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CONTROL STRUCTURES AND TECHNIQUES FOR BROADBAND-ISDN COMMUNICATION SYSTEMS

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ABSTRACT

A structured organisation of tasks, possibly hierarchical, is necessary in a BISDN network due to the complexity of the system, its large dimension and its physical distribution in space. Feedback (possibly supplemented by feedforward) control has an essential role in the effective and efficient control of BISDN. Additionally, due to the nonstationarity of the network and its complexity, a number of different (dynamic) modelling techniques are required at each level of the hierarchy. Also, to increase the efficiency of the network and allow flexibility in the control actions (by extending the control horizon) the (dynamic) **tradeoff** between service-rate, buffer-space, cell-delay and cell-loss must be exploited. In this thesis we take account of the above and solve three essential control problems, required for the effective control of BISDN. These solutions are suitable for both stationary and nonstationary conditions. Also, they are suitable for implementation in a decentralised coordinated form, that can form a part of a hierarchical organisation of control tasks. Thus, the control schemes aim for global solutions, yet they are not limited by the propagation delay, which can be high in comparison to the dynamics of the controlled events.

Specifically, novel control approaches to the problems of Connection Admission Control (CAC), flow control and service-rate control are developed. We make use of adaptive feedback and adaptive feedforward control methodologies to solve the combined CAC and flow control problem. Using a novel control concept, based on only two groups of traffic (the controllable and uncontrollable group) we formulate a problem aimed at high (unity) utilisation of resources while maintaining quality of service at prescribed levels. Using certain assumptions we have proven that in the long term the regulator is stable and that it converges to zero regulation error. Bounds on operating conditions are also derived, and using simulation we show that high utilisation can be achieved as suggested by the theory, together with robustness for unforeseen **traffic** connections and disconnections. Even with such a high efficiency and strong properties on the quality of service provided, the only traffic descriptor required from the user is that of the peak rate of the uncontrollable traffic.

A novel scheme for the dynamic control of service-rate is formulated, using feedback from the network queues. We use a unified dynamic fluid flow equation to describe the virtual path (VP) and hence formulate two illustrative examples for the control of service-rate (at the VP level). One is a nonlinear optimal multilevel implementation, that features a coordinated decentralised solution. The other is a single level implementation

that **turns** out to be computationally complex. Therefore, for the single level implementation the **costate** equilibrium solution is also derived. For the optimal policies derived, we discuss their implementation complexity and provide implementable solutions. Their performance is evaluated using simulation. Additionally, using an **ad hoc** approach we have extended previous published works on the decentralised coordinated control of large scale nonlinear systems to also deal with time-delayed systems.

Using a hierarchical structure we demonstrate the derivation of a particular solution for the control of service-rate. In particular we decompose the system, both vertically and horizontally. We provide local coordinated decentralised solutions at the lower levels of the hierarchy and more global solutions operating at slower time scales at the higher levels. At the highest level of the hierarchy, we extend published results on the control of service-rate to the case of a multiobjective formulation. At the lowest level of the hierarchy, we propose a novel link server protocol derived from heuristic arguments. At the intermediate level we use the dynamic service-rate control scheme, described above. Also, to demonstrate the flexibility and adaptability of the hierarchical structure an additional level has been formulated.

In this thesis, adaptive control theory and multilevel optimal control theory are applied to a variety of BISDN problem formulations, which demonstrate the suitability and power of these techniques in the BISDN context.

In summary, we offer an integrated structured approach to the effective control of BISDN that has the essential features of implementability, efficiency, effectiveness and robustness.

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- ii) A. Pitsillides, "Connection admission control (CAC)", Internal Report LTR0492, Laboratory for Telecommunication Research, Swinburne University of Technology, July 1992.
- iii) A. Pitsillides, "Report on the six month visit to Telecom Australia Research Laboratories, 6th March-August 31st 1992", Report LTR0692, Laboratory for Telecommunication Research, Swinburne University of Technology, September 1992.
- vi) A. Pitsillides, "Adaptive (feedback and feedforward) combined CAC and flow control for BISDN featuring high utilisation and bounded QoS performance", internal working paper, Laboratory for Telecommunication Research, Swinburne University of Technology, October 1992.

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- vii) A. Pitsillides, J. Lambert, "A Multilevel Control Theoretic Approach to Dynamic Bandwidth Allocation in Broadband-ISDN", TENCON'92, Melbourne, November, 1992.
- viii) A. Pitsillides, J. Lambert, B. Warfield, "A structure for the control of BISDN", ATRS'92, Adelaide, November, 1992.
- ix) M. Herzberg, A. Pitsillides, "A hierarchical approach for the bandwidth allocation, management and control in B-ISDN", ICC '93, Geneva, May 1993.

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TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
ACKNOWLEDGEMENT.....	iv
PREFACE.....	v
PUBLICATIONS RELATED TO THE WORK PRESENTED IN THIS THESIS	vi
LIST OF ABBREVIATIONS.....	xiii
GLOSSARY	xv
LIST OF ILLUSTRATIONS.....	xviii
CHAPTER 1 INTRODUCTION.....	1
1.1 BISDN in perspective.....	1
1.2 Motivation for our approach.....	2
1.3 Overview of the thesis	4
CHAPTER 2 TOWARDS A CONTROL FRAMEWORK FOR BISDN.....	7
2.1 Introduction	7
2.2 System behaviour in time and space.....	8
2.2.1 TrafficSources and Services.....	8
2.2.2 Network Physical Resources	8
2.2.3 Feedback Control System.....	8
2.2.3.1 Control Horizon.....	9
2.2.3.2 Control Functions	11
2.3 Hierarchical (multilevel/multilayer) control	13
2.3.1 The proposed hierarchical control structure.....	16
2.3.2 Time scales and decompositions	17
2.4 Modelling techniques for the dynamic control of BISDN	19

2.5	The cell-delay, cell-loss, buffer-space and service-rate performance and resource tradeoffs	20
2.5.1	Cell-transfer-delay and Cell-delay-variation (CDV).....	20
2.5.2	Cell-loss.....	22
2.5.3	The tradeoffs.....	22
2.6	Conclusions.....	24
CHAPTER 3 ADAPTIVE CONNECTION ADMISSION AND FLOW CONTROL		
	(ACFC)	25
3.0	Introduction	25
3.1	Review of CAC, flow control, and adaptive control schemes	26
3.1.1	Connection Admission Control (CAC)	26
3.1.2	Flow control	29
3.1.3	Adaptive control	30
3.2	Preliminaries.....	31
3.2.1	Network controllability and the controllable and uncontrollable groups of traffic	31
3.2.2	Control concept	34
3.2.3	Dynamic system model.....	36
3.2.4	Feedback of the network performance.....	38
3.3	Formulation and solution of the CAC and flow control problem.....	40
3.3.1	The adaptive Connection admission and flow control (ACFC) algorithm	40
3.3.1.1	Phase 1: Flow control.....	40
3.3.1.1.1	The adaptive flow control algorithm.....	42
3.3.1.2	Phase 2: CAC.....	43
3.3.1.2.1	The CAC algorithm No. 1	44
3.3.1.2.2	The CAC algorithm No. 2	45
3.3.1.3	Combining the CAC and flow control algorithms to obtain ACFC	46

3.3.1.4	Integration of ACFC with a hierarchically organised control system centred around the VP concept	46
3.3.2	Implementation aspects of the ACFC adaptive algorithm.....	47
3.3.2.1	Properties of the adaptive algorithm	47
3.3.2.2	Design variables of the adaptive algorithm.....	48
3.4.	Performance evaluation.....	50
3.4.1	Simulation test bed.....	50
3.4.2	The adaptive algorithm.....	52
3.4.3	Simulation results.....	54
3.4.3	Highlights of the performance evaluation.....	58
3.5	Strong properties of ACFC.....	59
3.6	Conclusions.....	61
Appendix 3.1:	CAC, sensitivity of the cell-overflow based approaches.....	63
Appendix 3.11:	Adaptive control using system identification techniques	68
Appendix 3.111:	ATM Switch design for control option 2.....	78
Appendix 3.IV:	The Addie-Zukerman model (used for our feedback signal)	79
Appendix 3.V:	Proofs and Derivations	82
A)	Derivation of the k-step-ahead prediction.....	82
B)	Derivation of the adaptive feedback and feedforward controller.....	84
C)	Proof of global convergence of the adaptive regulator.....	85
D)	Proof of some of the properties of ACFC	99
Appendix 3.VI:	Simulation cases A-F.....	102
CHAPTER 4 A NOVEL DYNAMIC SERVICE-RATE-CONTROL SCHEME FOR B-ISDN.....		
4.0	Introduction.....	120
4.1	Review of some related service-rate control schemes and nonlinear multilevel control.....	121
4.1.1	Service-rate control schemes.....	121

4.1.2	Nonlinear multilevel optimal control.....	122
4.2	Motivation of the service-rate control.....	124
4.3	The dynamic service-rate allocation concept.....	125
4.4	A unified state model for VPs.....	127
4.5	Formulation and solution of the dynamic service-rate control problem.....	129
4.5.1	The VPC optimal service-rate control algorithm: multilevel implementation with a quadratic objective function.....	130
4.5.1.1	problem formulation: multilevel implementation	131
4.5.1.2	solution; based on the multilevel algorithm	136
4.5.1.3	Illustrative example 4.1	139
4.5.1.4	Properties.....	145
4.5.1.5	Implementation aspects	146
4.5.2	The VPC optimal service-rate control algorithm: single level of control	147
4.5.2.1	problem formulation: single level implementation	148
4.5.2.2	solution: based on the costate equilibrium strategy.....	150
4.5.2.3	Illustrative example 4.2	151
4.6	Performance evaluation	153
4.6.1	Simulation test bed.....	153
4.6.1.1	DE Nonstationary Simulation (DENS) testbed	153
4.6.1.2	Control system type simulation (CSTS) testbed.....	154
4.6.2	Simulation results.....	154
4.6.3	Highlights of the performance evaluation.....	157
4.7	Conclusion	157
Appendix 4.I:	Nonlinear multilevel control theory.....	159
Appendix 4.II:	VP dynamic models described by the unified fluid flow equation	162
4.II.a)	M/M/1/ based models.....	163

4.11.b) M/D/1/ based models.....	167
4.II.c) General models.....	169
Appendix 4.III: Proofs of the service-rate control algorithms.....	170
Appendix 4.IV: Simulations A-G.....	175
CHAPTER 5 AN ILLUSTRATIVE HIERARCHICAL STRUCTURE FOR THE CONTROL OF SERVICE-RATE.....	188
5.1. Introduction	188
5.2 VPAM the higher level service-rate allocation and management scheme.....	189
5.2.1 Multiobjective VPAM model.....	190
5.3. The virtual path overall supremal unit (VPOSU) level.....	197
5.4 The VP Control (VPC) level.....	201
5.5. The lower level link service protocol (LSP)	202
5.6 Summary.....	204
Appendix 5.I: ϵ -constraint method	207
CHAPTER 6 CONCLUSION.....	209
6.1 Summary.....	209
6.2 Contributions of this work.....	210
6.3. Future extensions	213
6.4 Concluding remark.....	216
APPENDIX A.....	217
BIBLIOGRAPHY	218

LIST OF ABBREVIATIONS

ACFC	Adaptive Connection admission and Flow Control
AR	Auto Regressive
ARMA	Auto Regressive Moving Average
ARMAX	Autoregressive Moving Average with exogenous input
ATM	Asynchronous Transfer Mode
BISDN	Broadband-ISDN
CAC	Connection Admission Control
CARMA	Controlled Autoregressive Moving Average (also known as ARMAX)
CARIMA	Controlled Autoregressive Integrated Moving Average
CCITT	International Telegraph and Telephone Consultative Committee
CQ	Cyclic Queue
CSTS	Continuous System Type Simulation
DE	Discrete Event
DES	Discrete Event System
DENS	Discrete Event Nonstationary Simulation
DSCT	Discrete-State Continuous-Time
FIFO	First In First Out
FIR	Finite Impulse Response
GMV	Generalised Minimum Variance
GPC	Generalised Predictive Control
ISDN	Integrated Services Digital Network
LRPC	Long Range Predictive Control
LSP	Link Server Protocol
LQ	Linear Quadratic
LQG	Linear Quadratic Gaussian
LU	Local Unit
MA	Moving Average
MIMO	Multiple Input Multiple Output
MV	Minimum Variance
NPC	Network Parameter Control
OD	Origin Destination
OS	Overall Supremal unit
QoS	Quality of Service
RLS	Recursive Least Squares

SISO	Single Input Single Output
SIMO	Single Input Multiple Output
SU	Supremal Unit
TPBV	Two Point Boundary Value
UPC	Usage Parameter Control
VC	Virtual Channel
VP	Virtual Path
VPAM	Virtual Path Allocation and Management
VPC	Virtual Path Control
VPOSU	Virtual Path Overall Supremal Unit

Kendall notation for Queues

In 1952, D. G. Kendall described a shorthand notation that captures the essential characteristics of queuing systems, as follows:

Inter amval / Service time / Number of servers / {queue places, queue
distribution distribution discipline)

where (commonly) the following letters are used

M-Markov D-Deterministic G-General N-Number

Conferences and journal abbreviations:

ABSSS	Australian Broadband Switching and Services Symposium
ACM	Association for Computing Machinery
ATRS	Australian Teletraffic Research Seminar
CDC	Conference on Decision and Control
GLOBECOM	Global Telecommunications Conference
ICC	International Conference on Communications
ICT	International Conference on Telecommunications
IEE	Institution of the Electrical Engineers
IEEE	Institute of the Electrical and Electronic Engineering
IFAC	International Federation of Automatic Control
IFIP	International Federation of Information Processing
INFOCOM	The Conference on Computer Communications
ITC	International Teletraffic Congress
JSAC	Journal on Selected Areas in Communications
NOMS	Network Operations and Management Symposium
TENCON	Computers, Communication and Automation toward the 21st Century

GLOSSARY

In this glossary, we list some mathematical symbols and the common meaning of the main variables used in the thesis. A detailed explanation of their meaning, can be found within the text. An example of the variable's usage appears in the page listed under the page heading. Note that **commonly** capital letters are used for matrices, and small letters for vectors.

symbol	description	units	page
q^{-1}	shift or delay operator		38
$\alpha(q^{-1})$	polynomial in the shift operator q^{-1}		69
z	z-transform operator		48
Δ	differencing operator		38
Δu	incremental form of variable		38
\hat{x}	estimate of x		70
\tilde{x}	error between actual and estimated value of x		83
$E\{x\}$	mathematical expectation of x		79
$\{x\}$	sequence of x		70
$\lceil x \rceil$	is the next integer toward $+\infty$ (round up).		21
$\lfloor x \rfloor$	is the next integer toward $-\infty$ (round down).		33
$erf(x)$	error function of x		80
$erfc(x)$	complementary error function of x		80
A^T	transpose of matrix (or vector) A		69
\otimes	Kronecker product		128
0^n	a $n \times 1$ vector of zeros		128
$0^{n \times m}$	a $n \times m$ matrix of zeros		128
e^n	a $n \times 1$ vector of ones		128
$e^{n \times m}$	a $n \times m$ matrix of ones		128
∞^n	a $n \times 1$ vector of infinities		128
α, β, γ	Lagrange Multipliers		170

ε	noise		69
θ	parameter vector		69
λ	arrival or flow of cells (cell-flow)	cells/time unit	22
λ_o	control penalty factor		74
λ_f	forgetting factor		75
ν	costate vector		170
ξ	coordination variable		200
π	Lagrange Multiplier		170
ρ	throughput		99
σ^2	variance of variable		79
τ	time delay	time units	128
φ	past data vector		69
B, b	buffer size	cells	22
C, c	service-rate, bandwidth, capacity	cells/time unit	128
e	white noise		70
$f(x)$	general function of x		21
$G(x)$	general function of x		128
h	peak cell-rate	cells/time unit	44
\mathcal{H}	Harniltonian function		170
i, j	general indexing variables		38
J	cost function, objective function, etc...		148
k	discrete time delay (in integer multiples of the sampling time)		71
\mathcal{L}	Lagrangian function		199
m	mean value of variable		99
n	order of system		38
P_{loss}	probability of loss		22
$p\%$	pth percentile of the buffer distribution		79
p	pole location		49
t	time (continuous or discrete)	time unit	37
T	sampling rate	per time unit	53
u	control input		37

v	feedforward signal		37
v_1	feedforward signal 1; the average (over one control interval) total uncontrollable traffic flow	cells/control interval	52
v_2	feedforward signal 2; the average (over one control interval) of the cell queue length	cell places/ control interval	52
w	tradeoff weights		148
x	system state		128
y	system output		37
z	interaction variable		199

LIST OF ILLUSTRATIONS

	Page
Figure 2.1. Physical and temporal relationship in a network.	9
Figure 2.2. Factors influencing the control horizon.	10
Figure 2.3. A hierarchically (multi-level/multi-layer) organised control structure... ..	16
Figure 2.4. Example of a hierarchically (multi-level/multi-layer) organised control structure.....	18
Figure 2.5. Time delays for various traffic types over 100 kms link and 1000 cell queue.	20
Figure 2.6. Time delays for voice over 1000 kms link and 1000 and 10000 cell queues.....	21
Figure 2.7. Tradeoff between cell-delay and cell-loss.	2 3
Figure 3.1. Block diagram of the flow control concept.....	34
Figure 3.2. The adaptive feedback and adaptive feedforward control concept for CAC and flow control.	35
Figure 3.3. ATM switch simulator block diagram.	50
Figure 3.4. Block diagram of the adaptive controller and its standard settings.	53
Figure 3.5. Cell rate as a fluid flow.	63
Figure 3.6. Probability of loss surface.	66
Figure 3.7. The log of Probability of loss surface.	66
Figure 3.8. Contour plot of the log of the Probability of loss.	67
Figure 3.9. Structure of a general adaptive controller.....	68
Figure 3.10. ATM switch preprocessor.....	78
Figure 3.11. Controllable cells processor.	78
Figure 3.12. Closed loop system block diagram	87
Figure 3.13. Buffer cell occupancy frequency distribution.	103
Figure 3.14. Typical segments of the simulation run: 37200 and 6000 celltimes... ..	103
Figure 3.15. Video connection and disconnection simulations: video remains connected throughout simulation run.	105
Figure 3.16. Video connection and disconnection simulations: video disconnected after 20000 celltimes elapsed.	106
Figure 3.17. Video connection and disconnection simulations: video connected after 20000 celltimes elapsed.	107
Figure 3.18. Examples of video and data connections	108

Figure 3.19. Reference set to 20 buffer cell places	110
Figure 3.20. Reference set to 50 buffer cell places	111
Figure 3.21. Reference set to 75 buffer cell places	112
Figure 3.22. Simulation run for control penalty weight equal to 0.05	114
Figure 3.23. Simulation run for control penalty weight equal to 5.	114
Figure 3.24. Simulation run for control penalty weight equal to 150.....	115
Figure 3.25. Typical buffer histogram	115
Figure 3.26. Comparison of the controlled system performance with and without feedforward compensation.....	117
Figure 3.27. Evolution of the estimated control parameters over the length of the simulation run.....	118
Figure 3.28. Sensitivity of buffer occupancy to changes in the incoming traffic...	119
Figure 4.1. The control concept for the dynamic allocation of service-rate.	126
Figure 4.2. The VPC control structure and information flow.....	138
Figure 4.3. The VPC control structure and information flow for the 3-node example.....	145
Figure 4.4. ATM switching node.	163
Figure 4.5. A VP modelled by a series of ATM switching nodes.	163
Figure 4.6. DENS and CSTS for stationary background traffic.....	176
Figure 4.7. DENS and CSTS for nonstationary background traffic.....	177
Figure 4.8. VP buffer state: optimal service-rate allocation, $w_x = 5$, $w_c = 1$	180
Figure 4.9. VP service-rate: optimal service-rate allocation, $w_x = 5$, $w_c = 1$	180
Figure 4.10. VP buffer state: optimal service-rate allocation, $w_x = 1$, $w_c = 5$	180
Figure 4.11. VP service-rate: optimal service-rate allocation, $w_x = 1$, $w_c = 5$	180
Figure 4.12. Node 1 VP traffic buffer state.	181
Figure 4.13. Node 2 VP traffic buffer state.....	181
Figure 4.14. Node 1 allocated service-rate	181
Figure 4.15. Node 2 allocated service-rate	181
Figure 4.16. VP traffic buffer state at node 1 for changes in the service-rate reference values.....	182
Figure 4.17. Background traffic buffer state at node 1 for changes in the service- rate reference values.	182
Figure 4.18. Service-rate allocated to VP traffic at node 1 as the references on the service-rate are changed.	182
Figure 4.19. Service-rate allocated to background traffic at node 1 as the references on the service-rate are changed.	182

Figure 4.20. Buffer state for plentiful link capacity	182
Figure 4.21. Service-rate allocations for plentiful link capacity	182
Figure 4.22. The costate variable interaction term for a loaded network.....	183
Figure 4.23. The costate variable interaction term for a lightly loaded network ..	183
Figure 4.24. The interaction variable for a loaded network.....	183
Figure 4.25. The interaction variable for a lightly loaded network	183
Figure 4.26. Node 1 buffer state: dynamic service-rate allocation.....	185
Figure 4.27. Node 1 buffer state: static service-rate allocation.	185
Figure 4.28. Node 3 buffer state: dynamic service-rate allocation.....	185
Figure 4.29. Node 3 buffer state: static service-rate allocation.	185
Figure 4.30. Node 1 dynamically allocated service-rate.	185
Figure 4.31. Node 3 dynamically allocated service-rate.....	185
Figure 4.32. Node 3 VP traffic buffer state; service-rate allocated dynamically using the equilibrium costate solution.	186
Figure 4.33. Node 3 Service-rate allocation using the equilibrium costate solution.	186
Figure 4.34. Node 3 VP traffic buffer state; service-rate allocated dynamically using full costate solution.....	186
Figure 4.35. Node 3 service-rate allocated dynamically using full costate solution.	186
Figure 4.36. Demonstration of the existence of the costate equilibrium	187
Figure 5.1. Typical throughput fbctions	192
Figure 5.2. Three node network topology used for example 5.1.	194
Figure 5.3. Pareto set of the optimum service-rate allocation for case i	196
Figure 5.4. Pareto set of the optimum service-rate allocation for case ii	196
Figure 5.5. Functional values for case i	196
Figure 5.6. Functional values for case ii	196
Figure 5.7. The interactions between VPs sharing a link and the proposed solution to neutralise them via a higher level supervisor, the VPOSU	197
Figure 5.8. The information flow between the VPOSU and the VPC levels.	201
Figure 5.9. A single VP highlighting the link level.....	202
Figure 5.10. The link server outline.	203
Figure 5.11. Schematic of the proposed hierarchical structure for the dynamic service-rate allocation.....	206
Figure 5.12. Tradeoff hinction λ_{21} plotted against the hinction $D_1(U)$	207
Figure 5.13. Tradeoff fbction A_{21} plotted against the function $D_2(U)$	207
Figure 5.14. Pareto optimum solution in the decision space	208
Figure 5.15. Pareto optimum solution in the hinctional space.....	208