CONTENTS

	Prefa	e		<i>page</i> xi		
1	Intro	duction		1		
I	Net	work architecture an	d algorithms	5		
2	Mathematics of Internet architecture					
	2.1	Mathematical background: con	vex optimization	7		
		2.1.1 Convex sets and convex	The contract of the part of the contract of th	7		
		2.1.2 Convex optimization		11		
	2.2	Resource allocation as utility n	naximization	15		
		2.2.1 Utility functions and fa	rness	17		
	2.3	Mathematical background: stab	oility of dynamical systems	19		
	2.4	Distributed algorithms: primal	solution	21		
		2.4.1 Congestion feedback ar	nd distributed implementation	24		
	2.5 Distributed algorithms: dual solution					
	2.6	Feedback delay and stability		27		
		2.6.1 Linearization		29		
	2.7	Game-theoretic view of utility	maximization	30		
		2.7.1 The Vickrey-Clarke-G	roves mechanism	31		
		2.7.2 The price-taking assum	ption	34		
		2.7.3 Strategic or price-antici	pating users	35		
	2.8	Summary		41		
	2.9	Exercises		42		
	2.10	Notes		47		
3	Link	: statistical multiplexing	and queues	49		
	3.1	Mathematical background: the	Chernoff bound	49		
	3.2	Statistical multiplexing and page	cket buffering	51		
		3.2.1 Queue overflow		52		
	3.3 Mathematical background: discrete-time Markov chains					
	3.4	Delay and packet loss analysis	in queues	64		
		3.4.1 Little's law	e en Alby	64		
		3.4.2 The Geo/Geo/1 queue		67		
		3.4.3 The Geo/Geo/1/B queu	2	69		
		3.4.4 The discrete-time G/G/	l queue	70		

	3,3	Providing priorities: fair queueing	72	1 225		7.1.3 TCP-Vegas: a delay-based algorithm	
		3.5.1 Key properties	76	350		7.2 Routing algorithms: Dijkstra and Bellman–Ford algorithms	
	3.6	Summary	78	376		7.2.1 Dijkstra's algorithm: link-state routing	
	3.7	Exercises	79	lan.		7.2.2 Bellman–Ford algorithm: distance-vector routing	
	3.8	Notes	85	2.50		7.3 IP addressing and routing in the Internet	
				100		7.3.1 IP addressing	
1	Sche	eduling in packet switches	86	Tes		7.3.2 Hierarchical routing	
	4.1	Switch architectures and crossbar switches		200		7.4 MAC layer protocols in wireless networks	
	7.1	4.1.1 Head-of-line blocking and virtual output queues	87	1111		7.4.1 Proportionally fair scheduler in cellular downlink	
	4.2		88			7.4.2 MAC for WiFi and ad hoc networks	
	4.2	Capacity region and MaxWeight scheduling	90				
	12	4.2.1 Intuition behind the MaxWeight algorithm	96	0.37		7.5 Summary	
	4.3	Low-complexity switch scheduling algorithms	96	922		7.6 Exercises	
		4.3.1 Maximal matching scheduling	96	031		7.7 Notes	
		4.3.2 Pick-and-compare scheduling	102	585			
		4.3.3 Load-balanced switches	102	588	8	Peer-to-peer networks	
	4.4	Summary	105			8.1 Distributed hash tables	
	4.5	Exercises	106	590		8.1.1 Chord	
	4.6	Notes	109	105		8.1.2 Kademlia	
				100		8.2 P2P file sharing	
,	Sche	duling in wireless networks	110			8.2.1 The BitTorrent protocol	
	5.1	Wireless communications	110	206		8.3 Structured P2P streaming	
	5.2	Channel-aware scheduling in cellular networks		711			
	5.3	The MaxWeight algorithm for the cellular downlink	114			Control Control of the Control of th	
	5.4	MaxWeight scheduling for ad hoc P2P wireless networks	116	318		8.5 The gossip process	
	5.5	General MaxWeight algorithms	122	No.		8.6 Summary	
	5.6		125	816		8.7 Exercises	
	5.0	Q-CSMA: a distributed algorithm for ad hoc P2P networks	129	HY		8.8 Notes	
		5.6.1 The idea behind Q-CSMA	129				
	<i>5</i> 7	5.6.2 Q-CSMA	130	323			
		Summary	134	ESS	II	Performance analysis	
	5.8	Exercises	135	325		A Committee of the Comm	
	5.9	Notes	140	REF	9	Queueing theory in continuous time	
				Pro.	9	O.1. Mathematical hardwards continuous time Markov chains	
	Back	to network utility maximization	142	80		9.1 Mathematical background: continuous-time Markov chains	
	6.1	Joint formulation of the transport, network, and MAC problems	142	DET.		9.2 Queueing systems: introduction and definitions	
	6.2	Stability and convergence: a cellular network example	151			9.3 The M/M/1 queue	
	6.3	Ad hoc P2P wireless networks		1002		9.4 The M/M/s/s queue	
		Internet versus wireless formulations: an example	155	012		9.4.1 The PASTA property and blocking probability	
	6.5	Summary Summary	157			9.5 The M/M/s queue	
		Exercises	159			9.6 The M/GI/1 Queue	
		Notes	160			9.6.1 Mean queue length and waiting time	
	72.5		163			9.6.2 Different approaches taken to derive the P-K formula	
	Nota	ork protocole				9.7 The GI/GI/1 queue	
		ork protocols	165			9.8 Reversibility	
	7.1	Adaptive window flow control and TCP protocols	166			9.8.1 The M/M/1 queue	
		7.1.1 TCP-Reno: a loss-based algorithm	167			9.8.2 The tandem M/M/1 queue	
		7.1.2 TCP-Reno with feedback delay	170			9.9 Queueing systems with product-form steady-state distributions	

Contents

		9.9.1 The Jackson network	255				
		9.9.2 The multi-class M/M/1 queue	256				
	9.10	Insensitivity to service-time distributions	258				
		9.10.1 The M/M/1-PS queue	259				
		9.10.2 The M/GI/1-PS queue	259				
	9.11	Connection-level arrivals and departures in the internet	263				
	9.12	Distributed admission control	267				
	9.13	Loss networks	269				
		9.13.1 Large-system limit	271				
		9.13.2 Computing the blocking probabilities	274				
		9.13.3 Alternative routing	275				
	9.14	Download time in BitTorrent	276				
	9.15	Summary	280				
	9.16	Exercises	282				
	9.17	Notes	289				
10	Asymptotic analysis of queues						
	10.1	Heavy-traffic analysis of the discrete-time G/G/1 queue	290 291				
	10.2	Heavy-traffic optimality of JSQ	294				
	10.3						
		theorem	302				
	10.4	Large-buffer large deviations	307				
	10.5	Many-sources large deviations	312				
	10.6	Summary	317				
	10.7	Exercises	318				
	10.8	Notes	321				
11	Geometric random graph models of wireless networks						
	11.1	Mathematical background: the Hoeffding bound	323				
	11.2	Nodes arbitrarily distributed in a unit square	325				
	11.3	Random node placement	328				
	11.4	Summary	335				
	11.5	Exercises	336				
	11.6	Notes	339				
Refer	rences		340				
Index	349						