

Table of Contents

CHAPTER 1	Introduction	1
	1.1 Presentation of the problem	1
	1.2 Technical approach	3
	1.3 Concepts used in the dissertation	5
	1.3.1 A short overview of the ATM technology	5
	1.3.2 A short overview of resource management concepts	15
	1.4 The road map	16
CHAPTER 2	The reservation approach: On measures of statistically multiplexed connections in B-ISDN	17
	2.1 The reservation approach to statistical multiplexing in B-ISDN	18
	2.2 Network layers, time scales, virtual paths and resource abstraction	20
	2.3 The cell level allocation problem	24
	2.3.1 Source parametrization	24
	2.3.2 Traffic models	26
	2.3.3 Equivalent bandwidth at the cell level	27
	2.3.4 Asymptotic approximations of the cell level equivalent bandwidth	32
	2.4 The burst level allocation problem	33
	2.4.1 Fast resource reservation	34
	2.4.2 Equivalent capacity at the burst level with fast burst reservation	35
	2.5 Generalized equivalent bandwidths with application to bandwidth reservation in B-ISDN	39
	2.5.1 View 1: Equivalent bandwidth under bounded utilization	41
	2.5.2 View 2: Equivalent bandwidth under bounded mean values	41
	2.5.3 View 3: Equivalent bandwidth under bounded cumulative tail probabilities	42
	2.6 The call level allocation problem	43
	2.6.1 Asymptotic equivalent capacity at the call level	44
	2.7 Mapping the statistical measures to the semantic model of performance	45
	2.7.1 Characterization of multimedia services	46
	2.7.2 Fitting strategies	47
	2.8 Conclusions	49
CHAPTER 3	Lean resource management: giving up one hierarchy layer. The non-reservation approach	51
	3.1 Scrutiny of the layering approach	51
	3.2 The weakness of the statistical multiplexing assumption	52
	3.3 Why can't equivalent bandwidth be used for data traffic management	55
	3.4 The changing behaviour of traffic streams in very high bandwidth networks	61
	3.4.1 Delay behaviour	61
	3.4.2 Recovery of delayed cells	62
	3.4.3 The impact of losses	63
	3.5 A new approach: concurrency and resource sharing	64
	3.6 The trade-offs of data traffic	66
	3.7 Desired characteristics of the proposed resource management paradigm	67

CHAPTER 4

A class of protocols for lossless statistical multiplexing in ATM networks (Shuttlenet) 69

- 4.1 Rationale 69
- 4.2 The basic architecture 72
 - 4.2.1 Switch features 72
 - 4.2.2 End-system features 73
 - 4.2.3 The shuttles: embedded control messages 73
 - 4.2.4 Naming 74
 - 4.2.5 Configuration and routing 74
- 4.3 The protocols 74
 - 4.3.1 Enforcing zero loss for ATM point-to-point links 75
 - 4.3.2 Using distributed coordination to achieve long term minimum guarantees 83
- 4.4 Other proposals 93
 - 4.4.1 The ATM Forum proposal: Credit based hop-by-hop backpressure mechanism 93
 - 4.4.2 Fast Reservation Protocols (FRP) 95

CHAPTER 5

Fairness issues 97

- 5.1 The concept of, and a criterion for fairness 97
 - 5.1.1 Definitions 97
 - 5.1.2 The max-min fairness 98
- 5.2 Determining the fair rates 99
 - 5.2.1 General 99
 - 5.2.2 A distributed algorithm for computing max-min allocation rates on general topologies 100
- 5.3 Enforcing fair flows with the START-STOP backpressure mechanism 105
 - 5.3.1 Informal arguments 106
 - 5.3.2 Analytical bounds for the max-min behaviour of backpressure under asymptotic assumptions 106
 - 5.3.3 Typical behaviour of the backpressure mechanism 109
- 5.4 Fairness in the Shuttlenet 109

CHAPTER 6

Quantitative characterization of the proposed methods 113

- 6.1 Quantitative analysis using discrete event simulation 113
- 6.2 Required advance bandwidth reservation for the trace-driven buffered loss system 113
- 6.3 The simulation models of loss-less statistical multiplexing 116
- 6.4 The simulator 118
- 6.5 Protocol Behaviour 126
- 6.6 Trace driven simulation for very bursty traffic 132
- 6.7 Enforcing minimum guarantees for best-effort traffic 135
 - 6.7.1 The simulation model 135
 - 6.7.2 Typical behaviour of the backpressure mechanism 136
 - 6.7.3 The effect of the shuttles on the throughput distribution 144

CHAPTER 7

Implementation issues 147

- 7.1 Encoding 147
- 7.2 Supporting Shuttlenet in the network nodes 149
 - 7.2.1 Hardware support in the end-systems 149

CHAPTER 8	Lean management for the provision of Virtual Private Network services 165
8.1	Interconnection of customer premises networks 165
8.2	Using Shuttlenet for the provision of VPN best effort links with minimum guarantee 166
8.3	Consequences on customer equipment and applications 167
8.4	Consequences on network control: Intelligent Switching 168
CHAPTER 9	Conclusions and future work 169
9.1	Contributions of the dissertation 169
9.2	Directions of further research 171
9.3	A vision for the future 171
APPENDIX A	Resource management in B-ISDN: The engineering viewpoint. Implications on network performance 173
APPENDIX B	Index of abbreviations 203
REFERENCES	207

List of Figures

FIGURE 1	VP and VP/VC switches	7
FIGURE 2	Connection elements in B-ISDN	8
FIGURE 3	Examples of reference configurations	10
FIGURE 4	ATM cell	13
FIGURE 5	The ATM cell header structure at the UNI	14
FIGURE 6	ATM cell header structure at the NNI	14
FIGURE 7	A three dimensional framework for bandwidth management	19
FIGURE 8	Relationship between events, actions and response times	21
FIGURE 9	Network layers and time scales	22
FIGURE 10	Descriptors for a bursty source with exponentially distributed inter-arrival times	25
FIGURE 11	A two-state Markov chain source	26
FIGURE 12	The underlying Markov chain for N identical sources	28
FIGURE 13	The bufferless fluid flow model for the stationary approximation	31
FIGURE 14	Distribution of interdeparture times	53
FIGURE 15	Influence of burst size on the equivalent capacity of an individual connection	57
FIGURE 16	Simulation model for exercising the equivalent bandwidth	58
FIGURE 17	Network delay distribution function	62
FIGURE 18	Consecutive cell losses due to burst scale congestion	63
FIGURE 19	Backward access with termination condition	75
FIGURE 20	Dedicated buffer zones at the receiver	76
FIGURE 21	A simple START/STOP backpressure mechanism	76
FIGURE 22	START/STOP based on buffer thresholds	77
FIGURE 23	Backpressure on multiple point-to-point connections sharing a single bottleneck	77
FIGURE 24	Congestion propagation due to backpressure on bidirectional links	79
FIGURE 25	A tree with bidirectional links	81
FIGURE 26	Backpressure to one source from multiple destinations	82
FIGURE 27	Propagating the charged shuttle down the spanning tree	86
FIGURE 28	Collecting empty shuttles from the children and dynamic election of the new root	87
FIGURE 29	Best effort and minimum throughput network partitions	88
FIGURE 30	Propagation of the request signal	89
FIGURE 31	Propagation of the grant signals	90
FIGURE 32	Hop-by-hop credit based backpressure	93
FIGURE 33	Credit updating at the receiver	94
FIGURE 34	Credit based backpressure on multiple point-to-point connections	

	sharing a single bottleneck	94
FIGURE 35	Equal sharing of the bottleneck	100
FIGURE 36	Multiple links with bottlenecks	104
FIGURE 37	Final allocation for equal sharing	105
FIGURE 38	A Shuttlenet control cycle	110
FIGURE 39	Topology with bottlenecks and phase shift	111
FIGURE 40	Changing the phase of the round robin cycle	112
FIGURE 41	The simulated loss system	114
FIGURE 42	A simple leaky bucket model for the dynamics of the buffer occupancy	114
FIGURE 43	Predicted versus required bandwidth for a loss probability of 0.00001	115
FIGURE 44	Measurable bursty source parameters	116
FIGURE 45	A two-state Markov chain source	117
FIGURE 46	The multiplexer	117
FIGURE 47	Process dependencies for the generic simulator	119
FIGURE 48	Simplified code of a sim() process	120
FIGURE 49	Simplified code of a switch() process	121
FIGURE 50	Simplified code of a source() process	123
FIGURE 51	Simplified code of a cell() process	124
FIGURE 52	Simplified code of the queue() process	125
FIGURE 53	Stepwise variable bit rate source	127
FIGURE 54	Best Effort with Backpressure (BEB) buffer dimensioning	127
FIGURE 55	BEB mean protocol access delays	127
FIGURE 56	FRP mean protocol access delays	128
FIGURE 57	Comparison of mean protocol access delays	128
FIGURE 58	Mean access delays under sustained overload	129
FIGURE 59	Evolution of the mean input queue length	131
FIGURE 60	Overhead due to protocol messages as percentage of net load,	131
FIGURE 61	Overhead due to protocol messages under sustained overload	132
FIGURE 62	Multiplexer throughput under sustained overload	133
FIGURE 63	Mean queue length and protocol overhead after 30000000 trace cells	133
FIGURE 64	The ATM switch model for best effort traffic	135
FIGURE 65	Network configuration 1 with persistent sources	137
FIGURE 66	Throughput distribution for scenario IV, global backpressure	138
FIGURE 67	Throughput of d1 as a function of buffer size by global backpressure	139
FIGURE 68	Comparison between scenario IV and scenario V, global backpressure	139
FIGURE 69	Throughput distribution for scenario X, selective backpressure	140

FIGURE 70	Throughput of d1 as a function of buffer size by selective backpressure	140
FIGURE 71	Comparison between scenario X and scenario XI, selective backpressure	141
FIGURE 72	Network configuration 2 with persistent sources	142
FIGURE 73	Comparison between scenario XIV and scenario XV, selective backpressure	142
FIGURE 74	Rate distribution with variable load sources	143
FIGURE 75	Scenario for minimum guarantee	144
FIGURE 76	Minimum throughput versus backpressure	144
FIGURE 77	Minimum throughput distribution	145
FIGURE 78	ATM cell structure at the UNI	148
FIGURE 79	Layered protocol information	150
FIGURE 80	Splitting of the ATM header	151
FIGURE 81	Transmitter data flow in the network adapter	152
FIGURE 82	Scheduling of the VCI for transmission	153
FIGURE 83	The transmitter loop pseudo-code	156
FIGURE 84	The data structure for the virtual channel identifiers	157
FIGURE 85	Maintaining the allocation vector of the time wheel	158
FIGURE 86	The connection scheduler pseudo-code	158
FIGURE 87	Pseudo-code for re-scheduling an idle connection	159
FIGURE 88	Inserting connections in the transmission queue	160
FIGURE 89	The transmission queue "insert" pseudo-code	160
FIGURE 90	Pseudo-code for deleting the head of the transmission queue	161
FIGURE 91	Pseudo-code for processing the reserved bandwidth connection queue	162
FIGURE 92	Pseudo-code for processing the best-effort connection queue	163
FIGURE 93	Schematic flow of Shuttlenet messages in the switching nodes	164
FIGURE 94	Best effort links for the provision of VPN service	166
FIGURE 95	Hierarchy of the ATM transport network	175
FIGURE 96	Layered model of performance for B-ISDN	191
FIGURE 97	Conceptual illustration of random waiting time	195
FIGURE 98	Communication used for VPC/VCC management	197