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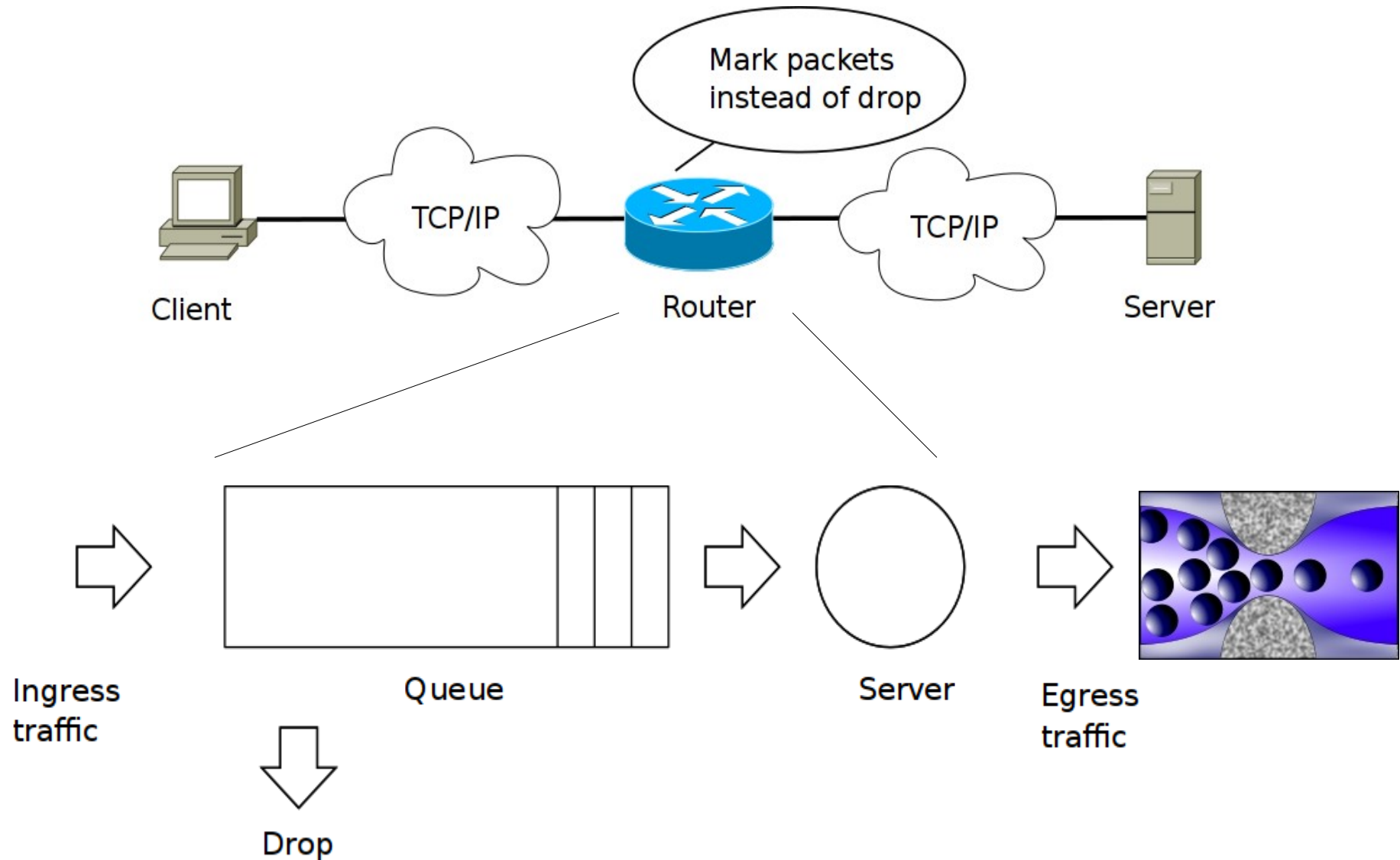
A Hysteretic Model of Queuing System with Fuzzy Logic Active Queue Management

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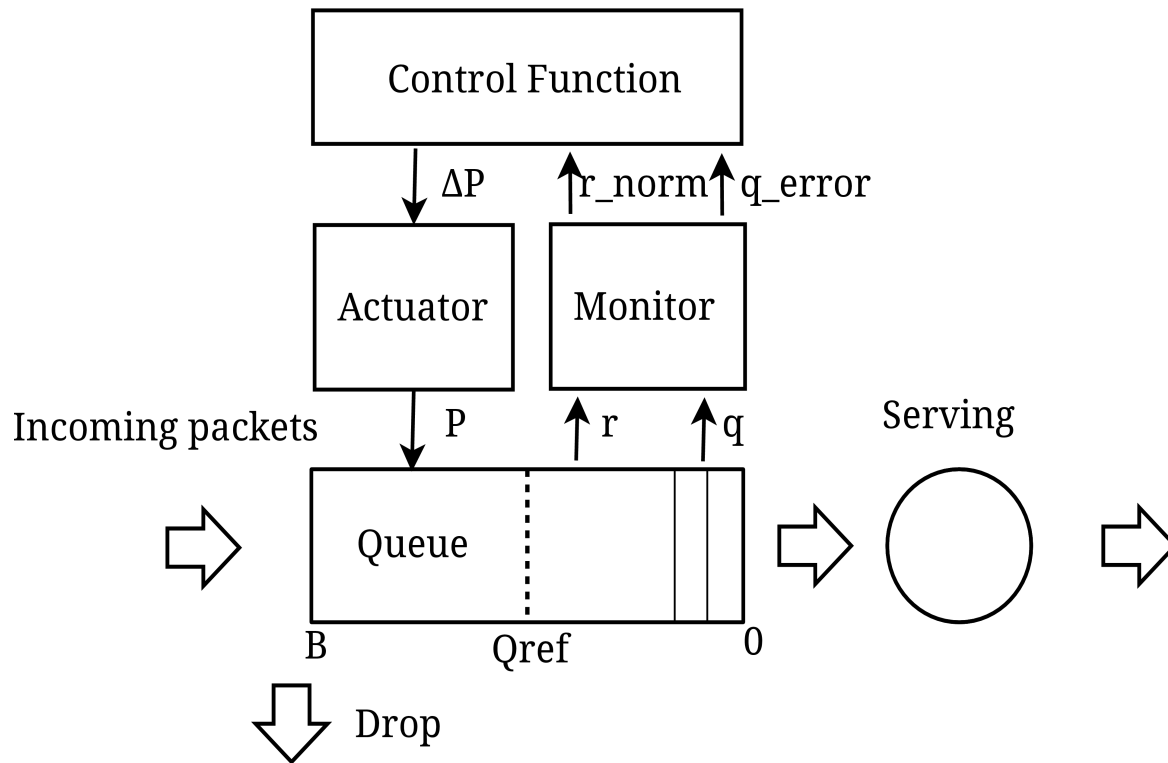
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St.-Petersburg 2014

Active queue management (AQM) for congestion avoidance



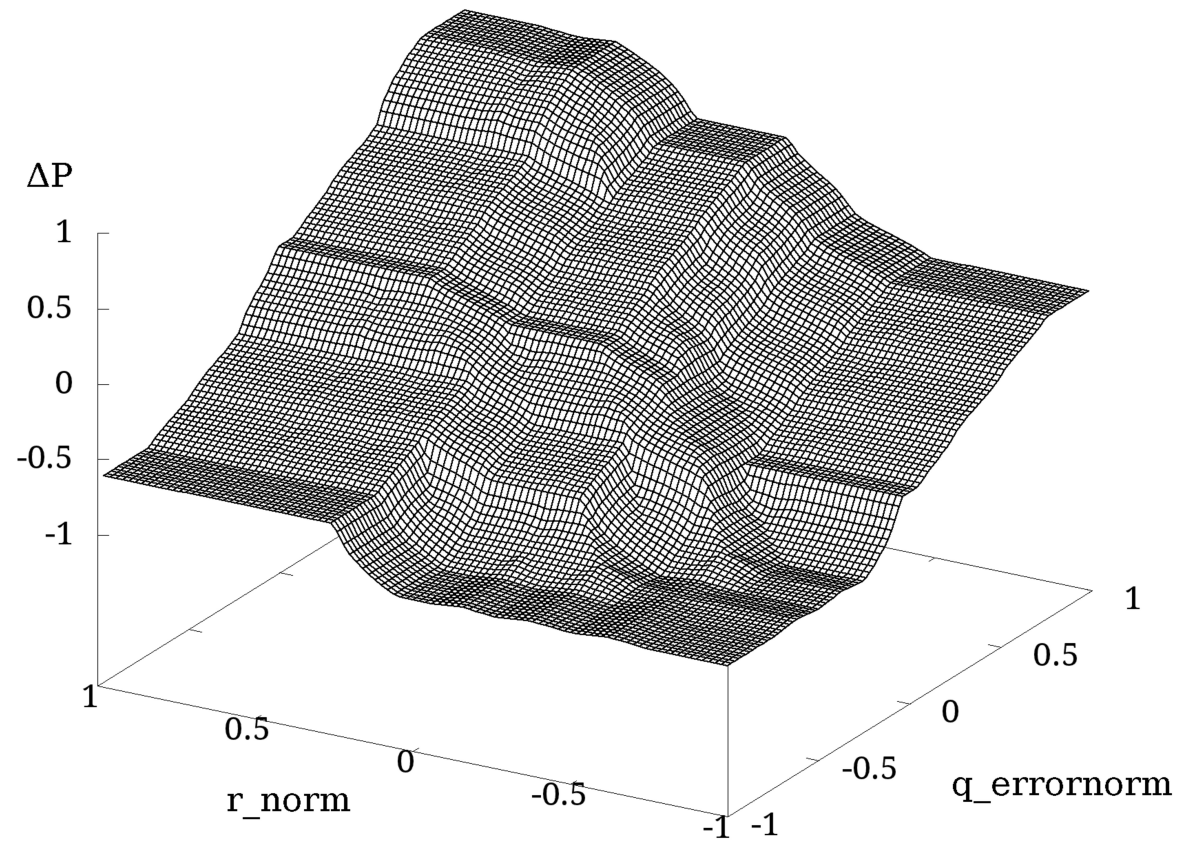
Data transmission system with AQM



$$q_{\text{errornorm}}^i = \begin{cases} \frac{q^i - Q_{\text{ref}}}{B - Q_{\text{ref}}}, & q_i \geq Q_{\text{ref}}, \\ \frac{q^i - Q_{\text{ref}}}{Q_{\text{ref}}}, & q_i < Q_{\text{ref}}, \end{cases}$$

$$r_{\text{norm}}^i = \begin{cases} \frac{r^i - \mu}{\mu}, & \frac{r_i}{\mu} \leq 2 \\ 1, & \frac{r_i}{\mu} > 2, \end{cases}$$

Control function for AQM



$$P^{i+1} = P^i + \Delta P^i \cdot P_{\max}, \quad i \geq 1,$$

Discrete system

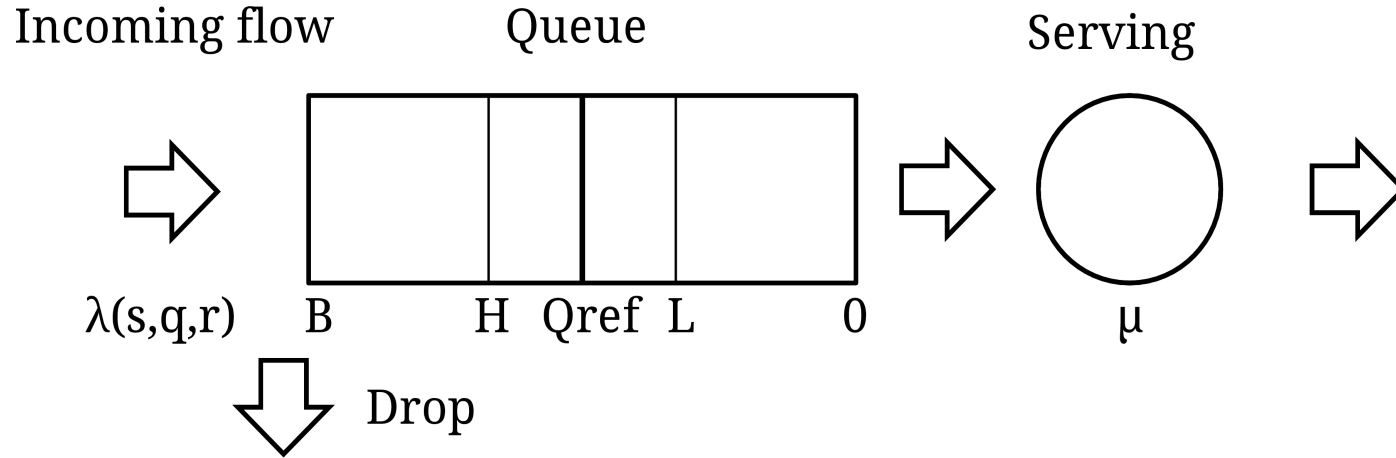
THE LEVEL OF THE TRAFFIC LOAD INTENSITY

Load level	" r " value	" r_{norm}^i " range
Small	0	$[-1; -0,6)$
Average	1	$[-0,6; -0,2)$
Normal	2	$[-0,2; 0,2)$
High	3	$[0,2; 0,6)$
Overload	4	$[0,6, 1]$

SYSTEM OVERLOAD STATUS

Overload status	" s " value
Small load	0
Normal load	1
Overload start	2
Overload	3
Load drop	4

Queuing system with thresholds



8 subsets of states:

$$X_{0,0} = \{(s, q, r) : s = 0, r = 0, 0 \leq q \leq Q_{ref}\},$$

$$X_{0,1} = \{(s, q, r) : s = 0, r = 1, 1 \leq q \leq Q_{ref} + 1\},$$

$$X_{1,1} = \{(s, q, r) : s = 1, r = 1, L \leq q \leq H\},$$

$$X_{1,2} = \{(s, q, r) : s = 1, r = 2, L + 1 \leq q \leq H + 1\},$$

$$X_{2,2} = \{(s, q, r) : s = 2, r = 2, Q_{ref} \leq q \leq B - 3\},$$

$$X_{2,3} = \{(s, q, r) : s = 2, r = 3, Q_{ref} + 1 \leq q \leq B - 2\},$$

$$X_{3,3} = \{(s, q, r) : s = 3, r = 3, H \leq q \leq B - 1\},$$

$$X_{4,4} = \{(s, q, r) : s = 4, r = 4, H + 1 \leq q \leq B\}.$$

Hysteresis load control

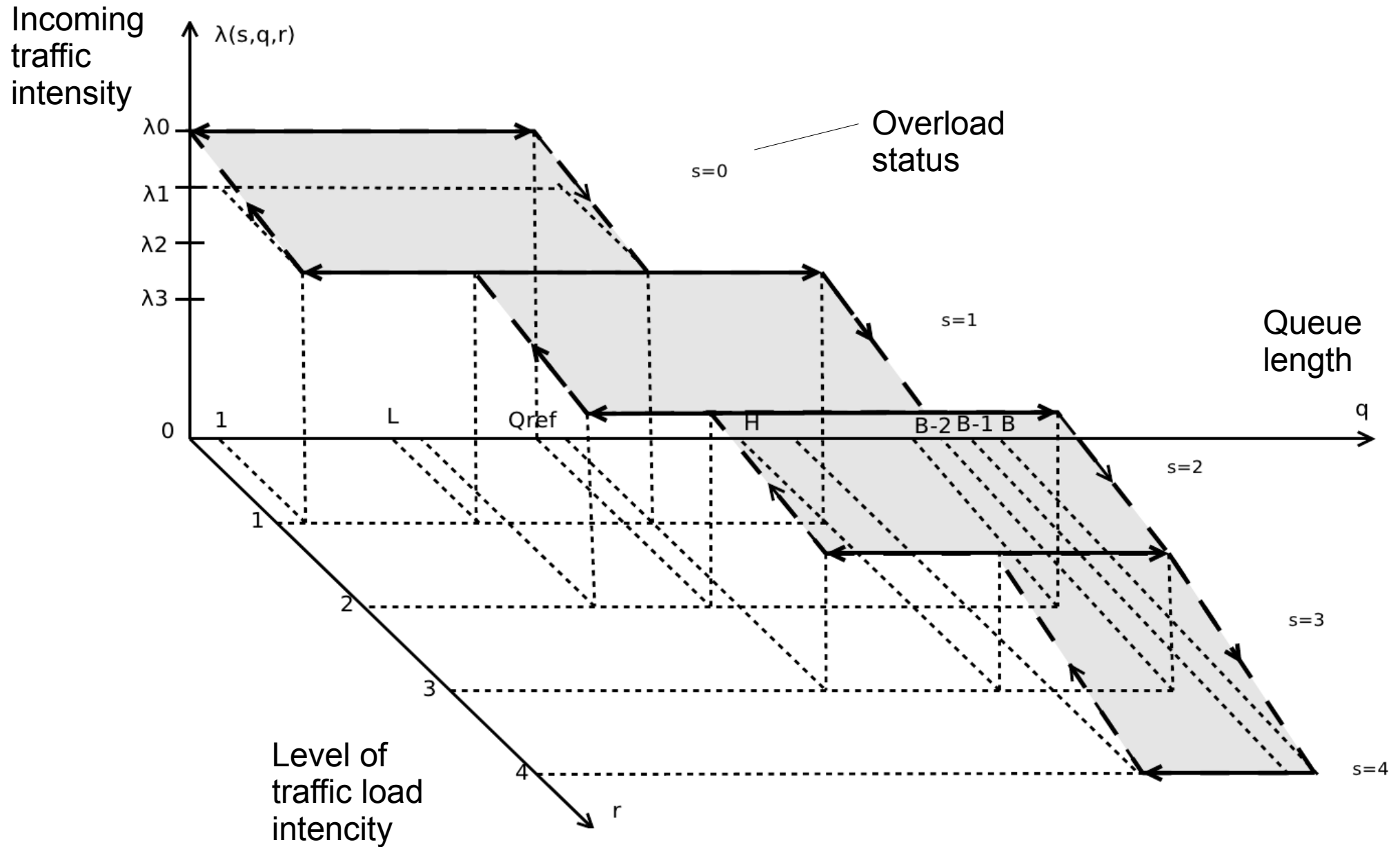
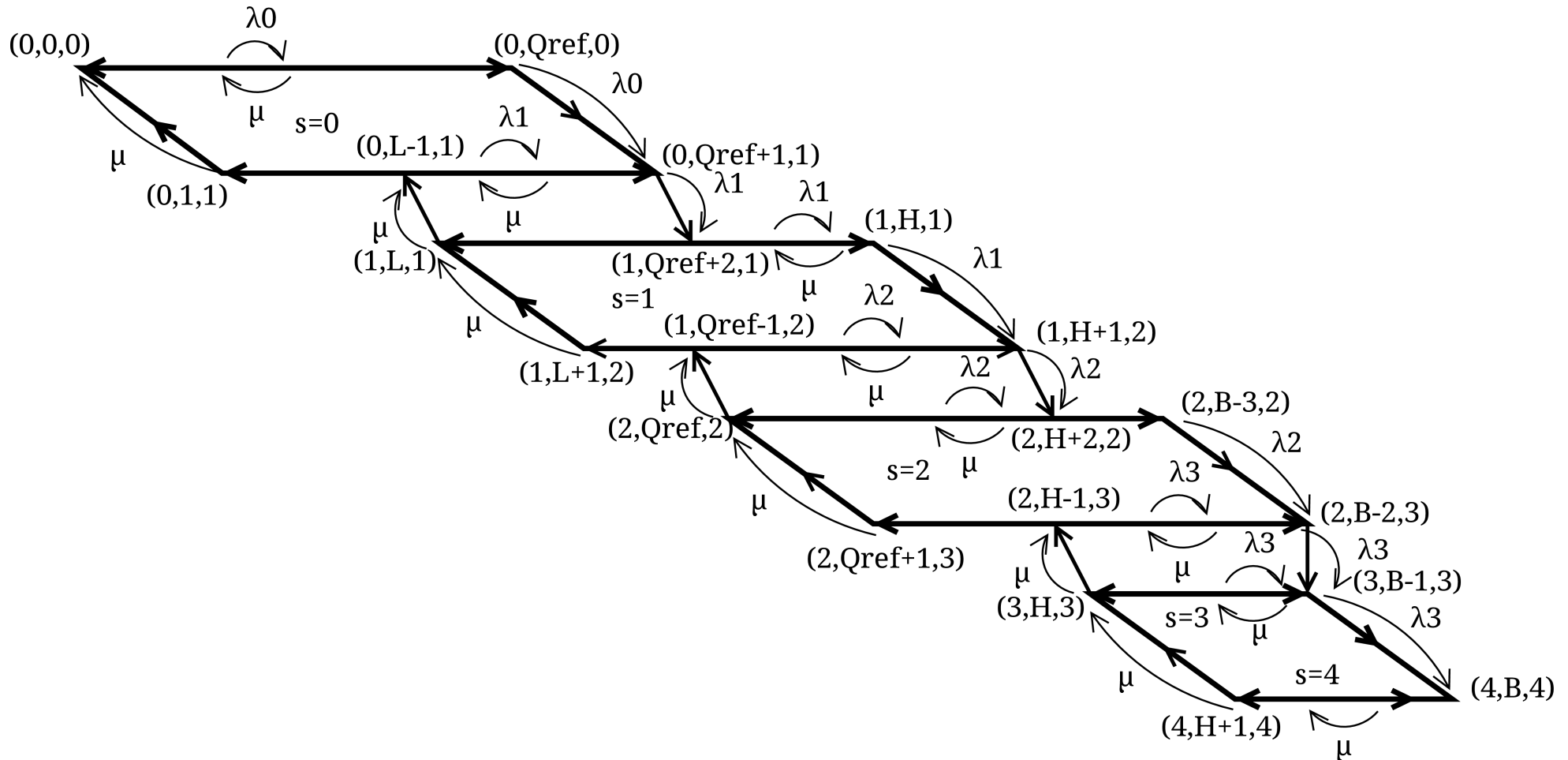


Diagram of the Markov process



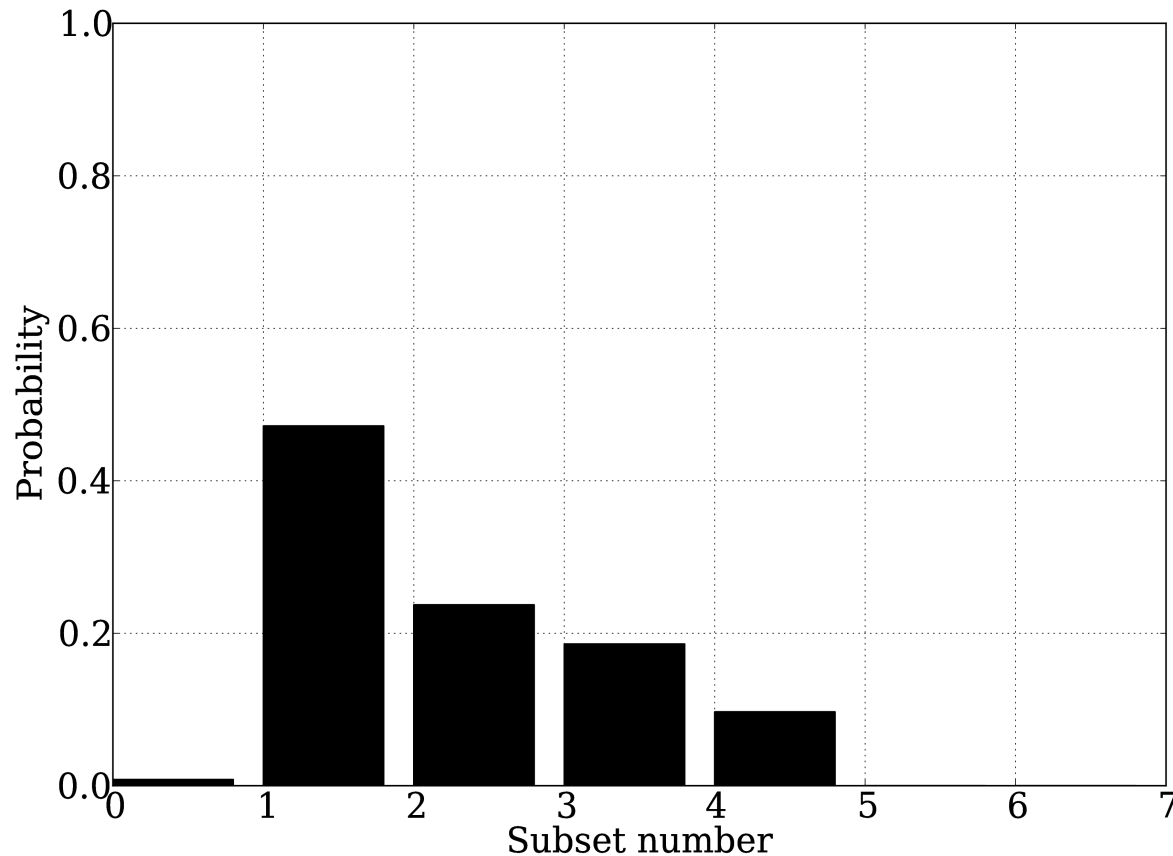
System of equilibrium equations

$$\begin{cases} \vec{p} \cdot \mathbf{A} = 0 \\ \vec{p} \cdot \mathbf{1} = 1 \end{cases}$$

STRUCTURE OF TRANSITION INTENSITY MATRIX $\mathbf{A}$

	$X_{0,0}$	$X_{0,1}$	$X_{1,1}$	$X_{1,2}$	$X_{2,2}$	$X_{2,3}$	$X_{3,3}$	$X_{4,4}$
$X_{0,0}$	D	U	0	0	0	0	0	0
$X_{0,1}$	L	D	U	0	0	0	0	0
$X_{1,1}$	0	L	D	U	0	0	0	0
$X_{1,2}$	0	0	L	D	U	0	0	0
$X_{2,2}$	0	0	0	L	D	U	0	0
$X_{2,3}$	0	0	0	0	L	D	U	0
$X_{3,3}$	0	0	0	0	0	L	D	U
$X_{4,4}$	0	0	0	0	0	0	L	D

Numerical analysis



$B = 50$, $Q_{\text{ref}} = 25$, $L = 20$, $H = 30$

A dimensions is 160x160

$\mu = 1$

$\lambda_0 = 1,95$

$\lambda_1 = 1,2$

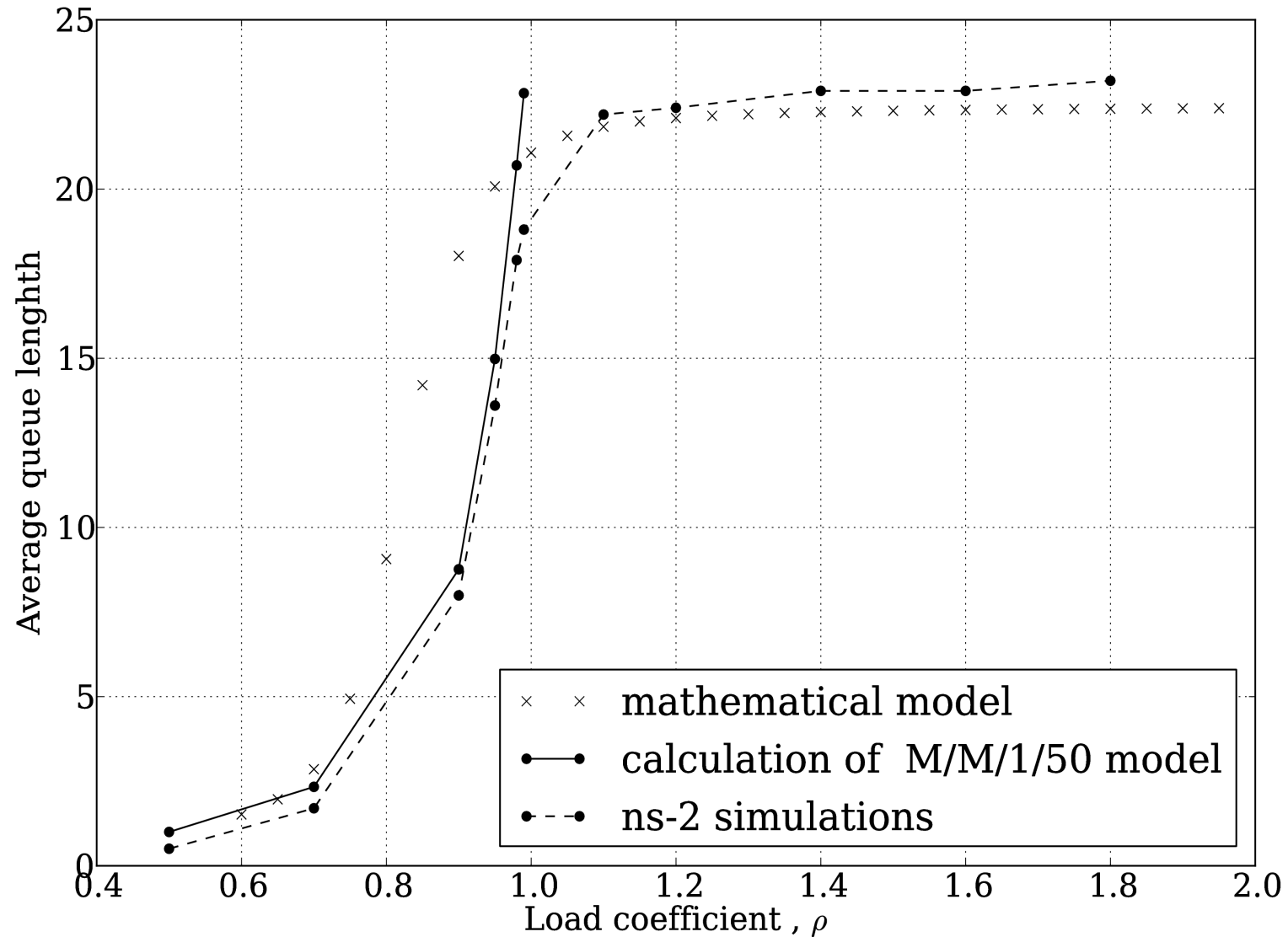
$\lambda_2 = 0,47$

$\lambda_3 = 0,43$

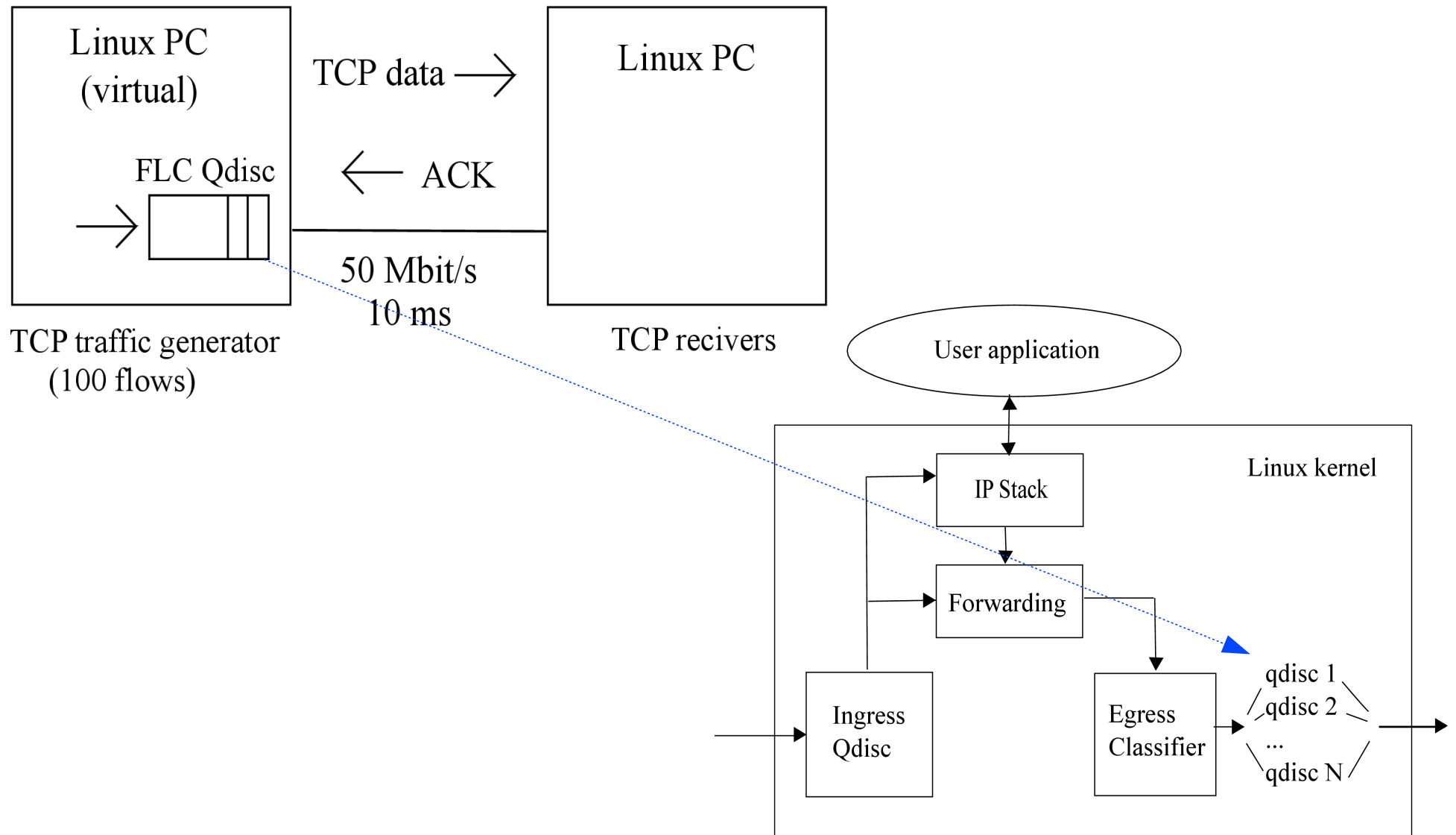
Probability of states $L < q < H$:

$P(Y) = 0,68$

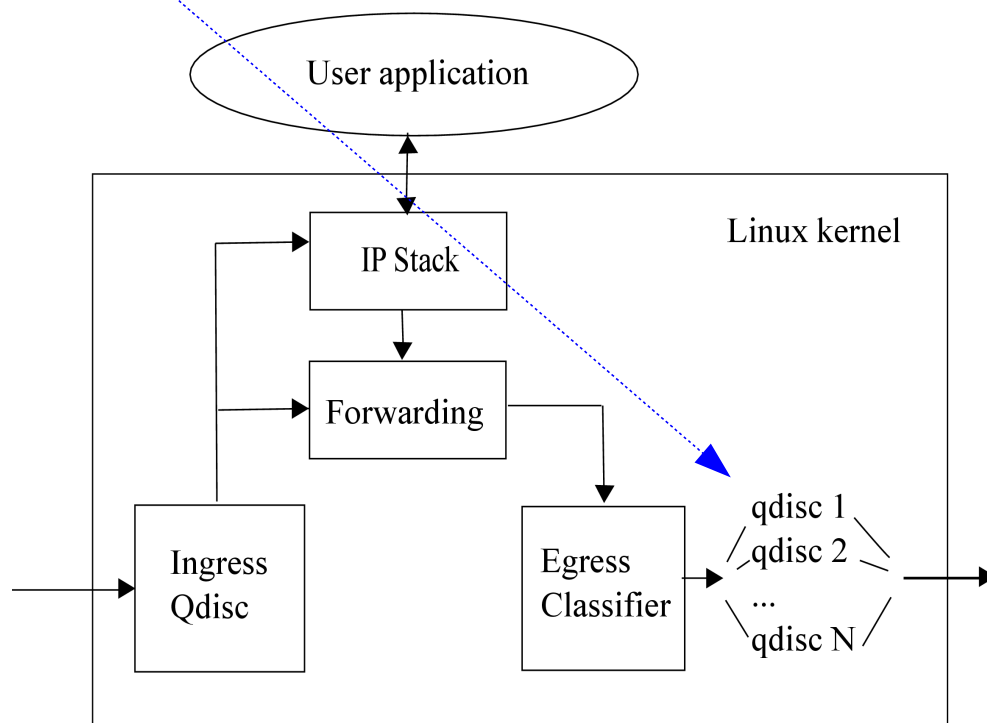
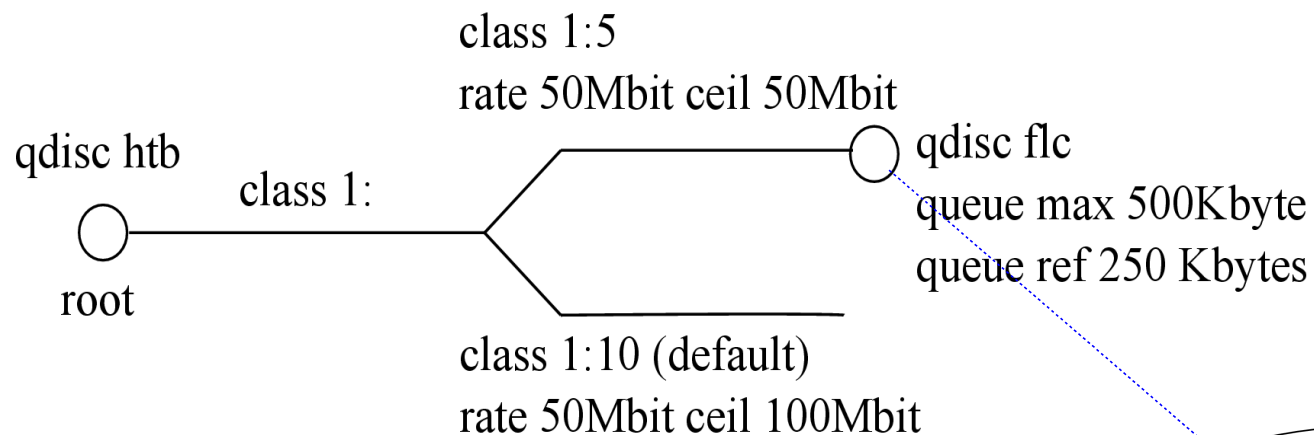
Average queue length (Load curves)



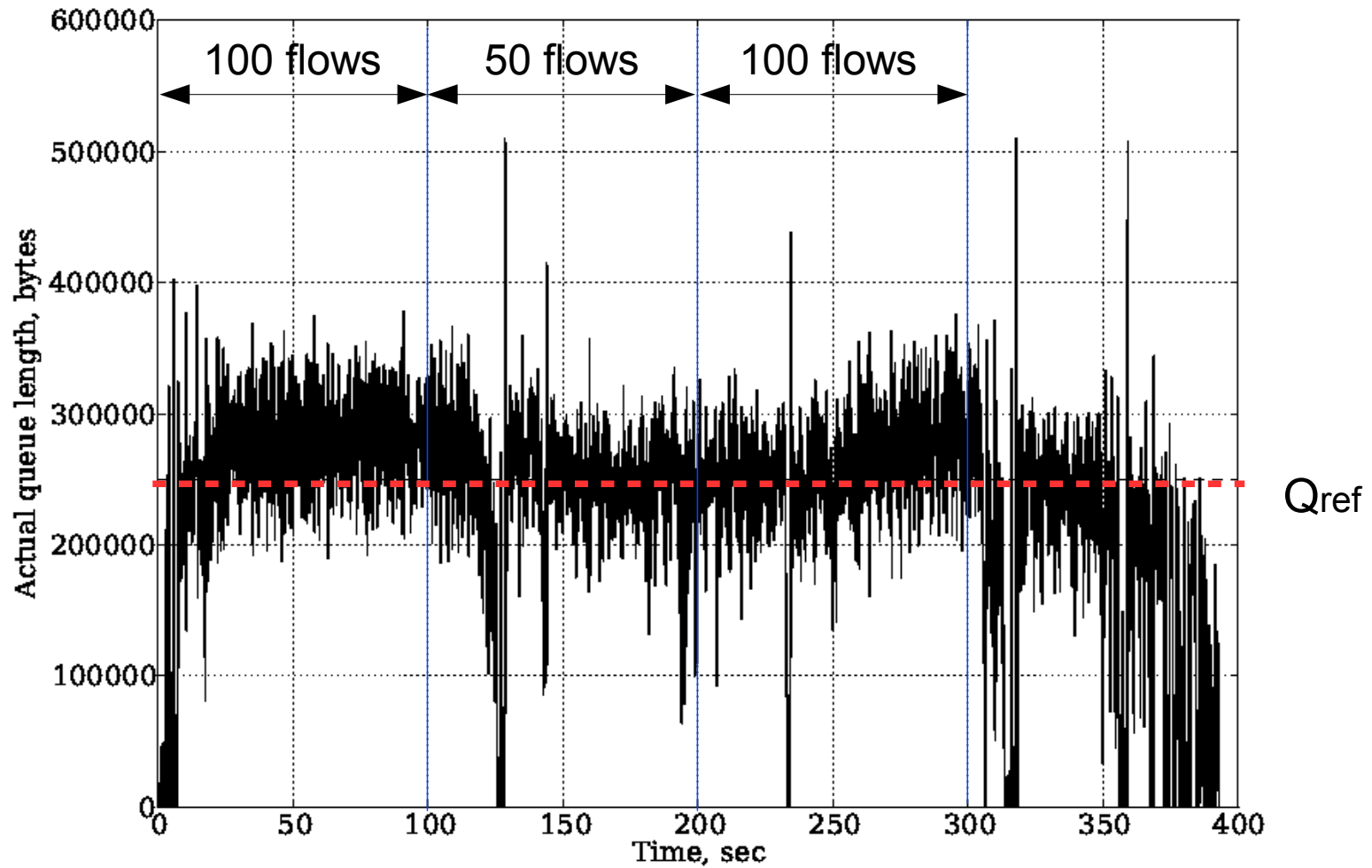
Linux kernel implementation



Traffic control

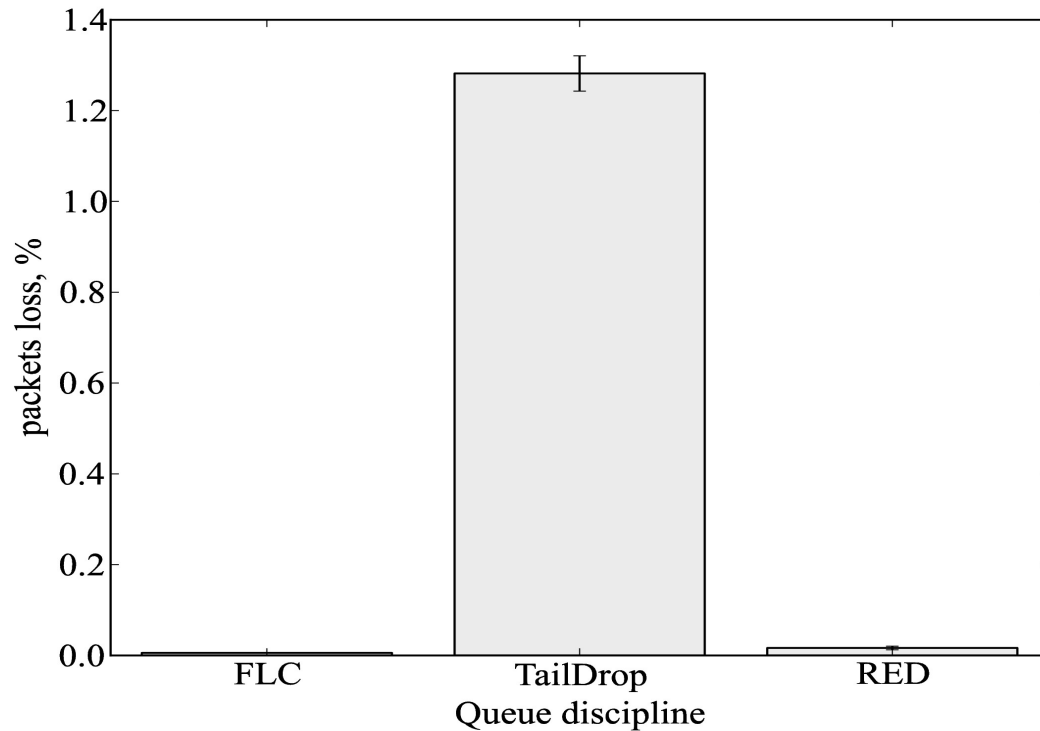


Queue length evaluation

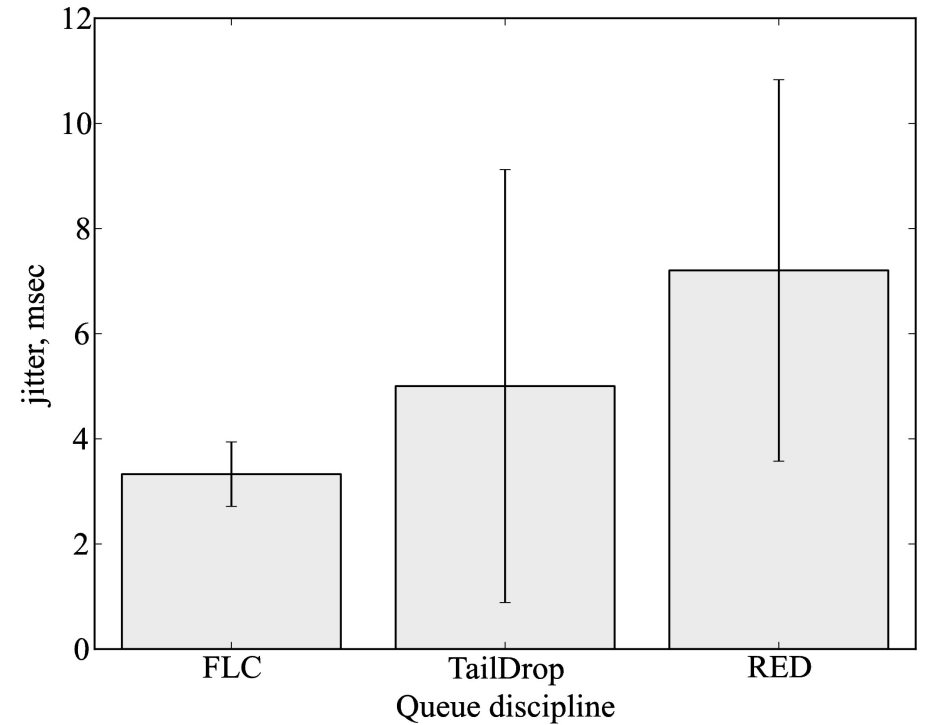


Measurement data mean values

Full packets loss, %



Jitter, msec



FLC implementation on a free source Linux-router (OpenWRT)

Architecture: MIPS
System-On-Chip: Broadcom BCM5354
CPU Speed: 240 MHz
RAM size: 32 MiB



```
root@net1:~# uname -a
Linux net1 2.4.37.9 #42 Tue Apr 6 15:59:04 CEST 2010 mips GNU/Linux

root@net1:~# tc -s qdisc ls dev br-lan
qdisc htb 1: r2q 10 default 10 direct_packets_stat 0
  Sent 1459353152 bytes 1150066 pkts (dropped 0, overlimits 0)
qdisc flc 5: parent 1:5 limit 500Kb
  qref 250000 q_lim 500000 p_rate0 6250 d_scale 343597 sampling 6 ecn
  Sent 1184030 bytes 839 pkts (dropped 0, overlimits 0)
  marked 0 early 0 pdrop 0 other 0
```

Thank you for your attention!



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