

# Contents

<b>1</b>	<b>Introduction</b>	1
1.1	Main Contribution	2
1.2	Other Contributions	5
1.3	Evaluation	6
1.4	Discussion	7
1.4.1	Why Per Flow Processing?	7
1.4.2	Scalability Concerns with Stateful Network Architectures	9
1.5	Organization	10
<b>2</b>	<b>Background</b>	13
2.1	Circuit Switching Vs. Packet Switching	14
2.2	IP Network Model	15
2.2.1	Router Architecture	15
2.2.2	Data Path	17
2.2.3	Control Path	21
2.2.4	Discussion	24
2.3	Network Service Taxonomy	25
2.3.1	Best Effort Service	26
2.3.2	Flow Protection: Network Support for Congestion Control	27
2.3.3	Integrated Services	29
2.3.4	Differentiated Services	30
2.4	Summary	33
<b>3</b>	<b>Overview</b>	35
3.1	Solution Overview	35
3.1.1	The Stateless Core (SCORE) Network Architecture	36
3.1.2	The “State-Elimination” Approach	36
3.1.3	The Dynamic Packet State (DPS) Technique	36
3.2	Prototype Implementation	43
3.2.1	An Example	44

3.3	Comparison to Intserv and Diffserv .....	47
3.3.1	Intserv .....	47
3.3.2	Diffserv .....	49
3.4	Summary .....	51
<b>4</b>	<b>Providing Flow Protection in SCORE .....</b>	<b>53</b>
4.1	Background .....	53
4.2	Solution Outline .....	55
4.3	Core-Stateless Fair Queueing (CSFQ) .....	56
4.3.1	Fluid Model Algorithm .....	56
4.3.2	Packet Algorithm .....	57
4.3.3	Weighted CSFQ .....	61
4.3.4	Performance Bounds .....	61
4.3.5	Implementation Complexity .....	62
4.3.6	Architectural Considerations .....	62
4.3.7	Miscellaneous Details .....	63
4.4	Simulation Results .....	63
4.4.1	A Single Congested Link .....	65
4.4.2	Multiple Congested Links .....	66
4.4.3	Coexistence of Different Adaptation Schemes .....	67
4.4.4	Different Traffic Models .....	70
4.4.5	Large Latency .....	71
4.4.6	Packet Relabeling .....	72
4.4.7	Discussion of Simulation Results .....	73
4.5	Related Work .....	73
4.6	Summary .....	75
<b>5</b>	<b>Providing Guaranteed Services in SCORE .....</b>	<b>77</b>
5.1	Background .....	77
5.2	Solution Outline .....	79
5.3	Data Plane: Scheduling without Per Flow State .....	80
5.3.1	Jitter Virtual Clock (Jitter-VC) .....	80
5.3.2	Core-Jitter-VC (CJVC) .....	82
5.3.3	Data Path Complexity .....	85
5.4	Control Plane: Admission Control with no Per Flow State ...	87
5.4.1	Ingress-to-Egress Admission Control .....	88
5.4.2	Per-Hop Admission Control .....	89
5.4.3	Aggregate Reservation Estimation Algorithm .....	90
5.5	Experimental Results .....	95
5.5.1	Processing Overhead .....	100
5.6	Related Work .....	100
5.7	Summary .....	102

<b>6</b>	<b>Providing Relative Service Differentiation in SCORE</b>	103
6.1	Background	104
6.2	Solution Outline	106
6.3	LIRA: Service Differentiation Based on Resource Right Tokens	107
6.3.1	Link Cost Computation	109
6.3.2	Path Cost Computation and Distribution	110
6.3.3	Multipath Routing and Load Balancing	111
6.3.4	Route Pinning	111
6.3.5	Path Selection	113
6.3.6	Scalability	113
6.4	Simulation Results	114
6.4.1	Experiment Design	115
6.4.2	Experiment 1: Local Fairness and Service Differentiation	117
6.4.3	Experiment 2: User Fairness and Load Balancing	119
6.4.4	Experiment 3: Load Distribution and Load Balancing	119
6.4.5	Experiment 4: Large Scale Example	121
6.4.6	Summary of Simulation Results	123
6.5	Discussion	124
6.6	Related Work	125
6.7	Summary	126
<b>7</b>	<b>Making SCORE More Robust and Scalable</b>	129
7.1	Failure Model	130
7.1.1	Example	131
7.2	The “Verify-and-Protect” Approach	132
7.2.1	Node Identification	133
7.2.2	Protection	133
7.2.3	Recovery	134
7.3	Flow Verification	134
7.3.1	Bufferless Packet System	137
7.3.2	Flow Identification Test	137
7.3.3	Setting Threshold $H_u$	140
7.3.4	Increasing Flow Identification Test’s Robustness and Responsiveness	142
7.4	Identifying Misbehaving Nodes	143
7.4.1	General Properties	144
7.5	Simulation Results	146
7.5.1	Calibration	147
7.5.2	Protection and Recovery	148
7.6	Summary	150

<b>8</b>	<b>Prototype Implementation Description</b>	153
8.1	Prototype Implementation	154
8.1.1	Updating State in IP Header	155
8.1.2	Data Path	156
8.1.3	Control Path	158
8.2	Carrying State in Data Packets	158
8.2.1	Carrying State in IP Header	160
8.2.2	Efficient State Encoding	160
8.2.3	State Encoding for Guaranteed Service	162
8.2.4	State Encoding for LIRA	165
8.2.5	State Encoding for CSFQ	166
8.2.6	State Encoding Formats for Future Use	166
8.3	System Monitoring	166
8.4	System Configuration	168
8.4.1	Router Configuration	169
8.4.2	Flow Reservation	169
8.4.3	Monitoring	170
8.5	Summary	170
<b>9</b>	<b>Conclusions and Future Work</b>	173
9.1	Contributions	173
9.2	Limitations	175
9.3	Future Work	177
9.3.1	Decoupling Bandwidth and Delay Allocations	177
9.3.2	Excess Bandwidth Allocation	178
9.3.3	Link Sharing	179
9.3.4	Multicast	181
9.3.5	Verifiable End-to-End Protocols	181
9.3.6	Incremental Deployability	182
9.3.7	General Framework	183
9.4	Final Remarks	183
<b>A</b>	<b>Performance Bounds for CSFQ</b>	185
<b>B</b>	<b>Performance Bounds for Guaranteed Services</b>	191
B.1	Network Utilization of Premium Service in Diffserv Networks	191
B.2	Proof of Theorem 2	193
B.3	Proof of Theorem 3	198
B.3.1	Identical Flow Rates	198
B.3.2	Arbitrary Flow Rates	204
B.4	Proof of Theorem 4	211
	<b>References</b>	213

Stateless Core: A Scalable Approach for Quality of  
Service in the Internet

Winning Thesis of the 2001 ACM Doctoral Dissertation  
Competition

Stoica, I.

2004, XVI, 219 p., Softcover

ISBN: 978-3-540-21960-6