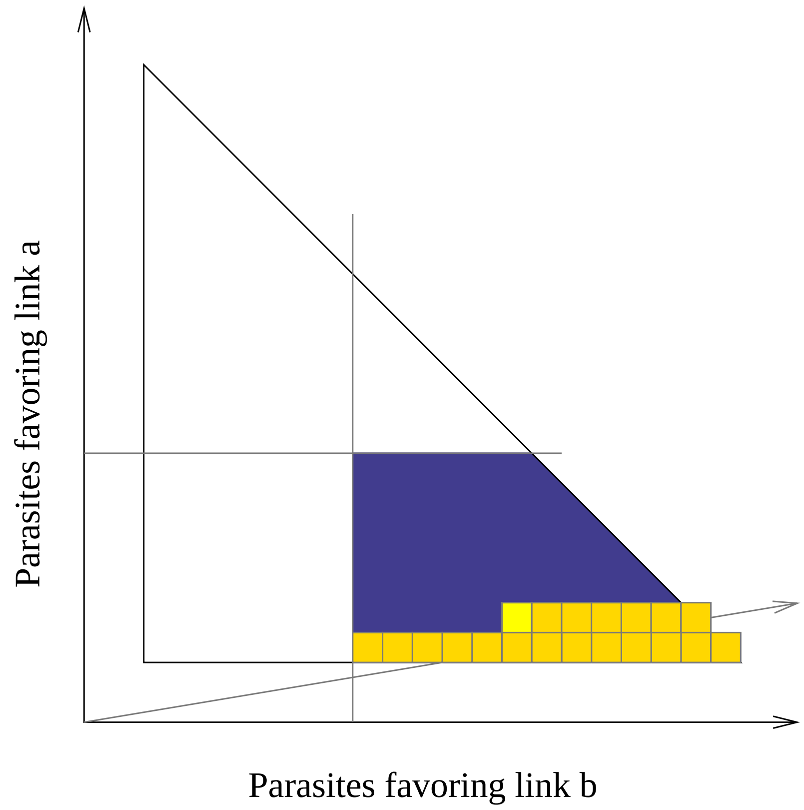
Solving

Calculate from right to left, bottom to top



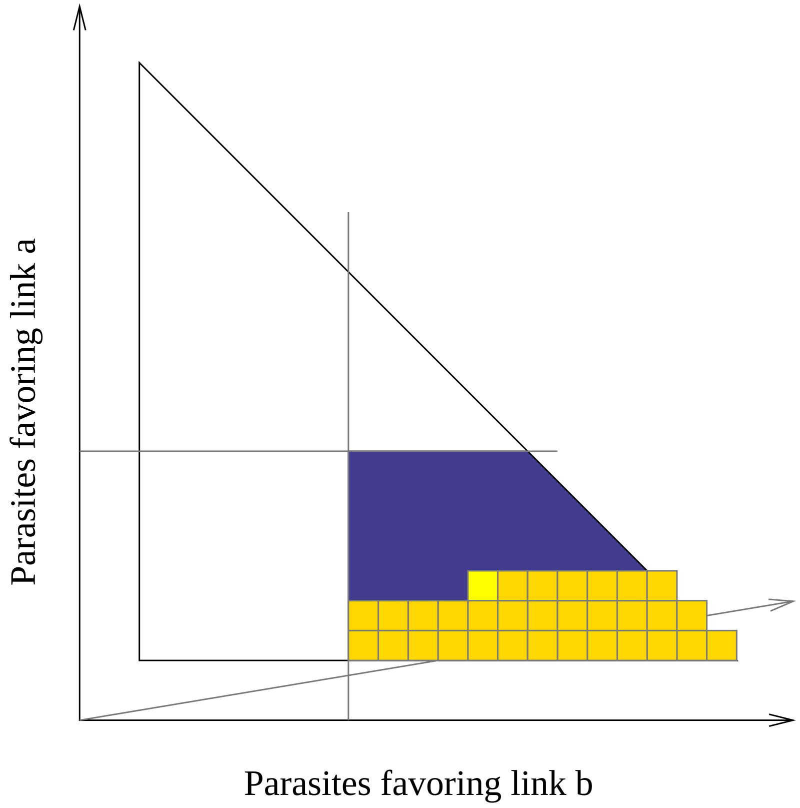
Solving

Calculate from right to left, bottom to top



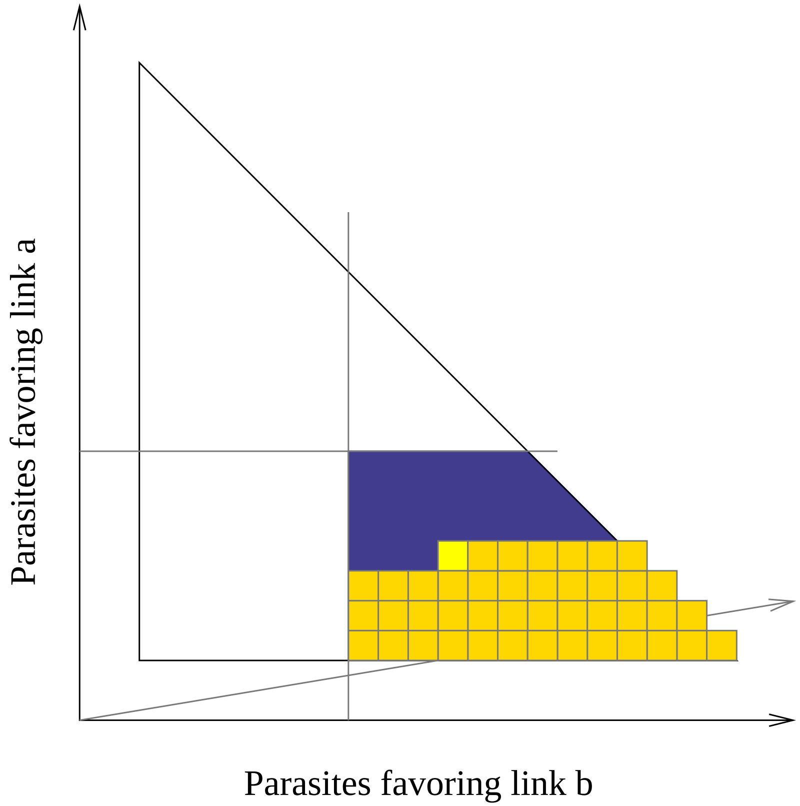
Solving

Calculate from right to left, bottom to top



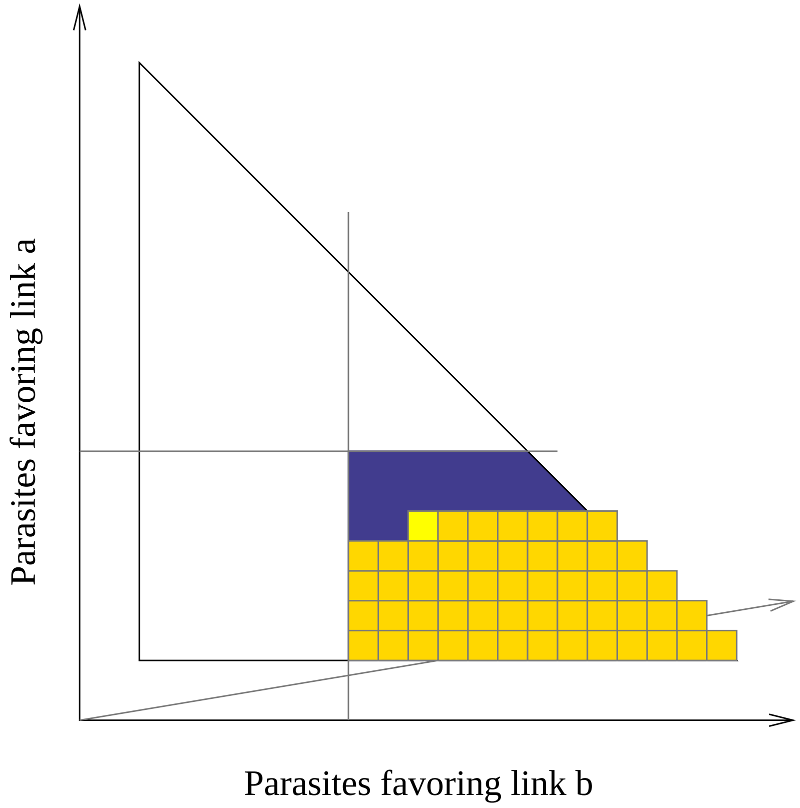
Solving

Calculate from right to left, bottom to top



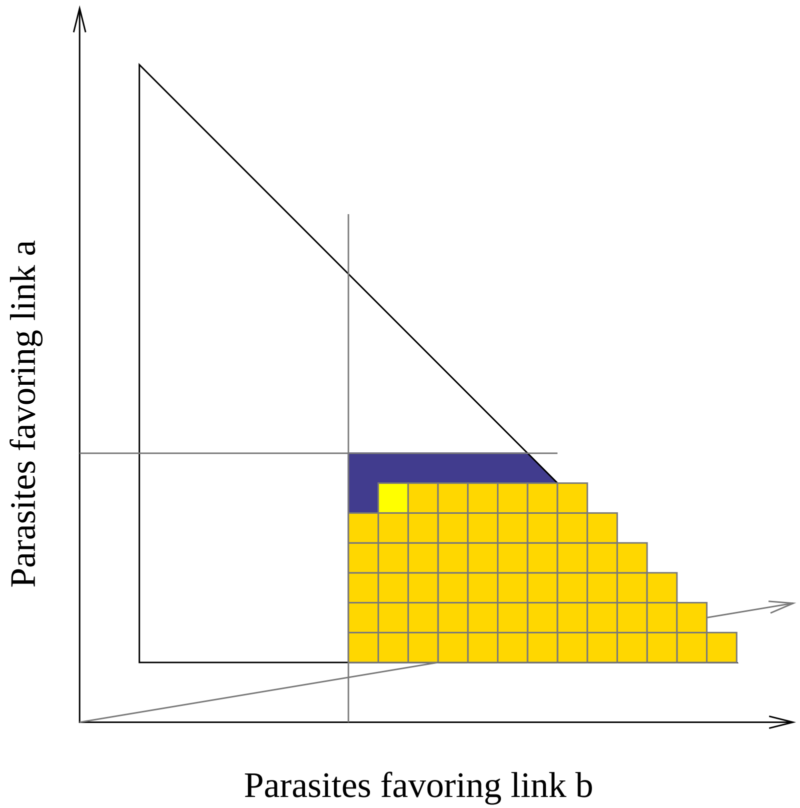
Solving

Calculate from right to left, bottom to top



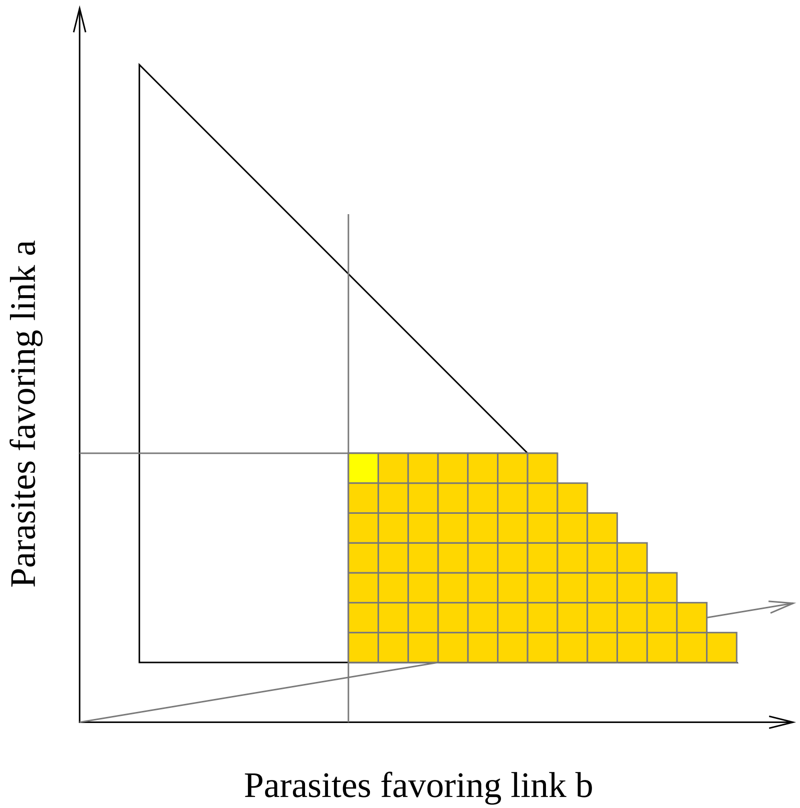
Solving

Calculate from right to left, bottom to top



Solving

Calculate from right to left, bottom to top



Results

Parameters:

$$\eta_{init} = 100 \qquad \eta_{min} = 25$$
$$\psi_{max} = 1000 \quad t = .95$$

	predicted
total	459.83
bad	80.0

Results

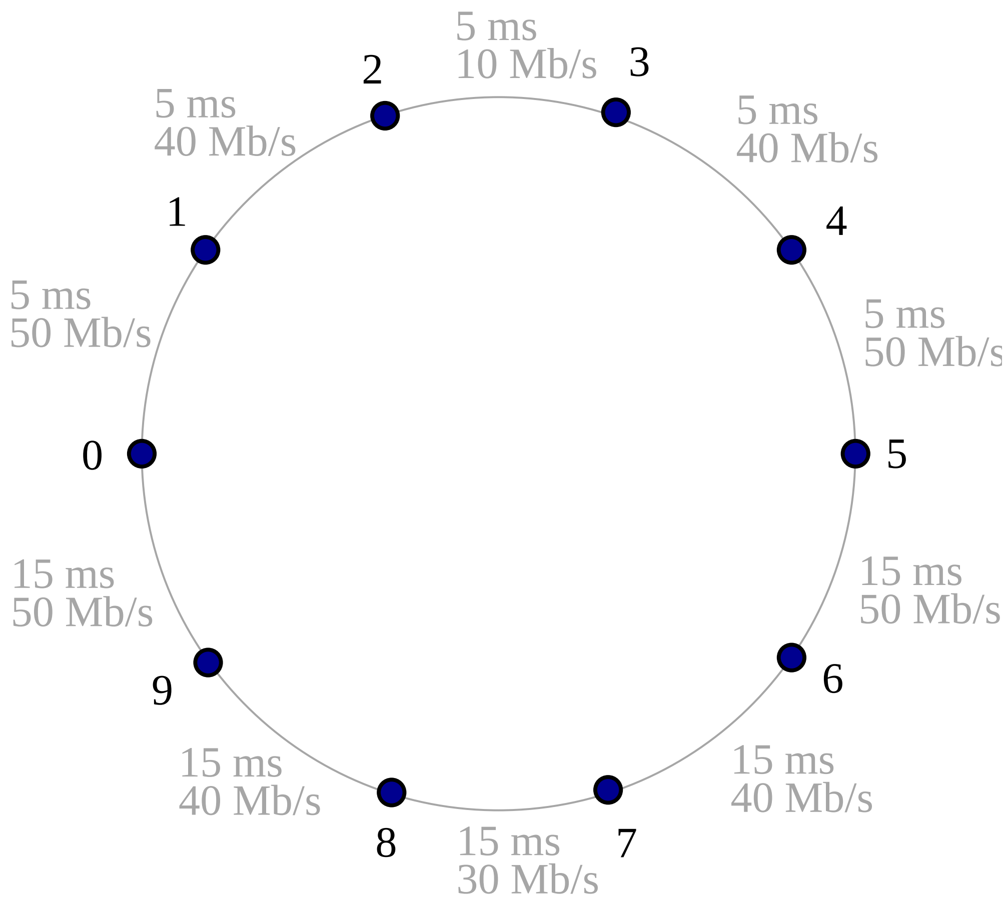
Parameters:

$$\eta_{init} = 100 \qquad \eta_{min} = 25$$
$$\psi_{max} = 1000 \quad t = .95$$

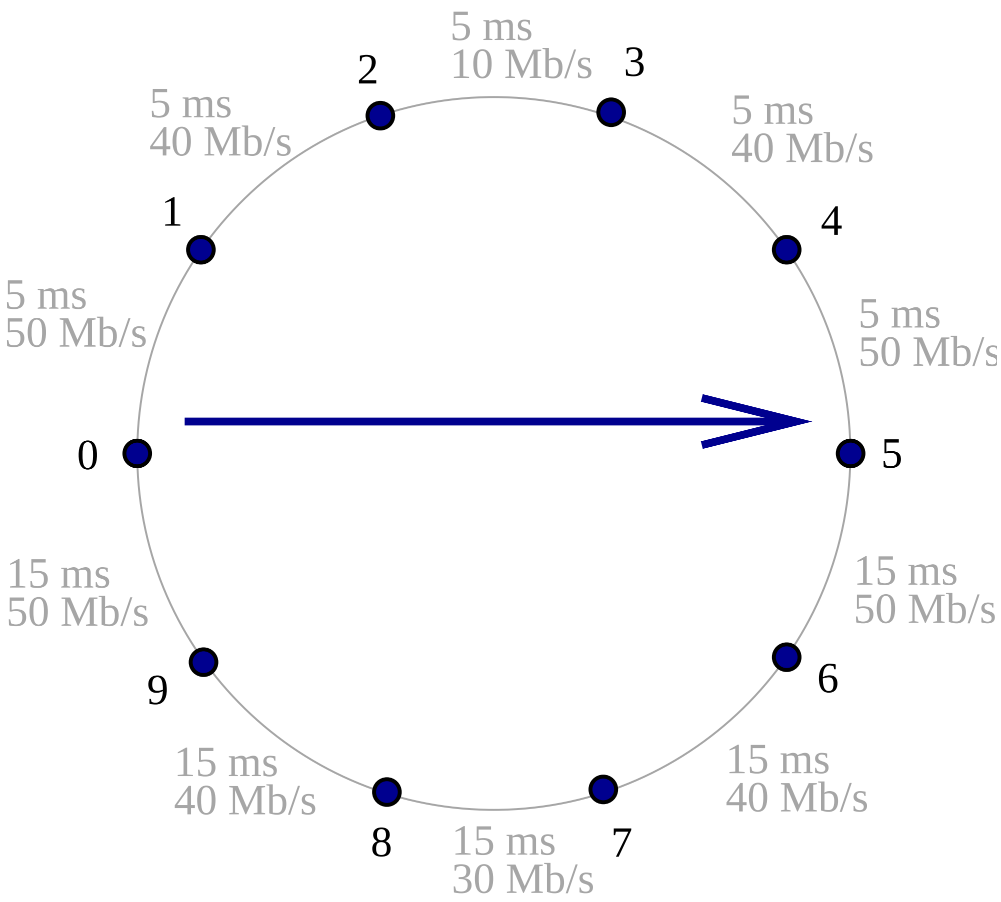
	predicted	*measured*
total	459.83	460.225
bad	80.0	80.271

Analysis of Static and Dynamic Operation on a Ring Network

Topology

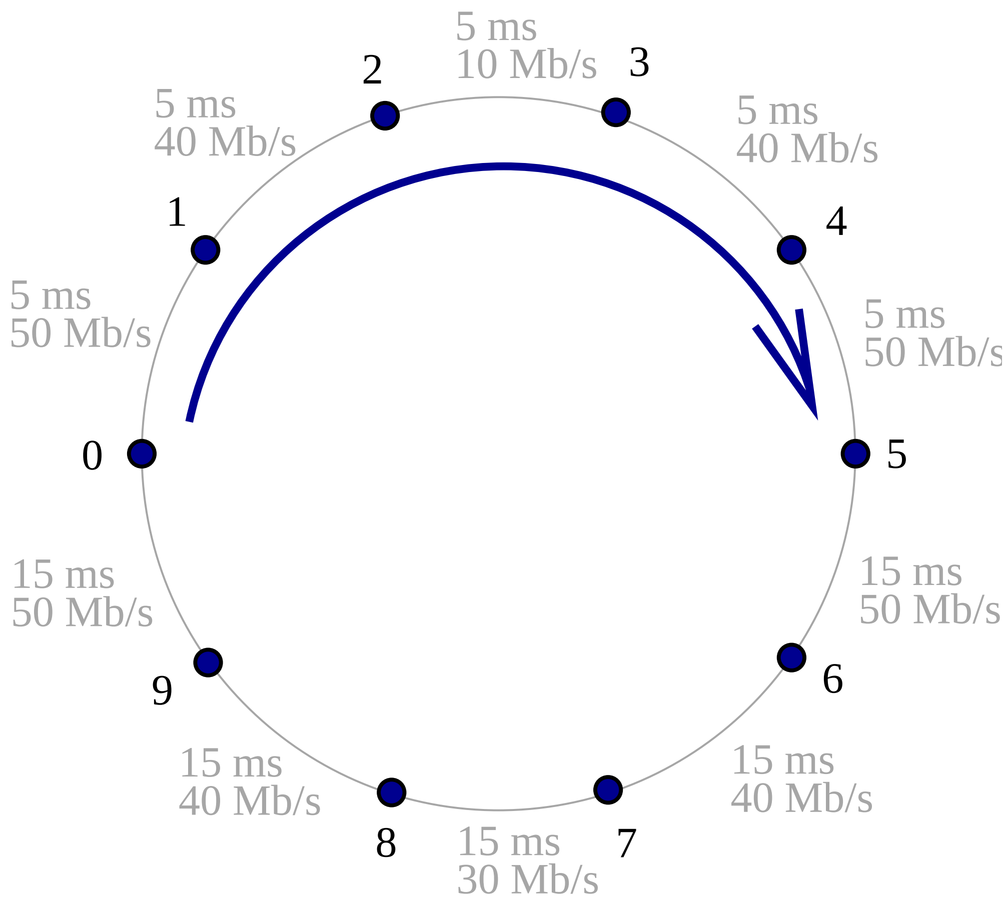

5 ms
10 Mb/s
2
3
5 ms
40 Mb/s
5 ms
40 Mb/s
1
4
5 ms
50 Mb/s
5 ms
50 Mb/s
0
5
15 ms
50 Mb/s
15 ms
50 Mb/s
9
6
15 ms
40 Mb/s
15 ms
40 Mb/s
8
7
15 ms
30 Mb/s

Topology

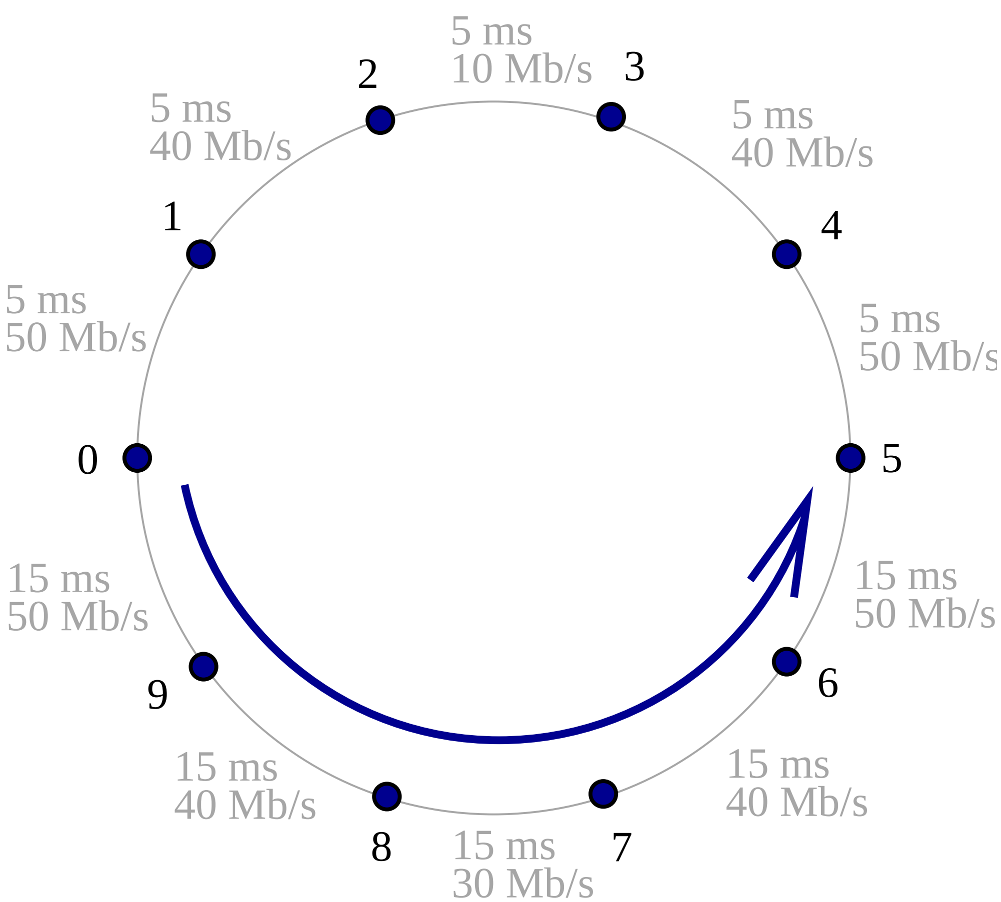


0
1
2
3
4
5
6
7
8
9
5 ms
50 Mb/s
5 ms
40 Mb/s
5 ms
10 Mb/s
5 ms
40 Mb/s
5 ms
50 Mb/s
15 ms
50 Mb/s
15 ms
40 Mb/s
15 ms
30 Mb/s
15 ms
40 Mb/s
15 ms
50 Mb/s

Topology

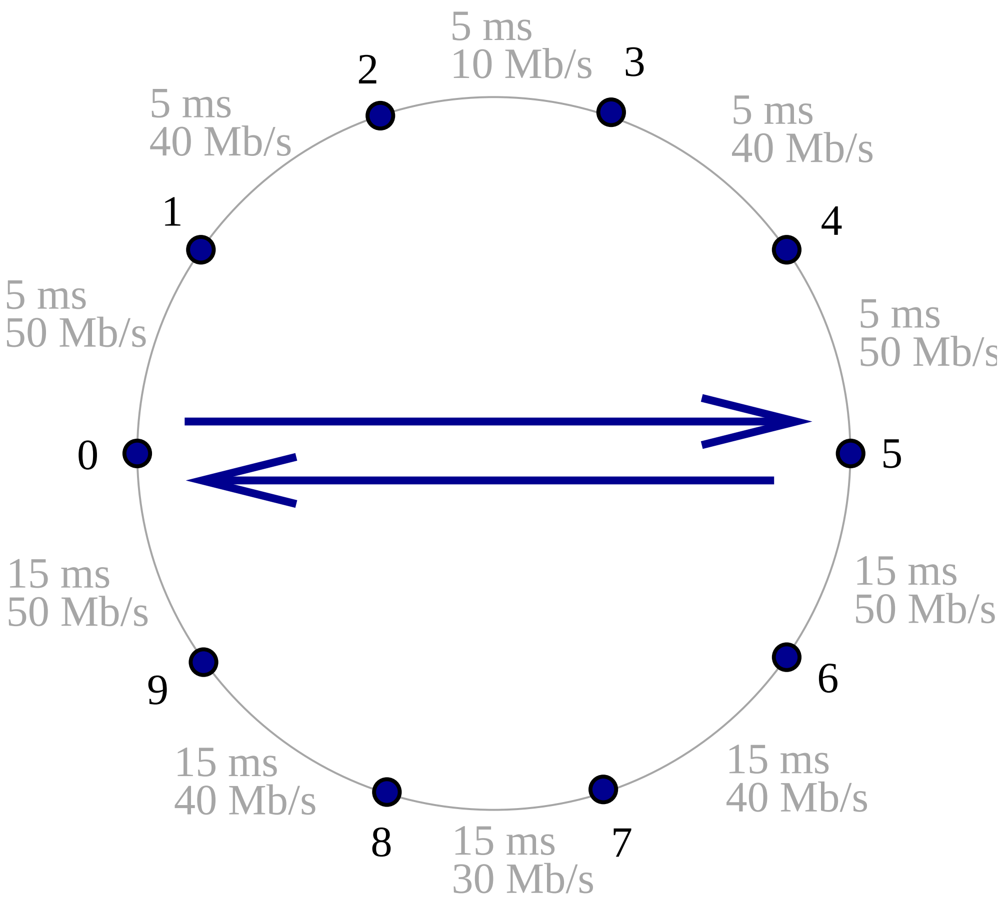

5 ms
10 Mb/s
2
3
5 ms
40 Mb/s
5 ms
40 Mb/s
1
4
5 ms
50 Mb/s
5 ms
50 Mb/s
0
5
15 ms
50 Mb/s
15 ms
50 Mb/s
9
6
15 ms
40 Mb/s
15 ms
40 Mb/s
8
7
15 ms
30 Mb/s

Topology



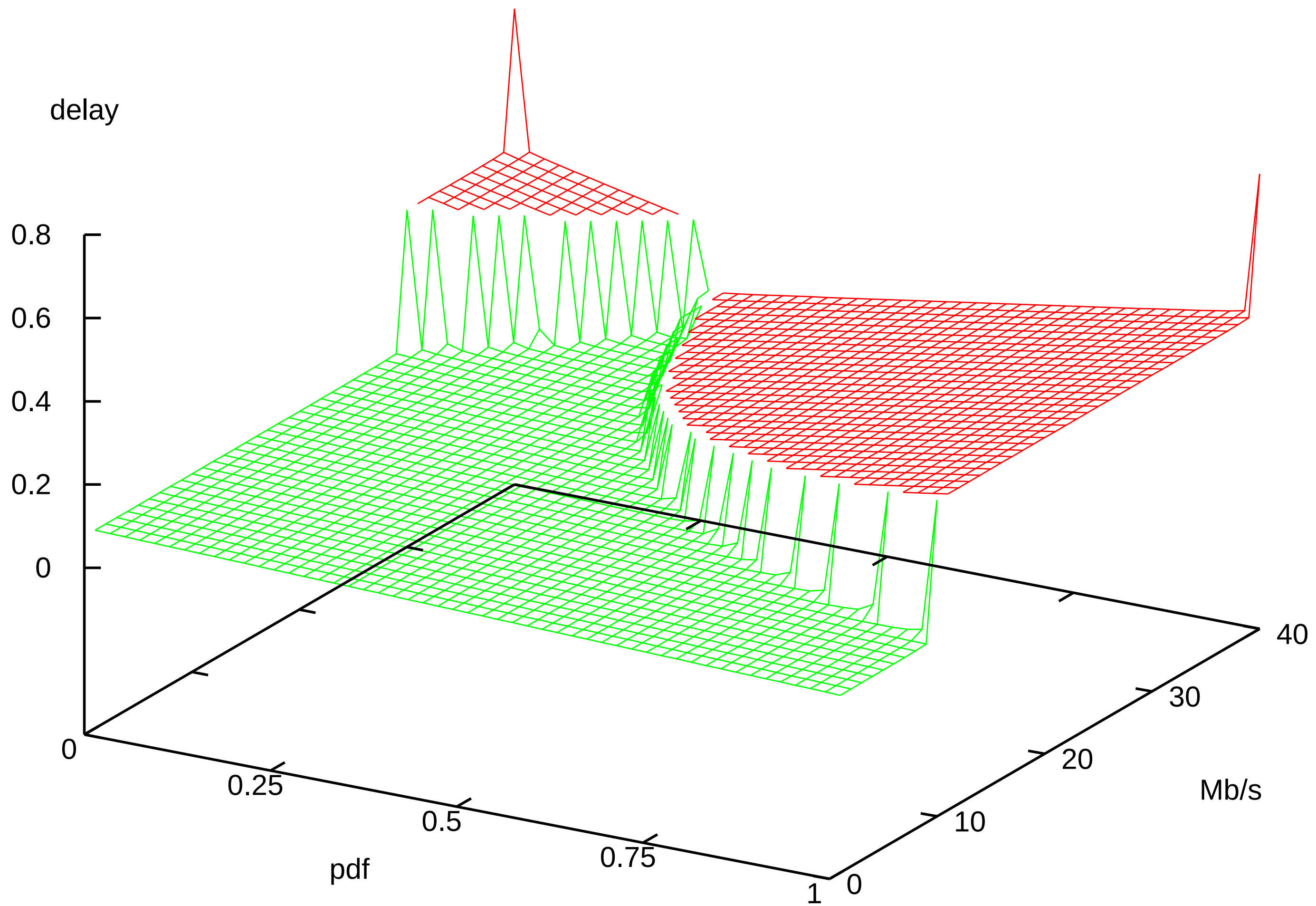
0
1
2
3
4
5
6
7
8
9
5 ms
50 Mb/s
5 ms
40 Mb/s
5 ms
10 Mb/s
5 ms
40 Mb/s
5 ms
50 Mb/s
15 ms
50 Mb/s
15 ms
40 Mb/s
15 ms
30 Mb/s
15 ms
40 Mb/s
15 ms
50 Mb/s

Topology

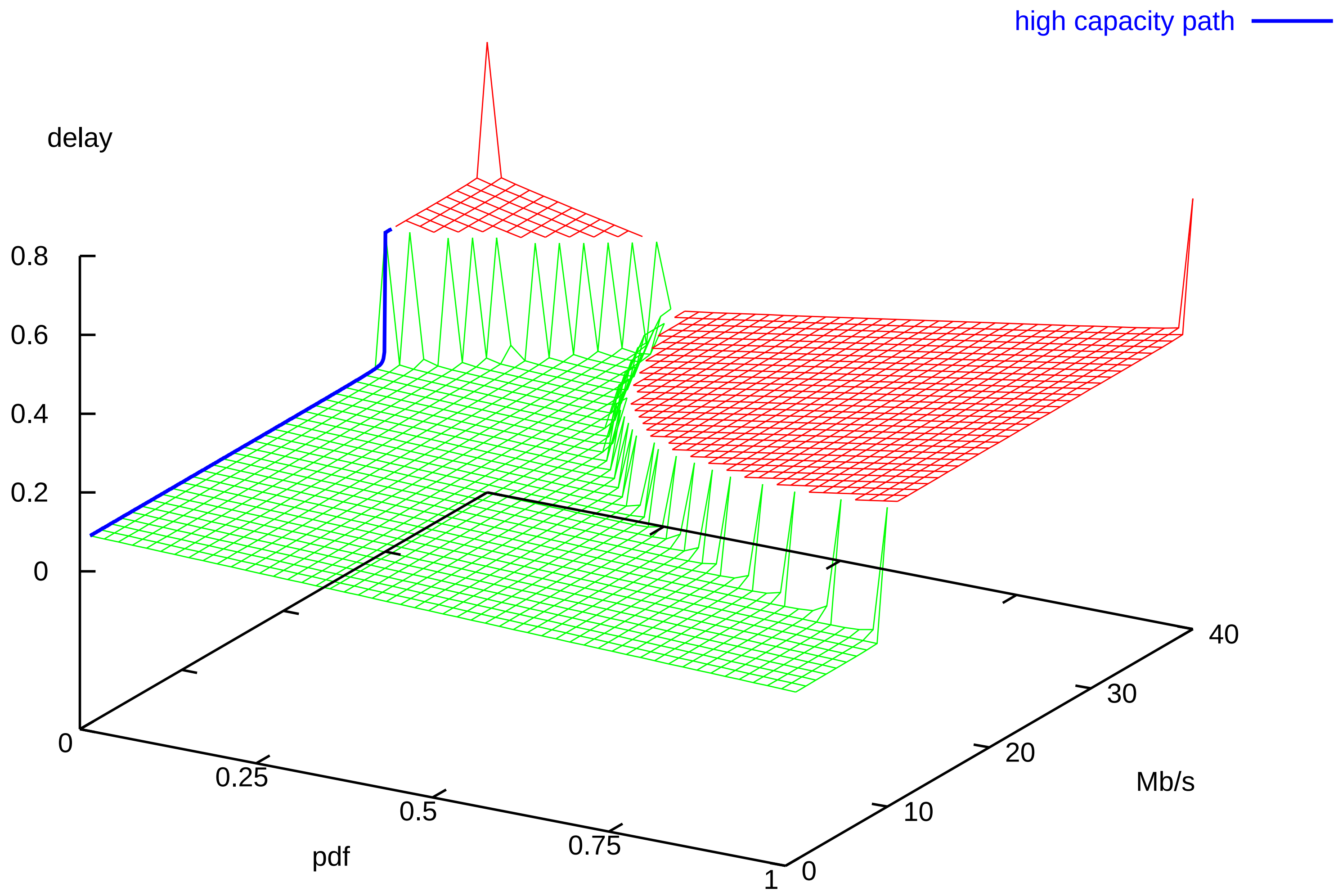


5 ms
10 Mb/s
2
3
5 ms
40 Mb/s
5 ms
40 Mb/s
1
4
5 ms
50 Mb/s
5 ms
50 Mb/s
0
5
15 ms
50 Mb/s
15 ms
50 Mb/s
9
6
15 ms
40 Mb/s
15 ms
40 Mb/s
8
7
15 ms
30 Mb/s

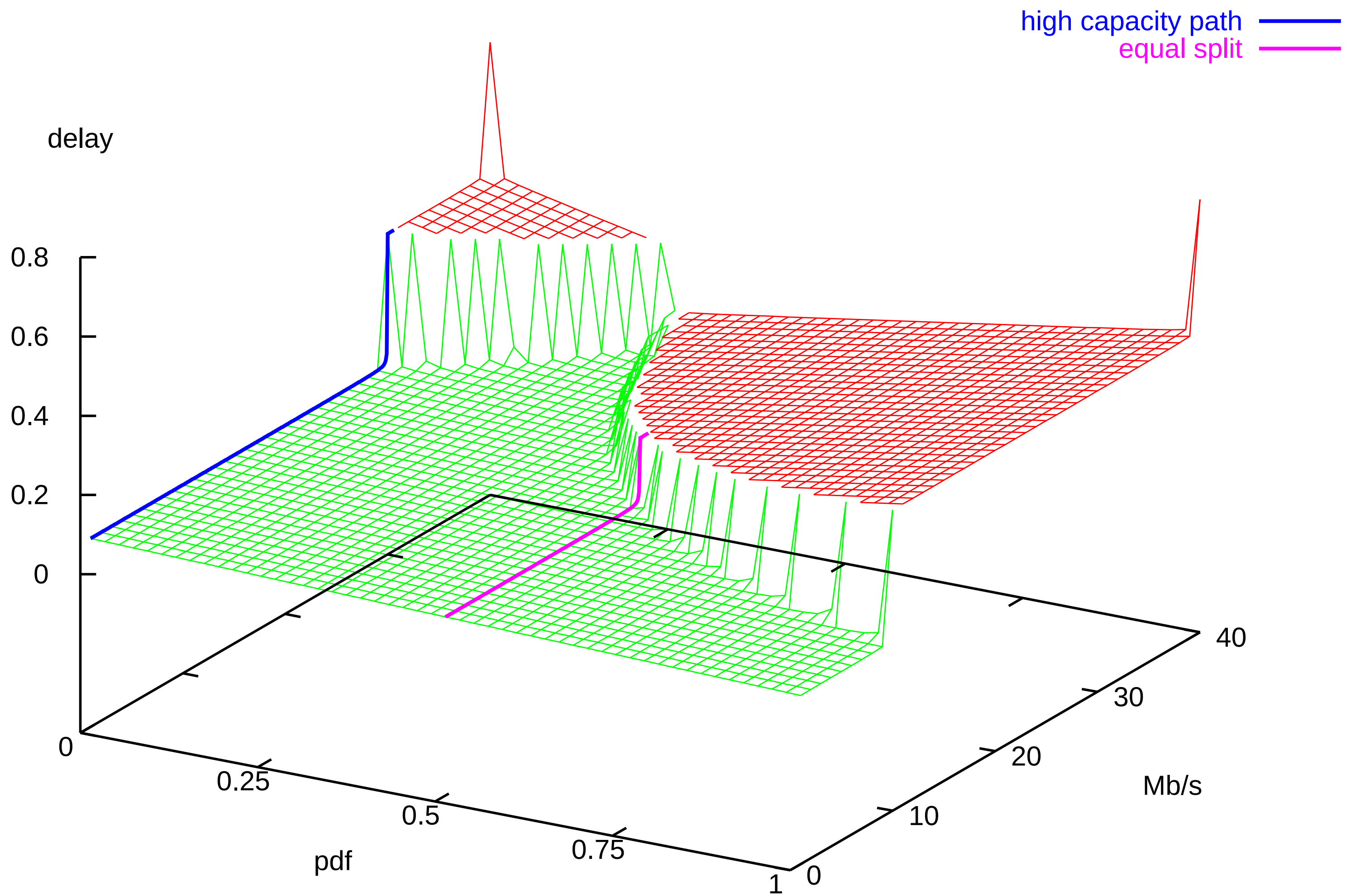
Solution Space



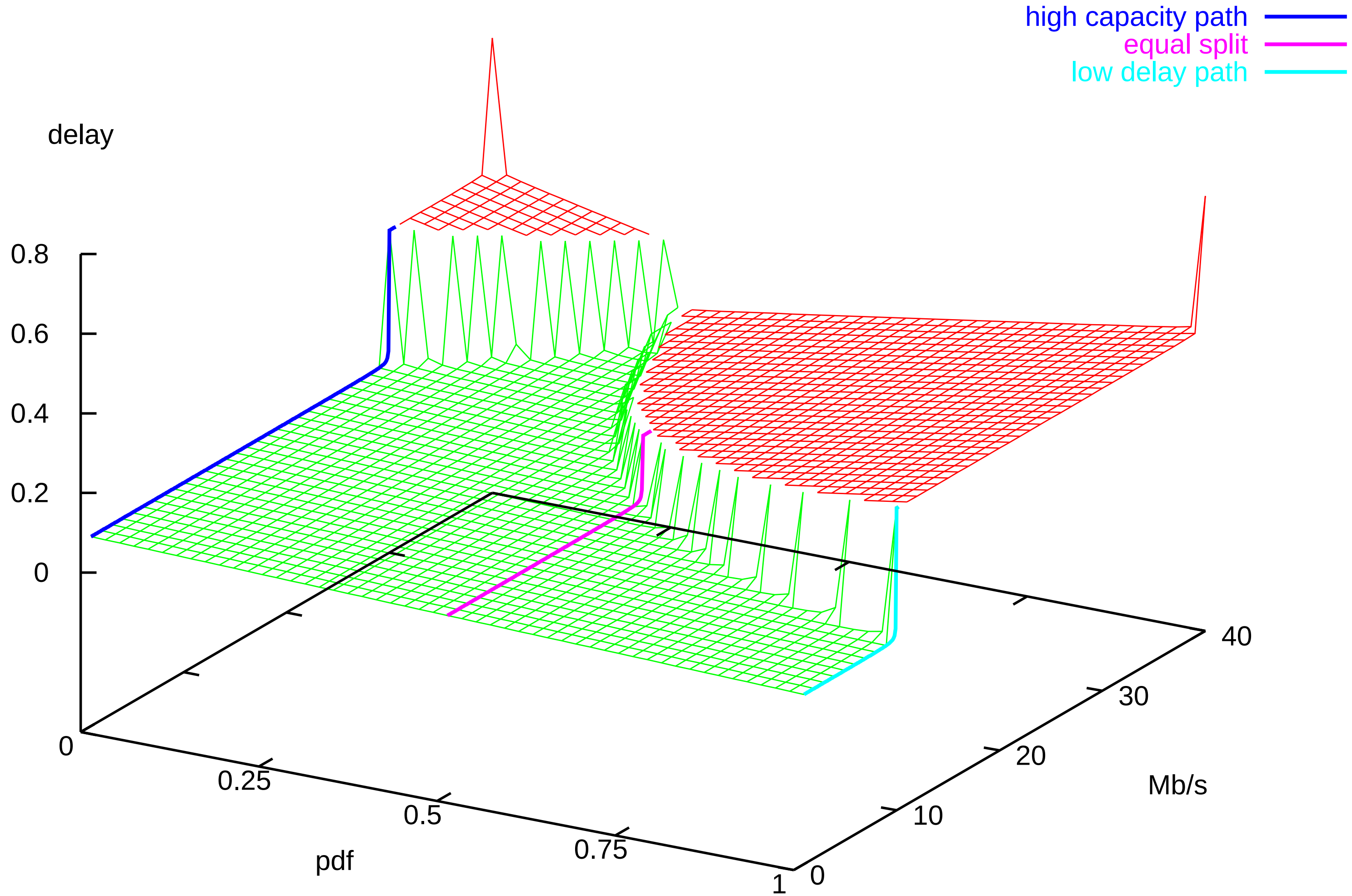
Solution Space



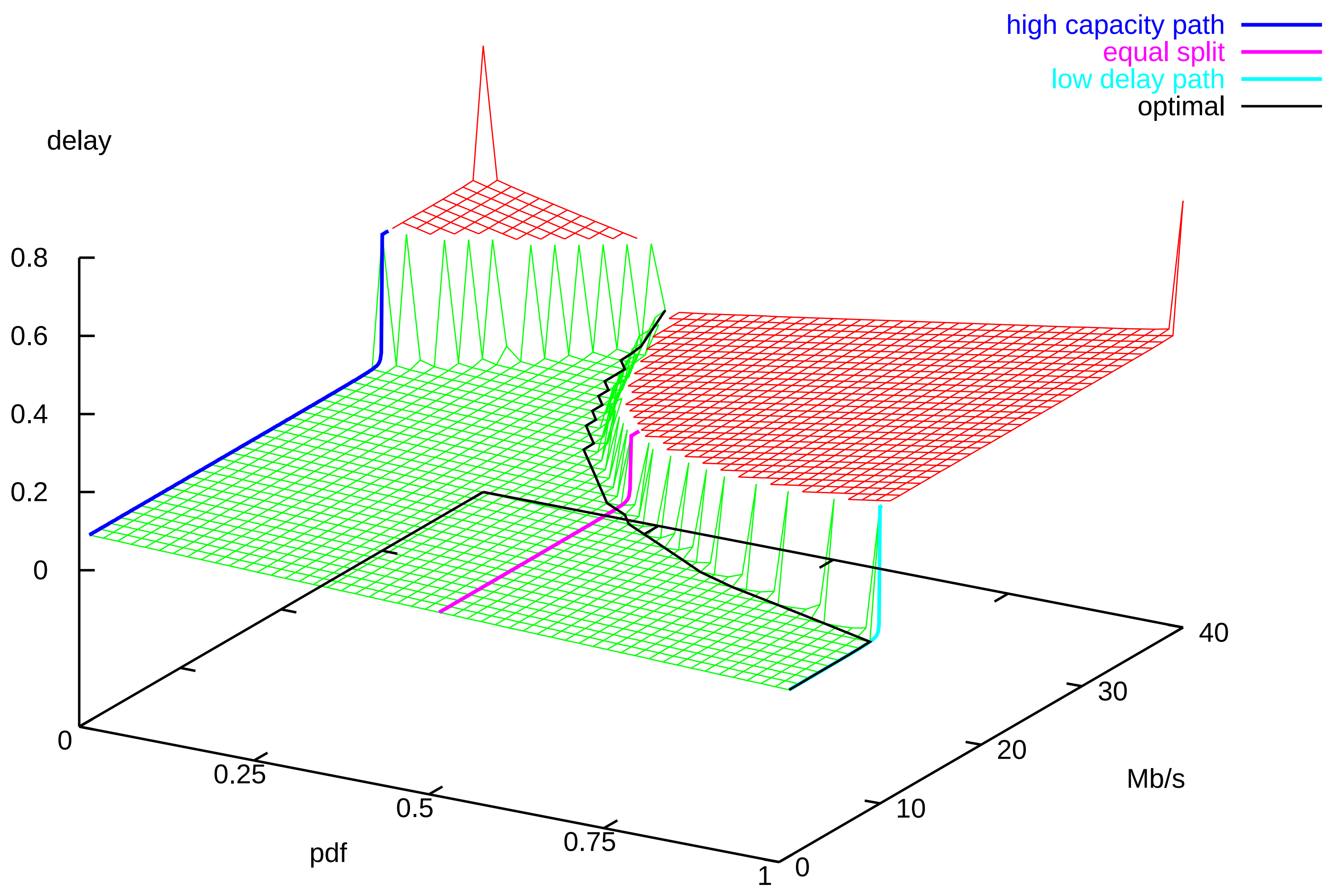
Solution Space



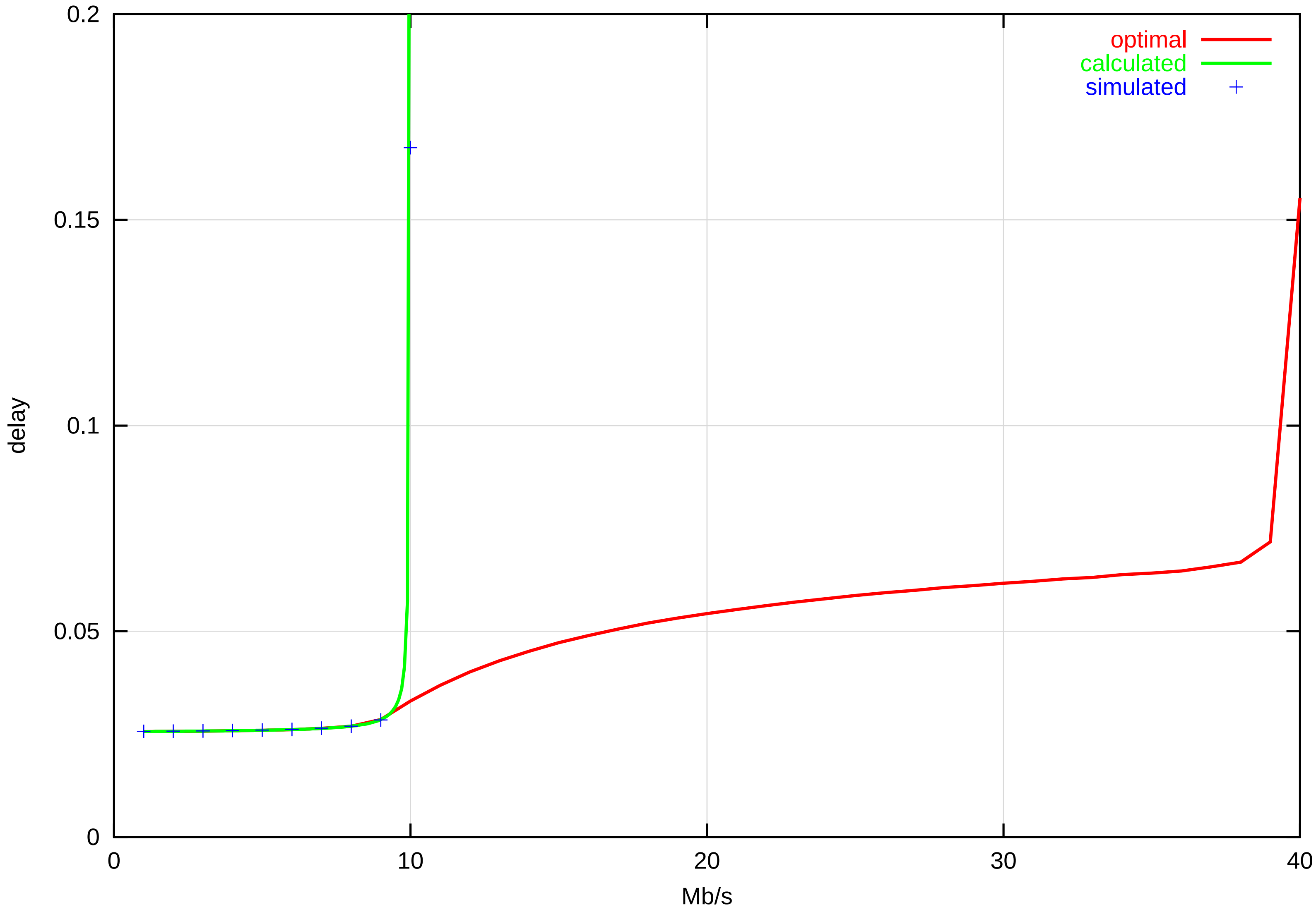
Solution Space



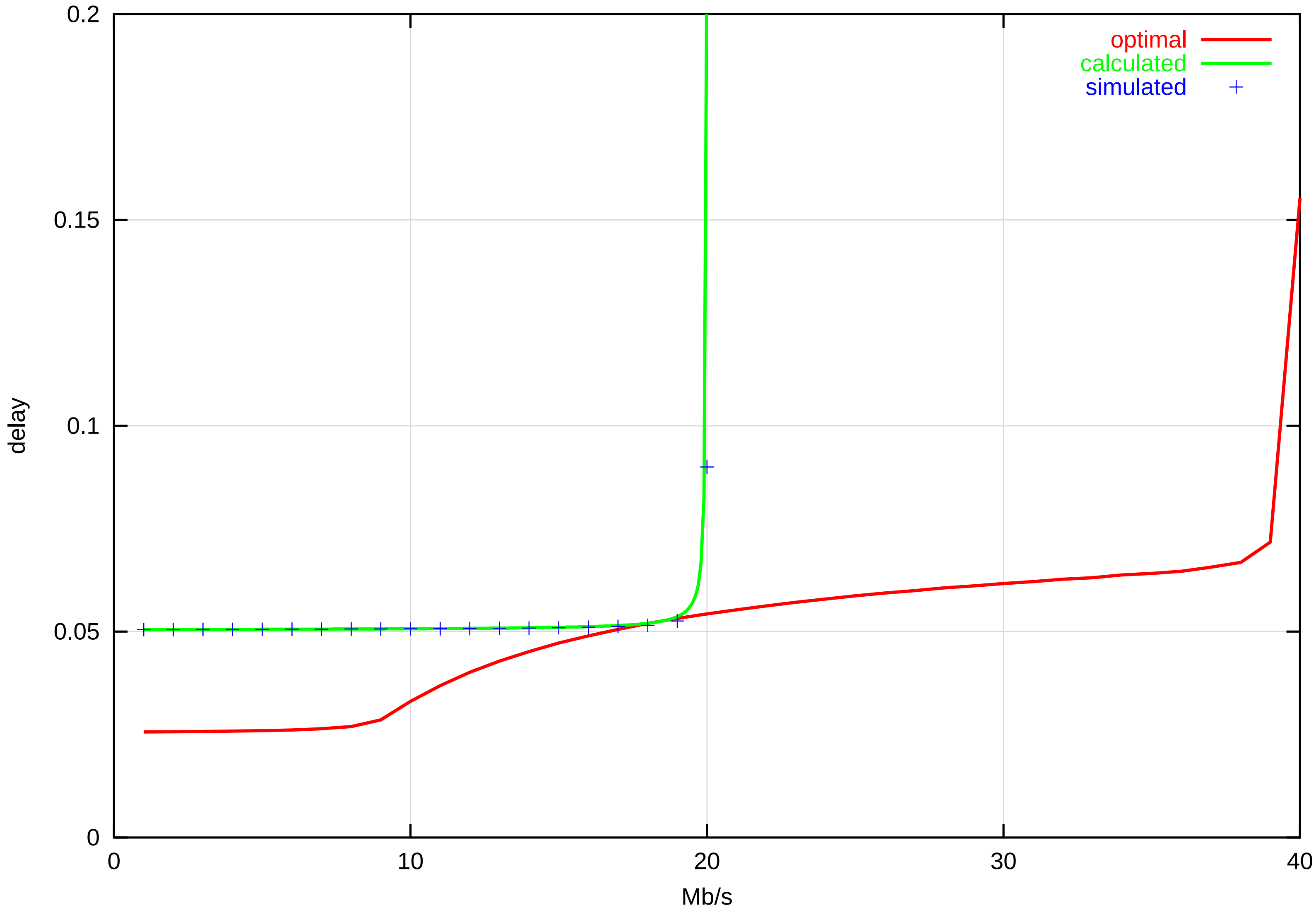
Solution Space



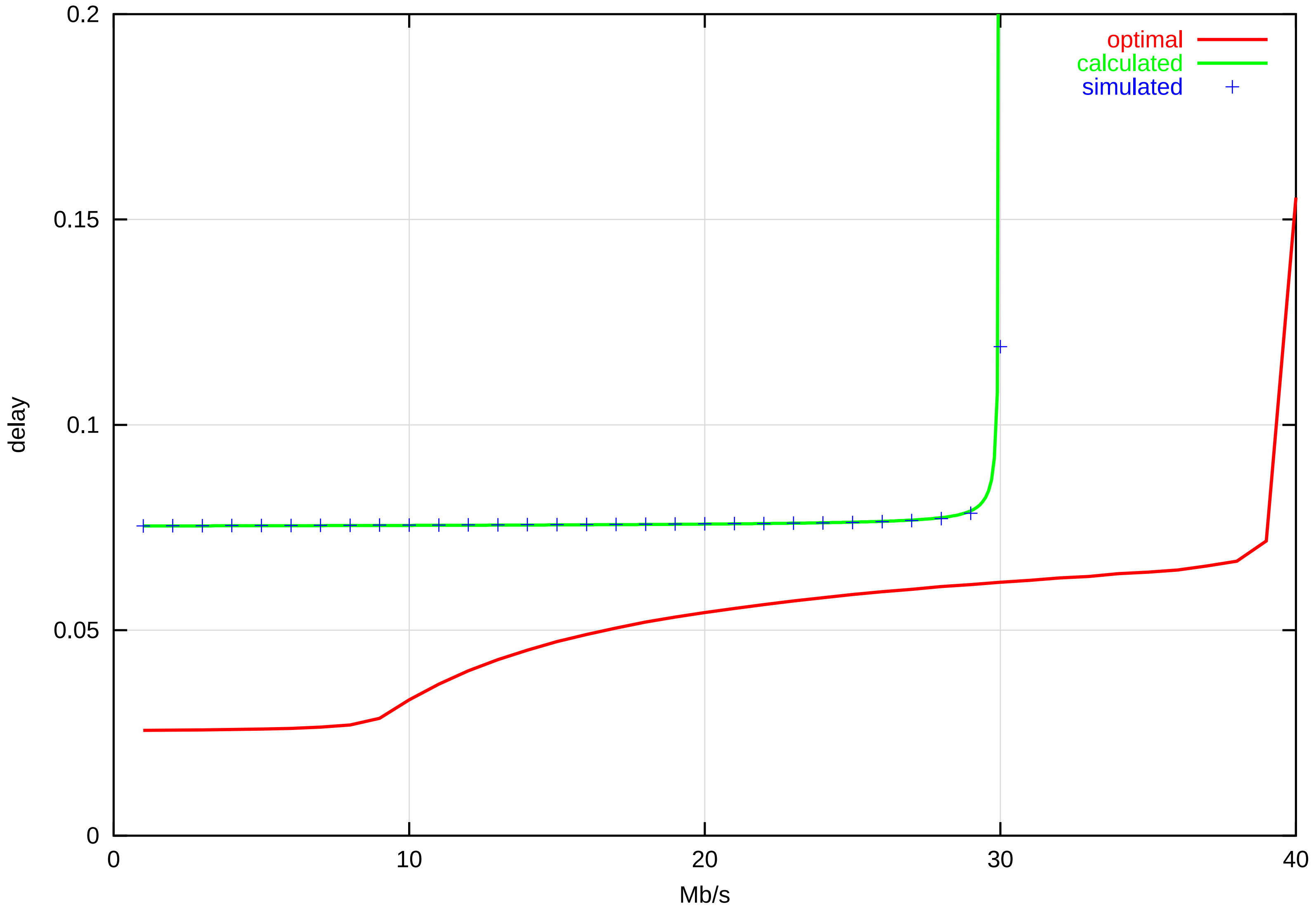
Static Results



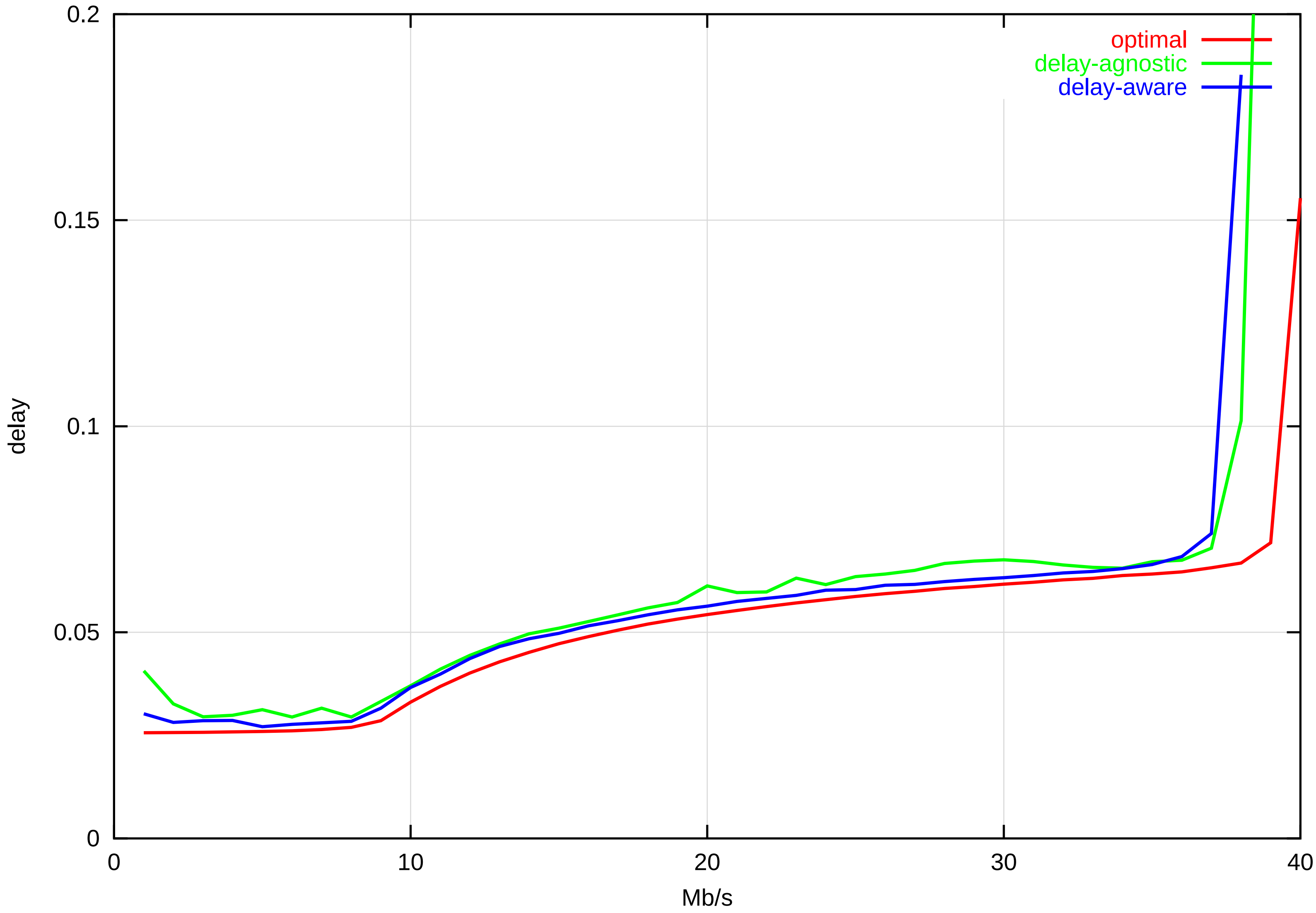
Static Results



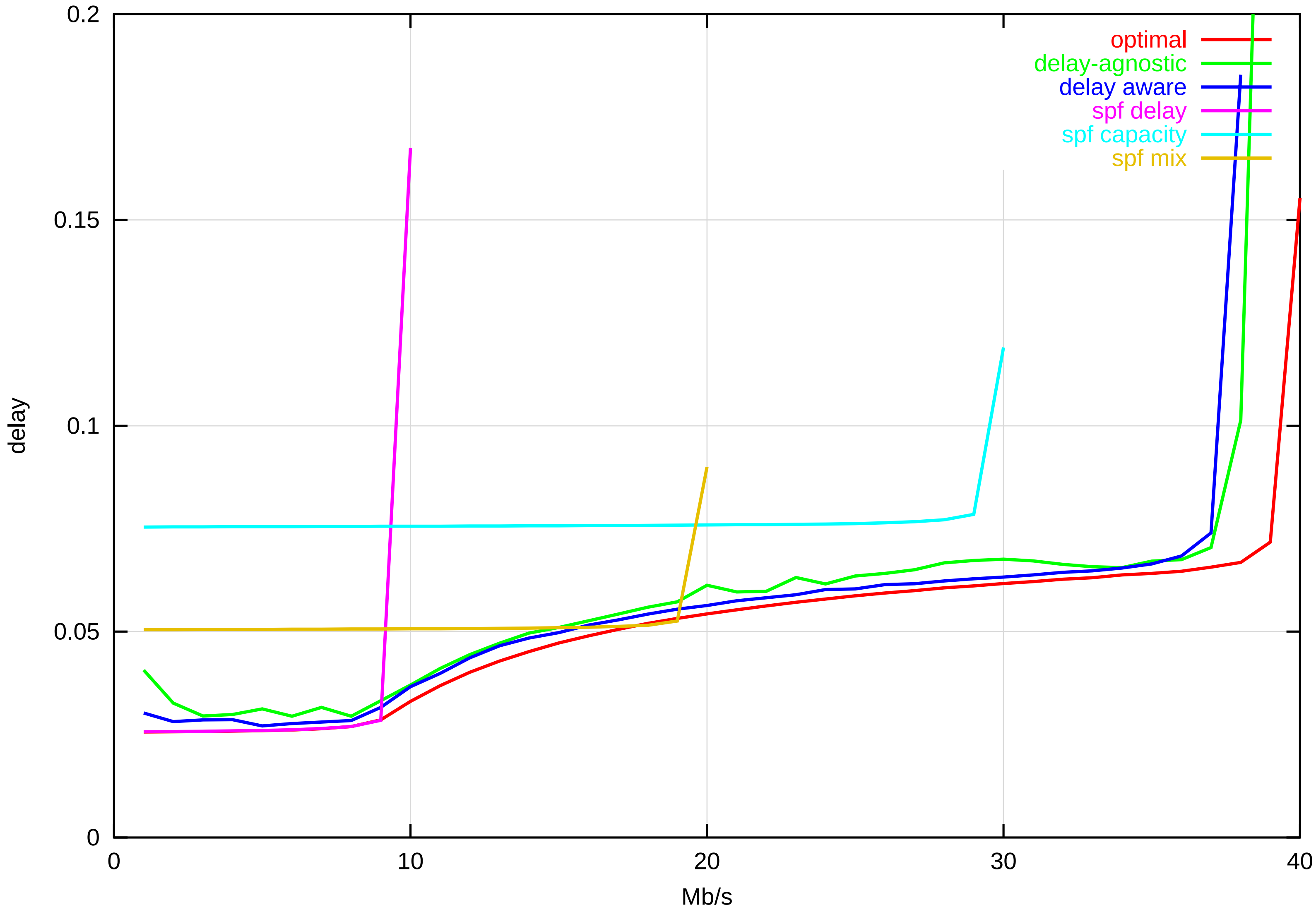
Static Results



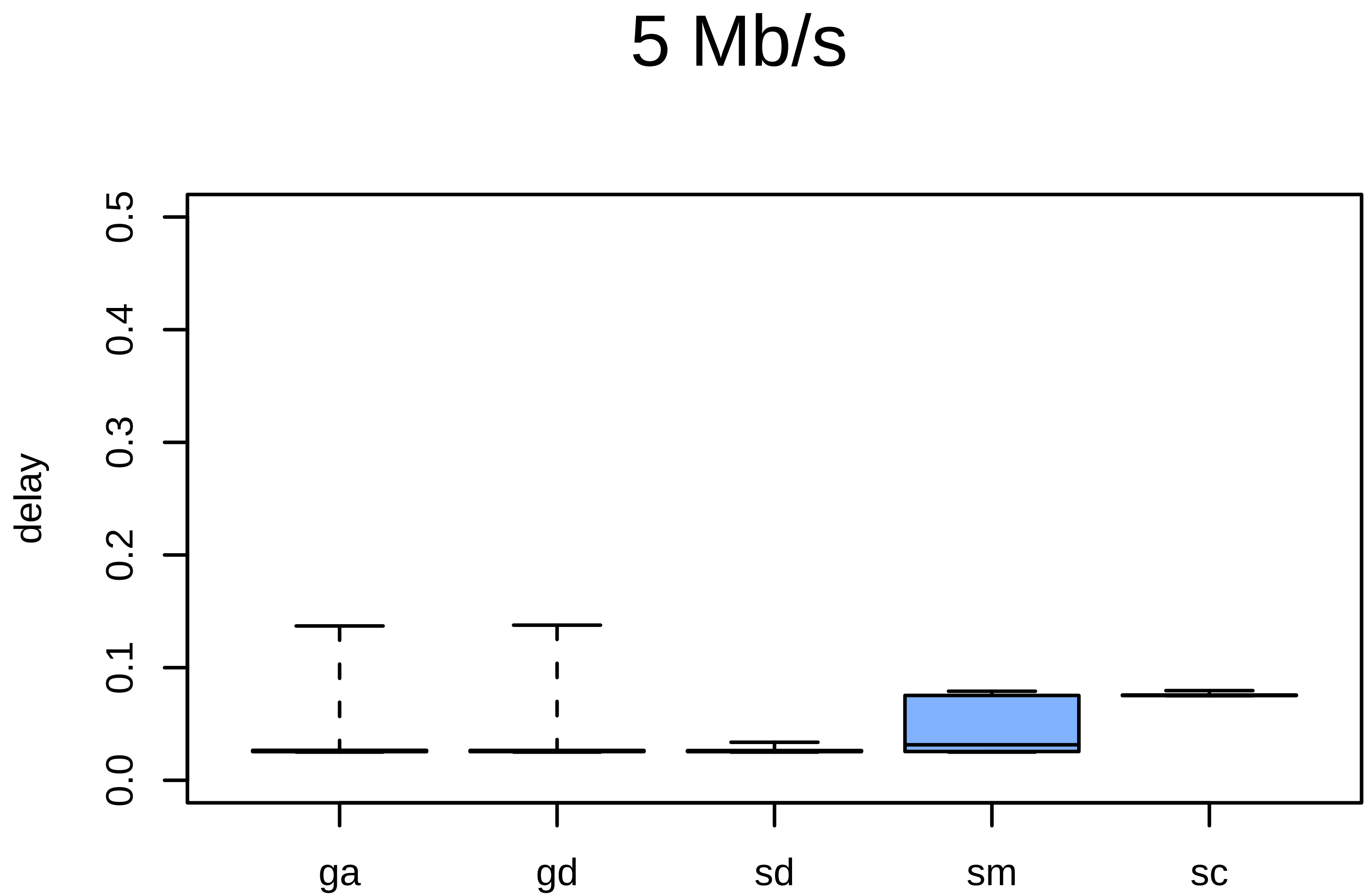
Static Results



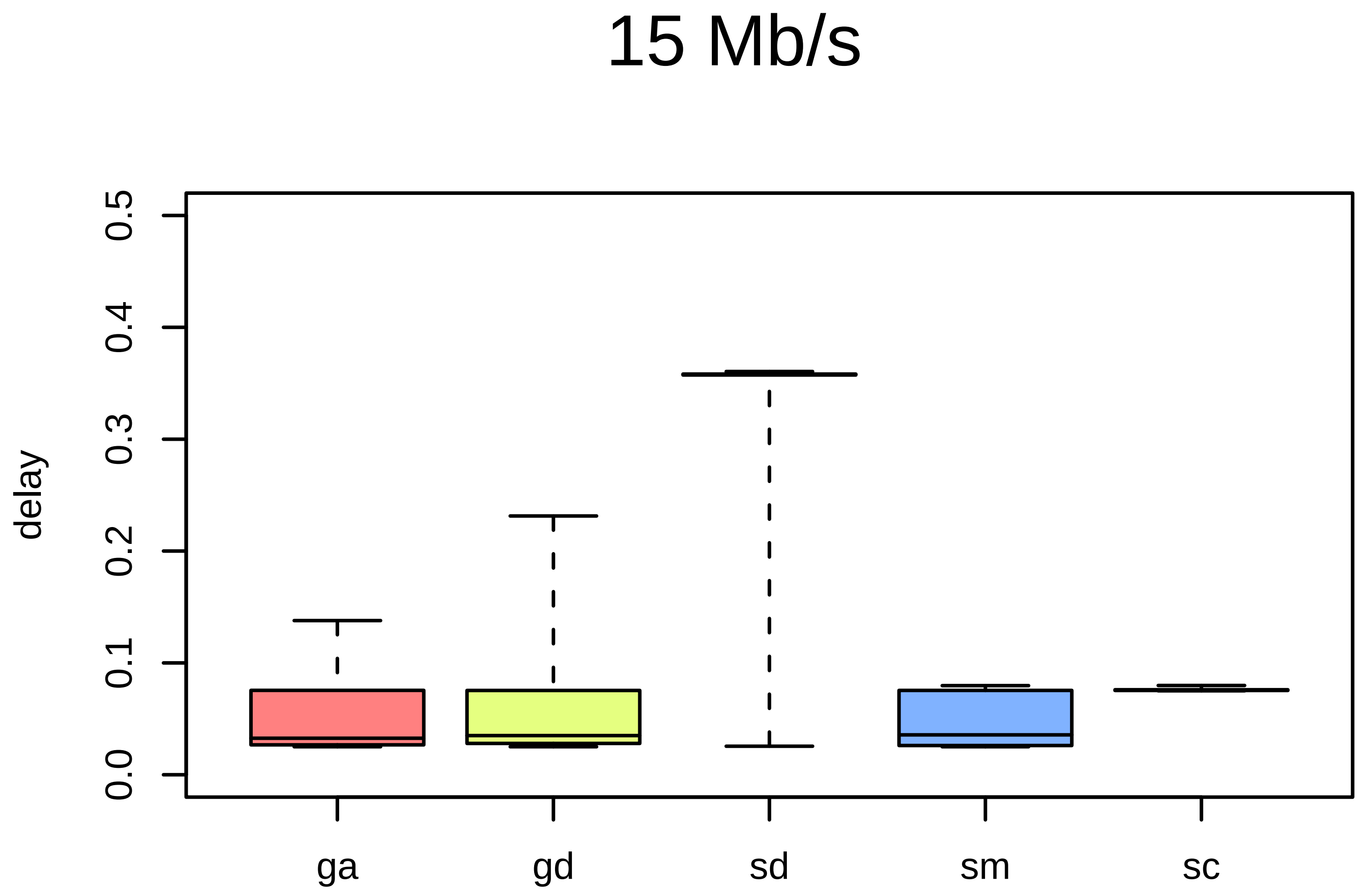
Static Results



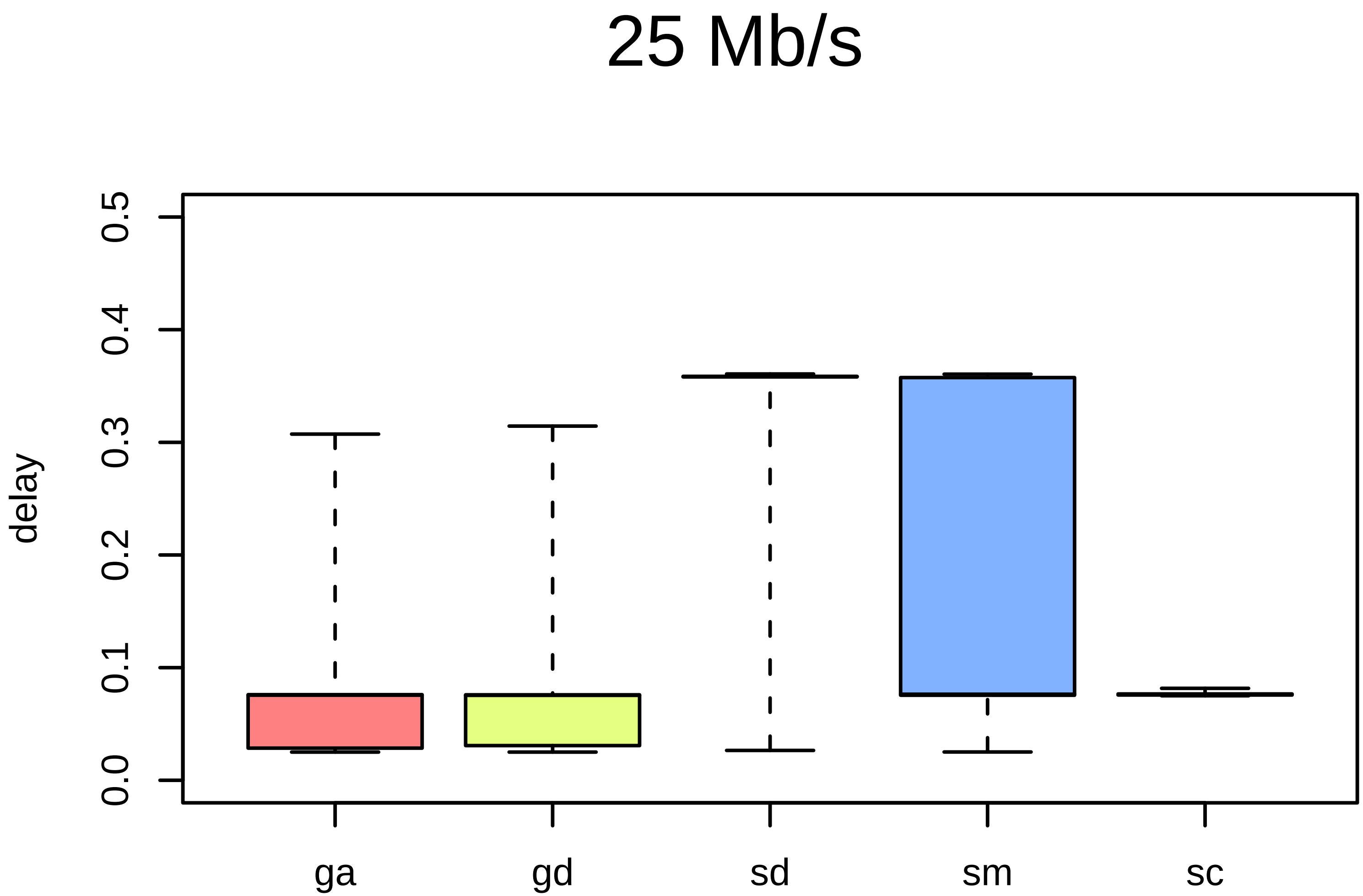
Delay Variance



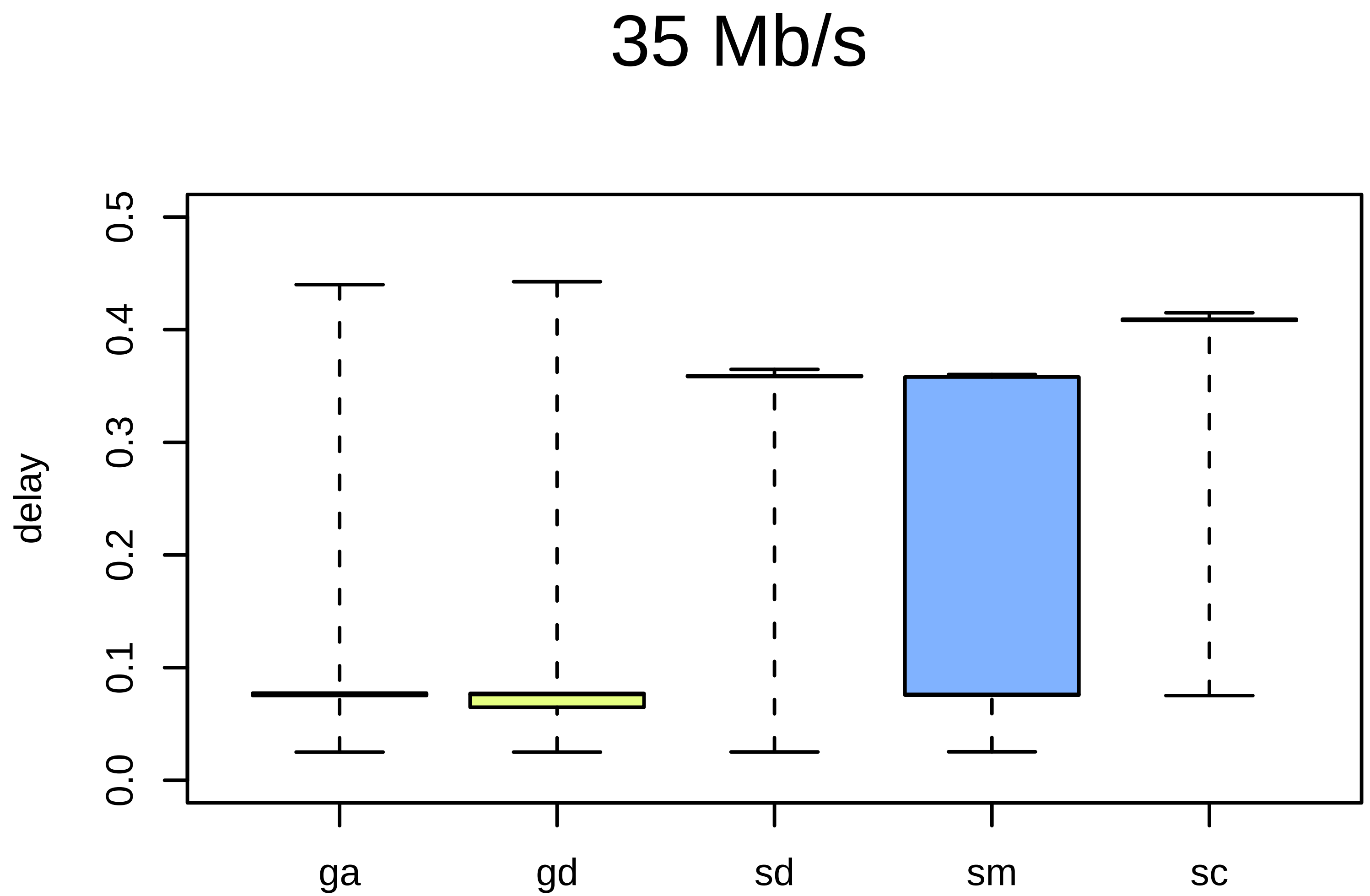
Delay Variance



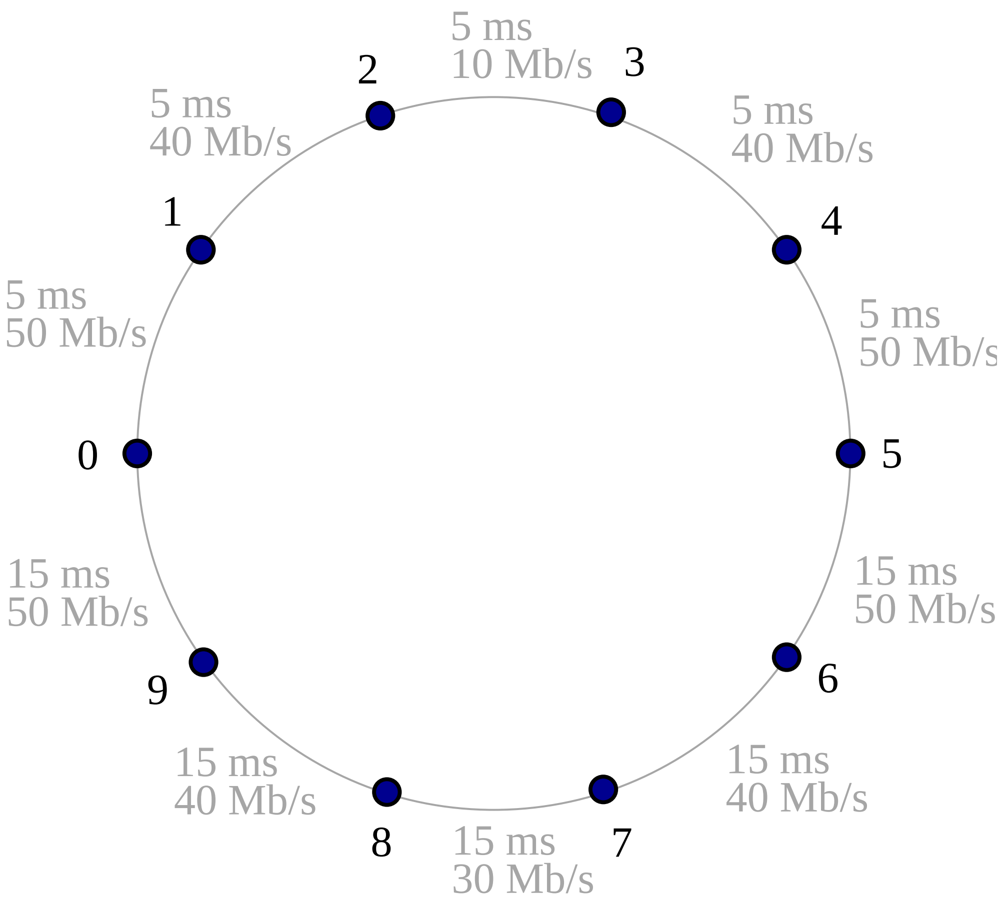
Delay Variance



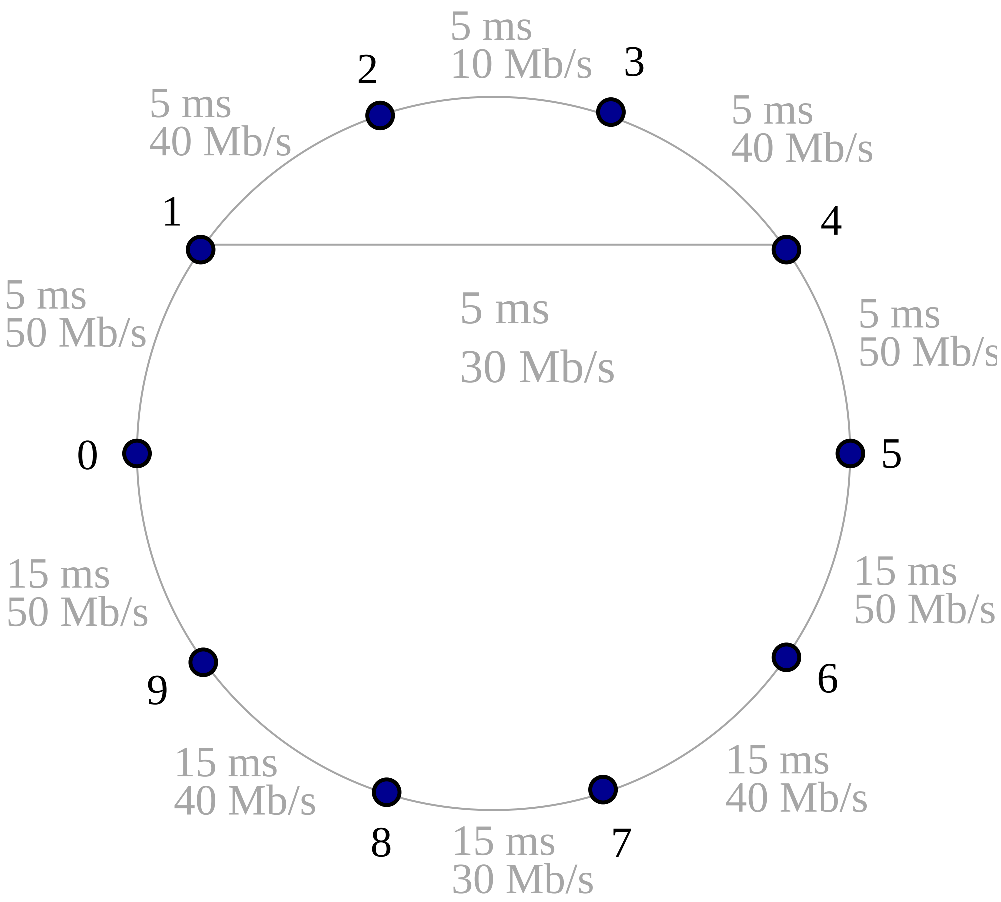
Delay Variance



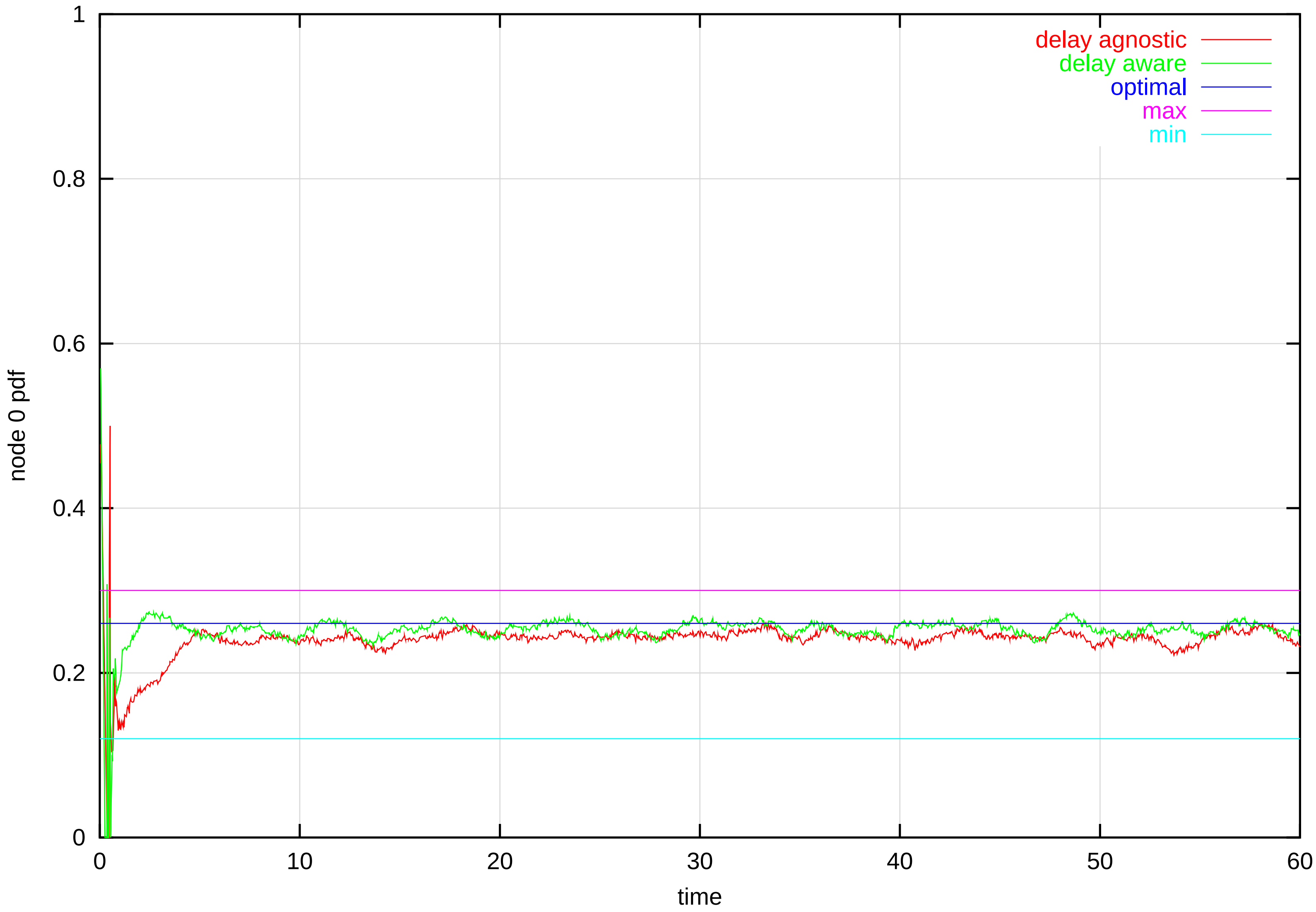
Adding a Link



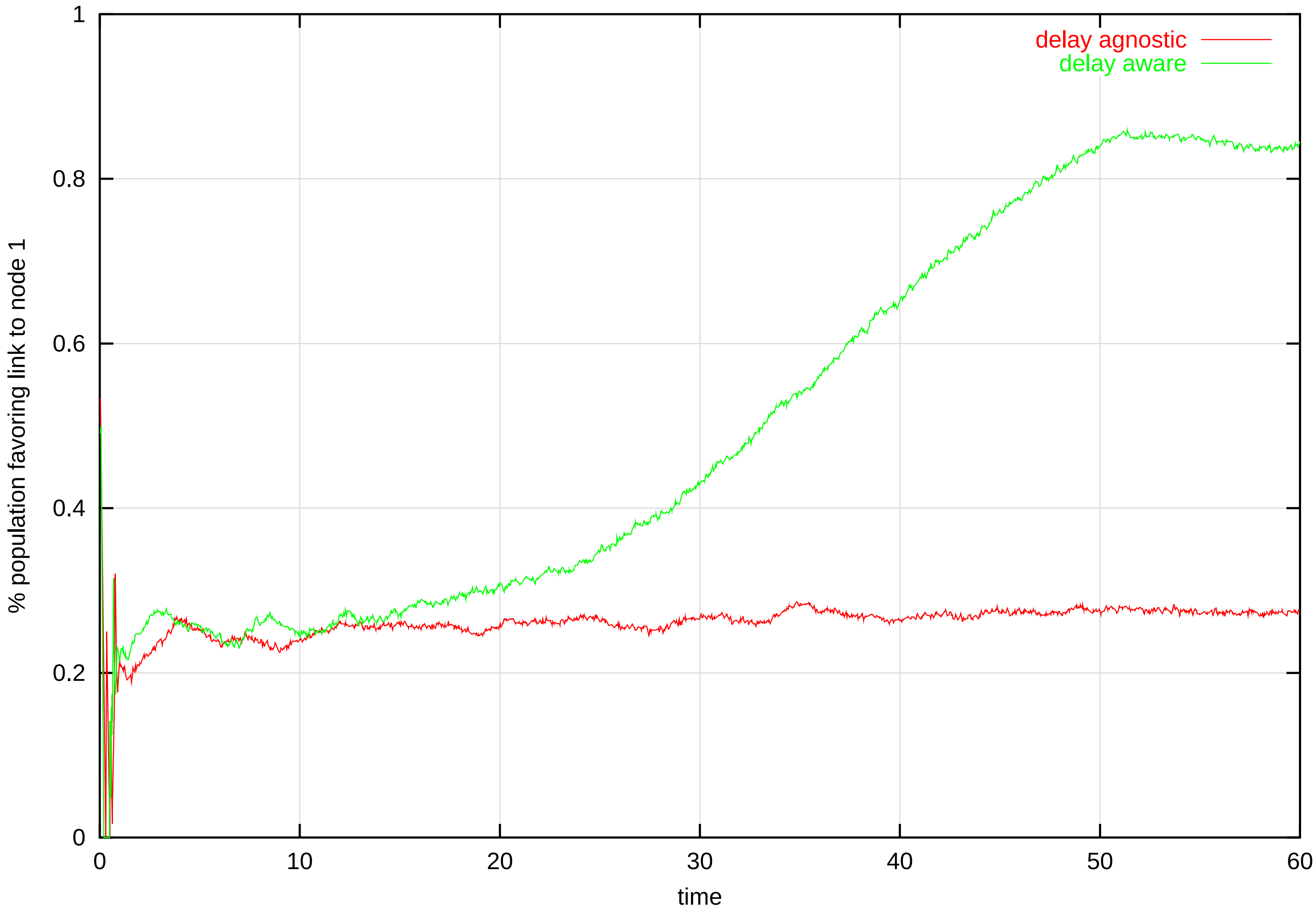
Adding a Link



Observed Behavior



Observed Behavior



Node 1 Adaptation

$$p_{1,2} = .5^{\frac{n_{1,2}}{\psi}}$$

Node 1 Adaptation

$$p_{1,2} = .5^{\frac{n_{1,2}}{\psi}}$$

$$i_{1,2} = \kappa^{\frac{n_{1,2}}{\psi}} p_{1,2} = \kappa^{\frac{n_{1,2}}{\psi}} (.5^{\frac{n_{1,2}}{\psi}})$$

Node 1 Adaptation

$$p_{1,2} = .5\frac{n_{1,2}}{\psi}$$

$$i_{1,2} = \kappa\frac{n_{1,2}}{\psi}p_{1,2} = \kappa\frac{n_{1,2}}{\psi}(.5\frac{n_{1,2}}{\psi})$$

$$p_{1,4} = .5\frac{n_{1,4}}{\psi} + \frac{n_{1,2}}{\psi} = \frac{.5n_{1,4}+n_{1,2}}{\psi}$$

Node 1 Adaptation

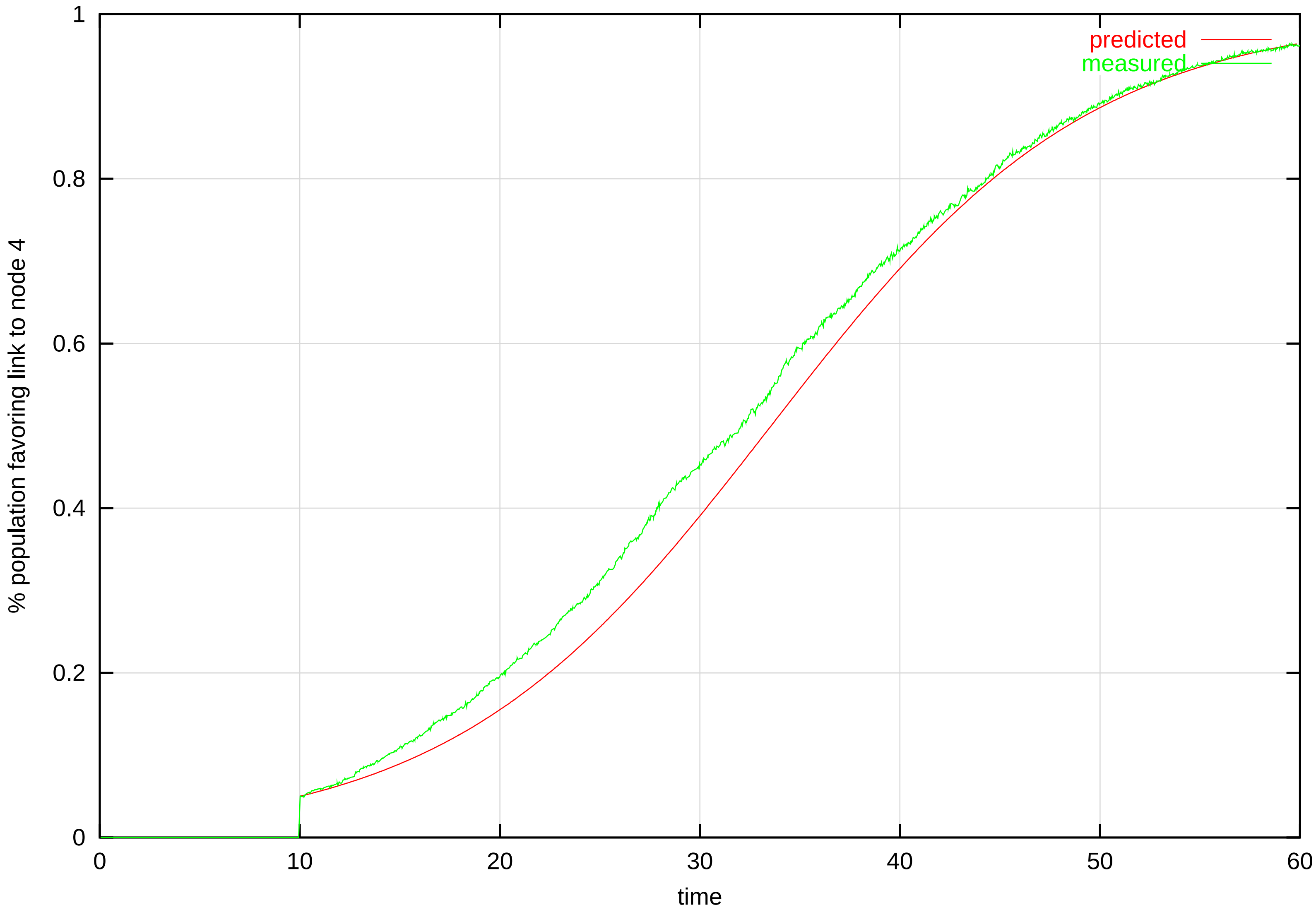
$$p_{1,2} = .5\frac{n_{1,2}}{\psi}$$

$$i_{1,2} = \kappa\frac{n_{1,2}}{\psi}p_{1,2} = \kappa\frac{n_{1,2}}{\psi}(.5\frac{n_{1,2}}{\psi})$$

$$p_{1,4} = .5\frac{n_{1,4}}{\psi} + \frac{n_{1,2}}{\psi} = \frac{.5n_{1,4}+n_{1,2}}{\psi}$$

$$i_{1,4} = \kappa\frac{n_{1,4}}{\psi}p_{1,4} = \kappa\frac{n_{1,4}}{\psi}\frac{.5n_{1,4}+n_{1,2}}{\psi}$$

Results - Node 1



Node 0 Adaptation

$$p_{0,1} = \frac{.5n_{0,1} + n_{0,9}}{\psi}$$

Node 0 Adaptation

$$p_{0,1} = \frac{.5n_{0,1} + n_{0,9}}{\psi}$$

$$p_{0,9} = .5\frac{n_{0,9}}{\psi}$$

Node 0 Adaptation

$$p_{0,1} = \frac{.5n_{0,1}+n_{0,9}}{\psi}$$

$$p_{0,9} = .5\frac{n_{0,9}}{\psi}$$

$$i_{0,9} = \kappa\frac{n_{0,9}}{\psi}p_{0,9} = \kappa\frac{n_{0,9}}{\psi}\left(.5\frac{n_{0,9}}{\psi}\right)$$

Node 0 Adaptation

$$p_{0,1} = \frac{.5n_{0,1} + n_{0,9}}{\psi}$$

$$p_{0,9} = .5\frac{n_{0,9}}{\psi}$$

$$i_{0,9} = \kappa\frac{n_{0,9}}{\psi}p_{0,9} = \kappa\frac{n_{0,9}}{\psi}\left(.5\frac{n_{0,9}}{\psi}\right)$$

$$\tau_{0,1} = |f|\frac{n_{0,1}}{\psi}$$

Node 0 Adaptation

$$p_{0,1} = \frac{.5n_{0,1} + n_{0,9}}{\psi}$$

$$p_{0,9} = .5\frac{n_{0,9}}{\psi}$$

$$i_{0,9} = \kappa \frac{n_{0,9}}{\psi} p_{0,9} = \kappa \frac{n_{0,9}}{\psi} \left(.5\frac{n_{0,9}}{\psi} \right)$$

$$\tau_{0,1} = |f| \frac{n_{0,1}}{\psi}$$

$$\tau_{1,2} = \tau_{0,1} \frac{n_{1,2}}{\psi} = |f| \left(\frac{n_{1,2}}{\psi} \right) \left(\frac{n_{0,1}}{\psi} \right)$$

Node 0 Adaptation

$$p_{0,1} = \frac{.5n_{0,1} + n_{0,9}}{\psi}$$

$$p_{0,9} = .5\frac{n_{0,9}}{\psi}$$

$$i_{0,9} = \kappa\frac{n_{0,9}}{\psi}p_{0,9} = \kappa\frac{n_{0,9}}{\psi}\left(.5\frac{n_{0,9}}{\psi}\right)$$

$$\tau_{0,1} = |f|\frac{n_{0,1}}{\psi}$$

$$\tau_{1,2} = \tau_{0,1}\frac{n_{1,2}}{\psi} = |f|\left(\frac{n_{1,2}}{\psi}\right)\left(\frac{n_{0,1}}{\psi}\right)$$

$$\rho_{1,2} = \begin{cases} \frac{\tau_{1,2}}{c_{1,2}} - .75 & \text{if } \frac{\tau_{1,2}}{c_{1,2}} > .75 \\ 0 & \text{otherwise} \end{cases}$$

Node 0 Adaptation

$$p_{0,1} = \frac{.5n_{0,1} + n_{0,9}}{\psi}$$

$$p_{0,9} = .5\frac{n_{0,9}}{\psi}$$

$$i_{0,9} = \kappa\frac{n_{0,9}}{\psi}p_{0,9} = \kappa\frac{n_{0,9}}{\psi}\left(.5\frac{n_{0,9}}{\psi}\right)$$

$$\tau_{0,1} = |f|\frac{n_{0,1}}{\psi}$$

$$\tau_{1,2} = \tau_{0,1}\frac{n_{1,2}}{\psi} = |f|\left(\frac{n_{1,2}}{\psi}\right)\left(\frac{n_{0,1}}{\psi}\right)$$

$$\rho_{1,2} = \begin{cases} \frac{\tau_{1,2}}{c_{1,2}} - .75 & \text{if } \frac{\tau_{1,2}}{c_{1,2}} > .75 \\ 0 & \text{otherwise} \end{cases}$$

$$\rho_{0,1} = \rho_{1,2}\frac{n_{1,2}}{\psi}$$

Node 0 Adaptation

$$p_{0,1} = \frac{.5n_{0,1} + n_{0,9}}{\psi}$$

$$p_{0,9} = .5\frac{n_{0,9}}{\psi}$$

$$i_{0,9} = \kappa\frac{n_{0,9}}{\psi}p_{0,9} = \kappa\frac{n_{0,9}}{\psi}\left(.5\frac{n_{0,9}}{\psi}\right)$$

$$\tau_{0,1} = |f|\frac{n_{0,1}}{\psi}$$

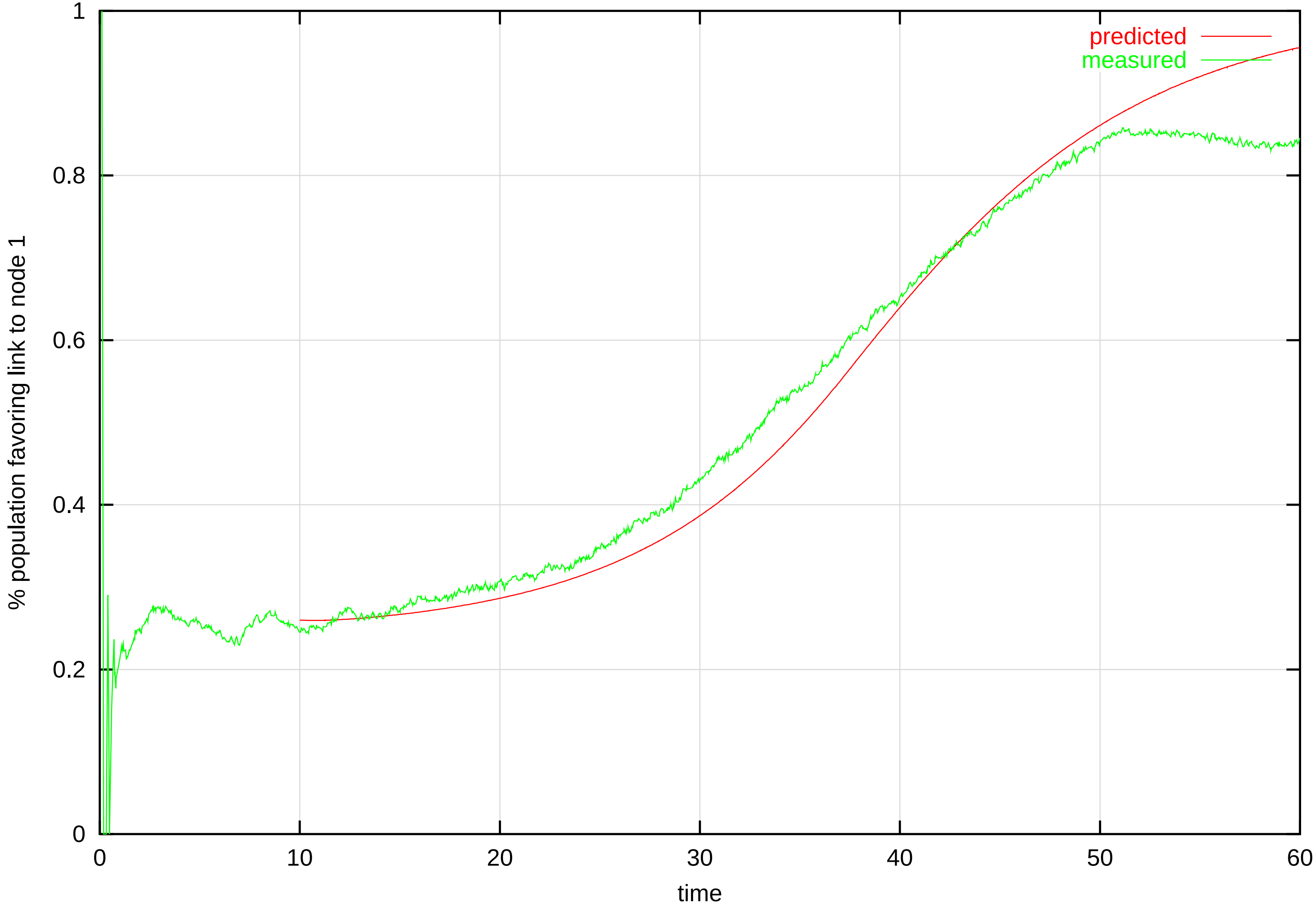
$$\tau_{1,2} = \tau_{0,1}\frac{n_{1,2}}{\psi} = |f|\left(\frac{n_{1,2}}{\psi}\right)\left(\frac{n_{0,1}}{\psi}\right)$$

$$\rho_{1,2} = \begin{cases} \frac{\tau_{1,2}}{c_{1,2}} - .75 & \text{if } \frac{\tau_{1,2}}{c_{1,2}} > .75 \\ 0 & \text{otherwise} \end{cases}$$

$$\rho_{0,1} = \rho_{1,2}\frac{n_{1,2}}{\psi}$$

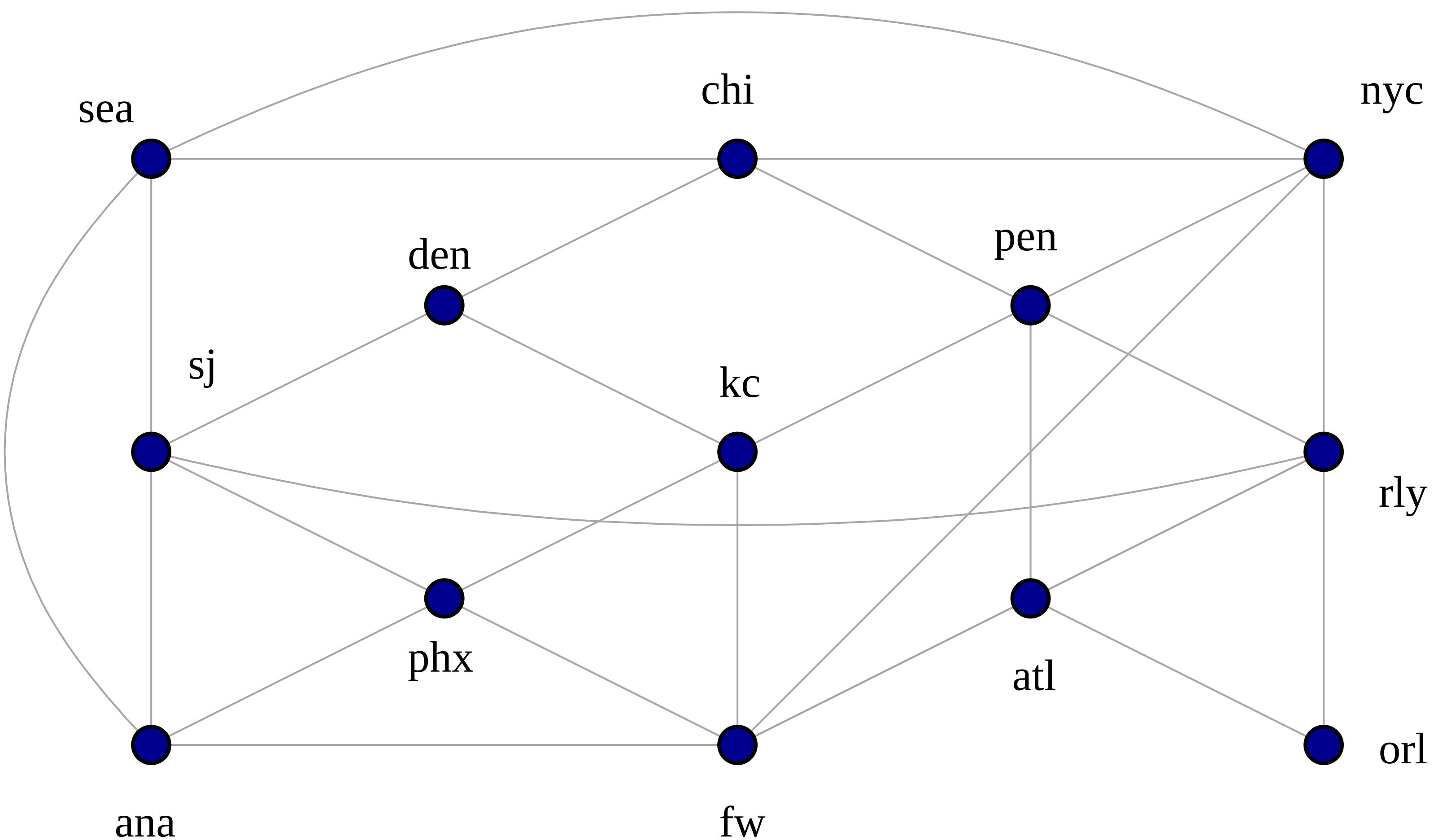
$$i_{0,1} = \frac{n_{0,1}}{\psi}\left(-\rho_{0,1} + (1 - \rho_{0,1})\left[\kappa\frac{.5n_{0,1} + n_{0,9}}{\psi}\right]\right)$$

Results - Node 0



Optimal Routing on a Regional Network

Topology



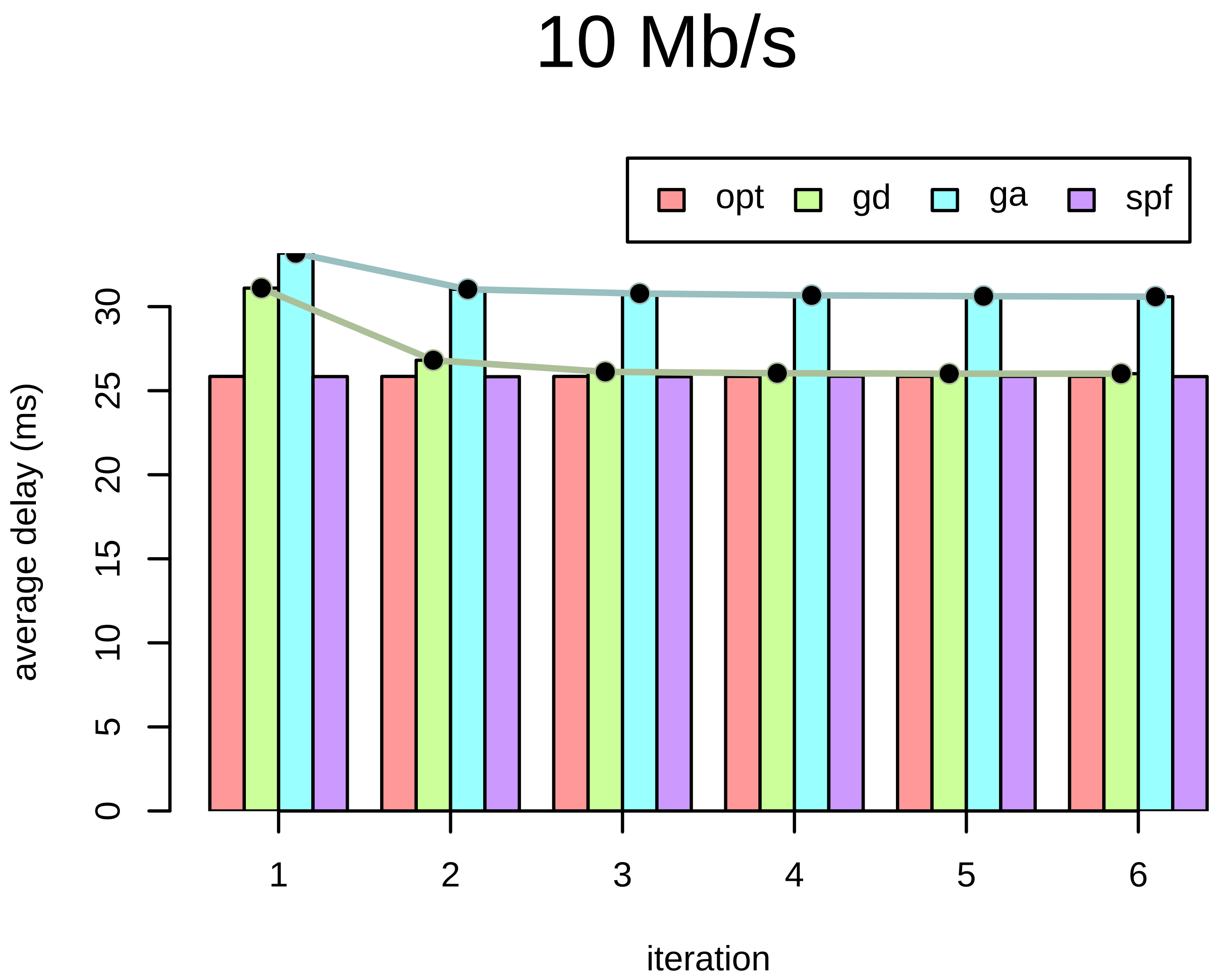
Optimization Problem

$$
\begin{aligned}
D_{f,nyc} &= P_{f,nyc,pen}[d_{nyc,pen} + \frac{k}{C_{nyc,pen} - U_{nyc,pen}} + D_{f,pen}] \\
&+ P_{f,nyc,fw}[d_{nyc,fw} + \frac{k}{C_{nyc,fw} - U_{nyc,fw}} + D_{f,fw}] \\
&+ P_{f,nyc,chi}[d_{nyc,chi} + \frac{k}{C_{nyc,chi} - U_{nyc,chi}} + D_{f,chi}] \\
&+ P_{f,nyc,rly}[d_{nyc,rly} + \frac{k}{C_{nyc,rly} - U_{nyc,rly}} + D_{f,rly}] \\
&+ P_{f,nyc,sea}[d_{nyc,sea} + \frac{k}{C_{nyc,sea} - U_{nyc,sea}} + D_{f,sea}]
\end{aligned}
$$

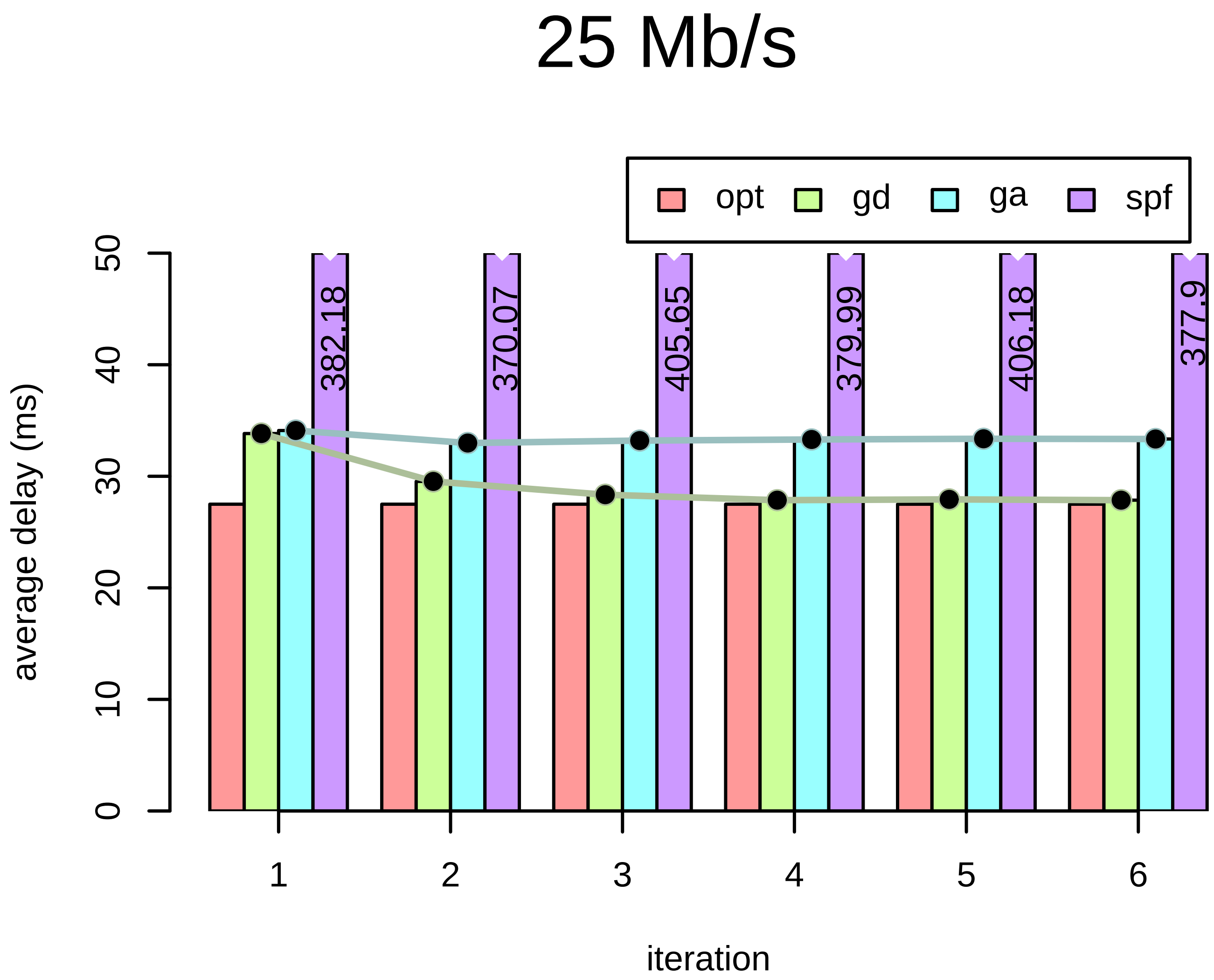
Generalized Form

$$
\begin{aligned}
D_{f,a} &= \sum_{b \in fs(a)} P_{f,a,b}[d_{a,b} + \frac{k}{C_{a,b} - U_{a,b}} + D_{f,b}] \\
1 &= \sum_{b \in fs(a)} P_{f,a,b} \\
T_{f,a} &= \sum_{b \in bs(a)} P_{f,b,a} T_{f,b} \qquad a \neq (s,d) \\
T_{f,s} &= |f| \\
T_{f,d} &= 0 \\
U_{a,b} &= \sum_{f \in F} P_{f,a,b} T_{f,a}
\end{aligned}
$$

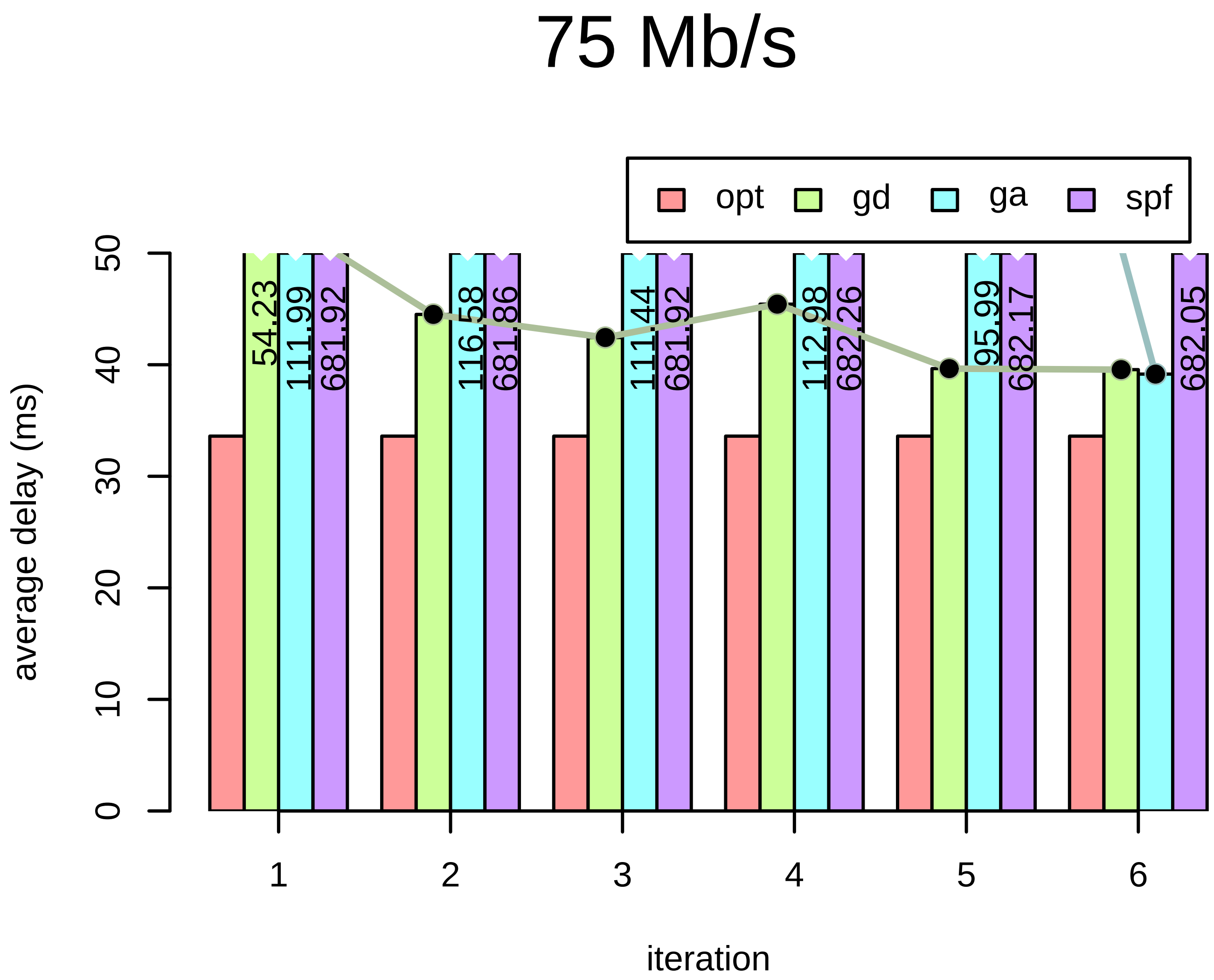
Single Flow: $nyc \rightarrow phx$



Single Flow: $nyc \rightarrow phx$

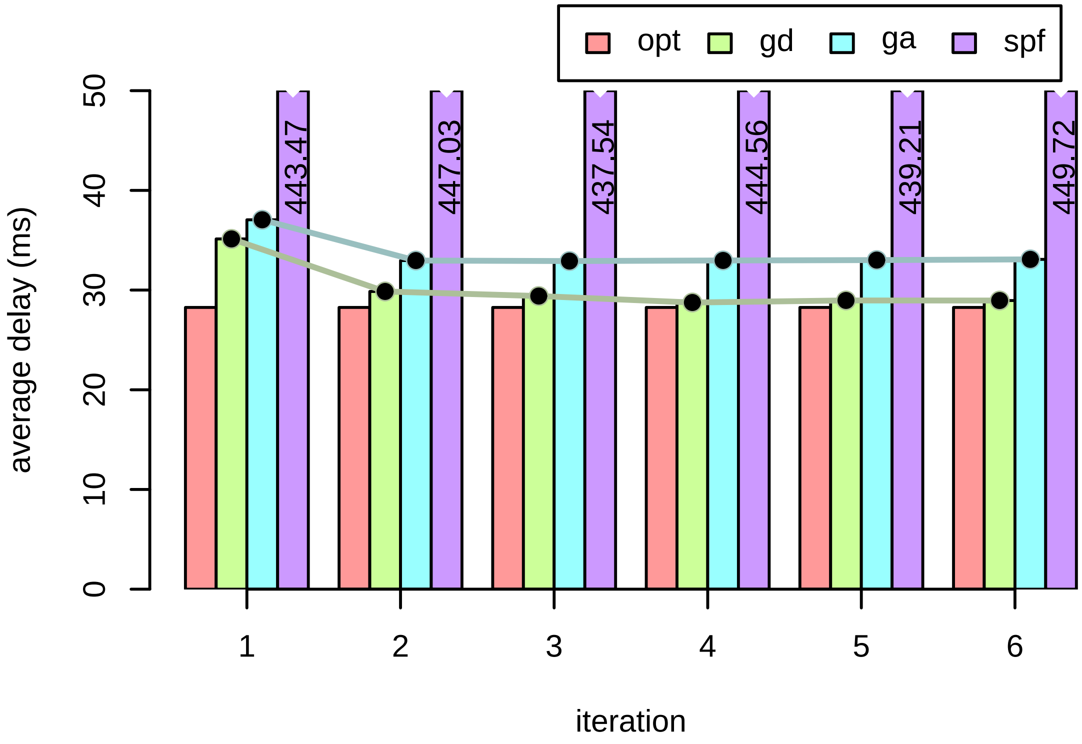


Single Flow: $nyc \rightarrow phx$

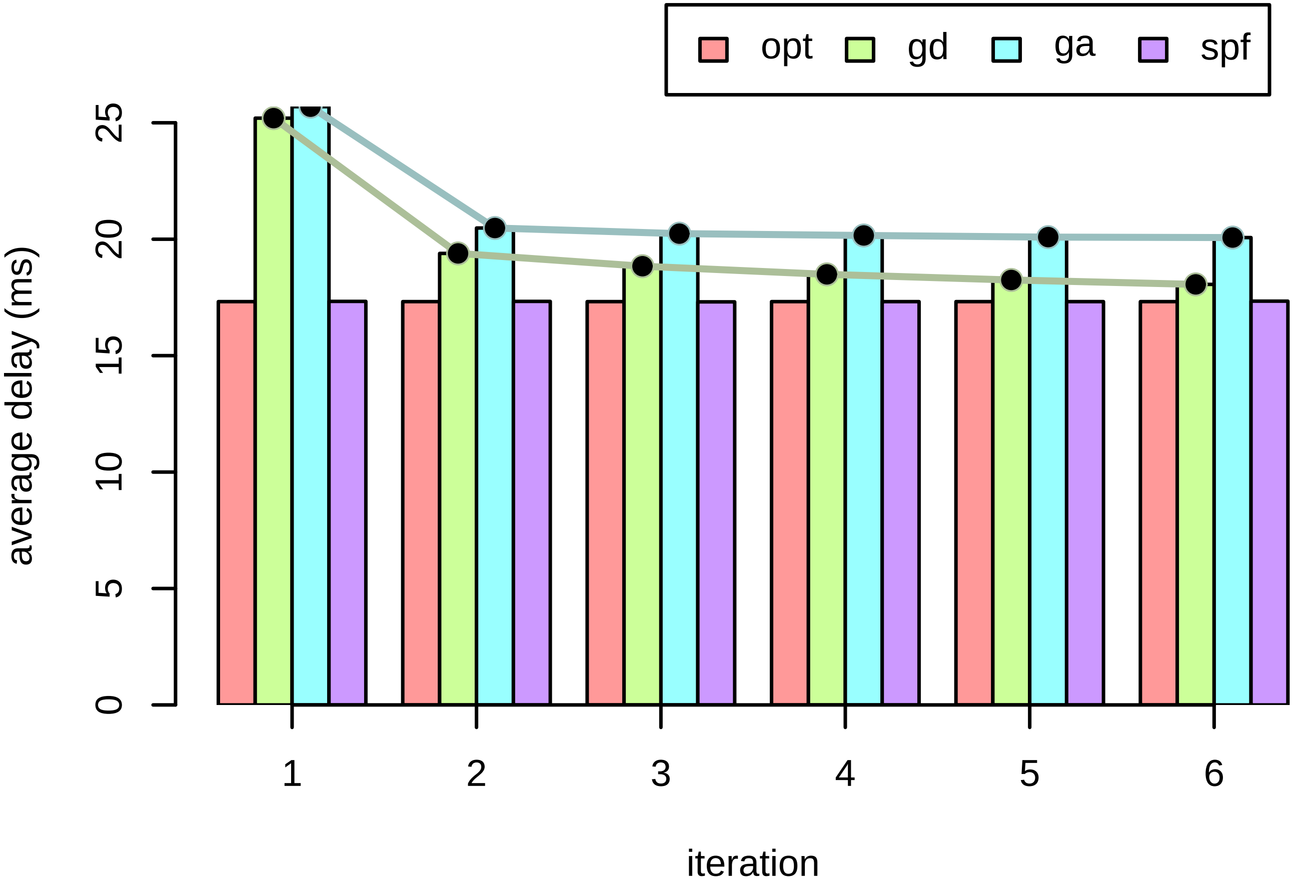


Adding a Second Flow: $atl \rightarrow sj$

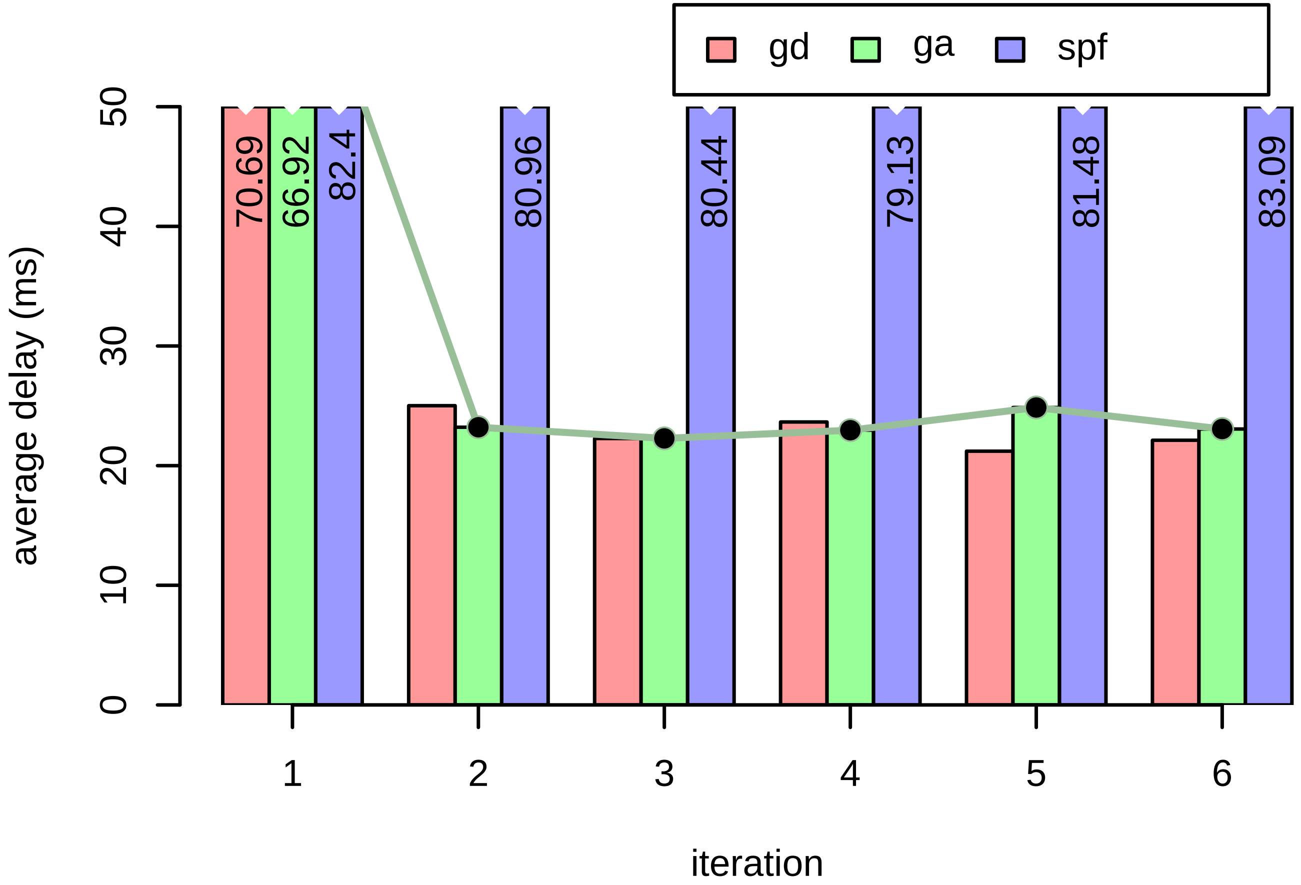
$nyc \rightarrow phx$: 25 Mb/s
$atl \rightarrow sj$: 40 Mb/s



All Pairs



All Pairs



gd
ga
spf
average delay (ms)
0
10
20
30
40
50
70.69
66.92
82.4
80.96
80.44
79.13
81.48
83.09
1
2
3
4
5
6
iteration

Summary and Conclusions

- The proposed heuristic is able to find near-optimal solutions for the topologies and flows studied
- The proposed heuristic requires no foreknowledge of the topology or traffic
- The behavior of the heuristic can be accurately modeled and predicted
- This approach represents a significant step in the opposite direction from most current routing research